Nebiyu Girgibo

Results of Seaside Energy Solutions in Land Uplift and Climate Change in the Kvarken Archipelago

A Mixed-Method Investigation

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Tiivistelmä

Tämä tutkimus käsittelee ensisijaisesti meren rannalla toteutettavia uusiutuvan energian sovellutuksia ja niiden yhteyksiä ilmastonmuutokseen ja maan nousemiseen. Mahdollisia sovellutuksia olivat vesistölämmönvaihdin ja sedimenttienergian tuotanto. Ehdolla olivat myös aaltoenergia, asfalttienergia, resurssit, pohjaveden hyödyntäminen, tuuliturbiinit, KNBNNO-materiaalit ja aurinkoenergiajärjestelmät. Työhön saatiin tilastollisia analyysejä varten pitkän aikavälin säätietoja (1959–2019) Ilmatieteen laitokselta ja veden laatutietoja (1974–2018) ELY-keskuksesta. Riskianalyysit tehtiin asiantuntijakyselyihin perustuen. Sedimenttilämpöenergian tuotantoa koskeva tieto saatiin kahdelta mittauspaikalta Vaasan Suvilahdesta. Mittausajankohdat olivat 8/2013–12/2016 sekä 9/2018. Tutkimusmenetelmänä oli monimenetelmätutkimus, jossa tehtiin sekä kvalitatiivisia tutkimuksia käsitteellisessä kehyksessä että kvantitatiivisia tutkimuksia kuten data-analyysit ja riskianalyysit. Ilman lämpötila nousi huhtikuussa ja heinäkuussa, minkä odotettiin epäsuorasti lisäävän klorofylli-a:n määrää esimerkiksi heinäkuussa osoittaen kasviplanktonin kasvua ja runsastumista vesiympäristössä. Vesien lämpötilojen odotettiin laskevan helmikuussa ja nousevan maaliskuussa, kesäkuussa ja heinäkuussa. Ilmas-tonmuutoksen vaikutukset hyödyttävät sedimentin lämpöenergian tuottoa ke-sällä. Se on kuitenkin paikkariippuvaista ja riippuu myös lämmönkeruuputkiston asennussyvyydestä. Riskianalyysi osoittaa, että peltobiomassa on ilmastonmuutokselle riskialttein. Vastaavasti vaikutus maalämpöön on vähäisin. Peltobiomas-saenergialla on suurimmat ympäristövaikutukset ja aurinkoenergialla/keräimillä pienimmät. Kvalitatiivisen tutkimuksen tulokset tukivat kvantitatiivisia tuloksia.

Tärkein johtopäätös on, että meren rannassa uusiutuva energia on pääsääntöisesti matalassa vedessä olevaa geoenergiaa. Useimmat sovellutukset hyödyntävät joinakin vuodenaikoina ilmastonmuutoksen vaikutuksia. Ilman lämpötilan todennäköisellä nousulla saattaa olla suoria tai epäsuoria vaikutuksia Merenkurkun saaristossa veden laatuun aiheuttaen veden lämpötilan ja klorofylli-a:n pitoisuuden kasvua joidenkin kuukausien aikana. Vaikka uusiutuvaan energiaan liittyvät riskit ovat pieniä, niitä on hyvä tutkia, jotta uusiutuvan energian käyttö säilyisi turvallisena. Saadut tulokset auttavat otettaessa uusiutuvaa energiaa käyttöön ja hyödynnettäessä sitä alueen kehityksessä. Tutkimus yhdistää veden laadun, ilmastonmuutoksen, maan nousemisen ja rannikon energiaratkaisut ja käsittelee niiden muutoksia Vaasan alueen läheisyydessä. On havaittu myös, että ilmastonmuutoksen vaikutukset paikallisesti poikkeavat maailmanlaajuisista odotuksista.

Avainsanoja: Geoenergia, sedimentin lämpöenergia, uusiutuvan energian riskit, ilmastonmuutos, veden laatu, maan nouseminen

Abstract

This research primarily considers seaside renewable energy solutions that result in climate change effects and their relation to land uplift. The possible solutions considered were water heat exchanger and sediment heat energy production; suggested were wave energy, asphalt energy resources, groundwater energy utilization, wind turbines, KNBNNO-material and solar systems. Long-term weather data (1959–2019) from FMI and water quality data (1974–2018) from ELY-Keskus were gathered and used for statistical analysis. Expert opinions were used for risk analysis. The sediment heat energy production data were from two sites (Ketunkatu and Liito-oravankatu) in Suvilahti, in the city of Vaasa, Finland (August 2013 – December 2016 and September 2018). A mixed-methods approach was used, with both qualitative studies, e.g., framework chart development, and quantitative studies, e.g., data analyses and risk analyses. The air temperature increased in April and July, which was expected to indirectly increase the chlorophyll-*a* level (e.g. in June), an indicator of phytoplankton growth and abundance in the water systems. Water temperatures were expected to decrease in February and increase in March, June and July. Sediment heat energy production uses climate change effects in summer, but is site-specific and dependent on installation depth. Risk analysis shows that climate change is the riskiest for field biomass energy and affects ground heat sources the least. Field biomass energy has the greatest environmental effects and solar energy/collector the lowest. In addition, mixed methods analysis shows support from qualitative studies for quantitative ones.

A key conclusion is that seaside renewable energy is mainly shallow geothermal energy and most of these solutions use climate change effects in some seasons. The likely increase in air temperature on water quality in the Kvarken Archipelago may have direct and indirect effects, causing water temperature and chlorophyll-*a* concentration to increase in some months. Though the risks of renewable energy are low, it is important to analyse them to preserve safe, renewable energy use. These results assist in implementing and managing renewable energy in regional development. The study combines water quality, climate change, land uplift, and seaside energy solutions and presents their changes in the vicinity of the Vaasa region. This shows that climate change effects on the local area differs from world expectations. A main contribution of the research is drawing relationships between different disciplines and topics, thus creating a sophisticated view of natural phenomena and seaside renewable energy solutions.

Keywords: Geo-energy, sediment heat energy, the risks of renewable energy, climate change effect, water quality, land uplift

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Abbreviations

AA-CES	Advanced adiabatic compressed air energy storage systems
AMOC	Atlantic meridional overturning circulation
AO	Arctic oscillation
ATES	Aquifer thermal energy storage system
AR	Assessment Report (e.g. AR4, AR5 and AR6)
ARIMA	Autoregression integrated moving average
AU	Africa Union
BOD	Biochemical oxygen demand
BTES	Borehole thermal energy source system
CCS	Carbon capture and storage
Chl-a	Chlorophyll-*a* concentration
DTR	Diurnal temperature range
DTS	Distributed temperature sensing method
DO	Dissolved oxygen
DOC	Dissolved organic carbon
EEA	European Environment Agency
EER	Energy efficiency ratio
ELY-keskus	Centre of Economic Development, Transport and the Environment (Elinkeino-, liikenne- ja ympäristökeskus)
ENSO	El Niño south oscillation
Et al.	And others
EU	Europe Union
EV	Energy Village
FCEA	Finnish Clean Energy Associations
FAR	First Assessment Report
FGI	Finnish Geospatial Institute
FMI	Finnish Meteorological Institute

GCM	Global climate models
GEU	Groundwater energy utilisation
GHGs	Greenhouse gasses
GSHC	Ground source heating and cooling
GPS	Global positioning system
Gt	Gigatonnes
GTK	Geological Survey of Finland
GWP	Global warming potential
H	Hypothesis
HAWT	Horizontal axis wind turbine
HELCOM	Helsinki Commission
IPCC	Intergovernmental Panel on Climate Change
IRB	Institution review board
IST	Ice storage tank
IUCN	International Union for Conservation of Nature
JY/JYU	Jyväskylä Yliopisto/University of Jyväskylä
KNBNNO	($[KNbO_3]_{0.9}[BaNi_{1/2}Nb_{1/2}O_{3-\delta}]_{0.1}$) material by the PLD (pulse laser deposition)
LEAP - RE	Long-Term Joint Europa Union (EU) - Africa Union (AU) Research and Innovation Partnership on Renewable Energy
LLGHGs	Long-lived greenhouse gases
LUKE	Natural Resource Institute Finland
NAM	North annular mode
NAO	North Atlantic oscillation
NCs	Nordic countries
NEP	New energy policy project
NGO’s	Non-governmental organizations
NH	Northern Hemisphere

NLS	National Land Survey of Finland
MMR	Monitoring Mechanism Regulation
MOC	Meridional overturning circulation
$MtCO_2$	Metric tons of carbon dioxide equivalent
Mtoe	Millions of tonnes of oil equivalent
m.y.	Millions of years
PCMs	Phase change materials
PDO	Pacific decadal oscillation
PNA	Pacific North American pattern
ppb	Parts per billion
ppm	Parts per million
RCM	Regional climate models
RE	Renewable energy
RES	Renewable energy sources
RERs	Renewable energy resources
RF	Radiative forcing
RQ	Research question
SAS	Statistical Analysis System
SAR	Second Assessment Report
SCADA	Supervisory Control and Data Acquisition
SEM	Structural equation modelling
SLE	Sea level rise estimate
SPM	Summary of policymakers
SPSS	Statistical Package for Social Sciences
SREs	Special report emission scenarios [IPCC (2000)]
SSTs	Sea surface temperatures
STEs	Sensible thermal energy storage systems
SYKE	Suomen Ympäristö keskus/Finnish Envrionmental Center

TAMK	Tampere Ammatti korkeakouluun/Tampere University of Applied Sciences
TAR	Third Assessment Report
TCB	Total coliform bacteria
TCS	Thermo-chemical storage
TDS	Total dissolved solids
TES	Thermal energy systems
TN	Total nitrogen
TP	Total phosphorus
TRT	Thermal response test
TSI	Total solar irradiance
UCG	Underground coal gasification
UHI	Urban heat island
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UTES	Underground thermal energy source system
VAMK	Vaasan Ammattikorkeakouluun/Vaasa University of Applied Sciences
VAWT	Vertical axis wind turbine
VIF	Variance inflation factor
VNS	Validity Network Schema
VY/UVA	Vaasa Yliopisto/University of Vaasa
WFD	Water Framework Directive
WQ	Water quality
WWF	World Wildlife Fund

Publications

This doctoral research contributed to the following publications:

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III. Girgibo, N.; Hiltunen, E.; Lü, X.; Mäkiranta, A. and Tuomi, V. Risks of climate change effects on renewable energy resources and their utilisation impacts on the environment. [Submitted/Under Review]. *Energy Reports.*

IV. Girgibo, N., Mäkiranta, A., Lü, X., & Hiltunen, E. (2022). Statistical Investigation of Climate Change Effects on the Utilization of the Sediment Heat Energy. *Energies, 15* (2), 435. https://doi.org/10.3390/EN15020435

Author's contributions to the publications

Publication I.

Original idea, writing the original manuscript, literature data gathering, systematic literature analyses, reviewing, editing and funding acquisition by the thesis author.

Publication II.

Original idea, writing the original manuscript, data gathering, data analysis, reviewing, editing and funding acquisition by the thesis author.

Publication III.

Original idea, writing the original manuscript, data gathering, data analysis, reviewing, editing and funding acquisition by the thesis author.

Publication IV.

Original idea, writing the original manuscript, data gathering, data analysis, reviewing, editing and funding acquisition by the thesis author.

1 INTRODUCTION

In this article-based doctoral dissertation, the research studies seaside energy solutions, land uplift and climate change in Kvarken Archipelago, a protected UNESCO world heritage site in the city of Vaasa, Finland. The research was primarily a statistical analysis of long-term data regarding air temperature changes and their effects on both water quality and meteorology. In addition, the research deals with geoenergy resources, such as sediment heat production; future land uplift effects related to general climate change; the Gulf Stream situation; and the structure of planned and implemented energy technologies. This first chapter introduces the research, including the background, the problem, the problem statement, the current state-of-the-art approach, objectives and methods (including the objectives, purpose of the research, research questions, hypotheses, motivation, conceptual frameworks, an overview of the methodology and the ethical questions raised), as well as presenting contributions and the structure of the theses.

The narrative of the doctoral research is as follows: land uplift in the area began about 10,000–11,000 years ago. Due to anthropogenic factors, climate change effects began to occur about 100 years ago. Consequently, water began to rise due to glacial melting, with ice sheet melting and water temperature both increasing. This sea-level rise has affected the land uplift effect in some areas. In the present day, our research group is trying to find and implement renewable energy resources (sediment heat energy production and water heat exchange) to combat climate change, since renewable energy is arriving in the Archipelago area. In addition, this research investigates the effect of climate change on geoenergy (sediment heat energy). In other words, the research centres around the relationship between land uplift, climate change, water quality, sea level rise and renewable energy. The research also deals with risks to renewable energies caused by climate change and related to land uplift, as well as risks to the environment from renewable energy use and production. During this period, with the Russian war on Ukraine having caused an energy crisis in Finland and the EU, in the wake of the COVID-19 pandemic, it is important to focus on the use of local renewable energy to overcome the shortage in energy production and the energy market.

The main contribution of this research is the idea of the use of climate change effects to our advantage, concretely to generate heat energy in the pursuit of combating and mitigating climate change. Since water heat exchangers were found to be more affected by climate change, summer heat production when using this equipment is expected to be higher. The Kvarken Archipelago protected UNESCO

World Heritage area was found to be affected by air temperature changes in terms of its weather data and water quality parameters. Risk analysis explored new terrain in climate change research by analysing the risks of climate change on renewable energy resources. This research found that sediment heat energy production can use climate change effects to its advantage, especially in summer. In winter, sediment heat energy will not benefit from climate change effects such as air temperature changes and increased solar irradiance.

The project site, Merten Talo (Swedish name 'Havets Hus') is in the Raippaluoto silta area, between the cities of Vaasa and Mustasaari. The Kvarken Archipelago protected UNESCO World Heritage area was chosen because it shows natural climate change fluctuations without human pollution. Hence, the area is and was protected from human pollution; as such, nearly identical environmental effects are expected to be found in this area in terms of water quality. The importance of the area also lies in the fact that these studies are expected to continue in the future. Therefore, the area is useful for determining the exact effects of climate change in protected areas in the past, present and future. This creates a much broader path for this research and the future development of possible research platforms in renewable energy, hydrology, limnology, meteorology and climate change studies and their forecast at the station.

Climate change affects the use of energy sources, such as wind turbine utilisation, and even produces risks. However, climate change effects can benefit us by increasing the temperature of the energy source, such as by using water heat exchangers and sediment energy under the water body. On the other hand, if the Gulf Stream is speed increasing, this will cause lower temperatures, which may significantly affect the use of water heat exchangers. It will be impossible in the future to use wind turbines because of wind storms, in some areas of the world (Girgibo 2021). However, since climate change causes increased average global water temperatures, it is possible to install water heat exchangers, which can be useful throughout the year.

In winter, there is now less or no ice above some areas of the sea, rendering it possible to use water heat exchangers and wave energy as a heat source. Furthermore, these changes can be useful worldwide, at least in cold areas. If the ice in Greenland melts rapidly at the current time, it will reinforce the Gulf Stream near Finland and likely cause cold temperatures in the region. In this case, the energy needs of the islands can be solved by delivering oil. Since land uplift is producing more land between islands, people can walk to deliver oil, if they can no longer use boats. This can be adapted as an energy management policy if it is not possible to use renewable energy. In addition to the higher carbon emission effect, islands currently have much higher costs for oil delivery (Final report 2011).

Climate change is a question of environmental changes and sustainability in energy. Due to climate change, the sustainability of energy usage is affected, with current human solutions being inadequate. Therefore, there must be a change in how societies receive energy. 'Energy and climate (2014)' stated that in its roadmap for 2050, Finland's long-term objective is to be a carbon-neutral society. The researcher believe humans must focus on renewable energy and its production to preserve the world and our way of life. One of the most common sources of pollution in Earth's climate is the release of CO_2 and other gases from energy production with fossil fuels. This study is a small solution for that specific area. However, this is how one can begin to contribute to ongoing solutions in the worldwide energy sector.

The contribution of this project is making energy usage renewable, at least in a particular area such as the Kvarken Archipelago, which can help solve the global causes of climate change. In addition, the research is expected to deliver new knowledge, improve existing knowledge and solutions, create understanding and motivate other people and nations to act the same. Climate change is not an issue that is limited one nation or people: it is a worldwide issue. Therefore, we have the responsibility to act together toward the common goal of combating climate change. In the past, when people faced a common problem, they found ways of collaborating and solving it together. Although this is what was expected, it nonetheless took humanity a long time to collaborate internationally at the global level.

This research was one way of acting towards the adaptation of solutions as well as addressing the study of climate change effects on water quality in the UNESCO heritage area at the archipelago in the city of Vaasa, Finland. At least here at the University of Vaasa and Vaasa Energy Institute, the issue of energy sustainability has not been thoroughly investigated in previous studies. This research made much more effort to make solutions sustainable by taking advantage of climate change. By 'taking advantage of climate change', meaning using possible outcomes such as water temperature increases, increased wind, increased water flow in rivers, and increased solar irradiance as renewable energy sources. The most important questions for the future are: are these advantages or energy sources sustainable for the future or merely a temporary solution? What can be done if the increases are extreme enough to cause damage to energy technology systems, such as wind turbine damage?

Some research gaps included taking advantage of the relations between climate change, water resources and energy use, the application of seaside energy and predicting future renewable energy capacity increase due to climate change effects. Specifically, this includes adapting to climate change effects on energy usage and combating climate change, as well as finding the climate change correlations between meteorology and water quality in long-term data. This is related to the idea that climate change has effects on water (UNESCO 2009). Similar, climate change causes aquatic environmental changes due to increased pollution (UNESCO 2009). Therefore, people must continue to move forward through these changes. In addition, this research addressed forecasting land uplift, described the effects on the Gulf Stream due to climate change in the areas considered, investigated and proposed new energy solutions and carried out risk analysis for energy resources.

The motivations behind this research were addressing global climate change by combating it with adaptations and working towards a better future; providing solutions to seaside energy requirements; and knowing the effect of climate change on water resources, meteorology, and the future and current state of land uplift.

1.1 Background

This subsection delivers a brief introduction to the background knowledge for this research. Additional literature review reports were written during this research work and published separately. Due to the limited number of pages in an article-based doctoral dissertation, the literature review chapter was all not included in detail. Rather, this section represents a brief overview of the background.

1.1.1 Climate change and land uplift

The relationships between climate change and land uplift are presented here.

1.1.1.1 Land uplift

This section delivers a short background on land rise or uplift in Finland. Interest in the study of land rise began 300 years ago (Kääriäinen 1953). At first, many believed that land shift was due to a decline in the amount of water in the sea and oceans. It was believed that this occurred because of the evaporation of water, the consumption of water by plants, and oozing of water through the floors of the oceans into the interior of the earth, following the explanations of the physicist

Anders Celsius. In 1621, some even taught that it was a sign of the end times (Kääriäinen 1953). However, the water decrease theory and the supposed coastline changes were determined to be false by 1747. Others thought about that water in the north was drawn to the equator by centrifugal force due to the rotation of the earth, such that more land shore appeared in the north. However, the true reason for the phenomenon became clear with time. The Finnish land surveyor Ephraim Otto Runeberg was the originator of the theory that land uplifts were due to the movement of the Earth's crust. It is said at least fifty scientists were working on the question of land uplift before the beginning of the twentieth century. Then, through accurate measurements, it was found that the water level varies across different regions, being higher in the northern Baltic region and lower in the southern regions (Kääriäinen 1953).

The literature on land uplift includes both older and newer studies, including some recent publications, such as Nordman et al. (2020). The current studies on land uplift are essential. Based on the older studies, data on land uplift collected in Finland has two categories: recent measurements and prehistoric data (Okko 1967). The prehistoric measurements are based on late glacial (Late Weichselian) and postglacial shoreline displacements determined by geological and archaeological methods, of which area a few. On other hand, the recent measurements are based on oceanographic, hydrographic and geodetic methods. However, two of the most common forms of determining land uplift are levelling and the use of tide gauges (Kääriainen 1953). It is also possible to determine previous sea level rises from historic pollen sedimentation studies by carbon dating. Moreover, according to Okko (1967), the relation between sea level rise and land uplift in the late Quaternary times was little studied in those days; even now it is difficult to gather literature in these areas. There are recent publications on the relationship between land uplift and sea-level rise in the city of Vaasa, such as Nordman et al. (2020).

Listed below are some possible causes of land uplift. The causes of land uplift found by Kääriäinen (1953) and others are the following [adapted from Girgibo (2021)]: 1. Continents attract water; the larger the continent, the more water it attracts. This phenomenon depends on various factors, such as the aridity of the continent and the degree to which water is present, since the more water in the continent, the more raindrops it attracts. 2. The mass of the land and its attraction causes the small sea in its vicinity to sink, meaning that the land seems to rise. 3. The attraction of ice masses in the polar region causes water to move towards the pole; thus, as the glaciers melt, water gradually recedes. 4. At times, the shrinking of the earth's crust causes vertical movement. 5. Ice masses from the Ice Age cooled the Earth's crust, which began to warm after the ice began to melt. 6. Changes in volume in connection with the crystallisation process beneath the earth's crust are also a cause of land uplift. 7. The movement of the earth's crust due to periodic variation is another fact, since the folding and levelling out of mountain ranges causes weathering formation. 8. The weight of the ice on the earth's crust; this is thought to be flexible, so that when the ice melts gradually it causes a rise to the equilibrium position. 9. Finally, there is a possible connection between earthquakes and land uplift.

Part of the Finnish land uplift was caused by earthquakes. The region of southern Lapland-Kuusamo and the end of Lake Vänern (i.e. both ends of the relatively long land uplift regions) are areas where earthquakes have caused some uplift in Finland (Girgibo 2021 and Löfman 1999). However, most of the land uplift was likely caused by melting of the ice that suppressed the Earth's crust during the ice age in northern Europe, around 11,300 calendar years ago (Heinsalu 2001). This is a type of land uplift caused that is present in parts of the Vaasa area. The melting causes a gradual rise to the equilibrium position (cause 8 in the previous list). According to Okko (1967, table three), the land rise of the Vaasa and Finland area is around 4.3–6.1 mm/yr and 3–8.8 mm/yr respectively. Based on other studies, the land uplift in Finland is stronger in coastal areas. Merten Talo's uplift ranges from 8 to 9 mm/yr, according to statements and pictures presented in (Ekman 1996) and (Girgibo 2021).

Climate change is connected to land uplift by the sea level effect, as can be seen in the theoretical model of Okko (1967). This model demonstrates that there is a relation between land uplift and sea level rise, whereby the calculation of land uplift must consider sea level rise in affected areas. Since sea level rise is caused by global temperature increases, there is a clear relation between climate change and land uplift. In addition, there are negative correlations between land uplift and sea level rise in the data gathered. On other hand, there is a clear positive correlation between temperature increases and sea level rise. The current relationship between sea level rise and land uplift was touched upon in the Kvarken area in Poutanen & Steffen (2014).

Bill et al. (2018) found that land uplift in Alaska has been occurring for millions of years. The area that they analysed had volcanic conditions, but it is worth considering that the land uplift has been present in some parts of the world for millions of years and that the Vaasa region land uplift has been continuing for the past 10,000 years. With this in mind, land uplift will also continue in the future and affect islands and shorelines. The next section further investigates and describes the relationship between climate change (sea level rise) and land uplift.

1.1.1.2 Effects connected to climate change and land uplift and future expectations

Land uplift is affected by climate change, primarily due to sea level rise conditions. Land uplift mainly consists in the rise of land on sea shores; hence, if sea level rise occurs at same time, the two phenomena can affect one another. According to the theoretical model of Okko (1967), there are three alternatives: 1) the sea level rise might be higher, causing a possibility of flooding or a decrease in the land uplift level (decrease in land size). 2) The effects might compensate one another so there is no net change. Finally, 3) the land uplift might exceed the sea level rise, causing the sea size to shrink. The finding of Norman et al. (2020) show that future land uplift in the Vaasa region is expected to continue to exceed sea level rise.

The changes in temperature due to global warming cause sea level rise by melting the ice in Antarctica, North Pole and South Pole glaciers and in Greenland. Based on recent publications, most of the predictions of the temperature increase are higher, meaning there is more anticipated sea level rise. The higher the temperature levels, the greater the sea level rise. As such, a higher expected future temperature should lead us to expect more sea level rise. This naturally leads to the question of how much sea level rise is expected in the Vaasa region.

Land uplift is a well-established phenomenon; indeed, in some places such as southern Alaska, it has been established to have been occurring for millions of years (Bill et al. 2018). Therefore, the continuity of land uplift might not be in question. Further, if climate change is not successfully combated, sea level rise is also expected to continue. Even if immediate actions are taken to stop CO_2 emissions, which is the ideal case, sea level rise will continue for a long time due to the carbon dioxide and other greenhouse gases already present in the atmosphere causing a rise in temperature globally. It is thus important to know whether sea level rise or land uplift will win in the Vaasa region, or whether the two will compensate one another.

Sea level rise is a phenomenon driven by the temperature increase in the environment. When the temperature increases the stored ice in the world melts; further, the volume of bodies of water expands due to an increase in water temperature. Sea level rise is facilitated and driven by the world temperature increase (global warming), which is caused by climate change. Knowing that climate change will increase global warming, one can expect greater sea level rise in the future. In Dasgupta and Meisner's (2009) study, it is estimated that the future sea level rise might be 7 m higher if all the Greenland ice melts and 70 m higher if all the Antarctic ice sheet melts. In such a case, the land uplift effect will be completely outweighed by sea level rise.

This connection between climate change (sea level rise) and land uplift was part of the idea studied in this research. Land uplift can further affect the implementation of seaside renewable energy, due to the difficulty of installing the necessary infrastructure on the seaside. Another aspect of the connection to climate change is that land uplift can be affected by increased sea levels. The focus of the research was the triangular relationships among climate change, land uplift and seaside renewable energy solutions. Indeed, knowing the connections between climate change effects, land uplift and the anticipated future trends in these phenomena is a vital part of the main idea. The next section deals with the impacts of climate change on water resources and quality.

1.1.2 Impacts of climate change on water resources and quality

A brief description of the relationships between climate change and water resources are presented here.

1.1.2.1 Impacts and factors affecting water quality in water bodies due to climate change

This section briefly explains the factors affecting water quality (WQ) due to climate change, specifically those affecting water bodies. The water quality parameters are listed on the next table, along with factors due to climate change that affect water quality and water bodies. Table 1 is useful in seeing which types of climate change factors will affect water quality. Based on the climate change factors, it is possible to predict the effect on the water quality parameters and vice versa. The IPCC (2007) suggests that the two main drivers of climate change are higher water temperature and variation in run-off. As seen in the following table (Table 1), temperature increases are one of the main factors affecting water quality in almost all water quality (WQ) parameter relations. Therefore, the table is useful in understanding the possible sources of climate change effects, which is necessary for researches of such as the present one.

Table 1. Impacts of climate change on water quality parameters (Shrestha et al. 2014).

Water quality (WQ) parameters			Climate Change Factors affecting WQ	Water body
Physico-chemical	Basic parameters	pH	Drought, temperature increase, rain fall	Rivers, lakes
		DO	Drought, temperature increase, rain fall	Rivers, lakes
		Temperature	Drought, temperature increase, rain fall	Rivers
	DOC		Temperature and rain fall increase	Streams and lakes
	Nutrients		Temperature and rain fall increase, droughts, heavy rainfall	Rivers, lakes, streams, ground water
Micro pollutants	Inorganic	Metals	Temperature and rain fall increase, droughts, heavy rainfall	Rivers, high alpine lakes, streams
	Organic	Pesticides	Temperature and rain fall increase, drying and rewetting cycles	Surface water and groundwater
		Pharmaceuticals	Temperature increase, rain fall	Surface water, groundwater
Biological	Pathogens		Temperature and rain fall increase	Surface water
	Cyanobacteria		Temperature and rain fall increase	Lakes
	Cyano-toxins		Temperature increase	Lakes
	Green algae, diatoms, fish		Temperature increase	Freshwater
	others		Temperature increase	Soils

1.1.2.2 The capacity fluctuation of water bodies due to climate change and its relation to energy

This section deals with water capacity fluctuations that affect possible energy sources because of climate change. The capacity of stream water is highly affected by climate change and the change in stream water varies from place to place. According to Shrestha et al. (2014), the Nile River is vulnerable to drought. As such, the effect of climate change leads to a reduction in hydropower production and increases conflicts between nations, which causes a decrease in agricultural use. Consequently, the reduction in hydropower is related to climate change and affects the use of water for energy. As mentioned, climate change is causing stream water reduction in some areas, causing a decline in hydropower plants due to the lack of sufficient water capacity to run the plant. This particularly affects those countries that primarily rely on hydropower, such as Ethiopia. Conflicts have arisen in recent years between river-sharing nations such as Ethiopia, Egypt and Sudan, which share the Nile River. Ethiopia is currently building a dam for electricity production, which the other nations do not want since it will reduce river flow capacity in their lands.

The reduction in the use of renewable energy (hydropower) sources in a country might cause a change to alternative energy sources, such as coal and fossil fuels. Therefore, the effects of climate change on water resources leads to an energy shortage, leading in turn to the use of non-renewable sources as a replacement. This further worsens climate change by increasing CO_2 emissions into the atmosphere, creating a vicious cycle. Figure 1 illustrates the relation, with water reduction leading to reduced energy production and further climate change effects on the cycle. The change in energy production due to water resource reduction is one type of relationship between energy, water resources and climate change. Another relation arises from the need for a plant or energy production unit to have fresh water for systems cooling, such as thermal power and nuclear power stations. That causes a reduction in freshwater, which in turn will cause the power stations to decline in their continuous production capacity.

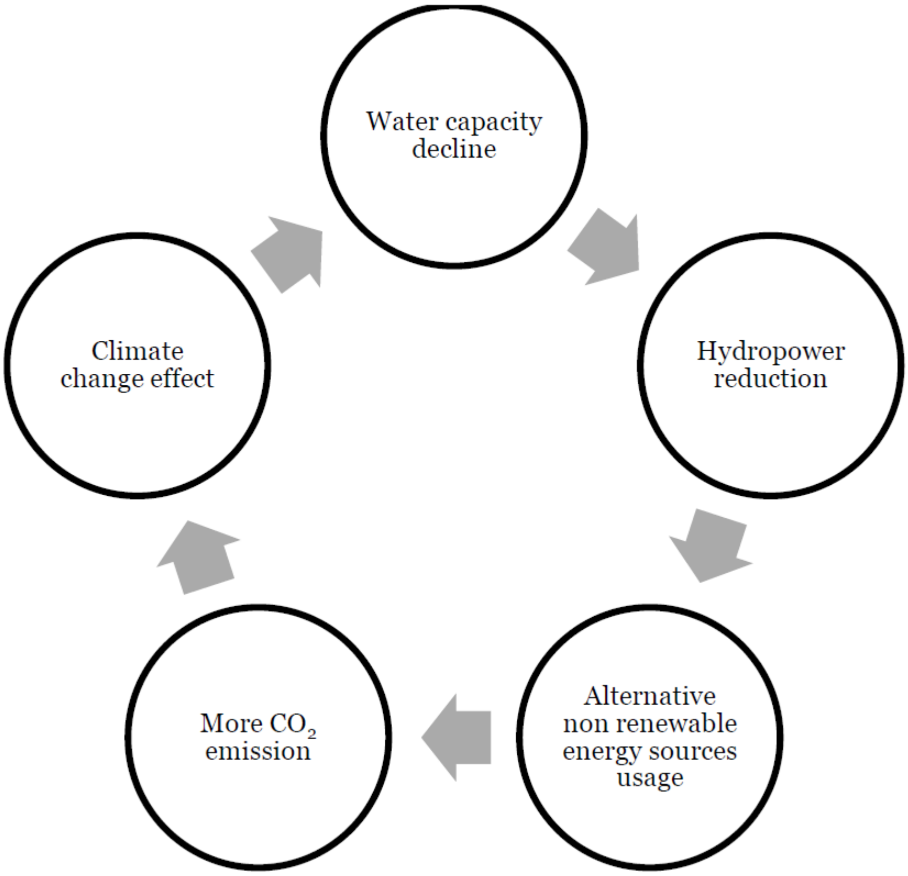


Figure 1. Examples of the cycle between climate change effects and water resource reduction, and the consequences of the cycle.

In short, then, water shortages limit hydropower energy usage and other possible energy solutions are developed by increases in water capacity. In the Kvarken Archipelago area of Finland, streams are increasing in capacity, according to Girgibo (2021). Huttunen et al. (2015) stated that water run-off will increase by 3–11% relative to 2001–2010 in all parts of Finland. Due to the increase in precipitation, based on the model, this might represent up to 25% of the run-off increases in other models, especially in the middle and southern parts of Finland. From the same study, run-off decreases in dry seasons by 2–13% due to the decrease or slight increases in precipitation in those seasons, which is due to an increase in evapotranspiration. Thus, the stream water increase is due to ice melting, water temperature increasing (causing an increase the volume the water due to thermal expansion) and increased rainfall in the surrounding areas. This leads to floods, erosion and other effects on the ecosystems. Girgibo (2021) described the expected environmental changes in the Kvarken, Archipelago area.

The streams in the protected UNESCO World Heritage area in the Archipelago are small, so there is no possibility of using them as a hydropower source. On other hand, the reason for sea level rise is an increase in incoming water to the sea. Even if the streams are too low in capacity for hydropower production, the increasing seawater can then be used to install water heat exchangers for heating purposes. Hence, the water in the sea is cooler in the summer and used to cool households, whereas in the winter, it can be used as a heating source. Furthermore, the other advantage of increased water capacity and sea level rise is the use of wave energy. Wave energy is ideal in island areas with seawater waves present in open areas almost throughout the year, or at least in summer. Wave energy will increase in the future because of the ice cover decline, leading to the suggestion that wave energy will be an ideal energy source for the coming years. In brief, wave energy provides the opportunity to use the relations between climate change effects and water resources for energy production. In other areas of the city of Vaasa, sediment heat energy production can benefit from temperature increases due to climate change. Sediment heat energy production is also an ideal solution that uses climate change effects to its advantage in summer.

1.1.2.3 Adaptation of climate change by using water resources as a medium in renewable energy systems

Our children and the future of our planet are at risk (Girgibo 2021). Global climate change forecasts are not positive. Knowing how to adapt to climate change makes it easier to combat it. In addition, adaptation is one of the action plans of the Paris Agreement on climate change (2015) signed by 196 countries. Carbon dioxide accumulation is a cause of climate change and water changes are one result of this (UNESCO 2009). Reducing carbon emissions is one form of combating climate change. Climate adaptation literature suggests that future actions must combine mitigation of and adaptation to climate change.

The use of renewable energy is the primary means of reducing carbon emissions from energy production technologies. Since greenhouse gases cause global warming, we can adapt or use the effect of global warming on water bodies as an advantage for energy sources or solutions. One of the effects of climate change is the greenhouse effect, the process where thermal radiation is absorbed and re-emitted by the lower atmosphere [(Shrestha et al. 2014); (Hannah 2011)]. Based on Shrestha et al. (2014) and an IPCC statement (2007), it is very likely that an anthropogenic increase in greenhouse gas concentration since the middle of the twentieth century has caused the global average temperature to increase. If these temperature increases will be present over a longer period, they might be used as energy source enhancements.

As a result, the adaptations planned for installation are water heat exchanger and borehole systems. Sediment heat energy also benefits from climate change, and this energy source thus represents an excellent solution to climate change adaptation. It is also possible to use groundwater and thermal energy source systems (GEU and UTES) in Vaasa and nearby regions. In addition, it is possible to use sediment heat production systems. GEU (groundwater energy utilisation) is a system that uses groundwater as a heat energy resource by pumping it to the surface and transferring the heat for use. It can be used for both heating and cooling systems (Arola 2015). One of the suggestions of this research is the use of GEU in the city of Vaasa. However, it requires experimental visibility investigation before it can be adapted. On the other hand, UTES (underground thermal energy storage) includes aquifer thermal energy source systems (ATES), borehole thermal energy source systems (BTES), sediment heat energy production, solar thermal panels, asphalt energy, and land and pond energy. Therefore, these renewable energies not only help us to adapt to or take advantage of climate change but also help replace non-renewable systems to reduce CO_2 emissions. The relations of these energy sources to water and climate change make them of interest for this research. Figure 2 shows the possible strategy of using taking advantage of the effects of climate change to help combat it.

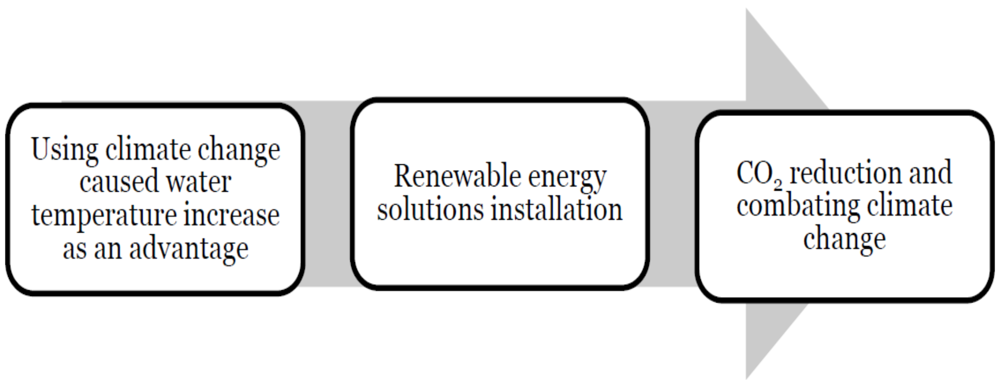


Figure 2. One form of combating climate change is by using its current effects as an advantage.

1.1.3 The start of a renewable energy project in the Kvarken area

There have been previous renewable-energy-initiated projects before the Merten Talo project. For example, the project 'Drop in Sea' dealt with an integrated hybrid renewable energy solution for island operations (Final report 2011). The 'Drop in Sea' project's final materials are used in this research as a starting point and as background material for renewable energy installations and for study in the Kvarken Archipelago area. The 'Drop in Sea' project was completed before the start of the research that forms the basis of this work. However, it helped in understanding the need for renewable energy solutions in areas considered, and as a source for those areas and for the specific renewable energy requirements for this research work. The project aimed to develop self-sufficient integrated energy solutions based on renewable energy resources in the local islands.

The overall objective of the 'Drop in Sea' project was to develop a service concept and product portfolio for the self-sufficient production of energy based on renewable energy sources in the independent small-scale target (island operation). Additional higher-level objectives included the development of a small-scale decentralised power generation value chain, covering a range of energy sources, and the use of automated production, distribution, and energy-efficient management and economy. The location of this project was the Northern Kvarken islands, located near the Kvarken Archipelago UNESCO World Heritage sites, as well as the area of the Merten Talo project, the water quality sampling points and the two weather stations, all of which are central topics for this research work. The 'Drop in Sea' project was in the island destination of Metsähallitus, Vaasa. There are empty coastguard and pilot stations, which are currently threatened with closure and were mainly intended for tourist use (Final report 2011). Appendix 1 presents the project sites, the water sampling points and the weather data collection station sites.

1.1.4 The UNESCO World Heritage Site in the Vaasa region of Finland

The particularity of the Kvarken Archipelago is that it has existed since time immemorial (Hietikko-Hautala 2012). As such, the study of this area is intrinsically special. This area serves as a sort of natural museum, since it experienced land uplift growth during the ice age. In addition, the Gulf of Bothnia, the narrow sea between Sweden and Finland, has also been an important transport route (Hietikko-Hautala 2012). Further, Hietikko-Hautala states in her book that the Kvarken Archipelago World Heritage site, whose official name is the High Coast/Kvarken Archipelago, belongs to both Finland and Sweden. This site was accepted to be a part of the UNESCO World Heritage protected areas on 12 July 2006, meaning that its recognition took 20 years. A group of local activists initially proposed the Kvarken archipelago as a Natural Heritage Site (Hietikko-Hautala 2012). Figure 3 shows the High Coast/Kvarken Archipelago UNESCO World Protected Site area.

'Kvarken is the narrowest part of the Gulf of Bothnia and forms a shallow threshold between the Bothnian Sea and the Gulf of Bothnia' (Hietikko-Hautala 2012). In Finnish, Kvarken is called *Merenkurkku*, meaning 'the throat or neck of the sea'. The southernmost part of Kvarken is about 30 kilometres north of the High Coast in Sweden. The distance between the outermost islands of the two archipelagos is only 70 kilometres. Northern Kvarken is the narrowest part of the Gulf of Bothnia (Breilin et al. 2004). 'The Kvarken Archipelago World Heritage Site lies in the eastern part of Kvarken, which is part of the Bothnian Sea, which in turn is part of the Baltic Sea – the world's largest brackish-water sea. Kvarken Archipelago, which is in the county of Ostrobothnia, stretches from the Mickelsörarna islands in the north to the island of Halsön in the south. From the city of Vaasa, the distance is approximately the same to the northern and southern extremities.' (Kvarken Archipelago and Merten Talo 2016).

Figure 3. The area and location of the High Coast/Kvarken Archipelago UNESCO World Protected Site (white circles) (Hietikko-Hautala 2012 and High Coast/Kvarken Archipelago presentation, Kvarken Archipelago and Merten Talo 2016).

Historical recognition process timelines

According to Hietikko-Hautala (2012), the timeline for the recognition of this World Heritage site as follows (lists of dates and explanations are taken directly from her book):

- 1986 – 'Finland ratifies the Convention Concerning the Protection of the World Culture and Natural Heritage'.
- 1989 – 'The World Heritage work group begins to investigate potential World Heritage Sites in Finland'.
- 1996 – 'The Nordic Council of Minsters' 'Verdensarv i Norden' report is published'.
- 1997–2000 – 'The first application is drafted according to the biological criteria'.
- 2000 – 'Expert Geologist Paul Dingwall from the IUCN (International Union for Conservation of Nature) visits Kvarken'.
- December 2000 – 'The Swedish High Cost (Höga Kusten) is granted World Heritage status'.
- 2001–2002 – 'The second application is drafted according to the geological criteria'.
- April 2002 – 'The Västerbotten Country Administrative Board (on the Swedish side of Kvarken) withdraws for preparations'.
- 2002-2005 – 'The third application is completed. The Finnish side of Kvarken is proposed to become an extension to the High Coast based on geological criteria'.
- 2005 – 'Evaluator Jim Thorsell from the IUCN visits Kvarken'.
- 2005-2006 – 'The application is considered by the UNESCO World Heritage Committee'.
- 12 July 2006 – 'The Kvarken Archipelago is approved into the UNESCO World Heritage List in Vilna, Lithuania'.
- 8 September 2007 – 'The inauguration ceremony for the Kvarken World Heritage Site is held, headed by President Martti Ahtisaari'.

What is World Heritage?

'World Heritage is a globally accepted international agreement for cooperation in searching for, examining, identifying and designating unique culture or natural sites whose preservation is considered exceptional value to the whole of humanity' (Hietikko-Hautala 2012). This is important both for humanity and for the protection of nature. The World Heritage Sites belong to all humans on Earth regardless of where they are located, according to the World Heritage philosophy (Hietikko-Hautala 2012).

According to Hietikko-Hautala (2012), the history of the establishment of the idea of World Heritage was as follows: After the Second World War, an international movement was born. Two simultaneous movements, one for the preservation of cultural sites and the other for the protection of the natural environment, were combined in an international agreement that came into existence in the year of 1972. In addition, in 1965, a proposal was made by the United States to combine international nature protection with the conservation of cultural heritage sites. Today this combination communicates an important message: that all humans can choose the manner in which they interact with and live in their environment (Hietikko-Hautala 2012).

The Kvarken archipelago was accepted for inclusion on the World Heritage List on geological grounds (Hietikko-Hautala 2012). This is important because geological formation is an ongoing process in Finland as well. Hietikko-Hautala state that the Kvarken archipelago also fulfilled the requirements that Geological Natural Heritage Sites should 'be outstanding examples representing the major stages of the earth's history, including the record of life, significant ongoing geological process in the development of landforms, or significant geomorphological or physiographic features' (Hietikko-Hautala 2012). This also provides excellent conditions for research work, which gives this area additional value, as Hietikko-Hautala states in her book. This means the study of the effects of climate change on water systems in this area, as in the current research, has the opportunity to see the natural environment without additional sources pollution, which in other areas' water systems can give incorrect values in understanding climate change effects in water quality analysis. In addditon, the area has unique features.

Two sites, the High Coast in Sweden and the Kvarken Archipelago in Finland, form a joint World Heritage Site (Hietikko-Hautala 2012). They are opposite in their topography (high elevation in the High Coast and low elevation in the Kvarken archipelago), although they are only 70 km apart (Hietikko-Hautala 2012). They both give a complete picture of the land uplift phenomena caused by the last ice age and its geological and biological effects, according to Hietikko-Hautala (2012).

The Ice Age and Land Uplift (based on Hietikko-Hautala 2012)

The story of the uplift of the Kvarken land begins when the Gulf of Bothnia and the whole of Fennoscandia was covered by the last continental ice sheets (Hietikko-Hautala 2012). According to the same text, when the ice started to melt, the Brock ice sheet gave rise to icebergs and eventually formed a wide bay flowing from Sweden, from which large icebergs drifted to the south. The birth of the Kvarken Archipelago was due to the flowing and melting of the retreating continental ice sheet and the movement of enormous masses (Hietikko-Hautala 2012). In addition, the Kvarken Archipelago is established on smoothly worn bedrock with special geological features, namely well-formed De Geer moraines. This geological feature is found abundantly in extensive fields in the Kvarken archipelago (Hietikko-Hautala 2012). The intention of the World Heritage designation is specifically to preserve these traces of the ice age for future generations, according to Hietikko-Hautala's (2012) book.

According to Hietikko-Hautala (2012), the land area of the Kvarken archipelago increases by a square kilometre every year. For instance, she states that 35 hectares of new land are exposed each year on the islands of Replot and Björkö. The annual uplift in the Kvarken archipelago and in the city of Vaasa in general is about 8–9 mm based on various references. Hietikko-Hautala (2012) states that this uplift is slower than in some areas in the world, such as on the coast of Canada and in Hudson Bay and James Bay, but that the phenomenon is better observed in the Kvarken archipelago than elsewhere. In her book, she explains that this is because the uplift is 'affected by the increase in the rate of land uplift together with the shallowness and low topography of the moraine archipelago'. This not only helps preserve the traces of the ice age, but also assists in seeing the actual area of the uplift phenomena. This is because new landscape formations are constantly being raised and become more visible, based on Hietikko-Hautala (2012).

The Kvarken archipelago is very shallow and rocky. Hietikko-Hautala (2012) stated that 'the deepest water is located on the southern and northern flanks of the submarine ledge in the kvarken stairs'. The deepest point is approximately 25 metres on the eastern side of Holmön in Sweden. The current uplift in Kvarken was caused by the end of the ice age, which had depressed the land, causing it to rebound. It was stated in Hietikko-Hautala's (2012) book as follows. 'Land uplift began with glacial melting when the earth's crust was freed from the burden of the continental ice sheet, up to 3 kilometres thick. The mass had pressed the crust down for approximately a kilometre and as the pressure was released it began to rise slowly. Uplift already began below the melting continental ice sheet and, initially, was noticeably faster than at present'. The same book states that until

2012, uplift was 800 metres and that 100–150 metres more land uplift remained and would continue slowly, without breaking, for at least another 10,000 years, unless a new area of glaciation placed additional weight on the ground.

1.1.5 Climate change mitigations and renewable energy

It is well-known that renewable energy usage is used to mitigate climate change effects or to reduce fossil fuel pollution. The main source of pollution and greenhouse gases (GHG) is energy production from fossil fuels. In addition, other significant contributors for GHG are energy use for power, industrial processes, mobility, the building sector including the construction sectors. Numerous books and articles suggest that renewable energy can be one way to mitigate climate change. One such reference is Hannah (2011) who suggests that using renewable energy is the correct strategy for the present and future. Implementing renewable energy at the local level, as in the Merten Talo project, provides a means of using this resource. In addition, this will help to mitigate climate change, at least in the future, when more local areas start to use renewable energy resources. Furthermore, it will facilitate the process of renewable energy usage in regional development.

By 2020, renewable energy sources (RES) are planned to represent 20% of energy consumption and 10% of transportation in the EU (EEA report 2018). In addition, it was stated that the new plan for 2030 is for RES to be 32% of energy consumption and 14% of transportation by the same year. Finland is planning to ensure 38% of energy consumption comes from renewable energy resources. Finland's plans have been progressing well. This plan and some elements that have been established show that the EU is working hard to reduce climate change pollution and limit further climate change effects. This is a very important step for the world, one that can make the EU an example of human progress towards solving our only planet's primary problem, climate change.

However, to meet these targets, further commitments are required, especially because some EU nations' final energy consumption has increased (EEA report 2018). In addition, it was stated in the report that 'Final energy consumption increase in EU member states are slowing down the pace of growth of renewable energy sources share across the EU'. On the other hand, renewable energy has some limitations that impede its use as a large-scale energy resource such as the cost of renewable energy solutions, its being limited to local areas due to the need for an energy source, lack of systematic infrastructure connecting renewable energy production to electrical grid and seasonal fluctuations that can limit the production of the required amount of energy, such as in solar and wind. To solve these problems, the use of hybrid renewable energy resources is recommended.

Hybrid renewable energy solutions have their advantages. Based on an article by Nakomcis-Smaragdkis and Dragutioovic (2016), an experiment performed in Siberia found that hybrid renewable energy can be cost-efficient and energy-efficient over time. This is one reason to build and utilise hybrid solutions, principally those coming from renewable sources and mitigate climate change. In their analysis, the authors study the use of geothermal heat pump heating/cooling, solar photovoltaic panels and small wind turbines to supply power. They also state that 'hybrid solutions/systems represent excellent solutions for remote area power applications, where grid expansion is costly'. This means that hybrid solutions are better for remote areas and islands. This can be one reason to use and build hybrid renewable solutions, in addition to the contribution of such solutions to mitigating climate change.

According to the EEA report (2018), because of EU reporting requirements [the Monitoring Mechanism Regulation (MMR)], most climate mitigation policies and measures were reported by the Member States in 2017. MMR aimed for a desired reduction in GHG emissions from fossil fuel-based energy consumption (29%), transport (21%) and energy supply (15%). This was often achieved by increasing RES shares. In the EU, this has been a very important practice for mitigating climate change by setting goals and creating regulations. About 70% of newly installed power worldwide in 2017 was of renewable origin (EEA report 2018). It is encouraging to see this increase in renewable energy resource utilisation, which promises progress in mitigating climate change.

The EU is the global leader in renewable energy usage per capita, but outside of the EU, there are countries that are rapidly increasing their renewable energy activity (EEA report 2018). It is important that the EU increase its activity to accelerate its transition so as to continue to be a leader in renewable energy use per capita in the future. China and India are currently very active users of renewable energy, which is encouraging for developing nations. However, they both also still use and install fossil fuel industries, which make EU to be the leader in renewable energy development. Among the challenges that remain for EU Member States are to reach EU climate and energy targets for 2030 and to become a sustainable, and low-carbon economy by 2050, thus satisfying the Paris agreement (EEA report 2018).

One example of how renewable energy can help resolve climate change is the following: 'The increased consumption of renewable energy in 2016 compared with 2005 levels allowed the EU in 2016 to. 1. Reduce its total GHG emissions by

460 $MtCO_2$, equivalent to 9.4 % of total EU GHG emissions. 2. Improve energy security by cutting demand for fossil fuels by 143 Mtoe, or roughly 12 % of total EU fossil fuel consumption. 3. Improve energy efficiency by reducing the EU's primary energy consumption by 35 Mtoe, equivalent to a 2 % reduction in primary energy consumption across the EU' (EEA report 2018). This is strong evidence of the effectiveness of the idea of solving climate change through renewable energy installation. To meet the Paris agreement, the EU must reduce its GHG emission by 80% to 90% by 2050 compared with the 1999 levels; in addition, it must decarbonise almost all energy-generating sectors. In pursuit of this goal, both renewable energy and energy efficiency are a key pillar of decarbonisation in the EU's transition to a low-carbon economy and society (EEA report 2018).

The use of renewable energy in the EU has been increasing both as a share of energy consumption and in absolute magnitude (EEA report 2018). Thus, it is replacing the fossil fuel market to a certain degree, which effectively reduces CO_2 emissions. 'According to EEA calculations, in 2016, the largest relative reductions in the consumption of fossil fuels were made by Sweden (32%), Denmark (26%) and Finland (17%), in proportion to their gross domestic fossil fuel use' (EEA report 2018). It is promising that Finland has one of the largest relative reductions, but compared to Sweden and Denmark, there is much to be done regarding the use of renewable energy. The same report said that the highest absolute fossil fuel avoided was recorded in Germany, Italy and the United Kingdom, where the most renewable energy is consumed. Figure 4 demonstrates the EU's experience of how the primary sources of GHG emission can be reduced by implementing renewable energy resources.

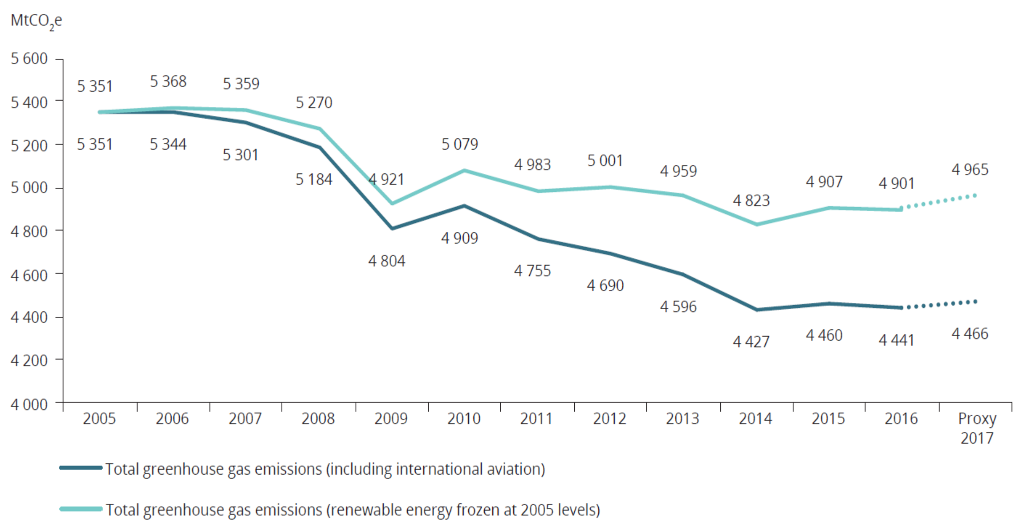


Figure 4. Estimated gross effect on GHG emissions in the EU (EEA report 2018).

The idea of using renewable energy to reduce climate change effects is demonstrated for the EU in the previous figure. The research thus concludes that renewable energy is an effective means of mitigating climate change at a significant level. The EU has been progressing in the development of renewable sources, which is a good example for the rest of the world. The share of renewable energy was 17% in 2016 and 17.4% in 2017, compared to 9% in 2005 (EEA report 2018). The same report also states that in most nations in the EU, including Finland, renewable energy is primarily used in heating and cooling, followed by electricity and transport in that order. Since most nations have some months of winter with lower temperatures and more snowfall, this can explain why heating is takes the largest share. Some years ago in Finland, the summer was also quite hot; it is certain that during that period, the energy used for cooling in the country increased.

The 2020 renewable energy development target had already been exceeded in 2017 for Finland, as well as for Sweden and a few other EU nations (EEA report 2018). The share of renewable energy in 2016 was highest in Sweden (53.8 %), then in Finland (38.7%), Latvia (37.2%), whereas Luxembourg (5.4%), Malta (6.0%) and the Netherlands (6.0%) had the lowest shares in EU. There is more to be done here in Finland to reach the Swedish level or above it. It is certain that this progress will minimise the causes of climate change, which is mainly due to GHG emissions. It is essential for nations that their people and community believe in the use of renewable energy. People may not have realised the capacity of renewable energy and its potential to safeguard our planet from problems such as pollution and climate change.

It is important to emphasise here that climate change can be solved or at least minimised by the massive implementation and use of renewable energy at a global level. It is also very important that renewable energy implementations be used when developing undeveloped nations. Some nations have greater resources due to climate change that can be used in renewable energy production. For example, in most African nations, solar power has been increasing over time. It is important for us to take advantage of this; merely criticising climate change does not solve anything. The greenhouse gas emissions decline illustrated in the above picture (Figure 4) can be achieved across the world. This means asking the right questions, believing, and implementing measures that protect our world by changing our previous behaviours.

For instance, in our implementation, one can take advantage of climate change when using water heat exchanger and sediment heat energy production equipment. This is because water temperatures are expected to increase in the future due to the air temperature increase associated with global warming. The higher the water temperature, the more heat energy can be extracted and stored by this equipment. Less fossil fuel used as a heat source fewer GHG emissions, and lower GHG emissions means fewer climate change effects, at least in the future. Hence, greenhouse effects are the main cause of climate change effects. Another example is that the lower the amount of ice present at sea, the greater the increase in wave energy. Similarly, the stronger the wind due to climate change in specific areas, the more wind energy can be used, and the greater the increase in solar irradiance, the more solar panels can be used for solar energy.

1.1.6 Climate change impacts on the gulf-stream

Based on the Pawlak & Leppänen's (2007) description, climate change in the Baltic Sea is related to global climate change, with projections in this area being based on global climate changes and local/regional climate change models with the combination of emissions scenarios due to greenhouse gases and aerosols. The global effects of climate might be different from the local effects. Therefore, it is important to consider both global and regional models in creating the future climate change forecast. In addition, the atmosphere has a greater influence on the sea ice pattern. The Bothania Sea, consisting of large ice sheet sectors, was governed primarily by atmospheric rather than marine processes, as highlighted by Clason et al. (2016). This has been further influenced by the higher temperature change in the Baltic Sea over the last few decades. Concretely, from 1861 until 2000, the warming of the Baltic Sea was about 0.08 ^{O}C per decade, but global warming for the entire world was about 0.05 ^{O}C per decade (Pawlak & Leppänen 2007). This shows that the change in warming in the Baltic Sea is somewhat higher than global warming.

The main idea here was to address whether the gulf-stream pattern changes were due to the melting of global ice sheets, as well as what the temperature of the surrounding area, including the nearby land and the Baltic Sea, will be in the future. Global warming already has caused higher temperatures and a longer frost-free season in the Baltic Sea (Pawlak & Leppänen 2007). The land and air temperature has increased all over the world, including in Finland. The future temperature forecast shows that a temperature increase is also expected in this area. The largest change noticed was a decline in the ice cover season, which decreased by 14–44 days in the Baltic Sea in the past century due to the early break-up of ice. As such, how low ice cover seasons influence the nearby land temperature should be investigated, since it is likely that this has been contributing to the temperature increase on land. The length of the ice season and the date of ice break-up shows a correlation with the NAO (North Atlantic Oscillation) (Pawlak & Leppänen 2007). This is important, since it shows that world climate changes influence local changes. In addition, the Atlantic meridional overturning circulation (AMOC) has a major impact on climate and its evolution during the industrial era is poorly understood (Caesar et al. 2018).

A similar pattern of winters with more precipitation than summers was observed in the Baltic Sea basin (Pawlak & Leppänen 2007), just as with Finnish landmasses. This has an influence of the temperature of the Baltic Sea. The southern area of river flow to the Baltic Sea has decreased, so that drier conditions are present in the southern area in summer and a decrease in salinity has been observed in the Baltic Sea to some extent, according to the same text. In addition, the ice thickness and melting time has decreased relative the past century. This is influencing the pattern of flow from the river to the Baltic Sea. It is very difficult to find a text stating the effect of the gulf-stream pattern. This pattern is mainly influenced by the melting of the Greenland and Antarctica ice sheets. If these ice sheets melt in large part or completely, cold water will flow into the northern part of the Baltic Sea, which might cause lower temperatures on land. We might imagine it would cause more warming, depending on the water temperature and how the Baltic Sea influences the nearby land, such as the western part of Finland and the eastern part of Sweden.

Further, when snowfall declines or ice cover disappears, the degree of snow reflectance/albedo declines, causing warmer water temperatures due to the presence of a heat sink. This might influence higher temperatures on nearby land. If one imagines future climate change effects, which mean less snow or ice cover and more intensive radiative forcing, there is also a chance that the melting of the ice sheets might lead to the second alternative, that the Baltic Sea Gulf Stream might cause higher temperatures on nearby land. The first alternative was stated in the previous above paragraph; the Gulf Stream might cause coldness on nearby land because cold water flowing from ice sheets melts in other parts of the world. The third alternative might be that there will no changes that exerts a substantial influence on the current effect of the Baltic Sea Gulf Stream in nearby countries. A more focused study must be conducted to identify which of these three possibilities will occur. This is a promising area of study for the near future. There will also be changes in water quality and other important physical and biological patterns, such as the water flow volume and pattern (hydrology changes and temperature changes) if changes occur in the Gulf Stream. Ecosystems in the Baltic Sea could change dramatically if the Gulf Stream change occurs.

According to Pawlak & Leppänen (2007), in recent years snow cover decline has been observed in southern Fennoscandia countries, whereas, in the northern part of these nations, the ice cover has become thicker. The authors also mention that in Finland, the ice cover became thicker in the northern and eastern parts (snow melt slowed), whereas the south and western sections saw a decline in ice cover thickness (snow melt intensified) toward the end of the period from 1946–2001, based on the same article. If these kinds of natural balances in nature and weather conditions progress, it is possible that no severe due to the Gulf Stream change in the Baltic Sea will be observed. This implies that the third option in the previous paragraph might apply in the future. On the other hand, if we consider the statement of Pawlak & Leppänen (2007), there is an indication that in the western Gulf of Finland summer (May – July) water temperature in the upper 30 m increased in the second half of the 20th century. If this seawater temperature continues to increase the second option might occur and the Gulf Stream might produce higher temperatures on nearby land.

Westerlund & Tuomi (2016) carried out an intensive study of Baltic Sea temperature and salinity profiles over two summers, but there is not much information about Gulf Stream changes. Greenwood et al. (2017), studied the Bothnian ice stream in the past, but their research also said nothing about the Gulf Stream changes. It is somewhat difficult to find exact statements or studies about the Gulf Stream pattern or how it may change in the future, which renders it difficult to know its consequences. Further study on this topic is recommended. On the other hand, Caesar et al. (2018) stated that, based on model simulations of warming in the Gulf Stream, the region is expected to warm in the future due to the northward shift of the Gulf Stream. These warming effects on nearby lands are the most pronounced during the winter and spring (Caesar et al. 2018). Thus, according to the same article, the second alternative, in which the future Gulf Stream causes warming in nearby regions is the most accurate forecast of the future Gulf Stream effect.

1.1.7 Climate change and how it was addressed

This section answers the question of the nature and definition of climate change [For the answer to this question, please consider seeing the definition of climate change from IPCC (2007) reports and Girgibo (2021)]. Climate systems studies is the necessary basis for understanding the causes and effects of climate change. In the past, the cycle of heating or cooling proceeded naturally. However, anthropogenic (human) effects have been proven to be the cause of current climate change (IPCC 2007, 2013 and 2014).

As stated in Hannah (2011) and Girgibo (2021), understanding climate change requires understanding the related issues, as follows: 1) Climate change biology (Hannah 2011) is a field that considers the interaction of biological ecosystems and changes in the climate. This discipline studies the impacts of climate change in natural systems. The future impacts of climate change, is a broad area that touches upon all dimensions of biology. 2) Chemistry of climate change: the greenhouse-gas effect is present in both land and water ecosystems. The reduction in the amount of calcium carbonate in water (saturation state), and the decrease in the earlier acidification of the sea, are caused by the dissolving of CO_2 in seawater. The saturation state has caused creatures to have insufficient calcium carbonate for their shells or skeletons because they used to get the calcium carbonate from the seawater. On other hand, the Climate Institute (2010) stated that the reduction of 0.5 pH in seawater caused an expected drop of 60% in the availability of calcium carbonate. The calcium carbonate secretion by mussels has been well-studied for a long time. The great scientist Charles Darwin was among those who studied mussels.

Species extinction, reduction in abundance, or range shift is observed in the presence of more acidic water, especially in diverse mollusc's sea creatures such as mussels and corals. This is because acidic water contains less calcium carbonate. The altered pH in the seawater is the direct effect of acidification. According to Armitage et al. (2010), in the past century, ocean water has become more acidic (a decrease in pH of 8.1 to 8.0) due to the presence of 30% more H^+ due to dissolved CO_2 pollution. This means that the environmental quality of the oceans has declined. Phytoplankton captures CO_2 and sinks to the bottom of seawater. CO_2 is necessary for photosynthesis, since it stimulates the growth of plants. Consequently, global vegetation can be affected by global warming and dissolved CO_2, but the complex effects of CO_2 on ground and water are not well-understood Armitage et al. (2010) and (Girgibo 2021).

According to Hannah (2011) and Girgibo (2021), in a greenhouse planet, CO_2 and water vapour exist in their natural state, but combustion produces CO_2 in higher quantities. The global temperature is disrupted by the production of these quantities of CO_2. The burning of coal, oil and natural gas has caused an increase in CO_2 (30%) in the past century. Although this was later facilitated by oil and natural gas, it was first primarily caused by burning coal. Princiotta (2011) states that as of 2015 in Europe there exists an agreement to stop using coal. This is considered a step forward in minimising CO_2 in the world. Altered plant growth and seawater chemistry are the direct effects of CO_2, but the main effect is global warming. The 'greenhouse effect' is defined as follows (Hannah 2011): Heat is 'trapped' by certain gases. The Sun's radiation warms the Earth's surface. Some of this radiation is absorbed and then re-emitted by the gases of the atmosphere, such as CO_2 and water vapour. Indeed, there is a net redirection of long-wavelength radiation from the atmosphere and back to Earth caused by part of the re-emitted radiation (IPCC 2007; Hannah 2011). The 'greenhouse gases' act like glass in a greenhouse, trapping heat from the Sun and warming the lower surface of the atmosphere.

To understand climate change, it is important to understand the climate system. According to the definition of the climate system in [Shrestha et al. (2014), IPCC (2013) and Girgibo (2021)], the atmosphere is the first component of the climate system. CO_2 has the effect of capturing and re-radiating the energy directed to space by the atmosphere. In the case of long-wavelength light radiation (heat), the atmosphere absorbs the heat and releases it to the land surface and ocean. Nitrogen (78%) and oxygen (21%) are the main components of the air, while the rest is water vapour and CO_2. The oceans are the second component of the climate system. The importance of oceans is that they contain water and dissolved gases. In addition, they reduce the accumulation of CO_2 in the atmosphere because oceans absorb CO_2. Storms like hurricanes release water vapour from warmer oceans (IPCC 2007). The climate is defined as average weather (Shrestha et al. 2014). The difference between climate and weather is that the climate can possibly be predicted 50 years from now, whereas the weather cannot be predicted more than a few weeks in advance (IPCC 2007).

Climate change is caused by CO_2 emissions and the results are evident in world water resources. During the Industrial Revolution, the use of fossil fuels such as coal and oil in industries and automobiles produced a considerable amount of CO_2 emissions. Afterwards, pollution has declined, primarily because industries have started to function with grid electric power. However, there is still considerable pollution at the current time, especially from cars and from energy production with fossil fuels. Even a small addition of carbon dioxide by humans can affect the carbon balance in the entire system (Hannah 2011). To reduce this, there have been different global agreements.

The international mechanism for addressing climate change is the United Nations Framework Convention on Climate Change (UNFCCC). This convention has been ratified by both developing and developed nations, including the United States of America. Preventing dangerous human interference in climate change is the goal of the convention (Hannah 2011). The objective is the stabilisation of greenhouse gas concentrations in the atmosphere, which helps prevent dangerous anthropogenic interference with the climate system. Therefore, this doctoral research aims to address that by implementing renewable energy solutions for coastal areas. There have been agreements made by nations around the world to minimise the causes of climate change.

Some of the best-known agreements on climate change are the Kyoto Protocol (1998) and the Paris Agreement (2015). The Kyoto Protocol (1998) is based on the following facts: a) global warming exists. b) anthropogenic CO_2 emissions have caused it. This commits state parties to reducing GHG emissions through an international treaty. This also extends to the 1992 United Nation Framework Convention on Climate Change (UNFCCC). In Kyoto, there were 192 parties in December 1997, which set emissions reduction targets for 37 industrialised countries (Hannah 2011). The protocol took effect on 16 February 2005 with the ratification of Russia and 184 nations overall. It was first adopted in Japan in 2005, Canada withdrew in December 2012 and the USA did not ratify the protocol at all (Paris Agreement (2015) and Girgibo 2021).

According to Pirliä (2000), the Kyoto Protocol defines three specific flexibility mechanisms. These are international Emission Trading, Joint Implementation and Clean Development Mechanisms. The Paris Agreement (2015) is a worldwide national agreement in minimising emissions through climate change adaptation. Unfortunately, the United States of America resigned in 2017 based on a decision made by American President Trump's administration. However, other nations are willing to participate in emissions reduction.

One way in which the Nordic countries participate in the previous two agreements (Kyoto and Paris) is by implementing renewable energy (Aslani et al. 2013 a & b). This research represents a local-scale implementation of renewable energy by taking advantage of climate change effects. Climate change can be a major resource for renewable energy systems. Among the useful climate change effects are: environmental temperature increases, useful for water heat exchangers; sediment heat production; groundwater as an energy source; borehole systems; and asphalt energy. Another possible effect is windy weather due to storms, which makes it possible to install vertical wind turbines. A third effect is wave energy, which could lead to energy transitions. All these energy systems are renewable energy resources. As such, implementing those methods not only will lead to adaptation to climate change, but also will satisfy the global commitment to the Kyoto Protocol and the Paris Agreement.

The steps to follow in satisfying the world's need for climate change mitigation, combat, and adaptation are first-world agreements. The general steps are detection, attribution and mitigation. The next step is to adapt them at the EU level and later at the Nordic level, and finally at the country level in Finland. Finland accepted the national commitment to satisfy the Kyoto protocol by the EU and to reduce emissions to the 1990 level (Pirilä 2000). Then the city of Vaasa will follow, and the local area will be used to produce or use the solutions proposed. In this case, renewable energy solutions can be implemented in the area of the UNESCO World Heritage Site and in other areas of the city of Vaasa. Figure 5 shows the steps involved in satisfying the mitigation, combat and adaptation strategies in this research.

The first study of climate change was carried out in the 19th century and examined the effect of CO_2 on our climate (IPCC 2007). Since then, numerous studies have been carried out. The diverse effects of climate change have been explored by numerous authors. The current research focuses on examining the effect of climate change on a particular area, the UNESCO World Protected Inheritance Area in the Vaasa region, in terms of water quality and meteorology. In addition, the research studies renewable energy solutions based on climate change effects and uses climate change effects as an advantage, including studying the effect of climate change on energy systems through statistical analysis and contributing to mitigating, combating, and adapting to climate change by setting an example.

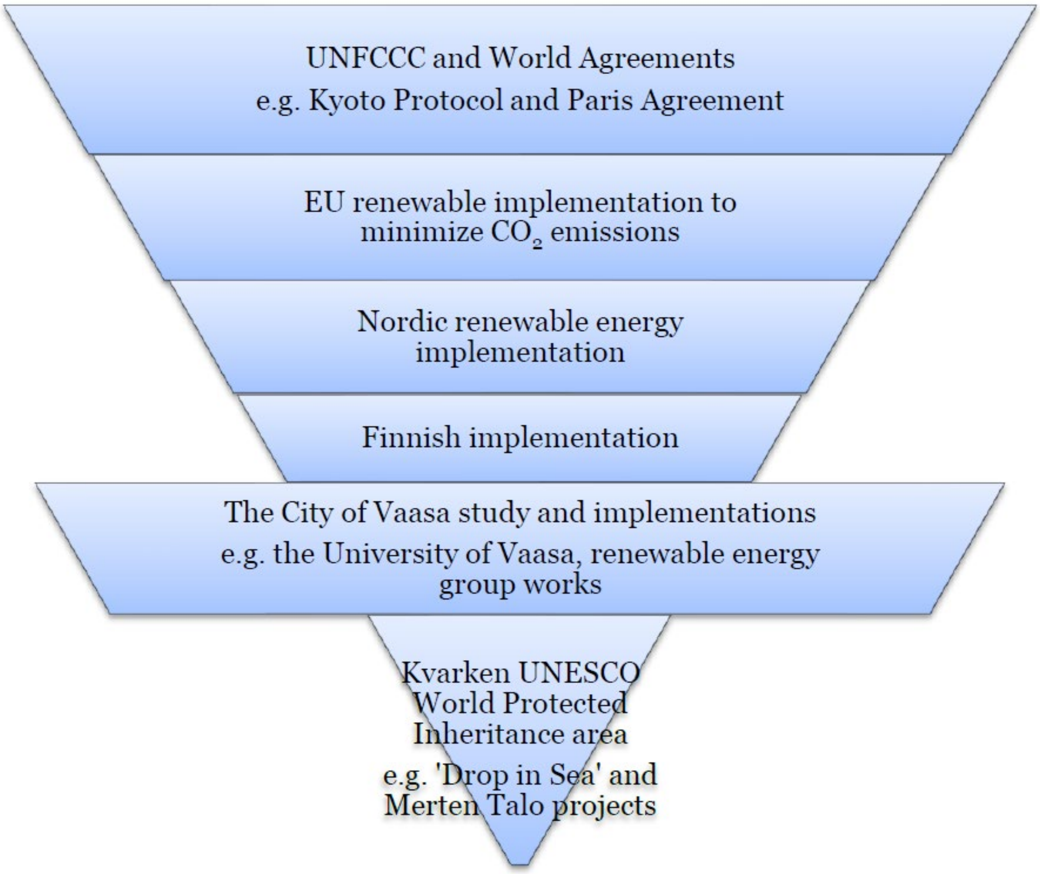


Figure 5. The research's general steps are based on mitigating, combating and adapting climate change.

1.2 Challenges and problems

The problems that this research addresses are presented in this section. The problems are climate change, pollution and energy insecurity. Currently, water is increasing in terms of sea level rise, river water capacity and volume because of snow melting, the heat expansion of water and the decline in the effectiveness of snow in reflecting the sun's energy. That leads to more heat in bodies of water, which in turns causes much hotter water and evaporation, erosion and floods. Another problem is that ice melting weakens the Gulf Stream, which might cause cold weather in Finland. It is also of note that the water level in inland rivers has increased, causing floods, as in the Seinäjoki (in Munakka, Kyrönjoki river) area. Further, in the current area of the Archipelago, fish are at risk. Phytoplankton will increase, snow is melting, the land is rising, and river water flow is increasing in this area. It is not possible to use hydropower generation in the small rivers of the islands as an energy source, due to the small size of the streams and the lack of sufficient water currents. The sea level is rising, salinity increasing and oxygen levels in water bodies are decreasing, which puts fish in danger (Girgibo 2021). My earlier study, Girgibo (2021) serves as the beginning of the basis or literature frame for this paragraph's problems.

The other problem stems from not knowing the meteorological weather variations due to climate change at the Valassaaret weather station and Vaasa Airport weather stations, which are near the Archipelago area. Moreover, it is not known if there are direct effects of climate change on water quality parameters at the current site. In addition, the future situation of the Gulf Stream and its consequences is also unknown. The idea was to investigate long-term water quality data and conclude whether there is variation due to climate change by using weather changes as an indicator of climate change effects. If there were effects on the long-term data, the study chose which water quality parameters to analyse for the current site. If no effects were found, the reason for this lack of effect on the long-term water quality data was determined for the current site by determining and investigating the water quality changes in other sources. The background and framing are based on earlier studies, the primarily resource utilised from a climate change perspective are IPCC reports.

The problem in the 'Drop in sea' project was that a non-renewable energy solution was used in the pilot houses (houses isolated on islands in the Kvarken area). Additionally, another problem was the sustainability of the current renewable solutions in the same project. One of the expected conclusions is that in the future, it may not even be possible to use wind turbines as a source of renewable energy, since storms and wind are so strong that turbines will not be able to remain standing in the current area; however, vertical wind turbines may be possible. In most of the world, wind power will decrease. The houses need replacement; hence they are currently unable to keep heat in the house. Moreover, the moisture already is damaging the house walls and floor. Increasing energy use efficiency is one area to focus on. This could imply insulating the windows and replacing them with permanent moisture-resistant walls and floors. Other suitable results of the 'Drop in sea' project were presented as solutions for the site.

One of the earlier publications (Aslani 2014) based solving the above problems was concerned with renewable energy allocation in Nordic countries. The study in question demonstrates the actions of Nordic countries in using renewable energy to address climate change effects and solve adaptation needs, as Aslani, A. (2014), did in his dissertation. Current climate change issues are such that they require solutions to act on in world agreements, such as the Kyoto Protocol and the Paris agreement. The publication acts on delivering these promised solutions for Nordic nations. Therefore, the idea was that the current research allocates those renewable energy sources to the Merten Talo area and performs other location analyses. This is to be built on the allocation of renewable energy solutions for the implementation in Finland in the local area of the Vaasa region for climate change solutions (see Figure 5 to understand the connections).

Are water heat exchangers suitable for coastal energy solutions? A suitable water heat exchanger was installed in Merten Talo, but it has been uninstalled due to disagreements with the Merten Talo project financers. Moreover, the knowledge of what to install had handled by experts in the area. The systems selected and installed were advantageous from a climate change perspective due to an increase in water temperature in water bodies. A connection between solar panels and the heat battery was one of the instruments suggested for on-site installation by the solar company. Groundwater energy utilisation (GEU) was also suggested as a local renewable energy solution for the city of Vaasa. However, its reliability for city use is questionable. This suggestion was built on Arola's (2015) dissertation work.

One of the main problems addressed in this research was the question of risk in renewable energy, which is rarely discussed in this field. The two questions addressed were: 1) the risks of climate change to renewable energy and their magnitude and 2) the magnitude of the risks of renewable energy use and production to the environment and the causes of these problems. The second part of this risk analysis was built on a previous article by Holma et al. (2018).

The analysis was also performed for sediment heat production to determine whether the climate change effect was advantageous for this system and if so in which seasons. That was the other problem addressed in this research as a part of the questions raised about coastal energy solutions. This research was primarily based upon various studies carried out at the University of Vaasa's renewable research group, mainly Dr Anne Mäkiranta's publications.

Land uplift is the other problem considered by this research. The land is rising, as is the sea level. Which is faster? Moreover, how will this behaviour change under future conditions? The researchers have tried to answer these questions. The other problem in need of investigation is how the ice road will be in the future. This was addressed in the literature review report publications. The question here is whether there will be an ice road (ice covering bodies of water) in the future. If so, what will be the extent of the ice? Knowing these questions will help to solve the problem of whether sea ice will exist in the future. The future situation of the Gulf Stream was also considered.

The World Heritage Site is the other point. For this site, new and demonstrative solutions are presented. The idea is to minimise the problem of companies not having a place to show their product/reference site. However, if there is a place to demonstrate the energy solutions, it will be easier to sell products to individuals as well as to companies. It is useful for companies to show to their customers products that are planned to be installed. In addition, the new solutions will be useful for the area community and the restaurant. As well, it will be adapted to climate change, combat it, and take advantage of it, and can be used as an example for other areas. The other useful outcome planned for the Merten Talo project was to create a research platform for Vaasa University in the new building, which was built in 2018. The Merten Talo project outcomes laid out in this paragraph became more difficult over time, however. Currenlty, no new installation locations were planned, at least for the water heat exchanger.

1.2.1 Problem statements

This section delivers the problem statement in connection with the research problem. The climate change situation has caused changes and problems in various societies. One such problem is that the climate change has been found to cause substantial deterioration in the water and environment of our world. In particular, the use of fossil fuels in energy sectors contributes to higher emissions. In coastal energy solutions, land uplift and climate change studies, the change in our climate creates situations where the water temperature is expected to rise by a minimum of 2 ^{O}C, during the 21st century. Sea level rise was 15–28 cm, according to the Climate Institute (2010) and IPCC fourth assessment, fish are migrating, phytoplankton's growth pattern has changed, the wind is becoming stormier, groundwater temperatures are increasing, solar radiation is increasing, global climate is warming, weather patterns are changing, and there is flooding, changes in Gulf Stream pattern, ice melting and more. The Gulf Stream might change the direction of coldness or warmth in nearby lands. The expected temperature change is much higher than 5 ^{O}C emissions continue to be high; therefore, these effects can be much stronger and more dangerous and addressing them is crucial to addressing climate change.

Investigating these effects and using them to decrease pollution can contribute to climate change studies. However, this research must investigate the local effects of water and meteorology, to adapt and use climate change as a resource for renewable coastal energy solutions and understand what to expect in the future. The future situation in the relation between climate change and land uplift is important. In addition, determining the risk of climate change to renewable energy resources is important. These problems affect all nations and societies, because the changes in the water and environment can disturb our living conditions. We all use water for different purposes, whether directly, to improve our surroundings or through ecosystems, as do fish. Climate change will cause changes. It is best to adapt to it and take measures to decrease the main cause of climate change, namely anthropogenic (human) pollution, which is mainly caused by carbon dioxide emissions from fossil fuel energy.

The literature discusses climate change as being likely to affect sea level rise. An increase in volume, turbulence and velocity is expected to occur in the water of Raippaluoto. Due to salinity and nutrient intrusion, both soil and freshwater will be polluted. Flooding and erosion are expected to rise. Particularly in the northern inland areas, but everywhere in the country, precipitation (rainfall) is predicted to increase. Cyanobacterial blooms are common in the Baltic Sea (Kanoshina et al. 2003), a trend that will worsen because of temperature increases. The cyanobacterial abundance is increasing and the Merten Talo area is expected to have higher blooming. Fish stock will be affected by both temperature and cyanobacterial blooming much more in the future. Among the disadvantages of climate change will be greater stormy winds. It is therefore possible that normal wind turbines will no longer be an option, which is one of the risks of climate change to renewable energy. Sea ice is decreasing but may increase if the Gulf Stream pattern changes. As already noted in other parts of the world, due to global warming, the overall temperature will increase. As such, there will be higher average wind, so that wind turbines will be favoured in Merten Talo (Girgibo 2021) and water temperature changes might facilitate the use of water heat exchangers.

One of the main arguments of this research is that local climate change effects are different from world predictions, something that the research intend to demonstrate so that other local studies will be carried out. The questions addressed herein are listed in the questions section (Section 1.3.3). Answering these questions, conducting hypothesis verification and addressing other related problems will bring about changes in society. Moreover, it will affect how societies behave regarding the effects of climate change.

1.2.2 Current State of-The-Art Approaches

The main approaches of this research, which represent the current state of the art, are the following:

1. Identifying the effects of climate change on water quality in the Kvarken Archipelago area, near the city of Vaasa. The method used was statistical analysis that combined long-term weather and water quality data.

2. Risk analysis and management for climate change effects vis-à-vis risks to renewable energy, along with the risks of renewable energy use and production to the environment. The data was collected by using expert evaluations for risk analyses.

3. Statistically verifying that the effects of climate change are advantageous for the use of sediment heat energy, at least in summer.

4. Development of a framework chart for land uplift. Answering whether land uplift dominates sea rise or vice versa for the Vaasa region and the whole Nordic.

5. Proposing local area renewable energy solutions as an example method to expand the massive use of renewable energy in the world to reduce, adapt to and avoid climate change effects, to mitigate GHG emissions and use climate change to our advantage.

1.3 Objectives and methods

1.3.1 Objectives

This section presents the objectives of the research.

The first objective is to set an example of the mitigation of climate change at the local level (reducing CO_2 emissions) by using renewable energy resources as a coastal solution. The other objective is to analyse the risk that climate change effects pose for renewable energy resources and to manage these risks. This means analysing climate change risks for energy. This will help us understand the exact situation pertaining to climate change. The research also seeks to show that sediment heat energy production is suitable for heating and cooling houses and that it can take advantage of the increased water temperature due to global warming and thus to set an example for worldwide use. Other goals include examining present and future climate change effects; conducting statistical analysis to see the effect of climate change in terms of weather change effects on water quality in the Vaasa region; and investigating the correlation between long-term water quality and meteorological data by using an embedded design, as well as doing the same for correlations between the water quality parameters and their interactions. This last objective helps predict the energy capacity increase in water temperature due to climate change, allowing one to take advantage of climate change effects.

The researcher also aims to understand and determine possible energy-efficient renewable energy resources and to implement and suggest renewable energy resources for combating climate change. The researcher further develops a literature framework chart for land uplift, including sources, patterns, consequences, measurement techniques and empirical procedure. Another objective is to identify the effects of climate change in Finland and study the land uplift conditions relate to climate change, since knowing what happens in future to our territory will help provide possible solutions. Other objectives are to provide an example of practical methods of future energy transition due to climate change; to explore the background, temporal processes, relationships and connections; forecasting the future (e.g. land uplift and the climate change situation) and adapting to it; and to relate the quantitative and qualitative studies performed.

1.3.2 Purpose of the research

This section presents the purposes of the studies that make up this research. In addition, a mixed-method purpose statement is presented below.

1.3.2.1 Purpose statements

The four main purposes of the research are described below:

1. The first purpose of the qualitative and quantitative study is to develop a framework chart, theoretical data analysis and prediction of land rise or land uplift effects. This also encompasses prediction and theoretical data analysis in the Vaasa region and Nordic over a long-term period that includes the past, present and future.

2. The second purpose of the quantitative study is to produce a statistical time-trend analysis, correlations and regressions of weather changes due to climate change and water quality from long-term data at the Kvarken Archipelago in the Vaasa region of Finland. The long-term time data period for weather data is 1959–2019 and for water quality data is 1974–2018.

3. The third purpose statement is for data analysis of quantitative data and of the qualitative study, namely, to analyse and manage the environmental risks of climate change for renewable energy and renewable energy use and production. This was conducted at the University of Vaasa by using an expert interview of renewable energy group members and others to investigate and gather data.

4. The fourth purpose statement for the quantitative study is to analyse climate change's effect on coastal energy solutions, with sediment heat energy production and other types of seaside renewable energy as representative of new solutions, such as the water heat exchanger.

1.3.2.2 A mixed method purpose statement

This mixed-method research addresses the climate change investigation, the land uplift forecasting, the analyses of renewable resources and additional goals. An embedded design is used, in which qualitative data are embedded with the major designs of quantitative studies, such as statistical data analysis and correlations and regressions between long-term water quality and meteorology data. Additional quantitative analyses were performed on renewable energy resources and risk assessment was conducted for renewable energy resources. The quantitative data was used to test the theory that predicted the correlation and regression both between water quality changes and meteorological data and within the water quality parameters. Climate change is expected to influence the protected UNESCO World Heritage area in the Vaasa region. In addition, the researcher carries out analyses of the use of different renewable energy resources as a means of adaptation, mitigation and combating of climate change. The Merten Talo site was planned to be used as a renewable energy reference site for companies. However, this was not successful. The qualitative studies were embedded in the larger design of data analysis before, after and during the clarification of the data analysis quantitative statistics, thus supporting and adapting the community usage of renewable energy to take advantage of climate change. The qualitative studies explored the land uplift effect by developing a framework chart based on systematic reviews, risk identification and review reports. The qualitative and quantitative studies together examine local effects to argue that climate change effects in the local area differ from what would be expected based on global values. In addition, at the beginning of and during the whole research period, literature review reports were made in Girgibo (2021), Girgibo (2022) and other publications.

1.3.3 Research questions

The research questions are presented in this section.

1. What are the future coastal energy solutions? Do sediment heat energy production and other seaside energy systems use climate change to their advantage, and if so, in what seasons?

Type of question: Mostly description and comparative, James and Slater pp. 203 (2014). Area: Seaside energy solutions. Field: Renewable energy. Precise aspect: The use of renewable energy resources in a coastal area. [Addressed in Purpose Statement 4, Publications I and IV].

2. What are the changes in water quality due to air temperature change effects? Why have long-term water quality parameters and meteorology changed over time due to climate change? If they have not, why are there no changes to them?

Type of question: Related to compositions and relations (factors), James and Slater pp. 203 (2014). Area: Climate change effects. Field: Meteorology and limnology. Precise aspect: The effect of climate change on water quality parameters and meteorology. [Addressed in Purpose Statement 2, Publication II].

3. What are the risks of climate change to renewable energy resources, and how severe are they? What is the nature and magnitude of the risks of renewable energy use and production to the environment?

Type of question: Description and classification, James and Slater pp. 203 (2014) Area: Climate change and energy management. Field: Connection between energy technology and management. Precise aspect: The relevance of climate change relative to energy risk management. [Addressed in Purpose Statement 3, Publication III].

4. Why and to what extent does the land uplift phenomenon happen and what are its consequences? How do qualitative data support the quantitative statistical data analysis in the case of land uplift and other effects?

Type of question: Existence and comparative, James and Slater pp. 203 (2014). Area: Land uplift, renewable energy and climate change. Field: Climatology, energy, geoscience and limnology. Precise aspect: The effects of land uplift in Finland in terms of limnology and energy. The mixed method methodology parts (methods) support or complement each other. [Addressed in Purpose Statement 1, All publications: Publications I–IV; including Girgibo et al. (2022 & 2023) and Girgibo (2021 & 2022)].

1.3.4 Hypotheses

Here, the suggested hypotheses are presented with a short explanation of the theoretical background of each one. H_0 (the null hypothesis) is the default hypothesis that obtains if the other hypotheses are not satisfied. If other hypotheses are found to be true, then the null hypothesis might be falsified. If the null hypothesis were true, then the research would try to find out determine why climate change had no effect on both water quality and meteorological data.

> **H_0 (null hypothesis):** Climate change does not affect weather patterns or water quality parameters. Moreover, there is no correlation between weather parameters and water quality parameters.

According to Dirks et al. (2014, tables and figures) in many cities of the U.S.A., the temperature expectation shows an annual increase. Based on the actual data forecast and models for the future years 2052 and 2089, a continued annual increase is expected. Similar patterns were also noticed in Finland. These trends are qualitatively the same for other predicted years, in the past, and in other areas of the world. The IPCC (2007, Figures TS.26 – 32, 10.4 – 9) shows that both in the model and actual data, the expected temperature increase is a well-established fact. The TAR (Third Assessment Report) confirms the projection of a global mean temperature increase of between 1.5 ^{O}C and 4.5 ^{O}C in 2090 – 2099 (IPCC 2007, Figures TS.27 and TS.32). The books by Hannah (2011), Shrestha (2014), Pirilä (2000), as well as other works, confirm these effects and indicate an expected water temperature increase of more than 2 ^{o}C. Local temperature investigations give researchers temperature change results for local studies. Based on the above information and the actual trends seen in past temperatures, the null hypothesis was formulated so that it might be falsified or confirmed. The statistical analysis of weather data and water quality data combinations can help falsify or confirm this null hypothesis.

> **H_1:** There is a climate change effect on temperature variation and weather patterns at minimum. The temperature is expected to increase in future environmental and meteorological data. Consequently, there is a possible relationship between long-term water quality and meteorological data. Moreover, it is possible to see local climate change effects.

This is the main hypothesis, that climate change effects are expected to be seen in weather data, water quality data and their relationship. Korhonen (2019) found in her dissertation that the freezing and melting times of ice in lakes had changed in recent times compared with the past. This may show that the change in air temperature is affecting the water temperature in water bodies. This is one piece of evidence that changes in weather due to climate change are influencing water body temperatures. If the water temperature is changing, it influences the other water quality parameters. For example, the amount of dissolved oxygen (DO) increases with decreasing water temperature and decreases with increasing temperature. Dissolved oxygen affects the survival of various aquatic species, such as zooplankton and many fish. In addition, other water quality variables such as oxygen saturation, total phosphorus, and total nitrogen can be influenced by climate change. In addition, Pastuszark et al. (2018) showed the relationship between water temperature in different regimes of water quality parameters. Therefore, climate change effects on air temperature affect water quality parameters indirectly. This hypothesis will be verified or falsified based on statistical analyses of the combined data (both weather and water quality data).

> **H_2:** The efficiency of seaside renewable energy solutions (e.g. sediment heat production) helps to combat, mitigate and adapt to climate change.

Climate change can be combated by using renewable energy resources (Hannah 2011), whose life cycles have lower or no carbon emissions, rendering them safer for the environment. Sediment heat production equipment uses climate-change-induced water temperature increases to its advantage in energy production. The use of a sediment heat production system or water heat exchanger will not create emissions of any kind and can replace other heating/cooling that produces carbon emissions. For example, on islands some houses typically use fossil fuels for heating or cooling (Final Report 2011). The use of fossil fuels causes carbon emissions. Replacing fossil fuel heating and cooling with water heat exchangers in islands and nearby harbours and by sediment heat energy production where possible will reduce carbon emissions from heating and cooling. Moreover, sediment heat production uses climate change to its advantage, which helps combat and adapt to climate change. Adaptation to climate change can be verified or falsified by statistically analysing data from sediment heat energy in Suvilahti, in the city of Vaasa.

> **H_3:** Land uplift will continue without declining due to climate change and ice road availability will decrease due to an increase in temperature and ice melt. Moreover, land uplift in the Vaasa region will increase in the far future.

Land uplift is expected to be higher than of sea-level rise, in at least the Kvarken archipelago (Nordman et al. 2020). This shows that without the effect of climate change, the sea-level rise in Nordic areas land uplift will mainly continue. However, far-future expectations might be different. Hence, the land uplift rate has a tendency to decline from its past rate and from its present one, which in turn would represent a decline relative to the past. Therefore, it is expected that in the far future the uplift rate might substantially differ from the current rate. The land uplift hypotheses can be verified or falsified by theoretical calculations and by comparing data on land uplift and sea-level rise. According to Korhonen (2019), the melting time of ice in lakes has shortened and the freezing time has become later. This is due to the lake water temperature increasing over time. This means in the future, water bodies will be warmer, which will cause the decline or even the disappearance of ice roads. This hypothesis can be verified or falsified by water temperature predictions based on statistical analyses of water quality data, land uplift forecast calculations and literature data comparisons.

> **H_4:** The ice thickness is decreasing because of melting, so it will be possible to use wave energy or other energy resources in the future.

It is certain that water temperature increases the melting of sea ice. Lake ice cover has been declining (Korhonen 2019). Hence, since sea ice has a similar melting pattern to lake water, it is expected that sea ice melting has been increasing and will increase substantially in the future. The global air temperature is increasing, leading to warmer water temperatures. If the water temperature gets warmer, ice accumulation will be late and the melting period will be earlier, leading to a short period of ice cover in seawater and lake water. If the ice cover is shorter, the availability and operation time of wave energy will increase, which creates many opportunities for using this type of energy. Whether the future water temperature will increase or not can be identified by statistical analysis. If the water temperature is increasing, the wave energy capacity will increase. After theoretical analyses of data and literature, this hypothesis can be verified or falsified. Regarding the Gulf stream, there is no concrete evidence of what will happen in the future and how it will affect ice accumulation in water bodies. This requires additional data and analysis and is recommended for future in-depth investigations.

> **H_5:** Due to the CO_2 increase in the atmosphere, solar radiation and the temperature increase, as a result of climate change, the growth of phytoplankton and algae will be much higher in the future. Moreover, the O_2 level will decline.

Climate change studies forecast more algae blooms in the future (IPCC 2013) in most waters of the world. This is mainly expected to occur due to an increase in the temperature of water bodies. Phytoplankton is a plant, and as such consumes CO_2 and sunlight for photosynthesis. If the intensity of these main components increases in the future, one can expect more phytoplankton growth in water bodies. Chlorophyll-*a* (Chl-*a*) is one of the water quality indicators of the abundance of phytoplankton. In our data, if the Chl-*a* forecast going to increase in the, one can certainly expect that this hypothesis can be confirmed. If not, it can be falsified. If the water temperature increases in the future, there will be less O_2 in water bodies, because cold water dissolves more O_2. Oxygen saturation data can also show what to expect in the future. The statistical analysis and forecasts of both water temperature and oxygen saturation can help us to verify or falsify this hypothesis.

> **H_6:** Risk analysis shows the possible risks. Further, it is possible to identify and estimate certain risks in renewable energy resources due to climate change and the risks of renewable energy use and production to the environment.

Holma et al. (2018) show us that there are some risks to the environment from renewable energy usage. Building upon the research of Holma et al., this doctoral research is expected to identify and confirm the risks of renewable energy use and production. Moreover, it will identify and estimate the climate change risks of renewable energy. The risk analysis process will verify or falsify this hypothesis. Holma et al. (2018) conducted one of the first studies on the risks of renewable energy use in Finland. The risk analysis of this doctoral research is also expected to build further knowledge on the basis of their study. However, performing a new analysis is always a challenge, since data shortages may be present, which was noted in the data collection process for this risk analysis.

1.3.5 Motivations

Here you can find the motivations of the research done in the doctoral work.

The first motivation was that initiating and participating in combating climate change were the forces driving us to adapt, mitigate and make a better future and leave a better world for future generations. The second motivation was to provide adaptive solutions for seaside energy requirements and help the community by using renewable energy solutions. The third motivation was that knowing the local effect of climate change on water resources, land uplift, meteorology and the future of snow ice road availability is an interesting topic for scientific investigation and further studies. The fourth motivation is that the true risks of climate change to renewable resources, and of the production of renewable resources use and production to the environment, have been little studied.

In addition to all the previous motivations, there were two personal motivations to carry out the doctoral research and write this dissertation. 1. One was personal growth: the desire to contribute something valuable to the world as a person. Since I was a bachelor's student, my reports always have been motivated by the desire to make a global contribution and create a better world for future generations. This doctoral research is an essential part of this long-time focus on contributing to the world. 2. The second personal motivation is a need to study new things and achieve career development. This study has been a great tool in satisfying my need to gain new knowledge and learn a new way of thinking and doing research. I hope that these motivations will continue driving me in future studies and researches.

1.3.6 Conceptual framework

This section introduces the conceptual framework of the current research. The theories described here were the basis for this research (See also Girgibo 2021). This conceptual framework consists of the following steps: 1. Identifying key concepts. 2. Evaluating and presenting research theories. 3. Validating the research at hand (why it matters) and 4. Formulating a logical structure for the research. The key concepts and theories presented are the greenhouse effect, the land uplift and sea-level rise theory, the water quality theory, sea ice decline and new energy possibilities. In addition, the topics and scope of the research are discussed.

The first theory deals with climate change primarily from the perspective of the greenhouse effect theory. The greenhouse effect theory explains how natural processes heat the atmosphere of the earth. The greenhouse effect causes global warming, which is the main effect of climate change disturbing ecosystems and species, disrupting how they live and produce food. The greenhouse effect is caused by the accumulation of greenhouse gases in the atmosphere over time, which trap heat in the atmosphere and increase the temperature of the surroundings. Further, greenhouse gases reflect heat radiation from the Earth back towards its surface. Figure 6 illustrates the 'greenhouse effect' and the possible types of radiation, including beam, diffuse and scattered radiation. These effects cause the warming of the Earth's atmosphere, its surface and its habitats. The main greenhouse gases are CO_2 and CH_4, with increased quantities of these gases have been generated by human energy and fossil fuel usage in the past and current centuries. These causes CO_2 accumulation continue in the present. To address the greenhouse effect, humans must act to reduce or prevent continued CO_2 emissions (IPCC 2007).

One way this research sought to address the greenhouse effect was by attempting to implement renewable solutions to minimise emissions and contribute to the reduction of climate changes effects. However, this was not successful and the new solution to address the planned reduction of greenhouse gases was a water heat exchanger. This instrument produces heat for houses from heat generated by bodies of water. The solutions were to show the impact of using renewable energy (e.g. a water heat exchanger) for heating instead of oil (diesel). The coastal energy solutions considered were the water heat exchanger (installation planned but not successful), sediment heat production and groundwater energy utilisation (GEU). Further, they are expected to reduce the greenhouse effect on the atmosphere of our Earth over time.

The second theory deals with the relationship between land uplift and sea-level rise. The first theory of land uplift and sea-level rise was the theoretical model developed by (Okko 1967). However, this research also accounts for sea-level rise in land uplift calculations. This is expected to support the theory in terms of the relation between sea-level rise and land uplift, as well as predicted future relations between sea level rise and land uplift. The next hypothesis, using formulas gathered from the literature, explains when calculating land uplift, one must account for the sea level rise effect when measuring from a given level. Take Y_s to be the sea level constant change at the present altitude of a shore formed t years ago. Then Y_s can indicate the amount of uplift in t years. The hypothesis was based on a study (Okko 1967) where the formula $Y = Y_S - H_S$ was proposed, where Y is the amount of uplift, Y_S is the land uplift constant at the present altitude of a shore formed t years ago and H_s is the sea level at a vertical distance. In other words, this means that the sea level and the crust are included in the altitude of the raised shore surface. This hypothesis proposes that in any estimate, the correction of the shore altitude by H_S (sea level at a vertical distance) is necessary to calculate the amount of uplift from a dated shoreline during a given period (Okko 1967).

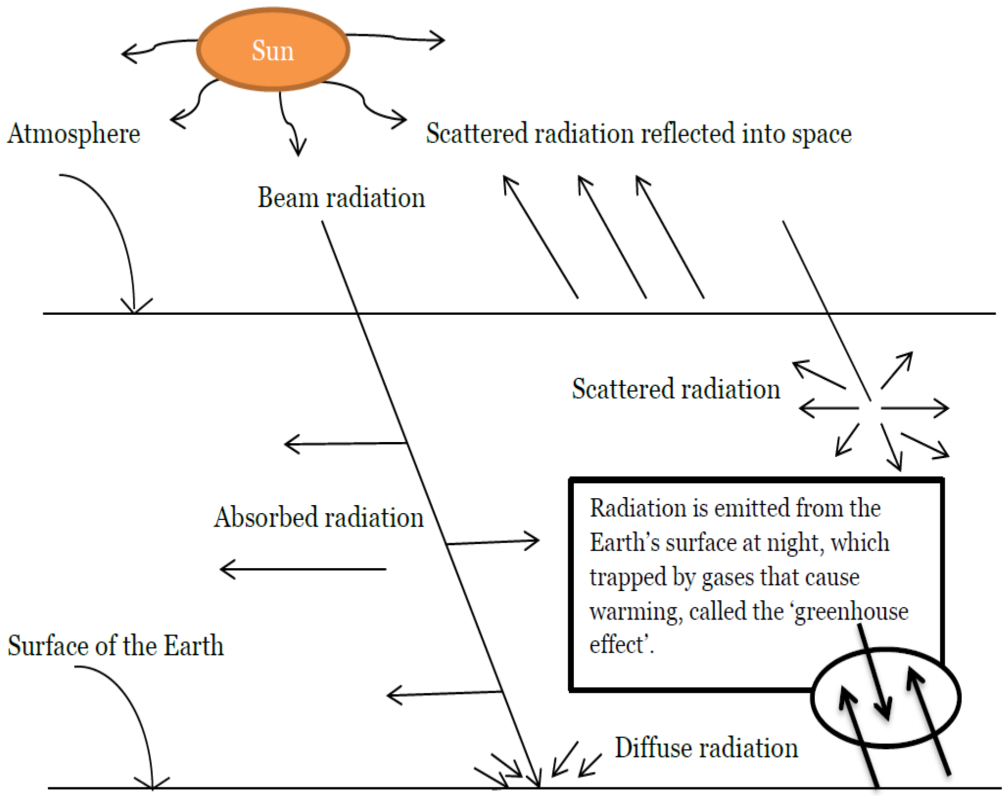


Figure 6. Different types of radiation, including radiation trapped by 'greenhouse gases' effect were modified from Sukhatme's (1984) solar radiation book with the support of Arrhenius's (1896) explanation.

Land uplift increase causes a reduction in the effects of sea-level rise in the specific area. The land uplift study that serves as one of the bases of this research (Girgibo et al. 2022) describes land uplift and climate change effects separately. It is thus concerned with the effects of sea-level rise as climate change occurs. The study explains that sea-level rise is facilitated by planetary temperature increases, primarily due to global warming. A theoretical model explaining sea level rise and land uplift was described, then different lenses were used to explain both relations. A forecast was then made based on the data from the literature. It was predicted that in the Nordic countries (Finland and Sweden), particularly the Vaasa region and the Baltic Sea, land uplift is expected to exceed the future sea-level rise. On other hand, the world forecast was the opposite, meaning that sea level rise will be higher, including flooding in considerable areas. In the calculation, theoretical formulas were used, and the above formulas were considered to some extent in the background in relation to the effects of land uplift related to sea-level rise.

The third hypothesis was that in the future, when there will be less ice and higher water temperatures, new energy possibilities will flourish because climate change will increase the water temperature and offshore wind capacity will change. One new energy source from seawater or other water bodies is the water heat exchanger [see Girgibo (2021) for more explanations]. This helps us to utilise the water temperature in water bodies by exchanging heat through a circulation liquid, namely water (GeoPipe 2016). In the future, when there is less ice, the use of this equipment will be ideal; not only will there be no ice to impede installation, but the decline in ice levels also will increase the water temperature to some extent, increasing the heat energy extraction by the water heat exchanger. The second ideal situation is for wave energy installation, since there will be less ice in seawater or even none. The installation of wave energy in the Baltic Sea near the City of Vaasa is limited due to the rocks in the seawater near the Archipelago. The applications of wave energy will increase in the future; the Baltic Sea has 24 TWh of energy economic potential [Bernhoff et al. (2005), see the explanations of wave energy in Girgibo (2021)]. The third energy production resource that will benefit from access to installation and easy maintenance of offshore production if seawater is free of ice is the wind energy turbine (Girgibo 2021). It will be easier to access offshore wind turbines in winter if the sea is ice-free. Sediment heat energy is also expected to benefit from the water temperature increase in certain seasons.

What is the topic of the study? The general goals of all the research sections include detection, attribution and mitigation. The study uses a mixed methodology design where an embedded design approach was implemented. The first study deals with investigating the actual climate change effect on water quality and resources in the local area (the UNESCO World Protected Heritage area). This part of the research contains a statistical study of historical data and future forecasts of regional climate change effects. It focused on providing knowledge and solutions. This was important, since each local region has different climate change effects.

Determining the nature of the effects in the local area will help researchers in biology, environmental studies or others. For instance, if researchers want to find out how the temperature increase in water resources affects fish embryos, the researchers could base their study on the results associated with local temperatures rather than the world estimate of 2 ^{O}C. This is important, since local temperature change are expected to vary greatly, reaching even 5–6 ^{O}C in some parts of the world at least. The other goal was predicting the future effect of climate change to some degree based on historical data, which sets a regional plan for environmental decisions, project implementations and economic forecasts and implementations.

The second part of the research centres around the investigation of new renewable energy solutions for adapting to and combating climate change. This part involves extending existing knowledge. This research section sought to initiate the use of renewable solutions in seaside areas and in many regions of the world in the future. Everything starts with one step, and this was the first step for the local community to implement the most efficient renewable energy resources possible as a solution to combating climate change and participating in creating global solutions. In our case, this involved investigation of sediment heat production, preliminary analysis of water heat exchangers and suggesting groundwater utilisation (GEU).

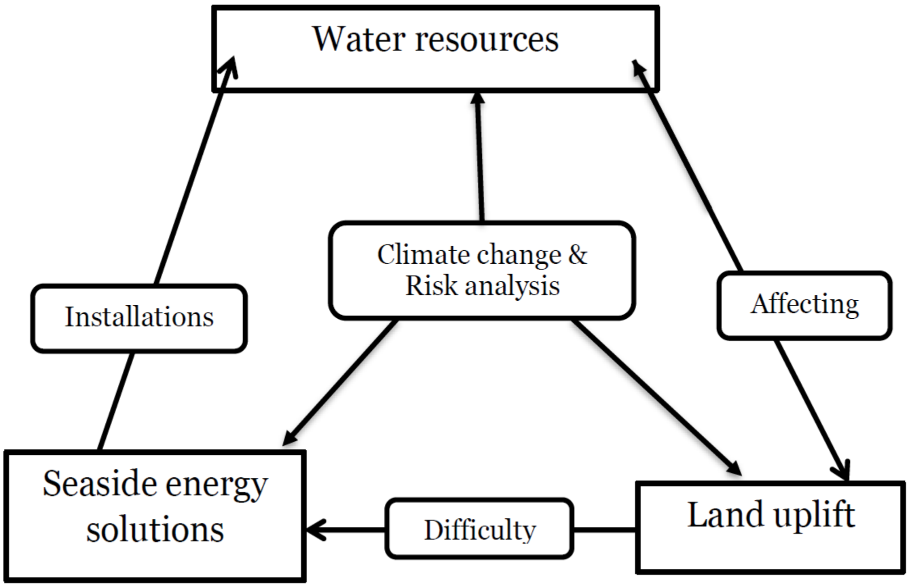
The third section of the research involved the relationship between land uplift and climate change (sea level rise) in the local area. The final studies focused on renewable energy risk analysis and management.

In terms of the scope of the study, the areas covered were renewable energy, climate change, land uplift and water resource quality (related to limnology). The main area of focus was renewable energy technology. The solutions investigated as a means of combating climate change were renewable energy resources. The scope also encompassed understanding the benefits of the energy technology resources in the area. The study of seaside energy solutions that use climate change to their advantage helps us to understand the best solution for the local area (coastal solutions). The research was thus able not only to implement the best solutions but also to propose new solutions using water heat sources, such as water heat exchangers and sediment heat production. These seaside solutions could be used in the future in other similar areas. Consequently, both the energy technology expertise required, as well as the limnology aspect of the water bodies as energy resources, needed to be studied in this research.

Climate change phenomena connect different fields. In our case, climate change not only connects the fields of energy technology and limnology, but uses both fields as a means of adapting to, mitigating and combating climate change effects on our environment. Future solutions seem likely to become more integrated in different fields and their utilisation of their expertise. One example is this research, which addresses climate change solutions by combining two different fields. Here, climate change is dealt with in two aspects. The first is determining local climate change effects on water resource quality and meteorology. The second is implementing energy solutions to contribute to combating climate change. The overall research combines four aspects: historical data analysis, investigation of renewable solutions on all the installed equipment, determination of the effect of climate change in a specific area and analysis of the risks of climate change to renewable resources and their management.

The other field connected to the focus of this research section on climate change in water quality determinations was limnology. Limnology deals with the physical and chemical aspects of water resources. Nearby inland water resources had the most data gathered in the historical data collection. Coastal renewable energy resource utilisation is useful for seaside areas primarily because there is plenty of water to use as a heat source in winter and as a cooling source in summer. The connection and correlation between different types of climate change effects on water quality parameters emerge in this field.

Figure 7 summarises the relationships among key concepts involved in this research. Climate change affects land uplift by increasing sea level rise. Global warming is the cause of the water temperature increase that causes ice melt (glacial melting or melting in the Antarctic or Greenland ice sheets) and of water expansion, leading to higher sea-level rise across the world. This relation between sea-level rise due to climate change and land uplift leads us to predict what the situation will be in the future. The work done in the field of climate change studies involved long-term historical data analysis of water quality and meteorology, which was one of the main contributions of this work. Subsequent studies (risk analysis and risk management) also addressed climate change. On the other hand, for land uplift, one of the main contributions was the forecast of the future balance between land uplift and sea-level rise: whether one of these will overcome the other. The other contribution is the development of a framework/schematic chart for land uplift. The relationship between land uplift and seaside energy solutions came from the difficulty in installing, transporting and using seaside renewable energy solutions, which was also noticed in the 'Drop in sea' project (Final report 2011). Another relation between seaside renewable energy solutions and climate change was the proposal of new renewable resources for combating, adapting and mitigating climate change (see Figure 7 for the list). Climate change can be also advantageous for seaside energy solutions.



Energy analysis and
and economic advantage

Finding out future land uplift effects
Forecasting and schematic chart development

Coastal energy solutions research and identification

- Water heat exchanger introduction
- Sediment energy analysis
- BTES (Borehole thermal energy systems) description
- Wave energy (deep water wave energy solution) description
- Vertical wind turbine as a solution to stormy wind speed risks
- KNBNNO-material as examples in the review
- GEU as a solution (also in the review of the groundwater article)

Long-term data analysis of climate change effects on water quality and meteorology

Climate change and renewable energy related researches

- Energy relevance, adaption and solutions
- New renewable energy solutions
- Risks identification, estimations, analysis and management
- Theoretical data analysis of land uplift

The qualitative study

- Land uplift schematic chart development
- Literature review article and reports

Figure 7. Core doctoral research illustration.

The topic matters because it encompasses and combines different disciplines with the aim of mitigating climate change and provides a land uplift forecast. It helps set community expectations for the future and the data analysis shows the correlations and the effects of climate change. The water heat exchanger is a future technology that uses climate change to its advantage. The risk analysis gives new insight. The research methods chosen were appropriate and rigorous. The research addresses the diversity of the disciplines included in the study, including a long-term historical data analysis on climate change that uses water and meteorological data. The reason for studying sediment energy temperature data are that it is a relatively environmentally friendly solution to some extent and is safe for household usage. The research presented show that there was no better research method than the mixed-method design. Among the different types of mixed-method designs, embedded mixed-method designs were chosen because they are sufficiently sophisticated and are appropriate for addressing the studies conducted here.

The research process involves the following parts: first, summarising the background information and setting the purpose; then laying out the questions and hypotheses; then providing a research design and methodology chapter along with a literature review. The next phase includes a deep literature review, along with using statistical analysis tools and collecting data. The writing of the literature review was carried out over the research period, and then an analysis of long-term data on water quality and meteorology from data gathered from different organisations (ELY-Keskus and FMI) was performed. In addition, a water heat exchanger was planned to be installed. The implementation site was Merten Talo. However, it was not successful, the water heat exchanger was removed and brought back to the University of Vaasa. There are plans to use it in the future.

The process of decision-making and framing begins with reading different resources about the methodology and other sections of the research process. After gathering general knowledge about the different processes involved, choices are made by evaluating the proposed questions and the hypotheses that the chosen element best fits. In different aspects of the methodology, such as the strategies, data collection, data analysis and philosophy of science, a method was chosen, then evaluated and modified by advisors. After the choice was made, as in the methodology, deep reading on research design was conducted, which helped to choose the best methodology. The methods for each question were chosen and developed, and data collection and data analysis plans were carried out along with a data management plan. Finally, the methodology chapter was created and written gradually in conjunction with the review of articles and various books about methodology. Afterwards, deep data analyses, risks analyses and result interpretation were carried out and the articles and a report (Girgibo 2022) were written and published.

1.3.7 An overview of research design

The research uses a mixed-methods research design. A mixed-methods research design utilises both quantitative and qualitative research methods for analysis, which has greater value than using separate research methods. Applying mixed methods overcomes the disadvantages of a single method. The complexity and flexibility of this design makes it desirable to implement in this study. Specifically, the research design was fixed and emergent mixed method design. In addition, the approach to the research design is classified as a typology-based approach and dynamic approach, as recommended by Creswell and Plano Clark (2011). Among the six types of mixed-method design, the choice was an embedded mixed-method design. The emphasis of the embedded method design on quantitative methods is supported by additional qualitative studies. The implementation of the qualitative aspects (reviews) were carried out, at minimum, before the beginning and at the end of the quantitative data analysis and experimental studies. All three embedded design subtypes were chosen. Those are the general quantitative methods emphasised: embedded design (Figure 9), the embedded experimental design model (Figure 10) and the embedded correlation model (Figure 11).

Mixed method embedded design was chosen because the research questions were answered mainly by quantitative data analysis with the support of qualitative analysis [Creswell and Plano Clark (2007) and (2011)]. In addition, the quantitative data analysis (correlation, regression and forecast analysis) carried out within water quality data and between meteorology and water quality data. In the embedded design model (Figure 8), the research planned to first analyse long-term historical climate data, then after an intervention, to perform further data analysis of climate change and the water body quality in the protected UNESCO World Heritage area in the region of the city of Vaasa in Finland. Later, data analysis of sediment heat energy resources was carried out. Before, during (optional) and after the experimentation, qualitative interventions were carried out (for the model, see Figure 10). Finally, the interpretations were made based on quantitative and qualitative embedded results. Figure 8 shows the embedded design that was planned and implemented in this research.

The embedded correlational model was the other research design choice within the embedded design aspect of the mixed methods research (see Figures 8 – 11). This design shows the correlations and interactions between long-term water quality data and long-term meteorology data and an energy data analysis of renewable resources. The correlational model also addresses each parameter of all the data considered. An alternative type, which might suit the research design chosen, was an explanatory design (also known as explanatory sequential design). This is a two-stage research method, where quantitative research is followed by a qualitative study. This was planned as an alternative approach if the embedded design chosen was not able to work for this research.

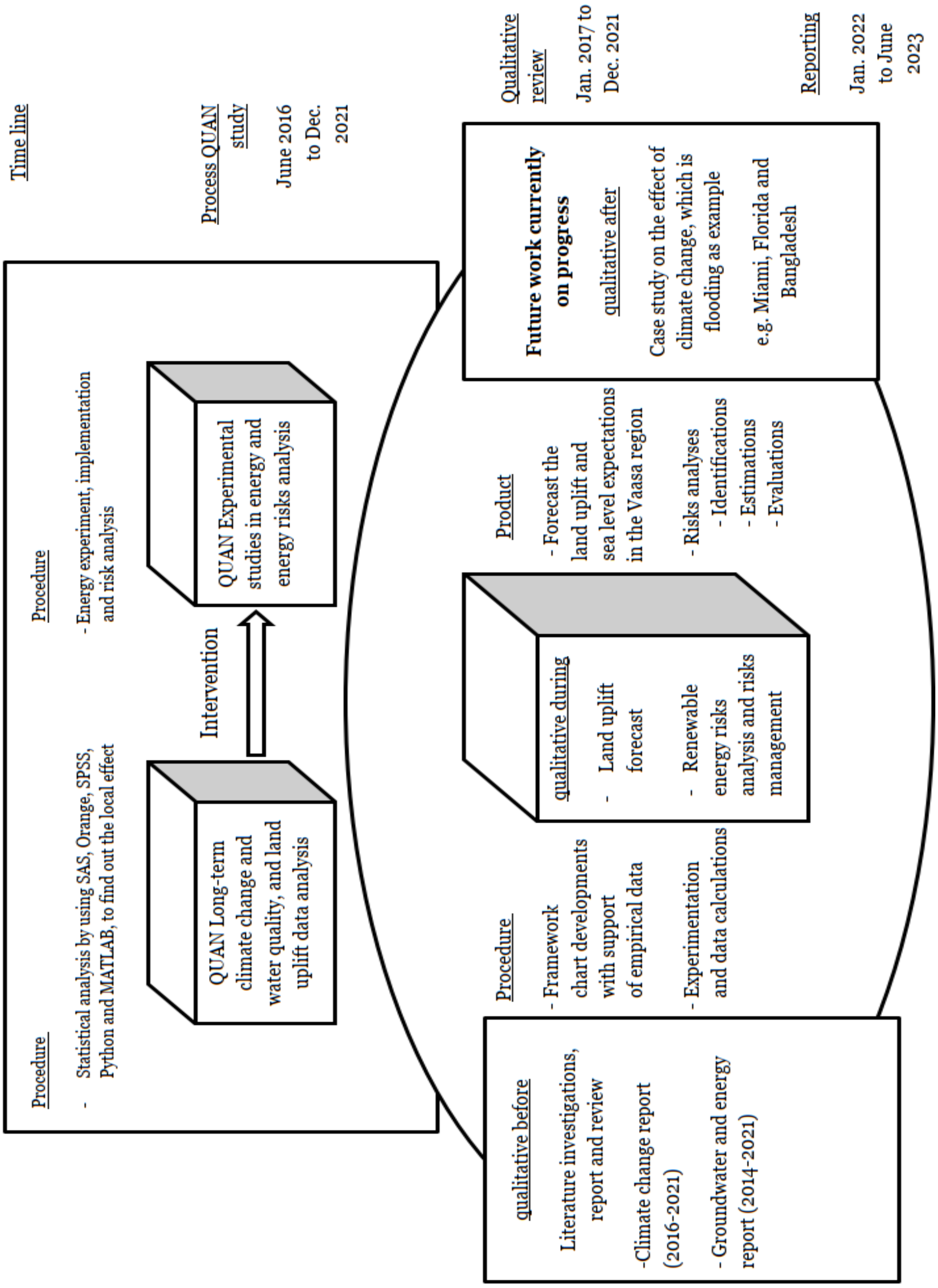


Figure 8. The mixed methods embedded design for the overall design of this research [based on Creswell and Clark (2011)].

1.3.8 Ethical questions raised

The main ethical question of the research is that the doctoral research work is relevant to people because the results may have a positive effect on their living conditions. Does climate change have an ethical side that the community should be concerned about? Indeed, climate change and its effects on the environment have an ethical aspect for the community. It is ethical to care about the environment and environmental pollution both at the current time and for future generations. Addressing ethical concerns in the community was a central focus. Was a data management plan required? Hence, since data analysis was involved for a larger data size, a data management plan was necessary. Therefore, data management plans and agreements were created that specified how to handle data during the research period and afterwards.

1.4 Contributions

The contributions of the research are as follows:

Among the contributions are detections, attribution and mitigation. The idea is to contribute to the study of climate change, use the consequent changes as energy sources, adapt and act as a part of the problem while thinking about the solutions. The research aims to provide knowledge and solutions (both replacement solutions and old solutions) to energy scarcity in the archipelago by using renewable energy resources (RERs). The determinations around regional temperature changes are useful for biologists studying in the region, since the world temperature average is not useful for all regions (Hannah 2011).

By extending existing knowledge, a new way of using sediment heat production in water bodies is analysed and investigated. The risk analysis and extended risk management determined the risks generated by climate change to renewable resources, which likely has not been done before. In addition, the risks of renewable energy use and production to the environment can provide an additional view, which is built on the findings of Holma et al. (2018).

New findings: the study shows the land uplift effect, the meteorological data changes caused by climate change, the effect of climate change on water quality in long-term data and the current climate change analysis. It takes effort to understand climate change and possible solutions to combating it in the areas of water, land and weather. The introduction of renewable energy to islands and Merten Talo and the statistical investigation of the Suvilahti and Vaasa sediment heat energy production sites are a means of working towards combating climate change. As well, risk analysis identification, estimations and evaluation were conducted for renewable energy resources risks caused by climate change and use and the impacts of renewable energy production on the environment. The next section lists the publications contributions.

1.4.1 Seaside renewable energy resources literature review (Publication I)

1. Showing a precise current literature review of seaside renewable energy solutions. This a new topic that previously had not addressed in depth.

2. Illustrating coastal geoenergy renewable resources in one figure; showing possible future renewable energy solutions in seaside areas and suggesting seaside renewable energy solutions for local area use.

3. Presenting a new way of taking advantage a problematic effect to overcome the problem itself. In other words, using the effects of climate change to our advantage to generate seaside renewable energy resources to combat and mitigate it.

1.4.2 The Kvarken archipelago area climate change effect on water quality (Publication II)

1. The effect of air temperature on water quality was investigated, and a significant effect was found. There is an effect of global warming (air temperature increase) that might cause changes in water quality mainly in a chlorophyll-*a* increase (Chl-*a*). This is a new finding that presents the effect of air temperature changes in the Kvarken Archipelago area.

2. Air and water temperature, Chl-*a* and other parameters are expected to increase in the future. This was shown and the parameters predicted using different statistical analyses.

3. Snow depth is expected to decline over time because of climate change effects, mainly global-warming-caused decline.

4. Several statistically significant correlations were found in the main variables analysed. The correlations were based on Pearson's correlation using the SAS Enterprise guide software.

5. The water quality status of the sampling water point was at least at a passable level, based on the SYKE water standard level, representing the

overall sampling points. It was found that the Et. Kaupa 1 (the worst) sampling point is at a good water quality level, representing the rest of the five sampling points.

1.4.3 Risk analyses on renewable energy (Publication III)

There are also several contributions from the risk analysis research:

1. The risks of climate change to renewable energy were addressed for the first time as a scientific investigation, to our knowledge.
2. The identification of risks to renewable energy due to climate change and of the risks of renewable energy use and production.
3. Estimates and analyses of the various risks to the renewable energy from climate change and of renewable energy risks to the environment were quantified in this research.
4. Evaluations show that types of renewable energy types are most affected by climate change and most affect the environment. Moreover, evaluations show the types of renewable energy that are the least affected by climate change and least affect the environment shown.
5. The comparison of renewable energy use and production impact on the environment with the results of Holma et al. (2018). It was found that most of the research results were similar to those of Holma et al. (2018). This validates that the risk analysis conducted shows the true estimates of the risks of renewable energy to the environment.

1.4.4 Sediment heat energy production (Publication IV)

In addition, there are several contributions from the sediment heat energy production analysis research:

1. The summary of statistical analysis shows natural fluctuations and patterns noted at one of the sediment heat energy production sites.
2. Dependency analyses show that sunny months are negatively correlated with distance from shore to depth and winter months are positively correlated.

3. Climate change is advantageous for sediment heat production, at least in summer. This result is new and confirms that sediment heat production can take advantage of climate change effects.

4. Sediment heat production is site-specific and depends on installation depth, even when the sites compared are located in the same body of water.

5. The optimal distance for sediment heat production is about 100–190 metres from the shore.

6. Starting in October, in the winter months, at about 30–50 metres distance from the shore, there is heat uptake to the households.

1.4.5 Mixed-method and land uplift contributions (All publications)

1. The research found that the qualitative studies support the quantitative studies, showing the benefits of using mixed-method investigations.

2. The results of the research establish a conceptual framework chart for the study of vulnerability and adaption to climate change that can benefit local, regional and global communities. The framework chart represents the first of its kind in land uplift publications, as far as we are aware.

3. The second contribution encompasses the theoretical calculations of temperature, sea-level rise and future land uplift. This contribution is based on the calculations of the future expected uplift and sea-level rise for the area around the city of Vaasa.

4. Predictions of the relationship between land uplift and sea level rise in the city of Vaasa, the Baltic Sea, Finland, Nordic countries (Finland and Sweden) and the world based on the literature.

5. A groundwater study showed that there is potential for groundwater energy utilisation (GEU) in the city of Vaasa.

6. Groundwater heating/cooling production might benefit from climate change effects, depending on how deep the groundwater or aquifer is located, local water flow patterns and seasonal variations.

1.5 Structure of the Dissertation

The dissertation is article-based and consists of five chapters, references, an appendix and publications. The first chapter is the introduction, consisting of the background, challenges and problems, objectives and methods, and contributions, among other sections. The second chapter is the methodology chapter. This chapter has an introduction and sections dealing with research design, data collection, data analysis, validity and reliability, limitations and assumptions, and significance. The third chapter is the results chapter, which presents four research questions and answers based on publications. The last two chapters are the discussions and conclusions. After the list of reference and the appendix, the final section lists the main publications that contributed to this doctoral research.

2 METHODOLOGY

This section explains the methodology of the research. The purpose of the methodology was to provide the most reliable means of solving the research questions raised. In addition, the choice of mixed-method research was due to the study's great complexity and the potential of this research design to increase confidence by using both quantitative and qualitative methods (O'Cathain 2007). Explaining to the reader the solution of the problems and questions that arose in this research is also essential to ensuring their engagement. This section begins with an introduction followed by an explanation of the research design (which also contains methodology, methods, and conceptual design), data collection, ethical issues, data analysis, validity and reliability, limitations and assumptions, and significance.

2.1 Introduction

This research is important in explaining the background and interpretations of climate change effects. One important aspect of this research consists of explaining the local effect of climate change in historical (long-term) data for water quality and meteorology and the relationship between them. Biologists and researchers require a local interpretation of the climate change effect, such as the local water temperature. Hence, determining the nature of the effects on water quality and meteorology is important to researchers, especially in terms of the effects on local areas. These local effects were investigated mainly by plotting the correlation and regressions between these two main data sets and within the water quality data parameters. The second important aspect of this research is to describe, allocate and analyse the most salient coastal renewable energy solutions, such as water heat exchangers, sediment energy, borehole energy storage, vertical wind turbines, wave energy, boreholes and more. The third important aspect of this research is determining the relationships between land uplift and climate change effects, such as sea-level rise. This is related to examining other natural phenomena in the local area to relate them to climate change effects (e.g. land uplift and sea-level rise relations). The fourth aspect of the research was to investigate risks to renewable energy due to climate change and renewable energy use and production risks to the environment. The general idea was to detect, attribute and adapt to climate change in the local area of the protected UNESCO World Heritage Site and other areas in the city of Vaasa, Finland. See also the questions and hypotheses raised in Sections 1.3.3 and 1.3.4.

Methodologies are general classifications of methods. Methodologies are classified into three groups: quantitative, qualitative and mixed methods. While methods are the specific procedural steps taken to solve problems, methodology refers to how research is undertaken, along with the theoretical and philosophical assumptions on which the research was based and the implications of these for the method or methods adopted (Saunders et al. 2016). The methodology was chosen based on the questions and hypotheses. The elements of the methodology include aims, strategies, research process, population and/or samples and reporting. The methods were further developed and data collection, ethical issues, data analysis, validity and reliability, practical usefulness, limitations and assumptions, and significance were addressed separately.

Why is the research topic important? Although climate change is global, little action is being taken globally. It is believed that climate change can be minimised by reducing CO_2 emissions, for which renewable energy is the most promising solution. Since the use of these actions (combating climate change by implementing renewable energy and studying its effects in the local area) by community and education sectors is quite new and contributions to combating climate change is quite limited, this makes the research topic important for combating climate change. In addition, it sets an example for local activities that might be carried out in other seaside cities, as well as investigating the effect of climate change on water quality in local areas and the risks of climate change for renewable energy, both of which have not been addressed in depth before and represent gaps in the literature and past studies.

2.2 Research design

This section illustrates and describes the research design of this research. The research perspective chosen was mixed methods research, which includes both quantitative and qualitative analysis methods. This methodology was chosen because it encompasses the most possible ways that the data can be analysed. This gives it the flexibility and complexity to produce excellent research. Moreover, the mixed methods strategy was chosen because of its advantages, some of which are the following, described in detail in Creswell and Plano Clark (2011): 1. The mixed methods design provides more evidence for studying research than either quantitative or qualitative research alone. 2. It provides answers to questions that cannot be answered by either individual method. 3. It provides a bridge across the sometimes-adversarial divide between the two. 4. It encourages the use of multiple worldviews or paradigms and 5. It is ‘practical’ in the sense that the research is free to use all possible methods to address a research problem.

The research design was a fixed and emergent mixed methods design. In this type, the use of quantitative and qualitative methods is predetermined and later implemented as planned in the research process. However, some procedures and analyses might emerge after looking at the initial historical data analysis of the research process and be added to the research work as an emergent section (Creswell and Plano Clark 2011). Consequently, the research design approach is classified as a typology-based and dynamic approach. As recommended by Creswell and Plano Clark (2011), this research used a typology approach because the researcher had less experience in mixed-methods research. A typology-based approach is the selection of a particular design to study purpose and questions and is also suggested for mixed-method research beginners (Creswell and Plano Clark 2011).

On another hand, the choice of mixed methods is due to the main advantages of this design: complementarity, offset and completeness, as listed in Table 3.2 of Creswell and Plano Clark's (2011) book. Complementarity means seeking elaboration, enhancement, illustration, and clarification of the result; in our case, the qualitative method is used clarify quantitative methods or analytical explanations. Offset, on the other hand, refers to both methods (quantitative and qualitative) having their strengths and weaknesses. Combining both produces better results by offsetting their weaknesses and bringing the strengths of both to the research. Moreover, completeness refers to bringing a more comprehensive account of the area of inquiry provided that both quantitative and qualitative research are employed (modified from Creswell and Plano Clark 2011). These are some explicit reasons why mixed methods research was chosen.

According to Creswell and Plano Clark (2007 and 2011), the six major types of mixed methods designs are the triangulation design, the embedded design, the explanatory design, the exploratory design, the transformative design and the multiphase design. Mixed methods classifications are given in Creswell and Plano Clark's (2007) mixed-methods research book, which illustrates the extent to which there are varieties of classifications among disciplines. For this study, of the four major types and two additional types mentioned in the 2011 book, the chosen type was the embedded design. All three subtypes of embedded design were chosen. These are the embedded design, the embedded experimental design model and the embedded correlation model.

Mixed methods embedded design was chosen because the research questions were answered mainly by quantitative data analysis with the support of qualitative analysis [Creswell and Plano Clark (2007 and 2011)]. In addition, energy analysis and correlation analysis were performed (Figures 9, 10 and 11). This constituted an interactive strand where both methods interacted between the quantitative and qualitative strands of the study (Creswell and Plano Clark 2011). Specifically, the secondary qualitative phase is built on the primary quantitative phase.

The timing was sequential: first, the researcher analysed the quantitative data, which was followed by a qualitative analysis embedded in the quantitative data analysis. The weighting or priority of the quantitative data was emphasised because most of the research questions require statistical analysis. The two data analysis types had an unequal weight was in this study, meaning that the primary aim was the quantitative method and the qualitative method was secondary. In addition, the quantitative and qualitative methods were combined by starting with data analysis. The specific choice was embedding qualitative data in the quantitative design. A general understanding of the research problem was gained from the rationale of this approach provided by quantitative data and then the subsequent analysis provides. Moreover, the mix of quantitative and qualitative methods took place in the design process, where the embedding of the qualitative analysis within the quantitative analysis helped in analysing the long-term data stage.

The main reason that an embedded design was chosen was to satisfy the need for analysing quantitative statistical data that would be supported by additional qualitative analysis. The quantitative statistical analysis includes the long-term climate change effect on water quality, meteorology, and energy. The first design is a two-phase embedded design, from the first subsection described by Creswell and Plano Clark (2007). Consequently, the design chosen was the general type of embedded design, which applies to the overall research performed. The first design is illustrated in Figure 9. The figure shows the qualitative study embedded within the main quantitative study, with the next step being an interpretation based on quantitative (qualitative) results. This is called a two-phase approach (Creswell and Plano Clark 2011).

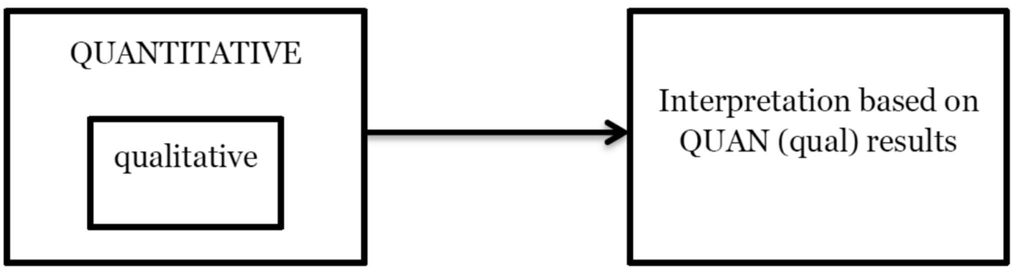


Figure 9. The first general research design chosen is a two-phase embedded design. Capital letters show priority [modified from Creswell and Plano Clark (2007)].

The next figure, Figure 10, shows the decision made on what to include in the embedded experimental model in Figure 10, which is further developed and illustrated in the first chapter of the overall design. Figure 10 shows the integration of the quantitative and qualitative aspects in the embedded experimental design. The bold section of the figure was where the main qualitative intervention took place. The steps planned were to first analyse the long-term climate data and then, after the intervention, to perform the data analysis of the energy temperature data collected in the UNESCO World Heritage protected area and the sediment energy data from Suvilahti in the city of Vaasa region of Finland. The experimental designs include measures where the analysis of long-term data was performed and then post-measurement data analysis was carried out. The qualitative intervention was performed before, during and after the analysis. However, most qualitative intervention was during or before the data analyses (literature review reports) and the subsequent qualitative analysis is planned to be a flooding case study (for future work). Finally, the interpretations were carried out based on QUANTITATIVE (qualitative) results. In addition, as described above, Figure 8 (in the introduction chapter) shows the overall mixed-method embedded design for this doctoral research [which was developed based on Creswell and Clark (2011)]. For a better understanding of the whole process that took place in this doctoral research, please see Figure 8.

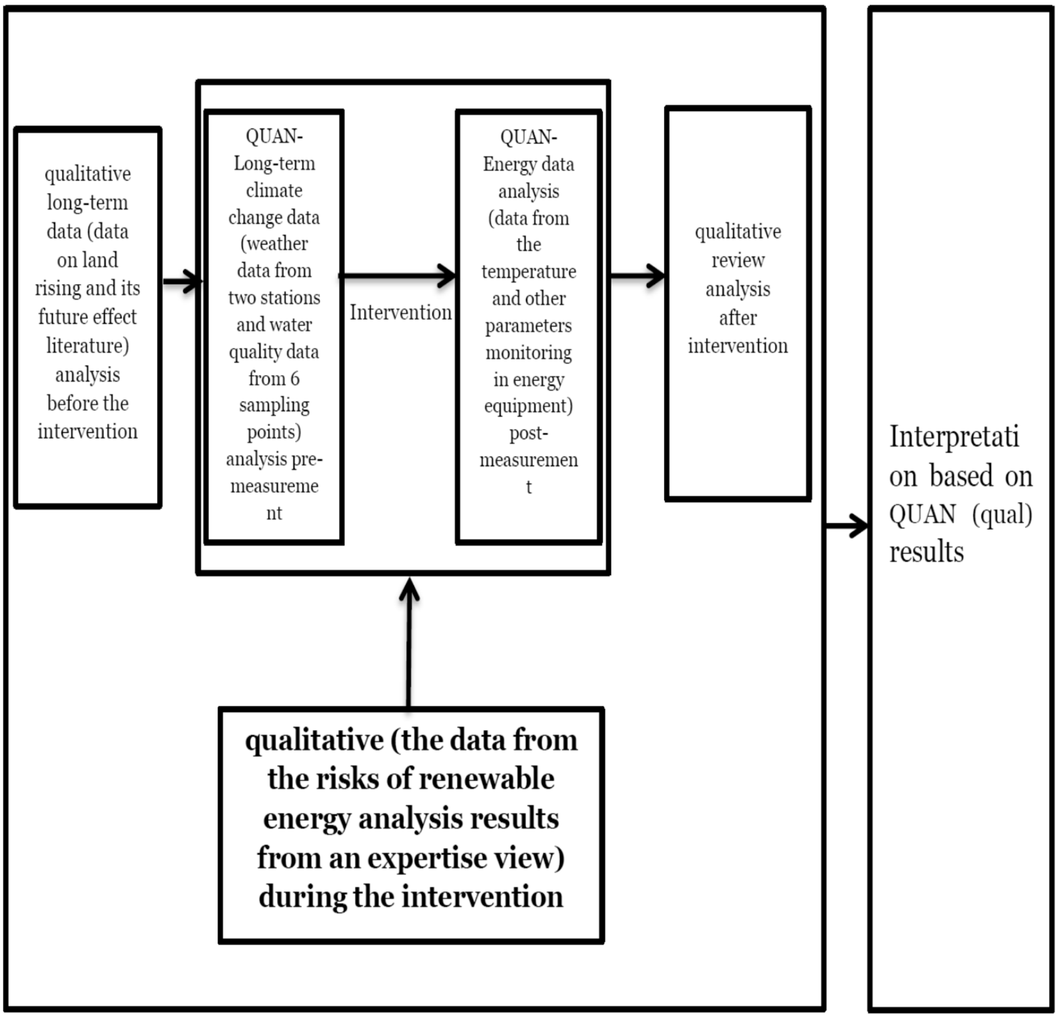


Figure 10. The preliminary embedded experimental model in the context of the research; the bold part is the choice of where the main qualitative analysis took place during the experiment. Uppercase letters show priority [modified from Creswell and Plano Clark (2007)].

The embedded correlational model was the third research design choice, with an embedded mixed-methods design. This determines the correlations and interactions between long-term water quality data, long-term meteorological data and sediment heat energy data analysis. This may show that climate change will be advantageous for energy solutions. The other correlations investigated were those within water quality parameters and with meteorological data. The same type of correlation design was applied to these correlations. Consequently, the appropriate chosen design is illustrated in Figure 11, which shows the embedded correlational model.

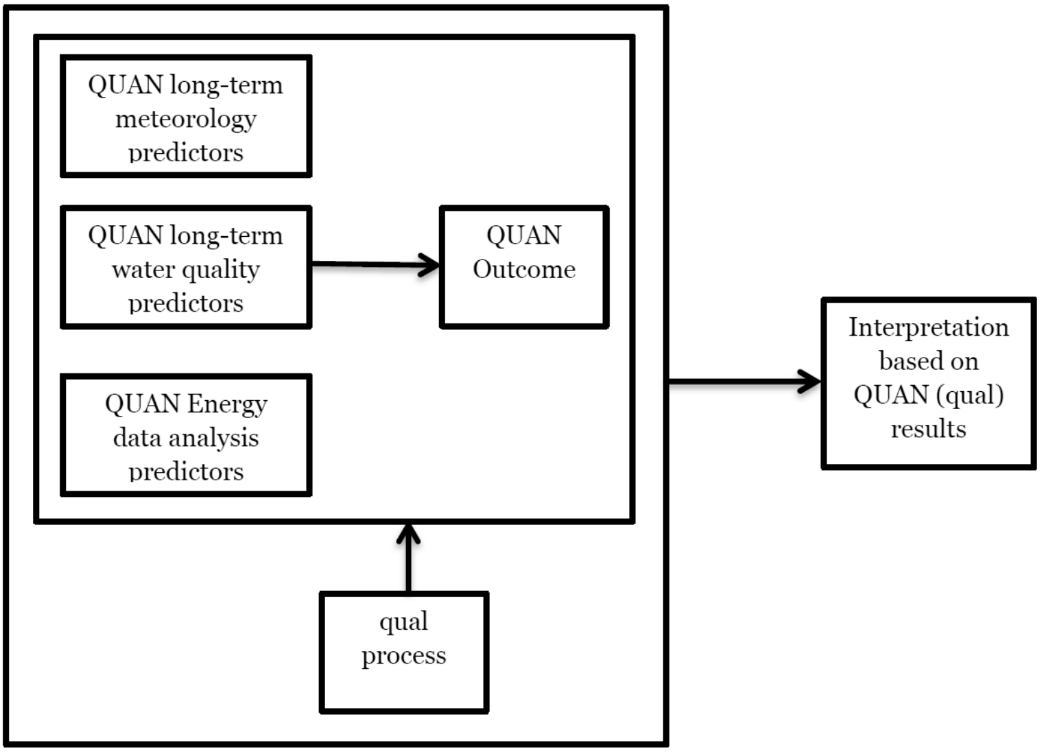


Figure 11. The type of embedded correlational model planned. Uppercase letters show priority in the process [modified from Creswell and Plano Clark (2007)].

In this context, data analyses were conducted from the end of 2017 to the end of 2022 in addition to data collection for analysis. The data analysis for heat energy was conducted on the same schedule. Specific dates are scheduled separately while taking research time fluctuations into consideration. The renewable energy resources installation and experimentation was planned to be done in Merten Talo (Raippaluodon silta area). However, this was not possible due to a disagreement. Consequently, the research analysis and writing were performed at the University of Vaasa in the Energy Technology department in the renewable energy group.

An alternative type of research design chosen was the explanatory design (also known as the explanatory sequential design). This is a two-stage research approach, where quantitative research is conducted first, followed by qualitative study. In our case, this embedded design research involved both quantitative and qualitative data collection and analyses simultaneously. As such, the two designs might be somewhat similar, but this alternative design is an option in case the embedded design did not work as planned. The alternative design (explanatory design) helps to explain the effect of climate change on water quality and meteorology. Afterward, correlations and other data analyses can be used to identify opportunities to use climate change to enhance renewable energy capacity.

2.2.1 Methodology

The methodology plans are detailed and the research process is described later. The methodology choices encompassed philosophy of science, aims, strategies, data collection, and data analysis. Consequently, the research process includes integrations between research designs, research, reporting and focusing and justifying the study. The integration of ethics with the research also plays a central role.

2.2.1.1 Philosophy of science

As a background for choice of methodology, one needs to identify the philosophy of science employed. Some possible philosophies of science were empiricism, interpretivism, constructivism, and existentialism. Empiricism focuses on observation and experience in gaining knowledge. The context of this study involved observing data (long-term and current data) and data analysis with experimentation (using experience if possible) to detect and attribute acquiring knowledge was essential to the current research. Empirical research can classified be descriptive empirical or normative empirical. With that in mind, study was descriptive and empirical, making it specifically an extensive descriptive empirical study. The next idea in the philosophy of science addresses interpretation. Interpretivism focuses on the interpretation and interpretation process, and is related to constructivism. To satisfy this in the research, a statistical data interpretation approach was planned and performed.

Constructivism views the establishment of knowledge in the research process as consisting of various degrees of approximation in accuracy and validity. The trends of constructivism include cultural constructivism, radical constructivism, rational constructivism, critical constructivism and genetic epistemology. Among these, the current research focuses on critical constructivism, in which product evidence, documents, experience and facts were studied. This was connected to the research context by data analysed on climate change, allowing the production of new or improved knowledge as the research progressed. In addition, the data analysis performed on sediment heat production and prelimnary study on water heat exchange as energy resources created new scientific knowledge. The long-term data for water quality and meteorology were obtained from different national organisations. In addition, when considering the social effect, constructivism respects the freedom of choice of researchers as individuals or community members and as well as community choice regarding climate change solutions and possible applications.

2.2.1.2 Aims

The aims of the research consist of the intentions and desires associated with the research outcome (the new evidence it generates) and at the beginning of the research process. The planned aims were to explore the background, the temporal process, relationships and connections, forecast the future and adapt, and interpretations as mentioned in the objective section (Section 1.3.1) of this research. The first planned aim was to explore the background. In the context of this research, that meant determining the effects of climate change on water quality and meteorology (in both cases from long-term data) by finding new knowledge and improving existing knowledge. Consequently, the land uplift that was investigated and its interaction with sea level, along with the difficulties in installing renewable resources in islands and roads on sea ice, created the background knowledge. The other background knowledge was founded on a statistical analysis of energy resources and risk analysis. The future work on flooding case studies is expected to show and explore an international perspective on climate change effects.

However, the second aim was studying temporal variation. In the context of the research, this was generated from the long-term (time series) data for climate change effects on both water quality and meteorology. The result shows the long-term time pattern with parameter fluctuations. The third aim to elucidate relationships and connections. This aim was satisfied in the current research by showing the connections and relationships between the two climate change studies (water quality and meteorology) and how the effects of climate change could be used as an advantage for energy resources. As well, the connections and correlations within water quality parameters were considered. The next aim was to forecast the future to some extent from all the long-term data by combining them with experimental findings. Moreover, the fifth aim was interpretation (attribution) of all data gathered during the research. In addition, another aim including carrying out studies such as sediment heat energy data analysis and risk analyses on renewable energy. All these aims focus on generating new knowledge, improving knowledge and extending existing knowledge. On the other hand, the aims were in pursuit of detecting, attributing and mitigating climate change by studying new renewable energy resources adapted to climate change.

2.2.1.3 Strategies

The strategies selected were empirical research, mixed method research (multi-method research), longitudinal research, experimental research and historical research. In the first step, the researcher struggled to choose between empirical and theoretical research. This research is an empirical study, a choice that was supported by the planned philosophy of science, which was empiricism. Empirical research explores experience and observations in the experiment, in this case in long-term data (historically saved data), and the results are utilised by making concrete observations and analysing them. The second choice was mixed method research (see the research design section in the current chapter). The reliability of the use of the mixed methods design for this research was found to be high because there have been many dissertations and researches carried out with mixed-method methodology [Mngumi (2016); Thomas (2016); Phdungsilp (2015); Elgin (2014); Patterson (2013); Houshialsadat (2013); O'Sullivan (2012); Von et al. (2011); Mcnamara (2008); and Cook (2006)] are among the examples.

Mixed methods research includes both qualitative and quantitative studies (statistical methods). The quantitative study was conducted using all data collected and gained from our university and other organisations in appropriate statistical studies. The statistical analysis also included a qualitative outcome in which the characteristics of the parameters were decided. For example, (optional) descriptive classical analysis is used in qualitative data and classification analysis. One example would be the classification of water colour observations as excellent, good, and bad based on the average measurement and standard classifications. In the research context, the quantitative data consisted of climate change studies, statistical analysis and renewable energy resource analysis. The qualitative research was used for studies that evaluated aspects such as the risks from climate change to renewable energy and the risks from renewable energy to the environment.

The next choice was longitudinal research, a type of research that enables the exploration of change and development over a long period. In the context of the current research, the long-term data in water quality and meteorology was expected to show a longitudinal pattern over time. Of the possible strategies, the final one is experimental research and historical research. The empirical component is included in the data analysis of energy resources, whereas the historical research dealt with climate change effects in long-term data for both water quality parameters and meteorology effect variation. Data collection and data analysis choices were made in Sections 2.3 and 2.4. Figure 12 shows all the plans and choices made in the methodology for this research, as well as presenting the data collection plan choices and data analysis methods.

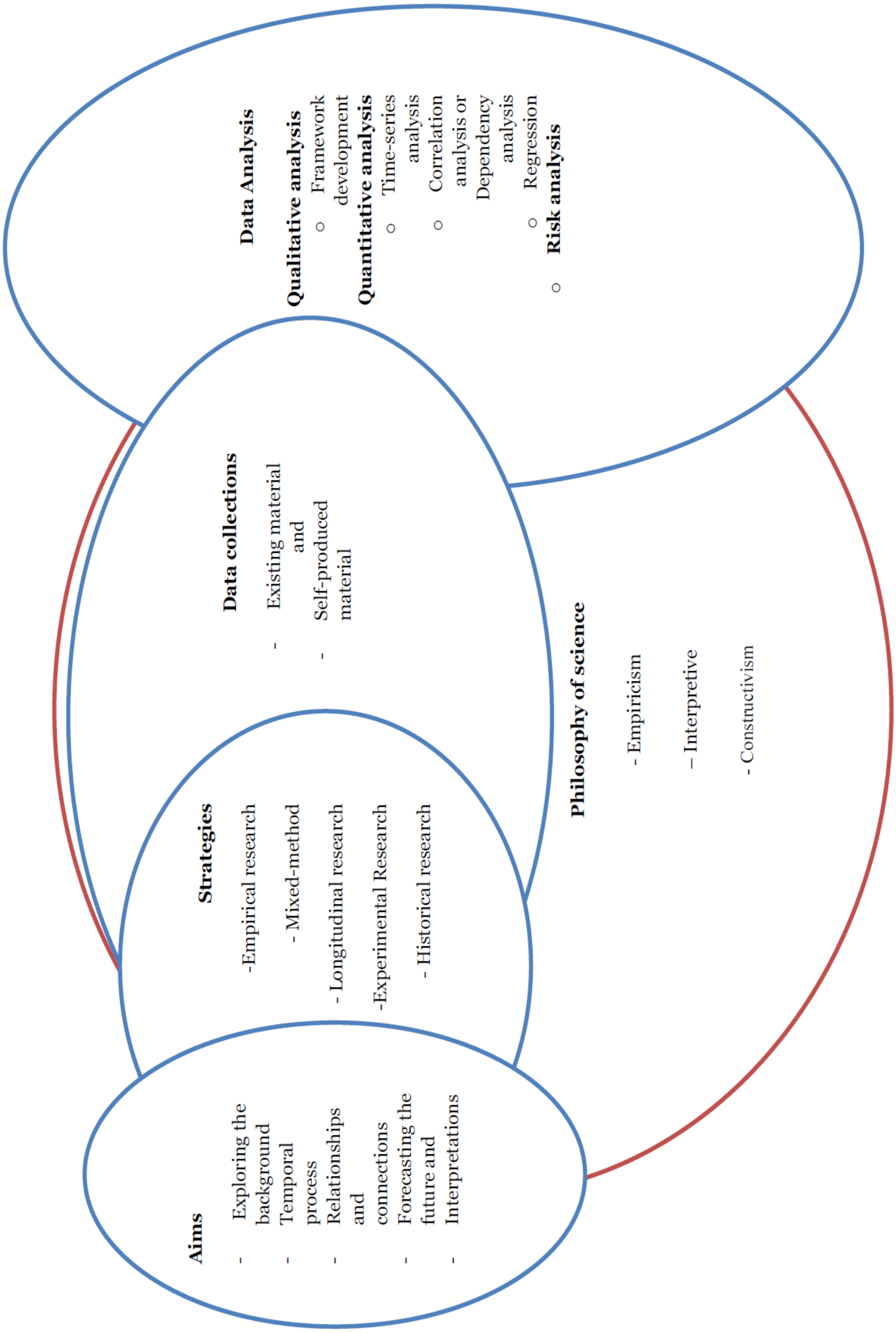


Figure 12. The methodology plan and choices made in each step of methodological development in the research process.

Why are the current methodology choices important? A methodology plan is one of the first steps of the research process, since it looks at the possible ways to analyse a given study. The current methodology choices were important because they represent the basic and advanced research methodology for the type of study conducted in the city of Vaasa. The way these methodology plans were created was by carefully considering the study types involved to answer the questions and to confirm or falsify the proposed hypotheses. These plans were chosen from numerous possible methodologies described by different organisations, articles, websites and books. The climate change study was broad and required a variety of methods, but the current methodology choices at each step, as shown in the previous and subsequent figures, satisfied the long-term data analysis of water quality and meteorology. In addition, the other sections of the energy data analysis and risk analysis were determined in the methodology choices.

This research not only investigates the actual local effects of climate change, but also determines solutions for seaside renewable energy utilisation and for the efficiency of the proposed system. Action to combat climate change cannot come from a single global solution, but must also involve local contributions. Therefore, the researcher believe that these type of actions and studies will advance our contribution to combating or at least minimising the effects of climate change on ecosystems and the environment. Local climate change effect research is also of great help to researchers who will work in this particular studying the environment and ecosystems. It will also create a better world for future generations and the current population. We must all have an answer for the next generation when they ask what we have done to avoid species extinction.

Why is the methodology of the proposed study appropriate and rigorous? According to Creswell and Plano Clark (2011), a mixed method embedded design can be used when there is a need to enhance the research through a second method (qualitative in our case). Hence, the primary methodology and methods were quantitative. However, the study was supported by various qualitative methods. Therefore, this shows that the proposed design was a rigorous choice for our type of research. In addition, the mixed methods design is good at mitigating the respective weaknesses of quantitative and qualitative analysis. The research was planned this way because the embedded mixed methods design was found to be sufficient for answering the proposed questions. It is also important not to forget the challenges to specialise in each method which can require time to acquire the necessary skills. However, based on the time plan and expertise involved, the mixed methods approach is appropriate and rigorous.

2.2.1.4 Research processes

The research process was as follows: after gathering background information, and determining the purpose, questions and hypotheses, the next step was to develop the research design and methodology section, along with a literature review. Doing so helped to link the ideas of the statistical local climate change analysis and the risk investigation; and other analyses were conducted. The next step after the deep literature review on the related topics chosen was the analysis of the long-term data on water quality and meteorology from different organisations to identify local climate change effects. In addition, other studies of statistical tools and a literature review were conducted throughout the research process. The water heat exchanger was tested after installation to determine its energy capacity. However, it was uninstalled and brought back to the University for future project use. The results and findings were presented with visual illustrations, written up and published. Then the discussions, recommendations and conclusions were written. The dissertation was written alongside the other steps of the research process. Figure 13 shows, a concept map (research design and development) of the overall research process.

Decision-making and framing were carried out by reading different resources dealing with the methodology and other sections of the research process. After gathering general information about the various processes involved, choices were made by evaluating the proposed questions and hypotheses to which the choices fit the best. After the aims, strategies, data collection, data analysis and philosophy of science were chosen, the advisor made corrections. After a choice was made, for example, in methodology, a deep reading on the research was conducted, which helped to choose the best methodology. In our case, this was a mixed methods design. Afterwards, the methods used for each question were chosen and developed. A data collection and data analysis plan were made along with a data management plan. Finally, the rest of the methodology chapter was carried out step by step, in conjunction with reading articles and books about methodology. Afterward, the data analysis and literature review were conducted. Risk analyses were conducted along with the preceding steps. The results from the data analysis and literature review were used to produce articles for publication in the journal. Finally, all results were presented in reports, articles and in this research work.

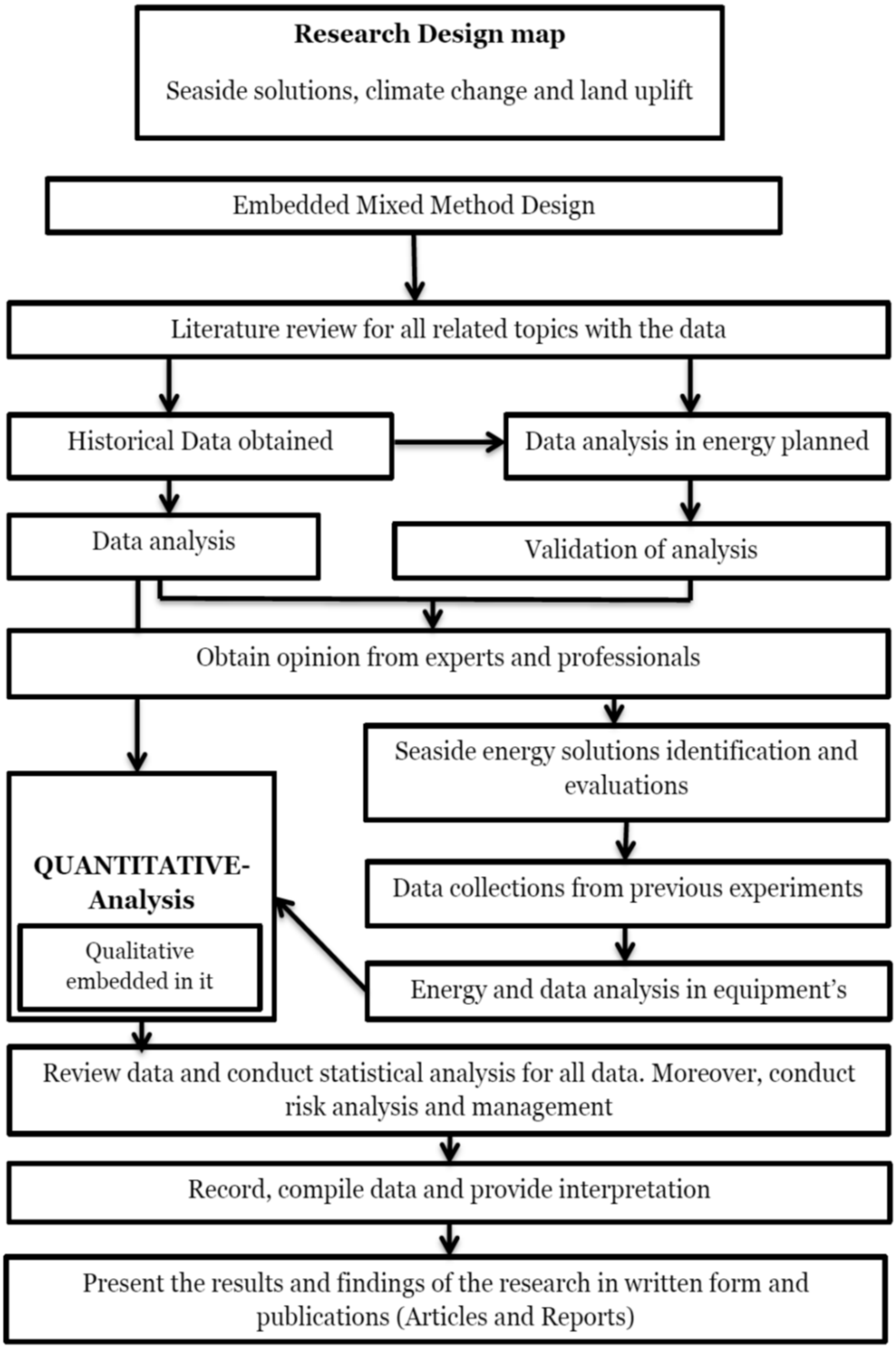


Figure 13. The concept map was built based on an example presented by James and Slater (2014) book. Capital letters (or QUANTITATIVE) show priority in the analysis.

The literature review gave an in-depth background of the literature and the topics and fields involved in this research: climate change, land uplift and water resources (water quality). These components will be published in journals as review articles in future. The literature review presents the backgrounds of the different disciplines involved in this research by focusing on specific topics in these disciplines. The review used a cause-and-effect lens to show the whole process of climate change and then concluded by showing different adaptation options. The land uplift review is used mainly to develop a framework chart. The water resource review investigates water quality and its relation to other aspects. Moreover, future seaside energy solutions were presented in depth in the renewable energy article, which was published as an article. The literature reviews are planned to be published as an articles and reports.

The data collection participants for this study on water quality and meteorology are the following: The water quality data for the Vaasa region was gathered from ELY-Keskus (from six sampling locations). ELY-Keskus has been collecting water samples from most water systems for decades. The meteorological data for the Valassaaret and Vaasa Airport sites are gathered from the Finnish Meteorological Institute (FMI). These data had not previously been analysed for other publications, particularly the water quality data.

2.2.1.5 Population and/or Samples

The sampling points for the water quality data can be seen in the map presented in Appendix 1 (see this map for sampling points, weather stations, the 'Drop-in-sea' project and the Merten Talo project sites). The six water quality sampling points were: Vav-11, F-16, Valörglippet, Vav-7, Vav-19 and Et. Kaupa 1 (Eteläinen Kaupunkiselkä 1). The two weather stations were located in the Valassaaret and Vaasa Airport sites.

Sediment heat energy data was obtained from the Suvilahti, Vaasa sites. Two sites were the Ketunkatu and Litto-oravankatu sediment heat energy production/temperature data collection sites.

2.2.1.6 Reporting

The data was reported by presenting important data analysis results. The data was displayed in tables, graphs, charts and other figures. The planned publishing methods were the following: The first report (Girgibo 2021) provided background knowledge on the effects of climate change and the use of climate change as an energy advantage and was titled ‘The effect of climate change on water and environmental resources in the Kvarken Archipelago area’. This report, in addition to giving background knowledge, contains a chapter on the analysis of the effect of climate change on energy resources. The second paper (Girgibo et al. 2023) was ‘The potential of using groundwater as a heating/cooling energy source in the Vaasa city region of Finland’. As the title indicates, the idea of groundwater (water resources) as an energy source, such as GEU (groundwater energy utilisation), for the city of Vaasa was suggested. The further publications are (Publication I and Publication IV), which deal with sediment heat energy production and seaside energy solutions. In a climate change study on water quality, one article is a statistical analysis of long-term data based on the suggested methodologies (Publication II). Possible additional articles on the relations between land uplift and climate change effects (Girgibo et al. 2022) and risk analysis (Publication III and Girgibo 2022) were planned. Among these publications, two were reports published in the Tritonia library (Girgibo 2021 and Girgibo 2022). All the other publication are journal articles.

2.2.2 Methods

2.2.2.1 Methods used for research question 1 (RQ1)

> What are the future coastal energy solutions? Do sediment heat energy production and other seaside energy systems use climate change to their advantage, and if so, in what seasons?

1. The seaside renewable energy resources literature review article used a systematic literature review. The literature data was gathered from three databases (Google scholar, Scopus and Web of Science). Evaluation and selections were made based on the title, the abstract and the paper’s overall contents. After selection, the articles and other resources were used in a systematic literature review development. See Publication I for detailed procedures and search keywords used in this article.

2. Sediment heat energy data analysis used the general data analysis procedure, as well as the eight-step procedures from Dytham (2011) listed in Publication IV. Some data analysis procedures used in Publication IV are described in Section 2.4 (in the data analysis section).

2.2.2.2 Methods used for research question 2 (RQ2)

> What are the changes in water quality due to air temperature change effects? Why have long-term water quality parameters and meteorology changed over time due to climate change? If they have not, why are there no changes to them?

1. Data gathering from different organisations was conducted first.

This process took more than one year of identifying the right organisation before until receiving the data. The data that were eventually gathered and used consisted of water quality data from six sampling points provided by ELY-Keskus and data from two weather station from the Finnish Meteorology institute website.

2. Data analysis

    a. Identifying variables of interest

During the first steps of the data analysis the main variables of interest for water quality and weather data were identified. For water quality, the variables of interest are: Chlorophyll-*a*, TP (total phosphorus), TN (total nitrogen), nitrate-as-nitrogen, turbidity, oxygen saturation, dissolved oxygen, Secchi depth, temperature and time. From the weather data, the variables of interest are all variables found in the data, namely air temperature, maximum air temperature, minimum air temperature, precipitation, snow depth, and time.

    b. Eight steps of data analysis

Various types of analysis were conducted over a long period (from 2017–2022). All analysis was conducted using SAS Enterprise Guide 7.1, Orange analysis tool, SPSS or Phyton. The statistical analysis conducted in SAS includes descriptive analysis, dependency analysis, analysis of differences (e.g. median tests), linear and multiple regressions, trend analysis and ARIMA forecast modelling. This analysis was conducted by using the SAS software procedures for each statistical analysis tool. Additional detailed procedures for this software can be found in Meyers et al. (2009). However, the general procedure used in the statistical analyses was based on Dytham's (2011) data analysis by using the eight steps of the general data analysis procedure, as described in Dytham's (2011) book and Publication IV.

3. Interpretation was performed during and after each analysis to identify the important results.

4. Reporting was carried out during the data analysis period. After identifying the important results for water quality and climate change, these results were written up in the Kvarken article (Publication II).

2.2.2.3 Methods used for research questions 3 (RQ3)

> What are the risks of climate change to renewable energy resources, and how severe are they? What is the nature and magnitude of the risks of renewable energy use and production to the environment?

The detailed procedures used for the risk analysis process were described in Girgibo (2022) the risk analysis report, which some procedures are adapted from Holma et al. (2018). The general procedure was: 1. Identifying risks, 2. Risk assessment/analysis: collecting expert data in two tables, the risks of climate change in renewable energy and the risks of renewable energy use and production to the environment, which was gathered through emails due to COVID-19 (corona virus) periods. The analysis of the data collection was then conducted and the participants were informed of the results via email. Moreover, 3. Risk evaluations, results and their interpretations were reported in Publication III.

2.2.2.4 Methods used for research question 4 (RQ4)

> Why and to what extent does the land uplift phenomenon happen and what are its consequences? How do qualitative data support the quantitative statistical data analysis in the case of land uplift and other effects?

- For the mixed methods question, a comparison between different topics, results and publications was performed to find out whether qualitative studies supported the quantitative ones or vice versa.

Land uplift questions materials and methods (See Girgibo et al. 2022 for more detailed information):

- <u>Literature data selection process</u>: The databases used in this literature review were Scopus, Google Scholar, Science Direct: Elsevier journals, Nature journals, and Google's search engine. The main descriptors used for searching were as follows: land rising and climate change connections, measurement of land uplift, compensation in land uplift, land uplift phenomena in Europe, land uplift in the Vaasa region, the Kvarken land uplift and inclinations in land uplift. The procedure used in the systematic literature review is shown in Figure 7 at Publication I and presents the methodology of literature used in this research. As well, it was presented in Figure 4 and Section 2.5 by Girgibo et al. (2022).

- Empirical model of climate change impact on the sea-level rise: Rahmstorf's (2007) ideas and formulas were used to calculate the future effect of sea-level rise based on the local and world temperature expectations.

- Land uplift, sea-level rise and their relationship: This was the theoretical background used for the overall analysis of land uplift and sea-level rise relationships.

- Cause and effect analysis of climate change (sea-level rise) and land uplift: The research used cause and effect theory as a lens, which was used in the overall analysis of the relation between land uplift and sea level rise displacement.

- Creating a conceptual framework chart development: This was performed during the literature review process of this research and involved the creation of a framework chart that gives the global framework for land uplift management.

- Empirical analysis of the Vaasa region land uplift and its literature data: This was developed and calculated based on Påsse and Andersson's (2005) publication and formulas as they are given in the framework chart, which was used for calculating far-future land uplift in the Vaasa region.

- Case study of the Vaasa region for the validation of the conceptual framework: Here the geographical area of Vaasa, Finland, was considered during the study development process. Table 2 presents the study topics of the framework chart development, together with the geographical areas studied for each topic. The choice of geographical area was determined during the literature synthesis and systematic literature review process. The focus area for the theoretical data analysis is centred on the Vaasa region. Four specific areas for theoretical data calculation – two in Sweden, and two in Finland – are presented in Table 3. The areas considered in the empirical data validation are also presented in Table 3. Data relating to land uplift and sea-level rise rates in these areas were collected and analysed from various literature sources.

Table 2. The specific areas considered for each section of the framework chart development.

Subsections of the framework chart development	**Specific areas considered for each subsection**
1. Causes of land uplift	The world in general
2. Patterns of uplift through time	Fennoscandia and the Sierra Nevada, USA
3. How to measure uplift?	The world in general
4. Consequences of uplift	Baltic sea area, Åland Islands, Sierra Nevada (USA), Kvarken archipelago, the northernmost Gulf of Bothnia (Finland), Fennoscandia, North America, Yakushima river basins (Japan), subtropical eastern Pacific, and Vaasa region (Vassor Bay)
5. Empirical procedure based on Påsse & Andersoon (2005)	Ångermanland (Sweden), S. Västerbotten (Sweden), Rovaniemi and Lauhanvuori

Table 3. The specific areas considered for theoretical data calculations for far-future forecasting and areas considered for empirical data validation analysis.

The areas used in theoretical data calculation		**General areas used for empirical data validation analysis**
Ångermanland		Baltic Sea
S. Västerbotten		Vaasa region, Finland
Rovaniemi		Finland (general expectations and forecasts)
Lauhanvuori		Nordic area (Finland and Sweden)
		World (general expectations and forecasts)

2.2.3 Conceptual design

A conceptual framework is ‘an argument about why the topic matters and why the means proposed to study it are appropriate and rigorous’ (James and Slater 2014). The conceptual framework was laid out in first chapter of this dissertation. However, conceptual design includes the design of interactions, experiences, processes, and strategies. The main design included consists of the interactions and process flow between different purposes of the research.

The main background topics and elements/analysis were climate change and renewable energy risks, which in turn come in two flavours: 1. Climate change risks to renewable energy resources and 2. Renewable energy uses and production risks to the environment. These main topics have two-way interactions between them and cover four specific topics: 1. Land uplift and sea-level rise relationships, 2. climate change effects on water quality, 3. Seaside renewable energy solutions, 4. risk analyses for renewable energy, and 5. Flooding effects in severely affected regions of the world (future work). Figure 14 shows the conceptual design, focusing on interactions and process steps and relations.

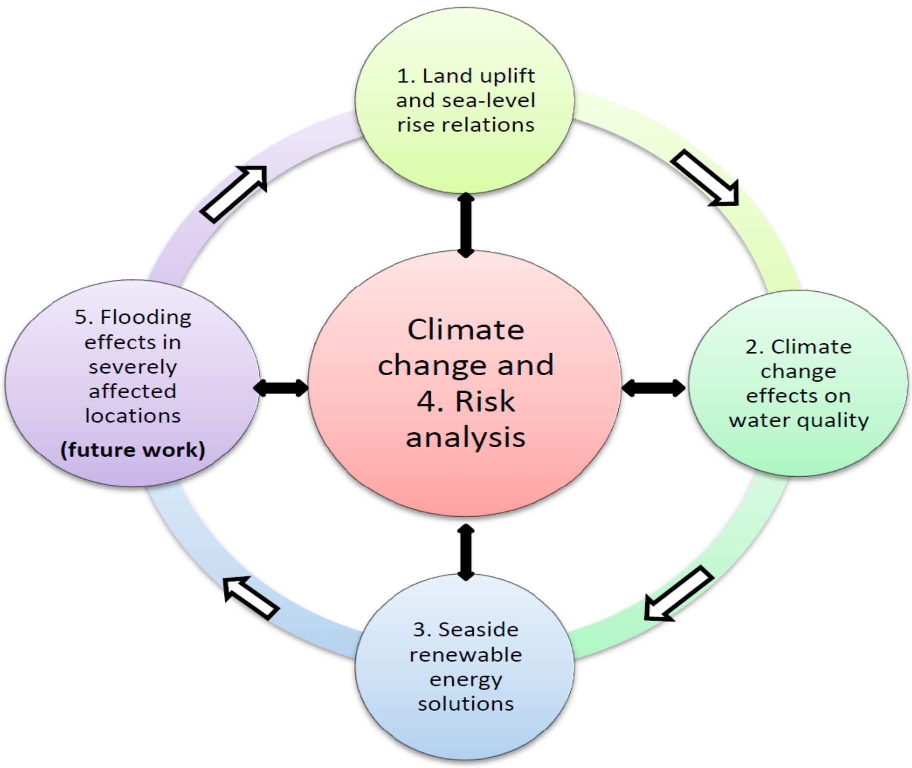


Figure 14. The conceptual design shows two-way relationships between each specific topic/purpose and the central background elements (indicated by small two-way arrows) and research process steps taken (indicated by the white arrow and directions).

The central elements of climate change and risk analysis are the main focus of this research, where both can have relationships with the rest of the more specific topics. Climate change as a central element was investigated in the literature review and in the publication of Girgibo (2021) in the local region. The risk analysis was primarily considered in the risk analysis literature review report (Grigibo 2022) and in Publication III, which addresses research question 3 and purpose statement 3. The relations between the central elements and the second topic (climate change effects on water quality) can include climate change effects on the local bodies of water influencing the water quality. This second topic and its interactions address research question 2 and purpose statement 2 of this research, including in publications (Publication II). The circular interactions with the different topics show that seaside renewable energy solutions (the third topic) act to combat climate change, and thus will change the effect of climate change on water quality in the far future. The next topic is the first topic (the relationship between land uplift and sea-level rise).

The interaction of the first topic (land uplift and sea-level rise) with central elements can arise from climate change influencing land uplift change by causing sea-level rise in the Vaasa region, Finland. This topic addressed research question 4 and purpose statement 1. This mainly was addressed in the literature review and publication (Girgibo et al. 2022). It acts as a comparison topic for the topic of flooding effect in severely affected location, which will be considered in future work. Comparing both topic 1 (land uplift) and the future work topic (flooding) shows that the local effects of climate change can be very different from the global expectations. The next topic is future work, dealing with flooding effects in severely affected locations as an example of the effects of climate change.

The interactions of the future work topic with the central element include elements such as climate change causing flooding in some areas of the world. This was addressed mainly in a future publication. Flooding has a usually negative but occasionally positive influence on seaside renewable solutions (e.g. wave energy production increase), which represents the relation between the topic of flooding and the third topic (seaside renewable solutions).

The interaction of the third topic with the central elements touches on both climate change effects and the risk analysis process. One interaction is that seaside renewable energy solutions are used as a mechanism for combating climate change by reducing greenhouse gases. The other interactions were with risk analysis. The interactions between climate change, renewable energy resources and risk analysis can be seen in one of the analyses of the main risks, which was ‘climate change risks to renewable energy resources’. Another interaction was ‘risks of renewable energy (including seaside energy solutions) use and production to the environment' (Publication III). The third topic addresses research question 1 and purpose statement 4 (Publication II and Publication IV). Seaside renewable energy solutions can act as a mechanism for combating climate change and thus change the effect of climate change on water quality (the second topic) and other sections in the far future. There are also unmentioned interactions and relations between various sections of the research topics in this conceptual design section. Here, the focus is solely on the main results of the research.

2.3 Data collections

2.3.1 Data types collected and used

The weather or FMI data were gathered from two weather stations in the Vaasa region over two periods: the Mustasaari weather station for the 1959–2011 period and the Vaasa Airport weather station for the 1959–2019 period. The data include precipitation amount [mm], snow depth [cm] and air temperature [°C].

Water quality or ELY-Keskus data include total phosphorus, unfiltered [µg/l]; total nitrogen, unfiltered [µg/l]; thermo-tolerant coliform bacteria [kpl/100 ml]; temperature [°C]; nitrate as nitrogen, unfiltered [µg/l]; nitrite-nitrate as nitrogen, unfiltered [µg/l], and Secchi depth [m].

Sediment heat temperature [in °C] data were gathered by the University of Vaasa research team at two sites (Ketunkatu and Liito-oravankatu) in Suvilahti, which were sediment heat energy collection sites in the city Vaasa, Finland. The data were from August 2013 to December 2016, gathered each month, as well as September 2018.

2.3.2 Procedure/instrumentations

During the research work, the researchers contacted the Finnish Meteorological Institute (FMI), ELY-Keskus (the Centre of Economic Development, Transport and the Environment), Finnish Geospatial Institute (FGI) and Metsähallitus (Finnish forestry organisation), along with online services, mainly Copernicus.eu, to assist us in collecting various types of data using their open access and closed access data sources. However, the way they collected the data and how one can retrieve the data effectively were not separately described by some organisations.

FMI told us that all the data are accessed through the online database and that we had to retrieve it ourselves. Unfortunately, due to the difficulty of the task, it took a very long time until we got help from our colleagues at the Novia Applied Sciences University, Vaasa branch. They have an excellent programmer who helped us to download all the necessary data from the two weather stations, Valassaaret weather station and Vaasa Airport weather station. After some time and after contacting various people in ELY-Keskus, the researcher got access to the water quality data from various sampling locations near Valassaaret and the Vaasa region, showing the various consequences of water quality related to climate change, and water pollution. Even land uplift effects might be visible on water systems. Both national and governmental organisations used standard measuring procedures and instruments to collect the data. Therefore, both data sets gathered from ELY-Keskus and FMI are trustworthy enough to be used in this research.

The total length of the Suvilahti seabed sediment heat collection pipeline was about 8 km (12 × 300 m and 14 × 300 m). The pipe was installed horizontally into the solid clay layer of the seabed sediment, by a horizontal drilling machine. The position of the pipes was at a depth of 3–4 m from the sea bottom of the Gulf of Bothnia. Sediment heat is extracted via this heat-collector pipe field in the sediment layer and separate heat pumps inside the individual houses. The network is also used to cool houses in the summer. The installation and validation of the sediment heat energy production pipeline and data collection via DTS (distributed temperature sensing) method was carried out by the Geological Survey of Finland (GTK). The pipeline was established at a housing fair in Suvilahti, Vaasa, in 2008.

2.3.3 Population and samples

The Finnish Meteorological Institute (FMI) collected data from 1959 to 2018 at two weather stations, namely the Valasaaret weather station and the Vaasa airport weather station. Only five parameters were obtained from the data gathered: Precipitation amount [mm], snow depth [cm], air temperature [^{O}C], maximum temperature [^{O}C] and minimum temperature [^{O}C]. All the data gathered were daily averages for both stations. Most days from 01 January 1959 up to 17 September 2018 were found at the Mustasaari weather station, but only 1959–2011 data was gathered from the Vaasa airport weather station.

Long-term water quality data (source ELY-Keskus) were gathered from the organisation data sets for the Kvarken area in the hope of finding the effect of climate change on water quality. The sampling sites were Vav-11, F16, Vaslörgloppet, Vav-7, Vav-19 and Et. kaupunginselkä 1 (Eteläinen Kaupunkiselkä 1). All water quality sampling sites, weather stations and project sites can be seen on Appendix 1 figure map. The variables collected were listed in the data collection section of this methodology chapter. The general period of all the sampling points was 1962–2018, with variation in some sampling points.

Sediment heat temperature (in ^{O}C) was the only type of variable that was collected from 0 up to 300 metres distance from shore to the depths of the water body. Data were gathered by the University of Vaasa research team at two sediment heat energy collection sites in Suvilahti (Ketunkatu and Liito-oravankatu) in the city of Vaasa, Finland.

2.3.4 Ethical issues

The main ethical issues of the research come from its potential to positively affect people's living conditions. In addition, some of the other ethical questions raised were described in Section 1.3.8 (Ethical questions raised). There are no ethical issues with the data, because the data collected did not include humans as a data source. The only ethical issues may arise after the analyses, since people will have to observe the effect of climate change in water systems, mainly on water quality. They then must act responsibly to avoid facilitating climate change by releasing greenhouse gases (GHGs) or other means. During this research process, a data management plan was created to avoid complications regarding data rights, where to keep it, who has access to it, how to share it, and how to handle data after the research work period. This data management plan was only for our research group, not for the data source organisations, because both (FMI and ELY-Keskus) organisations' data were publicly available for general use. Therefore, there are no ethical issues from sharing the data with other colleagues in terms of the data source organisations.

2.4 Data analysis

Data collection and gathering were described in detail in Section 2.3. The general modelling and statistical analysis methods are as follows: All analyses were statistical analyses using SAS (statistical analysis system) Enterprise Guide 7.1 (Meyers et al. 2009). Data cleaning and combining were done by using the Orange software package and Python (this is a modelling language). The methodology is based on the following step, shown in Figure 15, which gives the flow chart of all the methods used in the statistical analyses.

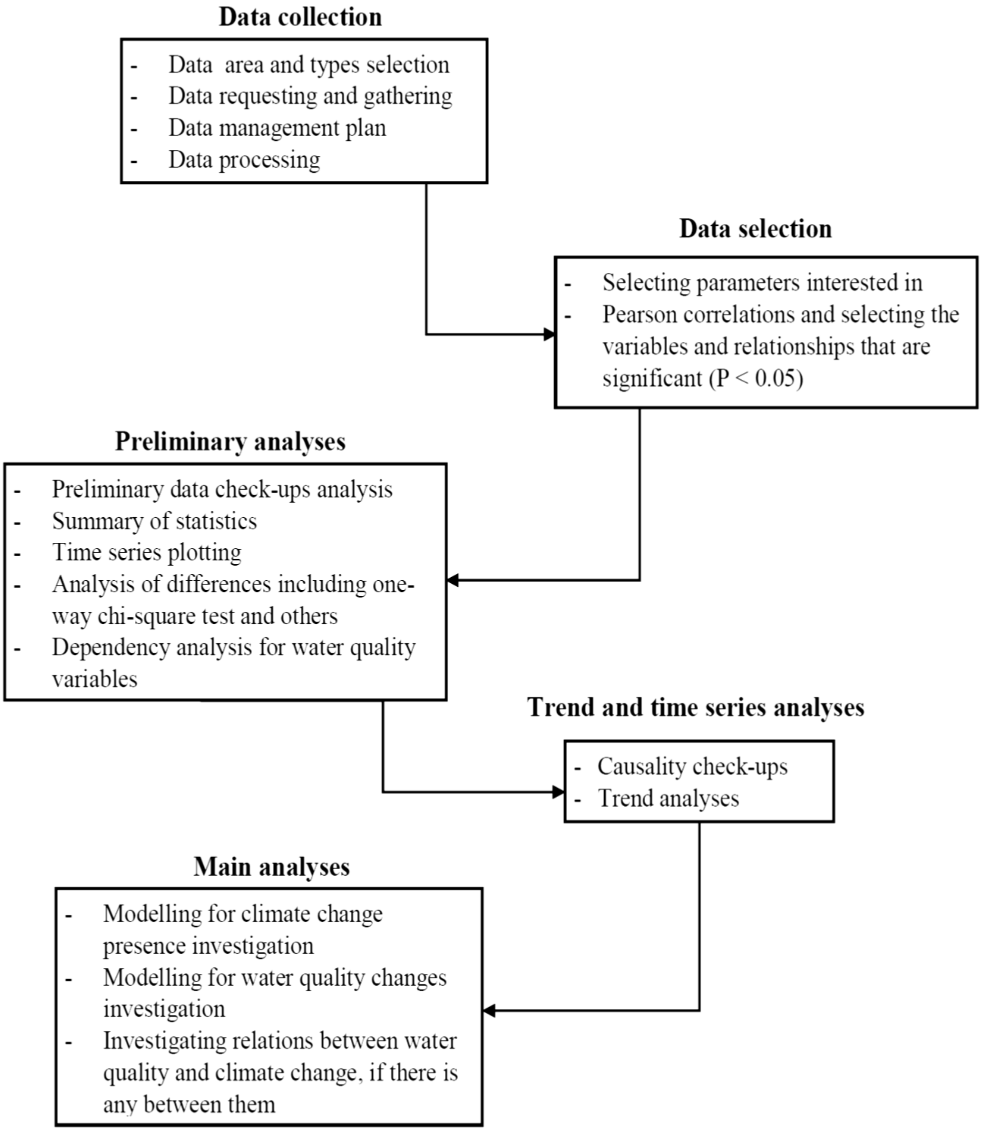


Figure 15. The flow chart illustrating the whole methods used in statical analyses.

2.4.1 Selections of variables

During water quality check-ups using the χ^2 (chi-square) method, the water quality status indicator used was the seawater water quality level, because seawater has stricter levels compared to inland water quality levels (see Table 2 in supplementary materials of Publication II). Even though the Et. Kaupa 1 (4f on Appendix 1 figure) sampling point is relatively near to the city of Vaasa and can have more inland water, it was representative enough because it passes the seawater quality status. After confirming the aforementioned elements, it was decided to use the 4f sampling point water quality data to be representative of the whole analysis.

Table 4 summarises the Pearson's correlation coefficients between chlorophyll-*a* and the key water quality and weather variables plotted in the time series graphs. These variables show the strongest positive or negative correlations. This dependency analysis helps to identify the relations between the important variables. Some of the correlation analyses failed to reject the null hypothesis (H_o) at a 5% significance level (suggesting that there was no correlation), and others were rejected (suggesting that correlation was not zero or there was linear correlation).

Table 4. Pearson's correlation coefficient summary for water quality variables and weather data from Vaasa airport. The results presented here are statistically significant (the null hypothesis is rejected). [P = probability (P < 0.05)].

	Chl-*a*	**Water temp.**
TP	0.55794, P < 0.0001	-
Secchi depth	-0.55085, P < 0.0001	-
Month	-0.25609, P = 0.0053	-
Turbidity	0.43998, P < 0.0001	-
Air temperature	-	0.89691, P < 0.0001

After the Pearson's correlation analysis, some model variables were selected based on probability (P < 0.05). The above Table 4 variables were selected for further investigation because they are statistically significant below 5% (rejecting the null hypothesis, which states no linear correlation).

2.4.2 Model equation used in main analyses

A causality check-up was done to determine the causality relations between weather and water quality data. There were dependent relations between different water quality parameters and weather data. Bayesian networks and the Pomegranate modelling software were used to investigate the preliminary relationships within the data. Some relations between different water quality variables were observed. However, the connections were not very clear and because of multicollinearity, it was not possible to use structural equation modelling (SEM) to find the relationship between water quality and climate change to confirm causality.

First, linear and multiple regression analyses were conducted to find out if there was an air temperature change effect on weather data (air temperature) using SAS Enterprise Guide 7.1. In addition, a linear regression of Chlorophyll-*a* and water temperature was conducted as representative of the most interesting water quality variable. Then multiple regression was carried out between air and water temperatures, confirming that there was a direct effect of air temperature on water temperature. The appropriate steps for filtering the variables that could be be used in linear and multiple regression were conducted during this step, including check-ups of Pearson correlation and scatter plotting for linearity, as well as checking for multi-collinearity by calculating the VIF (Variance inflation factor) in SPSS software and finding the best-fit line for regression.

The general linear model equation used is:

$$\hat{y} = \boldsymbol{a_1} + \boldsymbol{a_2 x} \tag{1}$$

Where, $\hat{y}$ = predicted values, x = predictor, a_1 = intercept and a_2 = slope.

The null hypothesis and alternative hypothesis are H_0: $\beta_i = 0$ and H_1: $\beta_i \neq 0$, which will be confirmed or falsified by probability.

Here β_i = regression coefficient, H_0 = the null hypothesis and H_1 = the alternative hypothesis.

2.5 Validity and reliability

The definitions of validity and reliability can be described as follows. Validity: 'Determines whether the research truly measures what it was intended to measure or how truthful the research results are' (Savin-Baden and Major 2013). Reliability: 'Is ensuring that the experiments can be repeated to measure the same thing again accurately' (Savin-Baden and Major 2013). Kirk and Miller (1986) stated that in a qualitative study, validity is handled during the field research period and reliability is addressed by documented ethnographic decision-making. Hiltunene et al. (2011), 'Validation of a research method means testing the method, where it is shown to be scientifically valid for the condition of the intended use. The validation evaluates both the performance of the method and its suitability for considered measurement. In particular, medical pharmacological and food research also considers any regulatory requirements. Validation is often already performed by the developer of the method or instrument method development work'.

2.5.1 Validity

The key criteria for the evaluation of an analytical method are specificity, accuracy, precision (repeatability, intermediate precision and reproducibility), and its detection limit, quantitation limit, sensitivity, working range and linearity, robustness and recovery (Belouafa et al. 2016). Additional points were mentioned by Brinberg and McGrath (1985) in the context of the meaning of validity: convergence, correspondence, differentiation, equivalence, generality, repeatability, and some others.

In quantitative research, factor analysis can be used to measure the degree of construct validity (Drucker-Godard et al. 2011). In qualitative research, we need to establish that the variable used to operationalise the studied concepts is appropriate. We also need to evaluate the degree to which our research methodology (both the research design and the instrument used for collecting and analysing data) enables us to answer the research question (Drucker-Godard et al. 2011).

In the next sections, the definitions of validity by Belouafa et al. (2016) and Brinberg and McGrath (1985) are used as a base to address all aspects needed to validate the research work done in this research. Based on Brinberg and McGrath (1985), the three recommended domains used in validating the process are the conceptual, the methodological, and the substantive. Here, these domains were addressed in all aspects needed to validate the research work under consideration.

2.5.1.1 Specificity

Specificity refers to the ability of a method to measure only the intended analyte (Hiltunen et al. 2011 and EURACHEM-FINLAND 1996).

The conceptual (abstract representation)

Climate change has been represented through water quality analysis as an abstract cause of future change, as a cause of risk for renewable energy, as an advantage for renewable energy, as affecting land uplift by sea level change, as cause and facilitator of flooding and as a connection between the different topics (water resources, land uplift, renewable energy and flooding) that were included in this research.

The water quality effects of climate change, particularly the change in chlorophyll-*a*, were specific enough to implicate both climate change and limnology. As a concept, climate change is a broad topic, where one can represent only one aspect of its effect on the environment at a time. Because the sampling area (the Kvarken archipelago) is a naturally maintained area, the sampling water represents only climate change effects, without direct human pollution. This shows the specificity of water quality as a representation of climate change as a concept in the Kvarken archipelago. In other words, the water quality measurement and analysis only measure the effect of climate change (the air temperature change), which is the intended effect to be analysed.

The specificity of the risk of renewable energy focused on two main parts, since risk as a concept is also very broad. In this research specificity, was focused only on the risks of renewable energy. Further, two pillar-specific concepts were analysed, as previously mentioned: the risks for renewable energy and the risks of renewable energy for the environment. These concepts are intended to showcase specific areas in the general concept of the risks of renewable energy.

Sediment heat energy data was analysed and presented, showing how heat energy production can take advantage of climate change, mainly in the summer. Thus, its specificity comes from the energy type chosen, geothermal energy. Within the category of geothermal energy, geo-energy, specifically sediment energy was chosen to present the effect of climate change as an advantage for renewable energy. Sediment energy was not only a good representor, but also a coastal energy solution. This connects water resources, climate change and renewable energy to make the analysis more specific. As well, water heat exchanger is the other type of renewable energy, whose energy comes from geo-energy. This equipment was considered in a preliminary analysis. However, the installation and continuous experimentation in the Merten Talo project were not achieved as planned. This also represents a specific technology that shows an advantage of climate change for renewable energy production.

Land uplift is represented mainly in the area of the city of Vaasa. Its connection with climate change is through sea level rise. The land uplift connection to sea level rise was analysed regarding future expectations. This topic specificity was due to the focus on change in the city of Vaasa and primarily in the Kvarken archipelago in particular. As a concept, land uplift is a specific topic in geophysics, and mainly local changes (intended change) were analysed. This presented local effects and phenomena, so to connect the analysis with changes in other areas, a framework chart was developed and implemented. Furthermore, Nordic changes were compared for both land uplift and sea level rise predictions.

The background of the whole project was connected to climate change and the risks of renewable energy, which represent the main field considered presented in this research. See Figures 7 and 8 for illustrations of the core and embedded design of this research.

The methodological (techniques used)

The methods implemented to identify the effects of climate change on water quality were various statistical analyses using SAS (Statistical Analysis System) Enterprise Guide 7.1, an internationally recognised, validated and specific software package. All analyses were intended to give a trustworthy result for the data input because of the use of trustworthy software, as long as the data input is correct. The software was also updated to the latest version. Meyers et al. (2009) is a reference for statistical analysis procedures to use SAS Enterprise Guide. General data analysis procedures were adapted from the internationally recognised statistical text of Dytham, C. (2011). Both procedure references were used in all data analyses conducted in this research, specifically those which used SAS software. Water quality and weather data were collected by the national organisation, which used their validated procedures for sampling and analyses. The water quality data were collected from ELY-Keskus (Center for Economic Development, Transport and the Environment) and weather data were collected from the FMI (Finnish Meteorological Institute). Both water quality and weather data were collected from the city of Vaasa or nearby sampling stations to acquire the most accurate data for the local area. The only problem that was that differences were noticed when combining the weather and water quality data twice. The first-round combination was trustworthy because the results of the analysis were as expected in most cases. However, the second-round combination seemed to have some problems. Therefore, all analyses were performed in the first round of combined data to avoid mistakes.

Risk analysis was carried with a similar procedure to that of Holma et al. (2018), namely, risk analysis based on data collection by expert viewing. The expert viewing is one of the well-recognised methods in risk analysis. All experts chosen have in-depth knowledge of at least one of the renewable energy technology types. Having a group of experts for data collection helps us to gather the best risk information for all types of renewable energy. Therefore, the expert view measures the nature and magnitude of the risks. The only limitation was that the number of experts was low, but the results were similar to those of Holma et al. (2018). This means that our results can indicate the direction of the risks and serve as a starting point for future in-depth investigation into the risk of renewable energy.

Sediment energy data analysis was conducted using SAS (Statistical Analysis System) Enterprise Guide 7.1, a trustworthy software package. Thus, its analysis methods and data collection show what they should measure. The data collection was carried out using our group expertise. The preliminary measurement for the water heat exchanger was performed by a thermal response test (TRT) trailer. This equipment has been used in our group for several years and the person who measures and calculated the result was an expert in the area. Therefore, both seaside energy types (sediment heat energy and the water heat exchanger) measurements and analysis can be assumed to have measured what they intended to measure. For sediment heat energy analysis, factor analysis was used to validate the inputs of the analysis and the overall results.

In the land uplift analysis, several formulas and procedures are used, as can be seen in (Girgibo et al. 2022). The references used for theoretically calculating the temperature and sea-level rises and future land uplift were from Rahmstorf (2007) and Påsse and Andersson (2005). A cause-and-effect lens and analysis were used to see the overall picture of the relations between land uplift and sea level rise. Several references were then used to identify and confirm their future expected relations. A framework chart was also created using references and literature data for the Vaasa region. A case study of the Vaasa region and various data from the literature were also used for the validation of the conceptual framework. In addition, comparisons with the literature were done for different areas, focusing mainly on the Nordic area. The whole methods and procedures were expected to show the intended analysis for the temperature, sea-level rise and land uplift. Please see Girgibo et al. (2022) for more information. Several sources of data were used. For example, multi-data sources can be used to ensure the validity of qualitative research (Drucker-Godard et al. 2011). Thus, the various literature data used in Girgibo et al. (2022) can validate the specificity of the method and the calculations used in the land uplift analysis.

The substantive (real-world systems and phenomena)

Climate change (air temperature change) and water quality data analyses are expected to show real-world effects in the local area (the Kvarken Archipelago). Hence, since the area is a naturally maintained area it is believed to represent the reality of climate change effects (air temperature change effects) on water quality. In addition, the water samples were measured in the local area over a long time. This means they are representative of the reality of water systems over a significant period.

Risk analysis was conducted at a general level, representing two aspects of renewable energy phenomena. Although the data collected in the risk analysis process were quite limited, this analysis is expected to inspire future in-depth analysis of both climate change risks to renewable and renewable energy use and production risks to the environment.

A sediment heat energy experiment was conducted in the real world (a sea located in the city of Vaasa). Therefore, the analysis is expected to show real phenomena, at least at the local level. However, the water heat exchanger could not be installed so there is no continuous real-world analysis. The preliminary analysis shows real-world results, because at the time of analysis the water heat exchanger was installed at the Meten Talo project site.

Land uplift is a local phenomenon occurring mainly in Scandinavia. Land uplift has been occurring in the site of the city of Vaasa for ≈ 10,000 years, making it the best site to show this happening in the Kvarken Archipelago. Analysing this area shows real events and is thus expected to show a real-world example.

2.5.1.2 Accuracy

Accuracy refers to compliance between the measured value of a large quantity and the actual value of the measured quantity (Hiltunen et al. 2011 and SFS GUIDE 99, 2010).

The conceptual (abstract representation)

The abstract concept of climate change for the whole world cannot be represented by local measurements alone. One of the hypotheses raised during the discussion was that ‘climate change effect in the local area is different from the global expectation’. This hypothesis was confirmed by our analysis, where some changes were differentially located, such as flooding and land uplift changes. The analysis of climate change and water quality relations performed in this research can accurately represent and show local effect differences from expected global value. The abstract representation can be seen in the analysis of the city of Vaasa given here. Some data analysis findings in water quality and weather change are compliant with the global expectations given by IPCC (2021).

The risk analysis seems accurate, because the experts who generated the data were very experienced in their respective renewable energy types. The only limit noticed was that the number of experts was not very high. However, this analysis can impel future in-depth analysis. As a concept, the risk analysis was represented by two elements: risk to renewable energy from climate change and risk caused by renewable energy to the environment. Thus, the accuracy of the abstract representation of risks to and from renewable energy was high. In particular, it was shown that this research's results were more or less similar to those of Holma et al. (2018). The article of Holma et al. (2018) was used as a method and concept source for these analyses. This served as one way of validating the accuracy of the risk analyses.

Sediment heat energy as a concept is representative of coastal renewable energy. The conceptual accuracy was good because this is a new type of renewable energy that is has a lot of potential for coastal areas near lakes or seas. Sediment heat energy production is representative of the new forms of getting energy use climate change to their advantage. Thus, sediment heat energy in the city of Vaasa adequately represents the concept of adaption using climate-change-induced weather changes to generate renewable energy.

Land uplift as a concept is accurate enough to represent local events. This is because land uplift is most common in Nordic nations and some areas of North America. The local realisations of land uplift in the city of Vaasa represent land uplift as a concept. Indeed, the city of Vaasa has one of the highest levels of land uplift compared with most parts of Nordic and North America.

All the concepts represented in this research were accurate enough to show the topic and focus of the research. Coastal energy, risks from and to renewable energy, land uplift and climate change were represented accurately and can be generalised for a larger size or different areas.

The methodological (techniques used)

One water sampling point [Et. Kaupa 1 (Eteläinen Kaupungin Lahti) sampling point] used in data analysis as a representative was checked by using the summary of the statistical analysis for comparison. Thus, the accuracy of the whole analysis was good. The method used for analyses herein can represent the types of analyses generally used in water quality data. Sample gathering techniques for water quality data were performed by ELY-Keskus by using national standard methods. The accuracy of the data was very high. Further, the SAS Enterprise Guide 7.1 data analysis software is the latest and best software for data analysis and its accuracy is internationally recognised. A general statistical analysis procedure was adapted from Dytham (2011).

The method and techniques used in the risk analysis were also used by Holma et al. (2018). This method is accurate enough to collect good data for risks from or to renewable energy. The experts chosen were knowledgeable about their own specific renewable energy types. It was noted that they could recognise and understand the different types of risks present in the renewable energy resource types. The generalisability of the method is at least at the national level; as such, the method is accurate.

The sediment heat energy data analysis and data collection strategies were based on national and international standards and methods. Distributed temperature sensor (DTS) optical cable planning and installation were carried out by the GTK (Geological Survey of Finland). They provided the first measurements for a 13-month period (2008–2009). The University bought the DTS device in 2012. The sediment energy data collection method used distributed temperature sensor (DTS) systems that originally were installed and used by the Geological Survey of Finland at the national level. The data collection was carefully designed and implemented before this research was started in 2008–2013. The data was collected by experts from 2013 – 2018. Thus, this method and data are also accurate enough to represent the general procedure for larger data collection. On the other hand, data analysis was performed by using the SAS software package. According to Meyers (2009) and Dytham (2011), the method and this software is internationally recognised. Therefore, the data analysis method for data collection and analysis is accurate enough to validate the analyses.

Land uplift methods were sufficiently accurate as well, at least for the local area. The framework chart developed can represent land uplift zones in most parts of the world. The sea-level and land uplift forecasts were for the local area (the city of Vaasa) and were built on Påsse and Andersson (2005). Formulas from Rahmstorf (2007) were also used to strengthen the analysis. These publications were trustworthy and can accurately be built upon, making our findings sufficiently accurate to be implemented in other areas and expand the results for a larger analysis.

The overall methodology of the whole research is a mixed-method investigation. This integrates both quantitative and qualitative methods, making the overall analysis more accurate. One of the advantages was that the limitations of quantitative and qualitative methods were balanced by using both in the mixed methods design. The mixed methods design was developed based on Creswell and Clark's (2011) mixed methods book. This internationally recognised work helped ensure the accuracy and generalisability of the research. Among the types of mixed methods, the embedded mixed methods design was found to be the most accurate for this research work.

The substantive (real-world systems and phenomena)

The climate change and water quality analysis are sufficiently accurate because they are easily extendible to larger area analyses, if similar data collection is conducted beforehand. All analyses were conducted by using internationally recognised methods and software. All data were collected by national governmental organisations that use standardised data collection and analysis methods. This means that whole analysis can be accurately implemented in real-world systems in a larger area or with other types of data. This means that the phenomenon of climate change, in terms of weather data and water quality, is addressed accurately.

Risk analysis as a phenomenon was addressed accurately enough to represent two aspects of risks: climate change risks to renewable energy resources and renewable energy use and production risks to the environment. Thus, these two pillars of risks related to renewable energy can be accurate enough to be replicable in other aspects of renewable energy or other resources. The only limitation was the number of respondents for data collection. However, this is a very good starting point for future risk analyses of renewable energy.

Sediment heat energy is a very good representative of the phenomenon of advantages due to climate change, which is accurate enough to represent seaside energy solutions and was implemented by the Geological Survey of Finland (GTK). This example of climate change advantages is accurate enough to be repeated and to represent overall renewable energy resources. Adaptation to climate change can be enhanced by using climate change to our advantage, such as for sustainable energy production.

Land uplift is represented at the local level. However, if the exact data and formulas are used, it is accurately repeatable for larger data without any alterations. The actual values were represented in good conditions that can be summed to a larger quantity. The local area concept is only applicable to those areas that are facing land uplift phenomena. Land uplift is area-specific; thus, summing over the whole world might be difficult because other areas might have other phenomena, such as flooding. However, the concept was generalised by developing a framework chart for those areas facing land uplift.

The different parts of the methodological inputs of the mixed method have good representative accuracy for broad classes of topics. That is sufficient representation of the global phenomenon in one research. Thus, this means that the research is accurate enough to represent the overall concepts of the mixed method analysis of climate change, land uplift, and seaside energy solutions.

Therefore, there is adequate representation of multi-disciplinary topics and their phenomena.

2.5.1.3 Precision (repeatability, intermediate precision and reproducibility)

Precision refers to the consistency of the values displayed or measured and obtained by repeated measurements when examining the same or similar objects under specified conditions (Hiltunen et al. 2011 and SFS GUIDE 99, 2010).

The conceptual (abstract representation)

Climate change and water quality as a concept can show consistency in different places that are in the same environment or naturally maintained area or at similar longitude and latitudes and subject to similar weather conditions. At a global level, different places can have different kinds of environments, and thus consistency might be difficult to achieve. However, as a concept, if the area is kept under specific conditions (naturally maintained and protected area), then the area can show the effect of climate change in water systems, as this research analysis of the Kvarken archipelago UNESCO protected area shows. This concept for assessing climate change effect has high repeatability and reproducibility with similar analyses in other areas.

Risk analysis and management are a good way of assessing the risks of renewable energy. In this case, repeatability and reproducibility can be achieved as long as the right type of expertise is present. The opinion of one expert might differ from that of another. However, the average results certainly can show similar patterns. It is very feasible to repeat the same concept in a different location, albeit probably with different results due to the area specificity of renewable energy sources and the manner in which some types are produced. Different risks to renewable energy from climate change can be present in different places.

As a concept, the investigation of the effect of climate change on sediment heat energy is very repeatable and reproducible in other areas and water bodies, since the precision of the concept is similar if the installation depth and area weather patterns are similar. The concept of using climate change effects to our advantage and adaptating to them is repeatable with limitations. Among these limitations is the fact that the effects of climate change is more often problematic, rather than being advantageous at all times or in all weather conditions.

Land uplift is a sufficiently precise concept; however, the concept is very much area-specific, as are its causes. This phenomenon of land uplift is unique to the city of Vaasa and Nordic areas. Thus, its precision is questionable because of its area specificity. However, the manner in which it was analysed and addressed is sufficiently precise (repeatable and reproducible).

The overall concepts addressed in this research were precise enough to render it repeatable. All methods and concepts were reported in depth within this research and in separate publications. Thus, the study procedure can be used to study the same concepts efficiently. The various aspects of multidisciplinary concepts were chosen to build connections between them and to create an overall embedded mixed methods approach that can be easily repeated. The relations between the concepts and within the concepts specifically can be reproduced as long as the same data is collected with the same methods and the location, environment and concept-influencing factors are kept constant.

The methodological (techniques used)

The connection between climate change effects and water resources was investigated by statistical analysis. The statistical methods and software used were internationally recognised, thus their precision was demonstrated by the developers. As long as the data input and method specification are similar, consistently precise results were found. However, if there is a small change in the data type (which might occur during when combining the weather and water quality data) or the methods, the results can vary significantly.

The risk analysis method was adequately precise, as demonstrated by its past use by other authors (Holma et al. 2018). The only limitation was the number of respondents in the data collection. This part was considered a starting point for better future risk analyses of renewable energy. However, the method was precise enough to show good results in the past (Holma et al. 2018), as well as in the current study. One example of this are the publications of Holma et al., that have been published in an internationally recognised peer-reviewed journal. Based on our expert knowledge, this method is sufficiently precise for risk analysis data collection. The research study generated similar results to that of Holma et al. (2018), as well.

The sediment energy data collection methods were demonstrated and were used by the Geological Survey of Finland (GTK). Thus, the fact that the method was used to collect data by the GTK means that similar results were collected by the University of Vaasa. This generally establishes the trustworthiness and precision of the method used. The data analysis of the collected data also used internationally recognised methods and software (SAS). As long as all aspects of data collection, such as the environment, the collection method and the specificity of the data analysis method, are maintained constant, one can expect to get consistently similar results.

The land uplift framework chart development is based on various publications. Therefore, to derive the same framework chart in other contexts might require similar publication reviews. This can limit the precision to a degree. However, the data calculations are precise enough because of the formulas used were developed by other publications (Please see Girgibo et al. 2022 for future land uplift calculations). All methods used in the research were sufficiently trustworthy and precise as long as the specific conditions of the research study were fulfilled.

The substantive (real-world systems and phenomena)

The concept of climate change effects and water resources quality can be repeatable if all conditions, including the environmental conditions (naturally protected area), the type of environment (archipelago area), and the data collection period were specified. The Kvarken archipelago is a unique environment, as a naturally protected area where both land uplift and sea level rise naturally interplay. Thus, it can be challenging to find a similar area to repeat the analysis. However, the statistical analysis software, water quality data collection and weather data collection adhere to international and national standards and their validity is proved, at least at the national level. As a concept, the connection between climate change and water quality is precise enough to replicate. One restriction is that the factors that influence water quality are of many types. Thus, careful consideration of the area’s environment and water is important to obtain precise results.

Risk analysis in renewable energy is infrequently addressed. Thus, the analysis as a concept is quite precise. However, differences in renewable energy risks are expected to be area-specific. The use of various experts in different renewable energy types is recommended to get an exact expert assessment in a specific area. The use of sediment energy as a concept to see the effects of climate change is adequately precise, since it shows the exact effect of climate change, but is specific to area and water type. Land uplift as a concept is well addressed and precise, because as long as natural variations exist, it is possible to study the same concept with area-specific results. All concepts are believed to be sufficiently precise and well-addressed in this research, with the main limitation of area specificity.

2.5.1.4 Sensitivity

The conceptual (abstract representation)

The research addresses various aspects of climate change, including its relation to water quality, renewable energy (coastal energy solutions) and land uplift. Addressing the different aspects of climate change can show the sensitivity of the research to the different aspects of one topic, namely, the effects of climate change, along with its connection to and risks for renewable energy. The sensitivity of the abstract representation of risk analysis in renewable energy was achieved by addressing the different types of renewable energy risks analysed. Climate change effects on renewable energy were presented by statistically investigating the effects of climate change on the use of sediment heat energy. This was sufficiently sensitive to show connections between climate change effects and renewable energy as a concept, particularly coastal renewable energy solutions.

The conceptualisation of land uplift was sensitive insofar as it addressed different aspects of land uplift in local and global locations through conceptual framework chart development and an additional forecast analysis calculation in the local area (the city of Vaasa). A mixed methods design is a recent idea that combines both quantitative and qualitative methods. The sensitivity of this mixed methods design was achieved by combining quantitative and qualitative methods to give a better understanding about the topic at hand.

The methodological (techniques used)

Climate change and the water quality analysis methods and data sensitivity were checked by variance inflation factor (VIF) analysis to check for multicollinearity and multiple analyses were conducted to verify whether the results were stable. The risk analysis method used expert evaluations. These experts have diverse knowledge of different types of renewable energy. This method helped us to use the diversity of the experts' knowledge and increase the sensitivity to represent the whole gamut of renewable energy resources. The renewable energy connection with climate change effects was well represented in the sensitivity of factor analysis as a means of validation for sediment heat energy utilisation. The sensitivity of the land uplift method can be represented by a conceptual framework chart that combines local and global patterns. The overall the mixed methods research achieved sensitivity by using both types of methods (quantitative and qualitative) in depth for each topic addressed in the research.

<u>*The substantive (real-world systems and phenomena)*</u>

Climate change effect sensitivity as a phenomenon has four flavours. The first one is to evaluate the effects of climate change on water resources, mainly water quality changes due to weather changes. The second flavour involves addressing the risks of climate change to renewable energy resources and of renewable energy use and production risk to the environment. The third flavour implies identifying the climate change effect advantages for generating heat by using the sediment heat generation technique. The fourth flavour deals with the connection between land uplift and sea level rise caused by climate change effects. Together, these represent the relations between climate change and energy technologies.

2.5.1.5 Uncertainty

Uncertainty analysis is often mistaken for analysis of measurement errors and error estimation (Hiltunen et al. 2011). The uncertainly can be split into uncertainty that can be (Type A error) or cannot (Type B error) be determined by statistical methods.

1. *Type A error uncertainty determination method*

Type A uncertainty determination covers 'uncertainty that can be determined by statistical methods' (Hiltunen et al. 2011).

<u>*The conceptual (abstract representation)*</u>

The uncertainties of the climate change and water quality relations can be determined by statistical methods. This is because the research question raised for this topic was answered by statistical analyses. Particularly in the methodological aspect, it was much easier to identify the uncertainties by statistical methods. The conceptual uncertainties of climate change effects are difficult to identify easily even in statistical analyses. First, it is important to filter out other sources of pollution that affect the water quality of water resources. This was not planned because there were not enough water quality sampling points in the Kvarken, Archipelago UNESCO protected area to collect data. Therefore, the sampling areas had to be sufficiently wide and those data had to be compared with data from protected areas for human pollution. By comparing both areas, this shows us that the protected area is naturally maintained and there is a similarity in averaged results with the unprotected area. This can be shown in a descriptive analysis comparison. After that, the researchers selected the poorest water sampling point to represent the effects of climate change in all areas.

The problem is that the sampling point Et. Kaupa 1 was used in the analyses and was not in the protected area. This means that it filters the climate change effects in this data alone. This sampling point was chosen because it has the worst average values. This means it can show the poorest conditions that can be expected due to climate change effects and might also be affected by other pollution sources. Statistically, one might not pinpoint only the effect of climate change on water quality because environmental pollution is very diverse and cannot be filtered out of this sampling site. Therefore, this is one of the limitations of our data analyses of the effect of climate change on water quality. The research can show only the worst expectations of climate change effects on water quality near the city of Vaasa, and relate all sample points in recognition of lack of longstanding and continuous water quality sampling points in the Kvarken Archipelago UNESCO World Heritage site.

The risk analysis and management concept uncertainty that can be identified in the statistical analysis is very limited. One uncertainty in the conceptual proof is that the data collected were limited. The justification for continuing the analyses with limited data was that this can inspire further in-depth research into renewable energy risks. This will involve collecting data from a wider number of renewable energy experts. Thus, in the future, these research results will be strengthened.

The investigation of the concept of the effects of climate change on sediment heat energy was statistically validated by factor analysis. The data as a whole were found to be valid for the analysis by using factor analysis. Therefore, for this concept, no uncertainties were found statistically. Land uplift and sea-level relations as concepts are difficult to identify, and the uncertainty of the concept is related to the limited data that this research. Therefore, the concept of uncertainty must be identified in depth in the case of Type B errors (uncertainty that cannot be identified statistically) method.

The overall concepts addressed in this research have both type A and type B error uncertainty identifications. Because it is a mixed methods design, more quantitative research uncertainties can be identified with the Type A error method, while more qualitative research uncertainties can be identified with the Type B error method.

The methodological (techniques used)

The methodology for evaluating climate change effects on water quality is statistical analysis. Therefore, uncertainties can be identified during the statistical analysis process (Type A error). Some uncertainties were identified during the evaluation and comparison of combined data. Uncertainties were noted while using different types of statistical analysis methods, resulting in different results. Then, by comparing different methods and research literature, the most trustworthy result was chosen to avoid uncertainties related to reporting wrong results and conclusions. Some uncertainties were avoided by analysing multi-collinearity between various variables before multiple regression analysis. This was achieved by analysing VIF (variance inflation factor) using SPSS (Statistical Package for Social Sciences) statistical software.

Risk analysis for renewable energy resources mainly employed qualitative and quantitative mixed methods. In is mainly qualitative, and thus a lack of statistical analysis identification of uncertainties seems guaranteed. Therefore, more uncertainties can be identified by the Type B error method instead of the type A error method. Identification of heat energy analysis uncertainties was overcome by using factor analysis by validating the data. There were no uncertainties identified before, during, or after the statistical analyses. Land uplift and sea level rise relations are also used a mixed methods approach. This qualitative analysis does not use statistical analysis for identifying uncertainties. Therefore, the land uplift study must use Type B error uncertainty identification. The researcher tried to identify more uncertainties using the Type B error method for these research goals.

The overall mixed methods research uses both Type A and Type B error methods in order to identify uncertainties. This can strengthen the overall validation process of the research. Mixed methods approaches had shown the advantage of all possible uncertainties being identified for each specific purpose, leading the research to be more trustworthy and valid. Most quantitative methods used in this research were used in the section dealing Type A errors (those that can be proved by statistical analyses) to identify the possible uncertainties.

<u>The substantive (real-world systems and phenomena)</u>

In the evaluation of climate change effects on water quality as a real world-system, it is very difficult to determine causality relations and their uncertainties based on statistical analysis (Type A error). Therefore, the best way to identify uncertainties in this phenomenon is based on the Type B error method. A similar situation is applicable to risk analysis of renewable energy resources. The sediment heat energy analysis case is different. The evaluation of sediment heat energy using climate change effects to its advantage was conducting using statistical methods in our article (Publication IV), which was published during this research work. The identification of uncertainties via Type A errors might be difficult even if the phenomenon was established by statistical analysis. The only way uncertainties were filtered was by using factor analysis for the data, which is described in other sections of this validation. The factor analysis shows the uncertainties at non-signficant levels in the data, which is a source of the overall analysis of the phenomenon.

Uncertainties in land uplift and sea level rise relations were not identified by statistical analysis (the Type A error method). Therefore, in both phenomena and real-world systems, uncertainties mainly must be identified by the Type-B error uncertainty identification method. Thus, there is almost nothing that can be said statistically.

The mixed methods research that was conducted on real-world systems and phenomena uncertainties used both Type A and Type B error identification methods. The description of the uncertainty in each element of the qualitative and quantitative research was presented here. However, no uncertainty can be identified statistically for the overall mixed methods design. Therefore, there are no uncertainties for the overall mixed methods research based on Type A errors.

2. *Type B error uncertainty determinations method*

Type B uncertainty determination is 'uncertainty that cannot be determined by statistical methods'. Type B uncertainty is not reduced by repeated measurement (Hiltunen et al. 2011).

<u>*The conceptual (abstract representation)*</u>

The effects of climate change (air temperature effect) on water quality concept uncertainties can mainly be identified by statistical analysis methods (the Type A error method). The type B error uncertainty identification method is not used for these concepts, except insofar as logical reduction in comparison and insofar as the decision-making process is based on statistical analyses. The lack of sufficient water quality sampling points in the Kvarken Archipelago UNESCO World Heritage area forced this research to use another sampling point outside this protected area. This produced uncertainty about whether the exact effects of climate change on water quality could be precisely identified. However, when comparing the average statistical summary results for all variables from all sampling points, the range is not wide. Thus, the strategy chosen may be representative of the effects of climate change in the local area. Projections and results from the representative sampling point (Et. Kaupa 1) are expected to show similar results to all other sampling points, with only minor differences. These differences are expected because Et. Kaupa 1 is located near the city of Vaasa and outside of the UNESCO World Heritage site.

The Type B error method can identify the uncertainties of risk analysis of renewable energy resources. The concept of risk analysis of renewable energy has uncertainties that can be generated by the small number of respondents. Thus, generalising the concept results on a global scale might not be accurate. However, as stated before, this concept analysis was planned as a starting point for broader risk analysis investigations. The researcher is aware of the small number of expert respondents for this risk analysis. The generalised averaged risk estimate levels might thus be different with a larger number of expert respondents.

Sediment heat energy analysis uncertainties were not generated by the Type B error method. Hence, sediment heat energy research used statistical analysis (the Type A error method). Conceptually, some results (the forecasts of water and air temperature and snow depth) were found to have some limitations, but were similar to those of the IPCC (2021) report. This leads to acceptance of the forecasts from this sediment heat energy research. This logical connection and cross-checking with other results to avoid uncertainties can be considered as using a Type B error method to confirm the concept.

Land uplift and sea level rise relations mainly use the Type B error method. One of the uncertainties arises in generalising the local result to the entire world. As stated, the principal limitation of land uplift research is that the areas studied may not necessarily represent the world's general uplift rates. On the other hand, this may confirm that local effects are different from general world expectations or forecasts. Thus, this uncertainty can be a means of confirming differences rather than representing a problem with the results. In this view, the land uplift and sea-level rise relation concept results presented in this research can be not generalised to the world and other regions, only to the local area. This would confirm the hypothesis that the climate change effects in the local area are different from the global average.

The overall mixed methods research is also addressed by the Type B error method, particularly those aspects that used qualitative methods. The generalisation of the results also uses the Type B error method more confidently, since generalising all results can involve comparison and conclusion procedure, which can be considered as a mainly qualitative method. One source of uncertainty can be that different methods might generate different results; thus, it is necessary to decide which one to accept. If such results appear, a deeper look at the procedure used to generate the results is considered.

The methodological (techniques used)

The research of the effects of climate change on water quality mainly used statistical analysis (the Type A error method) to identify uncertainties. The Type B method was mainly used for the confirmation or falsification of hypotheses in the Kvarken climate change report. The method used for the topic of climate change effects and water quality was mainly statistical analysis. Thus, here one might not identify any uncertainties by using the non-statistical method (the Type B error method). Before starting the statistical analyses, a logical descriptive method of comparing and choosing the representative sampling point was applied. The chosen sample point was Et. Kaupa 1, which is located outside the UNESCO World Heritage site. This leads to the question of the extent to which this sampling point can represent the exact effects of climate change. The two reasons to choose this sampling point were because it has large enough data and because the average summary of its statistics is similar to the rest of the sampling points. One other reason was that this sampling point was the worst, meaning that any finding in a protected area can be expected to be better than the results for this sampling point, even though factors other than climate change can affect the sampling point (Et. Kaupa 1).

The main uncertainties in the risk analysis of renewable energy resources can arise because the number of experts is too small. This is one of the uncertainties that can be identified by the Type B error method. The research tried to reduce this problem by comparing our findings with the publication of Holma et al. (2018) on the risks of renewable energy use and production to the environment. However, the climate change effect risks on renewable energy cannot be compared with Holma et al. (2018), because they did not study this aspect of risks. This aspect of climate change risks is unique to this research work. Thus, the uncertainties generated by the reliance on a small number of experts to respond to the risk analysis are still present. Both aspects of risks were planned to be a starting point for future in-depth analysis of risks related to and from renewable energy resources.

Sediment heat energy analysis consisted mainly of statistical analysis and uncertainties were mainly identified by Type-A error methods. Here, one can explain the uncertainties that can are generated by the ARIMA modelling forecast and how it was handled. In this forecast, the period of data used was not good enough to show exact predicted outcomes from the analyses for air and water temperature and snow depth. The reason why the forecasts were presented in an article in Publication IV was that the forecasts of similar variables done by IPCC (2021) show almost identical results. This confirms that the results were acceptable because similar patterns were found in other parts of the world. These forecasts present the worst possible outcomes of climate change. However, the UNESCO World Heritage site data might show less severe outcomes. This is because the data used in this analysis is from the sampling site of Et. Kaupa 1, located outside the protected area, but which is still near the Kvarken Archipelago in the city of Vaasa.

For land uplift and sea level rise analysis, empirical literature data validation was used in the article. This was done in Girgibo et al. (2022). Land uplift and sea level rise relations were combined with qualitative and quantitative methods. In the qualitative method, the framework chart development was performed. In this framework chart, one shortcoming was that it might not represent all areas in the world that experience land uplift. The research reduces this uncertainty by using research inputs from different locations to make the framework chart developed more representative of other regions. The other comparison analysis was mainly limited to Nordic areas or to the world generalised from such. Generalising to other regions might create limitations, since as this research shows, local effects can be different from global expectations. This generalisation was to make the only representative comparison.

The overall research mixed-method used both uncertainty identification methods. In doing so, the overall analysis was addressed and most of the time, both methods are presented in each section of the whole research. One difficulty or source of uncertainty can be how much one can compare both qualitative and quantitative methods. To avoid this obstacle, comparisons were performed in a generalised sense. This meant that, for example, the hypothesis confirmation or falsification of the Kvarken review paper can be supported by the climate change effect on water quality statistical analyses, leading to more concrete discussions and conclusions in this research. Similar patterns are applied in other research area topics.

The substantive (real-world systems and phenomena)

The climate change effect on the water quality of the Kvarken Archipelago in the city of Vaasa is representative of local climate change effects. As the archipelago is a real-world system, water resources can be influenced by different factors, such as pollution from human activities, climate change, weather pattern changes, point source pollution and the types of water systems. Human activities and point source pollution were filtered out for the UNESCO World Heritage site, since its protected status excludes human activities. However, the data analysis was based on a sampling point (Et. Kaupa 1) from outside the protected area. This raises a question of uncertainty: how can the analysis at this sampling point represent the water quality of the protected area? The research sought to resolve this by comparing the summary of the statistics from each sampling point. It was found out that the Et. Kaupa 1 sampling point was the worst, meaning that the results for the rest of the sampling points are expected to be better than for the Et. Kaupa 1 sampling point.

However, this can represent the rest of the sampling points, which need further in-depth identifications of human and point source pollution from Et. Kaupa 1. Thus, how can one select only the climate change effect on water quality? This was attempted by combining weather data and water quality data. The weather data is affected by climate change. Thus, if there is a correlation between weather data and water quality, it can represent the effects of climate change on water quality. The types of water systems were another challenge. It was noted that the water in the protected area is closer to the ocean. However, Et. Kaupa 1 is closer to the lake. This was solved by using seawater standards in Et. Kaupa 1. Since the seawater standard is much higher than the lake water standard, if the Et. Kaupa 1 satisfies this standard it can represent the protected area sampling points. It was found that Et. Kaupa 1 satisfies all the necessary standards for seawater quality. Thus, we attempted to avoid both sources of uncertainty, as explained in this paragraph.

Risk analysis of renewable energy resources as a phenomenon is not well addressed in the research field. This is one of the forgotten elements of energy technology as a research field, probably because renewable energy resources are a new field of study compared to the use of fossil fuels as energy resources. The low number of previous studies to confirm our results was one of the limitations. Confirming these research results was hoped to reduce the uncertainty generated from the small number of experts who participated in the risk analysis, since this limited the extent to which the risk analysis could be trusted or generalised. This only was performed by comparing the research result with Holma et al. (2018). That reduced the uncertainties and confirmed most of the results. However, differences were noted. Might these differences between the two types of research be due to the small number of experts? However, Holma et al. (2018) also used about 20 experts in various renewable energy resources. In this research, there were about 14 risk analysis experts, though originally about 25 experts were contacted. There are some differences between the two types of research; however, only small differences were noted in the results. It was believed that the research had reduced the likelihood of reporting wrong results from our research.

The exact sediment heat energy analysis results may be specific to each water system and area. It is confirmed that in sea water, sediment heat energy benefits from climate change effects, especially in summer. This results in uncertainties as to whether it can be generalised to all areas. The only difference expected is in heat energy intensity between the city of Vaasa and other areas. Based on various previous studies' explanations of different water systems, this belief seems well-founded. Also, the results are site specific because the depth of installation and water type can differ. Thus, by analysing real-world systems of sediment heat energy from sea and other waters, one may be able to confirm that climate change effects are advantageous for certain purposes.

Land uplift and sea level rise relationships in real-world systems or phenomena are practical in the local area, as also studied by Norman et al. (2020). The real phenomenon of the framework-chart-produced uncertainties can be generalised to the systems of the real world. The shortage was reduced by taking different resources from different locations, namely Fennoscandia, Sierra Nevada (USA), the Baltic Sea area, Åland Islands, the Kvarken archipelago (Finland), the northernmost Gulf of Bothnia (Finland), Fennoscandia, North America, Yakushima rivers basins (Japan), the subtropical eastern Pacific, the Vaasa region (Vassor Bay), Ångermanland (Sweden), S. Västerbotten (Sweden), Rovaniemi (Finland), Lauhanvuori (Finland) and generalised for whole areas of the world. The data and patterns of these different locations were used in different sections of the framework chart developed (see Table 2 in Section 2.2.2.4 to see in which section of the framework they were used). This can help by avoiding unexpected uncertainties due to not accessing all possible information at different locations.

2.5.1.6 Working range and linearity

Linearity refers to the ability of an analytical method to provide an acceptable linear correlation between results and sample concentrations of the test substance (Hiltunen et al. 2011).

The conceptual (abstract representation)

As a concept, the climate change effect on water quality is present at all sampling points, including the representative sampling point for the data analysis. The question is whether there were clear linear correlations between them in a conceptual sense. To our knowledge, the influence of humans is expected to have an effect on the data analysis representative sampling point (Et. Kaupa 1). However, in a statistical sense, it was noticed that there is a clear similarity between all sampling points. Thus, we chose this sampling point because it was the nearest one to the Merten Talo project site, it had enough data, and it was the worst sampling point and thus could show the extreme expectations in the local area. If things became better than these expectations, then the forecasts would be better than expected. Thus, the worst expectations were already reported by this research.

Risk analysis of renewable energy resources expertise view data can be considered as a sample of the true risks of renewable energy resources. There is no way to create correlations between the sample data analysed and the real phenomenon. Except for wave energy, all other renewable energy resource types were analysed for their risks. This might show a linear relation between the types of real renewable resource types and the sample analysed renewable.

In sediment heat energy production, there seem to be clear patterns between what is found and reality. As a phenomenon, sediment heat energy production patterns are expected to behave as was explained in Publication IV. The confirmation of the research result by comparison with other findings, in terms of the water temperature increase causing an increase in the sediment heat temperature showed clear linear relationships. There were similarities between different locations in the same seawater with the installation site specifications. Most of the findings come from the correlation analysis and the summary of the statistics, which are believed to show a clear result that is representative of all the seabed sediment. It noted that even in the same sea, there is an installation site dependence, as in the correlations between distance and sediment heat temperature.

The land uplift effect phenomenon may show a linear correlation with the sampling area changes. However, it might be not possible to have clear results that show the exact linear correlations. There are also clear relationships between land uplift and sea-level rise, which can be opposite in a specific area. The overall analyses presented in this research are mainly real systems analyses, in which it might be very difficult to show the linear correlations between samples and data. Thus, in this section, one can only generalise the validation process to these studies presented in the research.

<u>*The methodological (techniques used)*</u>

In the analysis of climate change effects on water quality data, there were correlations between different parameters at a single sampling point and the weather station data. However, we were not able to combine the water quality data for different sampling points. This was because of sampling data and year variations. Most sampling points have only a few years of data that can be combined with data from other sampling points. However, upon comparing the average values of variables from different sampling points, it is very clear that there have been similar patterns of change in concentration. This means that the sampling point for data analysis and the rest of the data sampling points have a very significant positive linear correlation. Although there is no statistical correlation to support it, the summary of the statistics is similar in aggregate. This is one of the main reasons to use one sampling point to represent the rest of the sampling points.

The method for risk analysis of renewable energy resources was adapted from Holma et al. (2018), who validated the whole process in their article. There is a clear similarity between this research's risk analysis and that of Holma et al. (2018) in terms of the types of renewable energy considered and the type of risks generated by renewable energy use and production. Therefore, the results are comparable. The types of renewable energy resources analysed in this research were a good representation of renewable energy resources in general. The only limitation was the number of experts who provided the data. However, this figure was very close to the number of expert data providers for Holma et al. (2018). Thus, both analyses are very comparable to one another. The results generated by both researchers were also substantially similar.

Sediment heat energy production methods show clear linear correlations between sample point distance and sediment heat temperature. The results for the sample points were believed to represent the whole sea even though installation site specifications were noted. It was confirmed that most of the years' statistical summaries show similar patterns, at least in one sampling site. There were only two installation points that represented the overall sediment heat energy analysis. It was found that sediment heat energy uses climate change effects to its advantage, as indicated by the linear correlations between water temperature and sediment heat temperature. The land uplift effect and all results of mixed method analysis did not have any correlation analysis; thus, linearity might not be relevant to this section in terms of methods.

The substantive (real-world systems and phenomena)

The effects of climate change on water quality show a dependency relationship between the weather and water quality data. For example, there is a linear relationship between air temperature (weather data) and water temperature (water quality data). Thus, the relation between climate change effect and water quality in the real system was well represented by the data analyses as far as possible. Risk analysis of renewable energy resources as a real-world system was represented by the effect of climate change on renewable energy resources, which is a novel contribution of this research. The researchers from the city of Vaasa and Turku, Finland and one researcher from Sweden can represent the effect of climate change on renewable energy, at least in the cases of Sweden and Finland. There are relationships between climate change effects and land uplift between Sweden and Finland. They are sister nations that have similar environments and weather patterns. Thus, it is believed that the risk analysis can be extended to Sweden to a certain extent, particularly in bioenergy terms, since the expert from Sweden has expertise in bioenergy.

Sediment heat energy production can represent a real-world system, since it is installed in a real sea water body. This seabed has characteristics that are very representative of Finnish waters. Having two installation sites shows there are clear differences between site specifications. Hence, since the sea is near the city of Vaasa and a part of Finnish waters there is a clear linear representation of the waters as a sample of Finnish water systems to some level. The land uplift effect is a local phenomenon that has a linear relationship to the land uplift phenomena in Nordic nations. Thus, it is a very good representation of the overall land uplift phenomenon if we consider land uplift in the city of Vaasa as a sample real-world system. All results of mixed methods modelling have been represented by these world systems, which show the phenomena of the seaside energy solutions, climate change and land uplift.

2.5.1.7 Robustness

Robustness can be defined as 'the ability to withstand or overcome adverse conditions or rigorous testing' (google.com, dictionary 2022).

The conceptual (abstract representation)

The abstract representation of climate change effects on water quality is credible because there is a clear correlation between the concepts or their variables. Thus, the different analyses implemented for testing show the robustness of the research in this topic. Statistical analyses proved almost all results multiple times. The abstract representation of this topic was due to the statistical analyses used to find out their relationships. Risk analysis of the renewable energy resources concept was developed using Holma et al. (20018) as a starting point. In that article and our research, all aspects and types of renewable energy were considered. Holma et al. (2018) led us to more accurate and trustable methods used for risk analysis. The experts used in our analysis were currently actively involved in renewable energy resources. Thus, the research is robust and able to adapt to unexpected results in terms of abstract representations.

The concept of sediment heat energy production is addressed in terms of investigating the influence of climate change. The research found that sediment heat energy production uses climate change effects to its advantage, at least in summer. This was tested at two sampling points with various statistical analyses that helped ensure the robustness of the research. The land uplift effect and sea-level rise relationship study also used various tests to show its robustness at the methodological and conceptual levels. All research in this mixed methods design was found to be robust, because various aspects and analyses of energy and climate change relationships were presented on five individual topics. Each study was unique by itself. However, each is a pillar of the main reach topic, climate change and renewable energy. The research is mainly focused on seaside energy solutions, land uplift and climate change and presented with various sophisticated analyses, which can withstand rigorous tests.

The methodological (techniques used)

The study on climate change effects on water quality used the broadest statistical analyses in conjunction, leading to the robustness of the research. The types of statistical testing used were summary statistics, time-series data presentation, distribution analysis, statistical dependency, analysis of differences, forecasts, regressions (linear and multiple regressions) and trend analyses. Each method used was evaluated for its limitations and the analysis was performed several times ensure robustness. Thus, these lists can show the robustness of the methods implemented on the topic of climate change effects and water quality. Risk analysis of renewable energy resources methods considered the risks of all types of renewable energy except wave energy. This shows the robustness of the material analysed. The number of experts (14 experts) was filtered down to average values to represent the overall results. Thus, each expert view considered in the result shows robustness to some extent. The sediment heat energy production study (Publication IV) used various methods to ensure robustness. The methods used were summary statistics, correlations, ARIMA modelling forecast, and validation by factor analysis. Checking the overall data with factor analysis ensured and reliable result, as well as contributing to the robustness of the methods used.

The land uplift effect used various methods, including framework chart development, local data forecasts and land uplift effects literature comparison. This led to more sophisticated and robust methods supporting one another. Better results were developed after combining all the methods.

The substantive (real-world systems and phenomena)

The effects of climate change on water quality were checked at six sampling points and two weather stations, leading to robustness in representing real-world systems. The risk analysis of renewable energy resources uses both aspects of risk, the risks of climate change to renewable energy and the risks of renewable energy use and production to the environment. To ensure robustness, the research presents the possible aspects of risks related to renewable energy resources. In addition, all renewable energy resource types were included in these analyses except wave energy, leading to the most sophisticated representation of the renewable energy risks phenomenon. Sediment heat energy production was implemented in a real sea water system, which is a very good representation of general real-world systems. Its input robustness was improved by having two installation sites for comparison, which led us to determine the area specificity of the sediment heat energy production. The land uplift effect phenomenon was connected with climate change through sea level rise. This analysis shows the real-world system both globally and locally. The various methods used helped increase robustness by representing real-world systems.

2.5.1.8 Triangulation or convergence, generality or credibility, replications and reproducibility

The conceptual (abstract representation)

The connections between climate change effects on water quality, risk analysis of renewable energy resources, sediment heat energy production, and the land uplift effect represented a real triangulation between the concepts, which share the central elements of climate change and risk (see Figure 7 in Section 1.3.6). All results of the mixed methods analysis report this overall converged research. Some results can be generalised to other locations, but most are specific to the local area. However, similar concepts can be applied to other locations, because the data used and concepts developed are based on internationally recognised methods, tools and theories. The studies proved to be very creditable because all aspects of their limitations were handled by different methods and explanations, as described in the validation and reliability sections of the research. Replication and the reproducibility of the concept are possible because all necessary methods were recorded, although not all methods used in the analysis were reported in this dissertation.

The methodological (techniques used) and the substantive (real-world systems)

All results of the mixed methods analysis use the convergence method to present the overall result by comparing and combining all aspects of quantitative and qualitative results towards conclusions. The generalisability or credibility of the effects of climate change effect on water quality was proven by using various methods to confirm the results. The process and procedures were repeatable because the methods used were general software analysis. Thus, one can arrive at the same result by using the same data, software and analysis methods. The repeatability for other locations is also very possible if a similar data period is available. Risk analysis of renewable energy resources was credible because experienced experts were used as risk analysis data sources. Also, the procedure had already been used by Holma et al. (2018). Therefore, the work is repeatable and reproducible in any location in the world.

Sediment heat energy production credibility was confirmed by a geological survey of Finland, which had installed the equipment and tested the data collection beforehand. The data analysis methods used were general international SAS software methods. Therefore, the credibility and repeatability or reproducibility were confirmed by the overall process used. The generalisability of the local water result might be specific to the similar water system and depth type because it is installation site specific. The general conclusions were valid for all types of water systems. The land uplift effect framework chart method is generalisable, but its repeatability or reproducibility might require similar documents for analysis. The data forecast for sea level rise and land uplift is area specific. Similar analyses can be performed by using the same formulas used in these analyses.

2.5.2 Reliability

The definition of reliability is 'the probability that the component will be able to perform a required function in stated conditions of service for a stated period' (Harrison 1972).

2.5.2.1 Continually unvarying (quixotic) reliability

Quixotic reliability: 'refers to the circumstance in which a single method of observation continually yields unvarying measurement' (Kirk and Miller 1986).

The conceptual (abstract representation)

The effects of climate change on water quality can generate similar results as long as the data combined are similar and from the same location. In addition, since the SAS software used is internationally recognised, no varying results can be generated if similar inputs are used. The difficulty lies in finding appropriate data types that were collected in the same period and if data is not combined correctly. The effects of climate change on the weather are very visible for the time being. This is true not only regarding water quality but in any other climate system. One can thus confirm the unvarying (quixotic) reliability of climate change and water quality as a concept or of the methodology used.

Risk analysis of renewable energy as a concept has been well addressed as a research gap. However, the concept also has continually unvarying (quixotic) reliability because both our analysis and the research of Holma et al. (2018) used a similar method and arrived at similar results. As a concept, it has no variation and produced similar results, indicating similar conclusions. Sediment heat energy production as a concept is reliable because the installation and the measurements were conducted at a real site. The installation and confirmation of the concept were done by the Geological Survey of Finland (GTK). Thus, as a concept, it is reliable enough to be used at a practical site. The observations and studies conducted by the University of Vaasa renewable energy group showed that the site and the concept of sediment heat energy production are quite reliable, with consistent results produced over time.

The relationship of land uplift and sea level rise as concepts has been addressed for a very long time. Thus, it is conceptually reliable. Continually unvarying results can be generated if only the area is sufficiently specific and similar methods are used. The main connection of land uplift with climate change is sea level rise, which affects the amount of land uplift visible on shores.

The methodological (techniques used)

The statistical analysis methods for the effects of climate change on water quality are continually unvarying (quixotically reliable) because they are internationally recognised and confirmed methods and software (SAS software), as long as similar input data are used. The risk analysis of the renewable energy method was used in at least two types of research (this study and that of Holma et al. 2018). Both types of research generate similar results, even though different types of expertise were used. This helps confirm that by using the method it is possible to generate continually unvarying (quixotically reliable) results. The sediment heat energy production method was also statistically analysed by using the SAS software. As stated in the above sentences of this paragraph, the method used in SAS software data analyses is a continually unvarying (quixotically reliable) method because it is internationally recognised and confirmed software. The sediment heat energy production testing experiment method was implemented by the Geological Survey of Finland (GTK). It also has previously been used by this organisation, confirming that the real results are collected from this experiment site.

The land uplift and sea level rise methods include framework chart development, forecast calculations and literature data comparisons. The forecast calculations were based on Påsse and Andersson (2005). Rahmstorf's (2007) formulas were also used to an extent to strengthen the analysis. These analyses were based on already published formulas; they thus generate continually unvarying (quixotically reliable) results.

The substantive (real-world systems and phenomena)

The effects of climate change on water quality as a real-world system are quite reliable and can be studied through time. This relationship is quite complex and varies over time because of different pollution factors. The factors that can influence water quality include climate change, point source pollution, non-point-source pollution, seasonal variation, type of water property and more. Thus, filtering out climate change effects on water quality is quite challenging. As far as this research is concerned, this relation between climate change and water quality as a real-world system is continually unvarying (quixotically reliable) as long as one filters out the other factors from the analyses. Most of the factors were likely filtered out in this research analysis and different methods were used to confirm the reliability of the results.

Renewable energy is a real-world system that has risks. The climate change risks to renewable energy resources and risks of renewable energy to the environment are the two common reliable risks that can exist throughout time. Their continuity as risks can be described as reliable because climate change will be present for a long time. Moreover, any kind of renewable energy resource can present risks to the environment, even if the risk is minimal in comparison with fossil fuels. Thus, this confirms that these phenomena can be considered reliable. Sediment heat energy production, as a real system, is continually unvarying (quixotically reliable) in terms of its methods, because the experiment is conducted at a real-world site where real weather, climate change and other factors influence it. Heat collecting pipes were installed underwater in coastal areas where they can be influenced by real-world effects. Thus, this suggests that the reliability as a phenomenon is real.

Land uplift and sea level rise are occurring in the real world. Thus, these phenomena are reliable for real-world systems. This phenomenon is area- and location-specific, but it is also happening in various sections of the world. If similar methods are used in the analysis and the study is conducted at the exact location, then it is expected that continually unvarying reliable results will be generated for real-world systems. As long as similar locations, methods and documents are used as data sources, it is believed that continually unvarying (quixotically reliable) results can be generated for real-world phenomena. Of course, in all cases, different researchers' conclusions and discussions can vary, since every researcher has their world view and understanding of concepts, facts and how they connect.

2.5.2.2 Stability through time (diachronic or test-retest) reliability

Diachronic reliability: 'refers to the stability of an observation through time' (Kirk and Miller 1986).

The conceptual (abstract representation)

The effects of climate change on water quality were observed through time. The occurrence of the concept over time produces stable results because the data were analysed using various methods of confirming the results. The analyses were tested and retested with different methods of confirming the results. Before that, it was confirmed that all the requirements for each specific method were met. This can be easily noted in the data analysis results and reports. All the results seem stable, but the forecast results with observed and forecasted data differ to some extent. The researcher had to choose which results to accept based on comparing the results of the three analyses (observed data, forecasted data and ARIMA modelling forecast). Those results appear to be acceptable as the result as long as the theory of the forecast expectations confirms it (see Table 3 in the supplementary material of Publication II).

The tests and retests for risk analysis of renewable energy are shown in this research work and Holma et al. (2018). Hence, the fact that a similar method used on the same topic generated similar results in both types of research can confirm stability over time (diachronic or test-retest reliability). This research covering risk analysis in renewable energy resources helps fill the research gap addressed in this topic. Thus, confirming most of the results of Holma et al. (2018) can create trust and reliability in the research gap addressed in this research. This creates stability through time for this doctoral research work.

The sediment heat energy production analyses were a continuation of Dr Anne Mäkiranta's work in sediment heat energy production at the University of Vaasa. Some findings addressed in Publication IV confirmed her previous results. By doing so, one can see stability through time via the reliability of results and the collected data over several years. Thus, this can show sufficient diachronic (test-retest) reliability in this research topic. Land uplift and sea level rise had been stable through time. Their reliability over time can be seen in the references used by Girgibo et al. (2022). Thus, one can understand that the concept is stable through time at specific locations in the world, which also confirms the diachronic reliability of the framework chart developed and of the forecast calculations.

The methodological (techniques used)

The methods used for the analysis of climate change effects on water quality analysis have diachronic reliability because the software used (SAS) is updated every year, and is internationally recognised and validated. Analyses can be done by any individual with long time intervals to create similar results if one inputs similar or identical data and uses similar procedures. This software makes the methods used in the analyses very reliable over time. The risk analysis of the renewable energy method was adapted from Holma et al. (2018). After a few years, the method used in this research thus have led to similar results. This confirms that the method is relatively reliable over time because both types of research produced similar results. In the future, similar risk analyses can confirm the method's continual reliability over time.

The sediment heat energy production data collection method was used by GTK (Geological Survey of Finland) and they have been using it at this and other sites as well. Since the installation in the year 2008, the method has generated data that is reliable over time, suggesting that the same is true of the data collection method. The data analyses were performed with the SAS software. All the confirmations and arguments made for the analysis of climate change effects on water quality in this section apply equally to the sediment heat energy analyses. Land uplift and sea level rise methods must be confirmed after some time. The formula and data used in the framework chart development were created in the past. The formulas are very reliable through time as long as similar data inputs are carefully employed. The framework chart development method requires the input of similar information documents to arrive at a similar framework chart development over time.

The substantive (real-world systems and phenomena)

The effects of climate change on water quality as a phenomenon are continuously reliable over time. The effects of climate change on the environment and on humans will be present in future even if we were to completely eliminate its cause (IPCC 2021, 2013, 2007). Thus, this phenomenon persists through time. One therefore concludes that this real-world system and the associated phenomena are diachronically reliable. The severity of climate change effects on water quality might vary in the current period and future, but it will be present as a phenomenon throughout time. Risk analysis of renewable energy as a phenomenon will be present in the future until all risks from all renewable energy types are minimised. The risks of renewable energy are small in comparison with those of fossil fuels; however, the phenomenon of risks to and from energy, or indeed in any real-world system or technology, is present through time and thus continuously reliable.

Sediment heat energy production phenomena are continuously reliable through time, since while there is a water body present, the possibility of producing heating or cooling from sediment layers is present. In the future, there even will be much more focus on sediment heat energy production because it is at some level a new technology. The relationship between land uplift and sea level rise will be present at least hundreds of years from now. Thus, perhaps the phenomenon may be continuously time reliable if the research consider hundreds of years as sufficient. In all cases of real-world systems, the intensity might change through time, but the underlying phenomenon will still be present.

2.5.3 Practical usefulness, applicability and generalisability

2.5.3.1 Practical usefulness

The levels described in the reliability, validity and practical usefulness of the outcome are important. The use of extreme case analysis was among the strategies described in Creswell and Clark (2011 page 213) to qualify reliability. That is what has been described so far in these validity and reliability sections. The author now describes the practical usefulness of the tasks performed in this research.

The analysis of climate change effects water quality data is expected to show the relations between the two fields. In so doing, one can identify the local effects of climate change on water quality. One of the minor hypotheses was that the expected effect of climate change on the world scale might differ from local expectations and findings. Thus, this research shows that future expectations might show similar patterns as global predictions. However, the local analyses are much more precise with respect to showing better results that further research can be based on. Future research can be based on this research's findings for the Kvarken Archipelago near the city of Vaasa, if further studies on the effect of climate change on water systems are conducting. This means that part of the practical usefulness of the research is that provides basis analyses for the relations between climate change and water quality. In addition, the research identifies the status of the water systems in sampling areas, which were found to be good or above good in terms water quality status levels.

Risk analyses of renewable energy help to allocate the exact risks associated with renewable energy. Thus, during the implementation of renewable energy, one can select and install the best renewable energy with minimal risks for the location. Furthermore, by knowing the risks of renewable energy, one can avoid or minimise its impacts on the environment. Renewable energy risks are uncharted territory for fields of study such as sediment heat energy production. The practical usefulness of these studies is that they can also advance their fields of study and fill research gaps. In addition, this research on the risks of renewable energy may serve to initiate better in-depth analysis in the future to minimise the risks of renewable energy or from renewables to the environment. It is likely that multi-disciplinary perspectives will bring more concrete research and results.

Sediment heat energy production data analysis helps in understanding and planning future energy production sites similar to Suvilahti, the city of Vaasa site. Suvilahti is the sediment heat energy production site, which is built in 2008 and is the University of Vaasa sediment temperature data collection and experiment site. The practical usefulness and novelty of the sediment heat energy study lies in researching a possible connection between climate change and the use of seabed sediment heat collection. This would help in the planning and construction of new sites in the future. The study on land uplift and sea level rise established a conceptual framework for studies of vulnerability and adaptation to climate change that can benefit local, regional and global communities.

2.5.3.2 Applicability

Climate change effects on water quality can help us assess the current and future status of water systems. This thus provides one safeguard regarding what and where to focus on in water resources management. In addition, the research results present the local conditions, providing the exact local status of the water. During future research, our results can be applied as the starting point and future expectations can be based on our results. While conducting research, researchers can consider local changes, instead of general global climate change effect expectations, because it was found that, world expectations of climate change consequences can be different from local expectations. In addition, all research performed in this research adds value, both in terms of knowledge, helping facilitate science and serving as the starting point for future developments.

Risk analyses of renewable energy applicability require choosing the right type of renewable energy and its management at specific sites. Knowing any technological risks helps to avoid or mitigate their impacts on the environment. For example, if a site is residential, then large wind turbines might create noise pollution. Thus, one can use solar energy instead of wind if both natural resources (wind speed and solar radiation) are present in the location. This implies that the management of an installation and avoiding impacts on the environment can be achieved or facilitated by knowing the science of renewable energy risks. Knowledge of the risks associated with climate change effects on renewable energy can be applied to identify resources that are subject to fewer risks due to climate change to optimise utilisation avoiding risks on them and their impacts on the environment.

Practical usefulness and applicability are related to some extent, especially in sediment heat energy production and land uplift studies. The applicability of the sediment heat energy study is in providing heating energy (in winter) and cooling energy (in summer) for 42 detached houses in at the Suvilahti, Vaasa site. Identifying the practical usefulness of climate change effects on sediment heat energy can help in the future management and applicability of sediment heat energy utilisation for heating and cooling. This would help in the planning of new heat production sites in the future. The applicability of the land uplift and sea level rise study is that of using the conceptual framework for studies of vulnerability and adaptation to climate change that can benefit local, regional and global communities. Said conceptual framework was developed in this doctoral research.

2.5.3.3 Generalisability (external validity)

The climate change effect on water quality at Et. Kaupa 1 is sufficiently representative of the rest of the sampling points. Since the rest of the locations are much closer to the Kvarken area, they were expected to show the exact effects of climate change. The proof is that the summary statistics analysis (mean, mode, median and standard deviations) shows that Et. Kaupa 1 was the worst site in water quality. However, even this site was found to be at least at a passable level compared with SYKE's (Finnish Environmental Centre) water quality standard. Even in the analysis, the water quality standards used were seawater standards (the most stringent requirement) to detect the smallest possible effects. All the indicator variables were found to be at least at a passable level, confirming that the sampling sites and the others were in good condition. Thus, the Et. Kaupa 1 results can be generalised to all six sampling sites located near the city of Vaasa and the Kvarken Archipelago area to present the worst possible conditions due to climate change.

The generalisability to other sampling points of the detection of climate change in Et. Kaupa 1 is questionable. However, the analyses were forced to use Et. Kaupa 1 sampling point data as representative because while combining weather data and water quality data, it was found that only Et. Kaupa 1 had enough combined data. It was not possible to use the rest of the sampling points because there was not enough of combined data generated. This is due to the different days or even months that weather data and water quality were collected at all sampling points except the Et. Kaupa 1. Therefore, climate change effects on water quality had to be detected in sampling points for Et. Kaupa 1 located outside of the UNESCO

World Protected area near the Kvarken Archipelago site in the city of Vaasa, Finland.

The risk analysis for renewable energy and the impacts of renewable energy on the environment can be generalisable, at least for Finland. Even though the number of respondent experts was less than Holma et al. (2018), it was found that the risk analysis study had similar results to Holma et al. (2018). Thus, one can generalise the results for Finland, since Holma et al. (2018) show similar results. The other point to mention here would be that the risk analyses performed in this research are a starting point for future broad, deep and multidisciplinary analyses. Addressing the research gap noticed in the risks of renewable energy use and production to the environment and climate change effect risks to renewable energy.

Sediment heat energy production analysis was performed at a real site where two locations were analysed for their sediment heat temperature data. Hence, the sediment heat energy production analysis is site specific, meaning that its generalisability is mainly in terms of the energy systems benefits from climate change effects on weather in the summer. It is possible that all types of sediment energy production can use climate change to their advantage, mainly in summer, since at a global level, there are expectations of increased air temperature according to IPCC reports. The generalisability of the other findings can depend on the site similarity (installation depth) of the data collection site and and the specific location to which it is generalised.

The land uplift and sea level rise framework chart can be generalised to most areas of the world, since the data used were representative enough for most parts of the world that have a land uplift effect. The future forecast calculations for land uplift and sea level rise were only local predictions. Thus, their generalisability is limited. Overall analysis is generalisable to most of the world as long the area specified can be met. The effects of climate change can be detected throughout the world in most climate systems. Thus, the research shows innovative ways of investigating and using these climate change effects to our advantage. In addition, it shows that the forgotten territory of renewable energy use and production risks and climate change effects on renewable energy. The effects of climate change and land uplift can be considered important. The research gap presents in new renewable energy (geo-energy) or sediment heat production is analysed statistically to detect different results, which are very generalisable for the possible sediment heat energy production sites in the world.

2.6 Limitations and assumptions

The main assumption was that the climate change effects (global warming) in the city of Vaasa region, as with global predictions, is expected to cause an increase in water temperature, which is supported by data analysis and forecasts of water temperature.

As one can expect in any scientific research, there are limitations arising from the restrictions of the current research: a single region was covered in the climate change and water quality data analysis and renewable energy analysis, but in the land uplift case, several areas were analysed. The types of energy solutions utilised are limited to address the requirements of specific islands. The water quality data might not address all types of water quality parameters, because the most important specific type of parameters was studied in depth. The type of climate change investigated is mainly human-driven (anthropogenic) climate change. The research constitutes a limitation in not analysing all aspects of climate systems for all available natural causes of climate change. In the risk analyses, not considering wave energy risks due to the lack of experts in the wave energy technology area can be considered a a minor limitation.

2.7 Significance

This section states the significance and social impact of the research.

<u>Theoretical significance</u>: answering each question will contribute to understanding and explaining the topics: 1. The study of climate change effects on water quality helps in understanding that changes in water quality causes an unsuitable environment for species. However, understanding the exact effects of climate change in areas such as UNESCO World Heritage sites seems to be a gap in the literature. These findings can help researchers to carry out practical work in water bodies and the environment. 2. Identifying next-generation economic heat resources can help in combating climate change effects by replacing fossil fuels, which are used at least for household heating. 3. One of the most important contributions is the risk analysis of climate change risks to renewable energy and the risks of renewable energy use and production. Hence, there is a wide gap in the literature and studies of this particular risk analysis area can significantly contribute to theories and applications for renewables. 4. The research methodology is quite new. It can pave the way for similar studies on mixed methods in energy technology. In addition, the findings for the future land uplift expectation, framework chart development and comparison of land uplift and sea level rise in several areas can be a significant contribution.

Additional significance and social impacts include using the available water and climate for energy resources. The research also combines different data sources to assess the real climate and water quality situation in an environmentally protected area. It combines both qualitative and quantitative data in a mixed methods research. The use of both qualitative and quantitative methods helps to overcome the disadvantages of using each of these methods separately. Another reason is that it this is a new method, which helps to connect the doctoral research with the current trends in research. The method delivered a significant contribution, so it uses both methods in an embedded mixed method research design. Introducing renewable energy solutions to climate change effects as an adaptation mechanism is very important for society to participate in combating climate change. The local area (UNESCO World Heritage site and its vicinity) effects of climate change on water quality and meteorology are essential to apply the results in local research. Real-life long-term climate change studies have significance in advancing the understanding of the physical mechanisms affecting climate change. The result will confirm climate change effects on water quality and meteorology.

In addition, meaningful results and methods were obtained from data analysis of seaside energy resources, mainly sediment heat energy production. Adapting to and mitigating climate change is useful for participating in global climate change challenges. Using climate change as an advantage through the use of water resources for energy purposes helps in combating, mitigating and adapting climate change. The social impact of the study is quite significant because it illustrates the future possible energy solutions at the seaside, providing a framework for how societies may participate in adapting to and combatting climate change.

The significance of the study is in combining water quality, climate change, land uplift and seaside energy solutions and presenting their changes in the local area near the Vaasa region. Doing so shows that the climate change effect on the local area differs from global expectations. Demonstrating the increased expectation of chlorophyll-*a* (phytoplankton abundance) shows that the effects of climate change in the future might be very significant in comparison with the current time. The land uplift in the Vaasa regions will be higher in comparison with sea-level displacement, which is very different from other parts of the world where flooding has dominated. In the far-future land uplift is expected to decline, leading to a different state of the local area. The water quality status of all six sampling points shows is at least good, showing that the area is well maintained.

The risk analysis of renewable energy use and production impact on the environment was a continuation and confirmation of the publication and results of Holma et al. (2018). The risks of climate change to renewable energy were a research gap addressed and a significant contribution to this research. The research also connected and presented the connections and risks between climate change effects and renewable energy. Both risk analyses were significant in addressing risks associated with renewable energy, which so far has not been addressed in research. The social significance of these risk analyses lies in identifying, estimating and evaluating the risks of renewable energy. To start using the new solutions, society needs to know the possible associated risks in using these renewable energy resources. These studies help in building the implementation and management of renewable energy resources at the regional level.

3 RESULTS

3.1 Introduction

The introduction of the results was given via brief descriptions, summarising the articles in two tables (Table 5 and Table 6) and illustrating the relations between the articles in Figure 16.

3.1.1 Summary of the articles and their relations

A summary of the information contained in the articles included in this dissertation can be found in Table 5 and Table 6. All four publications have undergone a scientific blind peer review process. All these four articles were published or under review in international, well-known journals. The supporting articles by Girgibo et al. (2022) and Girgibo et al. (2023) were published in international, lower-profile journals. Additional supporting reports [Girgibo (2021) and Girgibo (2022)] were published in the Tritonia library reports series.

Table 5. Summarising information from the four dissertation articles: title, publication context, authors and contribution.

Article	**Publication I**	**Publication II**	**Publication III**	**Publication IV**
Title	Seaside Renewable Energy Resources Literature Review	The air temperature change effect on water quality in the Kvarken Archipelago area	Risks of climate change effects on renewable energy resources and their utilisation impacts on the environment	Statistical Investigation of Climate Change Effects on the Utilisation of the Sediment Heat Energy
Publication context	Climate *(MDPI publisher journal)*	Journal of Science of The Total Environment	Journal of Energy Reports (Submitted/Under Review)	Energies *(MDPI publisher journal)*
Author Co-authors	Nebiyu Girgibo	Nebiyu Girgibo (Corresponding) Xiaoshu Lü Erkki Hiltunen Pekka Peura Zhenxue Dai	Nebiyu Girgibo (Corresponding) Erkki Hiltunen Xiaoshu Lü Anne Mäkiranta Ville Tuomi	Nebiyu Girgibo (Corresponding) Anne Mäkiranta Xiaoshu Lü Erkki Hiltunen

Article	Publication I	Publication II	Publication III	Publication IV
Contributions	Original idea, writing the original manuscript, literature data gathering, systematic literature analyses, reviewing, editing and funding acquisitions by the thesis author.	Original idea, writing the original manuscript, data gathering, data analysis, reviewing, editing and funding acquisitions by the thesis author. Others – data gathering (by Erkki Hiltunen), reviewing, editing and funding acquisitions.	Original idea, writing the original manuscript, data gathering, data analysis, reviewing, editing and funding acquisitions by the thesis author. Others – reviewing, editing and funding acquisitions.	Original idea, writing the original manuscript, data analysis, reviewing, editing and funding acquisitions by the thesis author. Others – data gathering (by Anne Mäkiranta), reviewing, editing and funding acquisitions.

The publication I was designed and written by the thesis author alone. It illustrates the current background literature review for seaside renewable energy solutions. It aims to answer some sections of research question 1 (RQ1). Publication II shows how air temperature affects water quality parameters, including water temperature and Chl-*a* in at least some months. Publication II aims to answer research question 2 (RQ2).

Table 6. The purposes and aims of the dissertation articles, relation to the thesis, novelty and findings.

	Publication I	Publication II	Publication III	Publication IV
Purpose and aims	To review possible seaside renewable energy solutions.	To assess expected changes in water quality using long-term historical water quality and climate data.	To identify, estimate and evaluate risks of renewable energy production and use to the environment, including seaside energy solutions and climate change effect risks to renewable energy.	To obtain new evidence about a unique heating and cooling system in order to describe its status and operation, temperature distributions, correlation tests, and dependency analysis.

	Publication I	**Publication II**	**Publication III**	**Publication IV**
Relation to the thesis	The current review of renewable energy seaside solutions.	Investigating whether there are expected changes in other water quality parameters and water temperature benefiting seaside energy production.	Risk analyses of geothermal energy, including the water heat exchanger and sediment heat energy production.	An experimental and statistical analysis showing how seaside energy solutions utilise climate change effects in local areas and specified seasons.
Novelty	Framing a problematic effect as an advantage to help overcome the problem.	Showing the effect of air temperature change on water quality in the Kvarken Archipelago in a naturally protected area.	The following new renewable energy sources and their risk evaluation were considered in this study: sediment heat, asphalt heat and water heat exchangers. Risks of climate change. on renewable energy.	Researching a possible connection between climate change and the utilisation of seabed sediment heat collection.
Findings	Illustrating seaside geo-energy renewable resources in a single figure; showing possible future renewable energy solutions in seaside areas and suggesting seaside renewable energy solutions for local area use.	There might be indirect effects of the likely increase in air temperature on water quality in the Kvarken Archipelago, in particular causing water temperature and chlorophyll-*a* concentration to increase in a few months at least.	Even if the risks of renewable energy are much smaller than those of fossil fuels, they are significant enough that they cannot be ignored. These findings are crucial in the implementation and management of renewable energy in regional energy development.	A new insight into and confirmations of the benefits of climate change effects for renewable energy production, which thus can be used to combat and mitigate climate change more efficiently.

Publication III identifies the environmental risks of the production and use of renewable energy, including seaside energy solutions, as well as climate change effect risks to renewable energy. It aims to answer research question 3 (RQ3). Publication IV identifies a possible connection between climate change and the utilisation of seabed sediment heat collection. It aims to answer some parts of research question 1 (RQ1). To address the last section of RQ1, additional investigations were conducted and the result was published in Girgibo et al. (2023). Hence, the study is a mixed methods investigation, corresponding to research question 4 (RQ4) regarding including other local environment effects such as the land uplift effect. To answer RQ4, publications I – IV, Girgibo et al. (2022), Girgibo et al. (2023), Girgibo (2021) and Girgibo (2022) were used. The overall relationships between the different publications, topics and research questions (RQs) of the research can be seen in Figure 16.

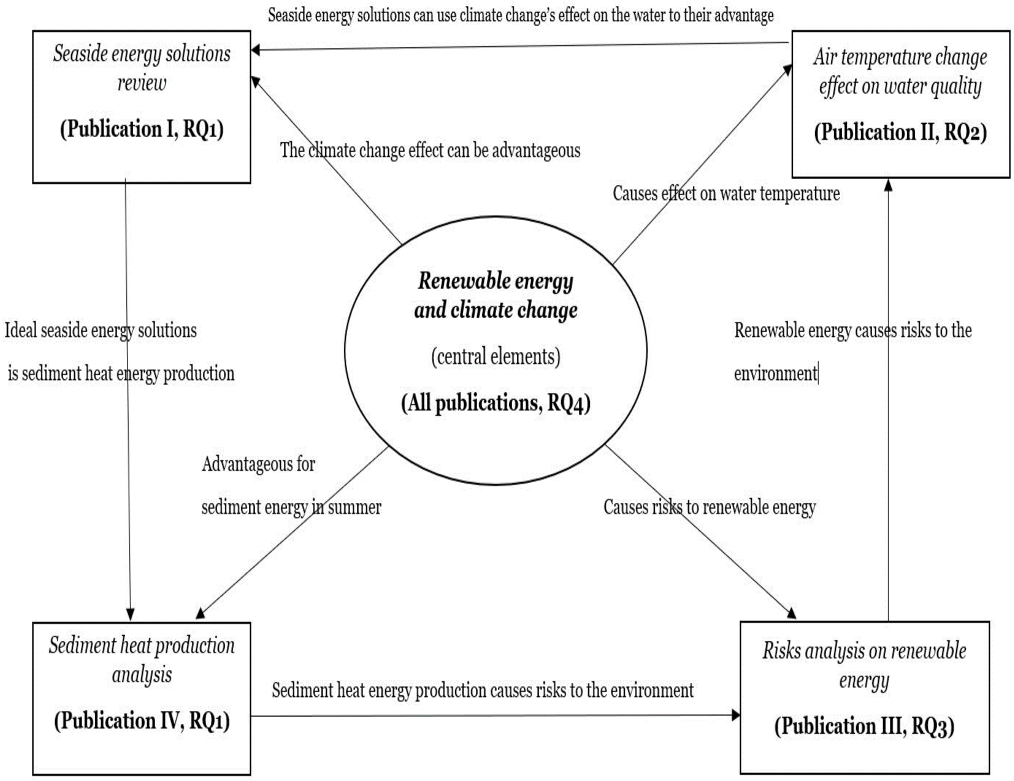


Figure 16. The overall relationships between different publications, topics (in italics) and research questions (RQ).

3.1.2 The study topics are related to and built on the following works

The University of Vaasa renewable energy research group has worked on (1) Alireza Aslani's PhD study, performed on Nordic renewables utilisation and the evaluation of renewable energy studies (Aslani 2014); (2) Pekka Peura's PhD dissertation, which shows the beginnings and development of sustainability and to some extent the Energy Village concept (Peura 2013); and (3) Anne Mäkiranta's PhD dissertation (Mäkiranta 2020) about renewable energy solutions in which sediment energy and asphalt energy had an influence. These are the most related works in our research group to this research. These dissertations contributed to this research of energy solution sources, Nordic renewable utilisation and sustainability guidance. As well, the renewable energy research was influenced by the related PhD study on GEU (groundwater utilisation) by Arola (Arola 2015). Climate change studies were used, of which the most influential works were the IPCC studies (IPCC 2007, 2013, 2014, 2019 and 2021) and the TAR (third assessment report), which used quantitative evaluation. Risk analysis has one main contributor, the related work of Holma et al. (2018) on renewable energy risks to the environment. Further, Sokka et al. (2016) influenced the risk analysis of renewable energy. Land uplift was influenced by discoveries performed by Nordman et al. (2020) regarding land uplift and sea level rise in the Vaasa area. Additionally, Poutanen and Steffen (2014) study on the Kvarken archipelago land uplift.

The data analyses of climate change and water quality (limnology) background literature were influenced by a variety of resources. These are (1) Kauppila's PhD study of water quality (Kauppila 2007). (2) Räike et al.'s (2020) water analysis study. (3) Korhonen's PhD study on snow patterns in water systems (Korhonen 2019). (4) Huck's (2012) book on data analysis. (5) Helsel's (2002) and Hirsch et al.'s (1982) book on data analysis. (6) Hirsch et al.'s (1982) trend analysis article. (7) Wetzel's (2001) limnology book, which provided background for water science. (8) Fan and Shibata's (2015) example of analysis between water quality land use and climate change scenarios. (9) Rankinen et al.'s (2016) description of the influence of climate and land use change on nutrient fluxes from Finnish rivers to the Baltic Sea. (10) Huttunen et al.'s (2015) analysis of the effects of climate change. (11) Paudel et al.'s (2018) analysis of water quality change and seasonal variation in root respiration. (12) Pearl (2009) on the meaning of causality. (13) Ylhäisi et al.'s (2010) precipitation analysis in Finland and (14) Peura and Sevola's (1992) study of acidification in lakes of the Kvarken archipelago in the Gulf of Bothnia (Finland and Sweden). These books, dissertations, articles and papers are the main documents on which this doctoral research is built.

3.2 Seaside renewable energy resources literature review

Contribution to:

> <u>Research question 1 (RQ1)</u>
>
> "What are the future coastal energy solutions? Do sediment heat energy production and other seaside energy systems use climate change to their advantage, and if so, in what seasons?"

Main reference:

Publication I

Addressing RQ 1 through the investigation on seaside renewable energy resources was conducted through a systematic literature review in Publication I. The goal was to provide background literature regarding the use of climate change effects as support for shallow geothermal energy (seaside energy) production. A schematic of the possible geothermal-energy solutions near the seaside was illustrated in Figure 1 of Publication I and in the Appendix 2 section of this dissertation. In addition, the possible seaside area renewable energy solutions were described in Publication I. These include a water heat exchanger (illustrations and data can be seen in Figures 2, 3, 4 and Table 1 in Publication I), sediment heat energy production, wave energy, asphalt energy resources, groundwater energy utilisation (GEU), wind turbines, KNBNNO materials and solar equipment. These seaside energy solutions explanations were one of the gaps in this research. It was found that most of these resources or solutions, but particularly shallow geothermal energy, can use climate change effects to their advantage to a certain extent. This statement was proven for sediment heat energy production in Publication IV. However, the advantages of renewable energy production are limited to certain seasons. For example, for sediment heat energy, climate change effects are advantageous only in summer.

One of the gaps in the literature that was analysed was the use of water temperature increases for heat energy production by using a water heat exchanger. Filling this gap is important and interesting, since given that climate change effects are present in our environment, we must use them to our advantage. An innovative way of solving the problem is by using the consequences of climate change to help create solutions. Additional calculations were made for the water heat exchanger, as described below.

Preliminary evaluation or TRT analysis for water heat exchanger

The TRT (Thermal Response Test) was used to determine the preliminary effectiveness of heat energy production by a water heat exchanger. Tapio Syrjälä (reported here with his permission), a member of the renewable energy research group at the University of Vaasa, conducted this primary TRT. TRT explanations and research were conducted in Kattilakoski (2017) and one can utilise this reference to further understand TRT. This test data was collected during the installation time of the water heat exchanger in 2018 at the Merten Talo project site. Currently, the water heat exchanger is no longer installed, due to a disagreement with the project financer.

Heat transfer with water-ethanol liquid calculation after analysis

Initial data

- Ethanol 30 w%, Water 70 w%
- Density is 965 kg/m^3 (measured, it cannot be calculated from base values because ethanol molecules are mixed with water molecules).
- Heat capacity per cubic metre 4150 kJ/(m^3·K) or per litre 4.15 kJ/(L·K)
- Heat capacity/mass = [4150 kJ/(m^3·K)] / (965 kg/m^3) = 4.30 kJ/kg·K

TRT Calculations result (by Tapio Syrjälä used by permission)

$$P = m\,\Delta T\,C_p \quad (2)$$

Power = mass flow*(flow temperature into the tube - flow temperature out from the tube) * heat capacity/mass = $m\,\Delta T\,C_p$

T_{in} = 10.16 °C, T_{out} = 9.06 °C -> ΔT = 1.1 °C = 1.1 K

Heat power P is calculated from the liquid properties and measured values of mass flow and T_{in}, T_{out} are temperatures:

P = 0.87 l/s * 0.965 kg/l *1.1 K * 4.30 kJ/kg·K = 3.97 kJ/s = 3.97 kW

It was previously calculated that P had to be the same as the setup power 4 kW and measurements were of electric power.

The heat transfer between heat transfer liquid and seawater:

- Heat transfer from water exchanger (from heat transfer liquid) to sea.
- Medium temperature of liquid is

$$T_m = (T_{in} + T_{out})/2 \quad (3)$$

- T_m = (10.16 + 9.06) °C / 2 = 9.61 °C
- T_{sea} = T_s = 7.0 °C
- The heating power P has to be the same as the heat flow $\dot{Q}$ because of conservation of energy.

$$\dot{Q} = \dot{q} \, {*}\Delta T_{s;} \quad \text{where, } \Delta T_s = (T_m - T_{sea}) \quad (4)$$

- ΔT_s = (9.61 – 7.0) °C = 2.61 °C = 2.61 K
- When $\dot{Q} = 3.97\ kW$, then $\dot{q} = \dot{Q} / \Delta T_s$ = 3.97 kW / 2.61 K = 1.52 kW/K
- This value $\dot{q}$ tells us the efficiency (specific power) of the heat exchanger.
- For a typical case, the heat transfer liquid and rock temperature difference ΔT_b is nearly 6 K
- If we use this temperature difference, we get $\dot{Q}$ = 6 K * 1.52 kW / K = 9.12 kW
- Typical 200 m deep boreholes produce a maximum of 40 W/m -> 8.0 kW

The tested water exchanger was 1.12 kW more efficient than a typical borehole heat exchanger. This is an important finding, since it means that a water heat exchanger is much more power capacity in comparison with a deep (200 m) borehole. Thus, the use of this water heat exchanger equipment for heating and cooling can be a great benefit.

Hence, there is not a lot of information about seaside energy solutions, so analysing this topic also fulfils one gap in our knowledge. The lack of combating climate change with energy solutions and adaptation measures by the education sector and local community in local seaside areas is important as well. In addition, CO_2 emissions reduction is addressed herein. At this point, it is important to recommend the use of the effects of climate change to combat and mitigate it, which has further consequences for an increasingly renewable energy production mechanism. Building relationships between different topics and disciplines is also very important. For example, the connection between climate change effects as a heat energy source and water resources at the installation location is one type of relationship. The main conclusion was that renewable energy can be used efficiently for regional development by using climate change effects to our advantage, particularly in seaside solutions. The research and development of renewable energy is a way to improve resources and spur use of these energy resources. Using small and diverse solutions in local areas, such as replacing energy usage with RE solutions, will reduce climate change worldwide if adapted over time.

3.3 The air temperature change effect on water quality in the Kvarken Archipelago area

Contribution to:

Research question 2 (RQ2)

‘’ What are the changes in water quality due to air temperature change effects? Why have long-term water quality parameters and meteorology changed over time due to climate change? If they have not, why are there no changes to them?’’

Main reference:

Publicaiton II and Girgibo (2021)

To address RQ2, studies were conducted on the relationships between water quality and weather data. The background study was Girgibo (2021) and the detailed results were presented in Publication II. The main findings were presented as follows: The central variable in this study of water quality data is chlorophyll-*a* (Chl-*a*), which is an indicator of the amount of phytoplankton present in water systems. This is mainly influenced by nitrogen and phosphorus. The five relations that show a linear relationship at 5% ($P<0.05$) statistical significance are: 1. Chl-*a* and TP; 2. Chl-*a* and Secchi depth; 3. Chl-*a* and month; 4. Chl-*a* and turbidity; and 5. Water temperature and air temperature. The other correlations analysed showed no linear relationship. A summary of these results is presented in Table 4 in Section 2.4.1.

Air Temperature (weather pattern changes): the result shows, for seasonally corrected data, that the coefficient of determination (R^2) is 0.0181, meaning that only about 1.8 % of the total variation in air temperature can be explained by this regression model. The percentage of data explained is very low and its trustworthiness is very questionable. So, if time is incremented by one year, it increases the value of air temperature on average by 0.20158 units. Because the probability of the model is 0.0334, which is less than 0.05 (5% significance level), we can reject H_0 for the explanatory variable. R^2 is less than 2% for the data explained by this analysis, so the research concludes that there is not enough evidence to confirm the presence of a significant effect of climate change in the area for all months together.

However, there were statistically significant air temperature changes in the Kvarken Archipelago in April and July. The R^2 for April was 0.2109, meaning that the model explains 21.09% of the variation in air temperature. For July, R^2 was

0.1207, meaning that the model explains 12.07% of the variation in air temperature throughout the data collection period (Figure 3 of Publication II). This means there are changes in air temperature in April and July, based on our data sets analysis. The Table 7 presents the yearly average for April and July, giving the air temperature intercept, the slope, R^2 (goodness-of-fit coefficient) and $P > F$ (model probability) based on observed data (1959 to 2011). More articles by using FMI data were published recently Sohail et al. (2022) and Pakkala (2023).

The two indicators used for water quality are chlorophyll-*a* and water temperature, with the results given below. The indirect causality path indicates that air temperature influences water temperature and further influences the growth and abundance of phytoplankton biomass, indicated by chlorophyll-*a* concentration. However, this indirect causality was not confirmed due to multicollinearity in the data.

Table 7. The data set analysis results for linear trend fitting: intercept, slope, R^2 (goodness-of-fit coefficient) and $P > F$ (model probability) for air temperature. Model: $\hat{y} = a_1 + a_2 * year$, where only the statistically significant *($P < 0.05$)* results are presented here.

Original Vaasa airport data set/observed data 1959 – 2011				
Yearly averaged monthly air temperature (1959 – 2011)	**Intercept (a_1)**	**Slope (a_2)**	**R^2**	**P > F**
April (48 years of data)	-87.29270	0.04515	0.2109	0.0009
July (49 years of data)	-46.31031	0.03144	0.1207	0.0155

<u>Chl-*a* (Chlorophyll-*a*) (water quality changes)</u>: for seasonally corrected data, the coefficient of determination (often denoted R^2) is 0.0067, so this regression model can explain only 0.6% of the total variation in Chl-*a*. The percentage of data explained is very low, so its trustworthiness is very questionable. With an increase of one year in the time, the value of Chl-*a* increases on average by 0.04779 units. Because the *p*-values are 0.2128, which is greater than 0.05, this is not statistically significant based on the seasonally corrected data set. We thus do not reject H_0 for the explanatory variable. The linear regression model does not exist for each month. However, a statistically significant increase was seen in May, June, July, August, September and December (See Table 8 for the results).

Additional data mining shows that the result for Chl-*a* regression is:

$$\hat{y} = 9.63156 + 0.03725 * \text{Phosphorous} - 2.73417 * \text{Secchi Depth} + 0.06193 * \text{Turbidity}$$

Where, $\hat{y}$ = Chl-*a*. (See Section 2.4.2 for basic formula 1 and its descriptions).

<u>Water temperature (water quality changes)</u>: for seasonally corrected data, the coefficient of determination (R^2) is 0.0180, so this regression model can explain only about 1.8% of the total variation in water temperature. The percentage of the data explained is very low. Its trustworthiness is very questionable (See Table 5 of Publication II for this result). With an increase of one year in the time, the value of the water temperature increases on average by 0.10764 units. Because the p-values of the model are 0.0340, which is less than 0.05 (5% significance level), we can reject H_0 for the explanatory variable. R^2 indicates that less than 2% of the data is explained by this analysis, suggesting that there is not enough evidence to confirm that the water temperature increases in the area each month.

However, as the following equations show, there are statistically significant results for February, March, June and July. See Table 8 for the water temperature and Chl-*a* analysis results, which are statistically significant. Also, the graphics for air and water temperature analyses are found in supplementary materials in Figures 7–11 of Publication II. The statistically significant monthly ($P < 0.05$ or 5%) results for water temperature are displayed in the following formulas:

$$\hat{y}\ (\text{February}) = 653.31373 - 0.32290 * \text{year}\ (R^2 = 0.6137,\ P\ \text{model} = 0.0073)$$

$$\hat{y}\ (\text{March}) = -453.26039 + 0.22876 * \text{year}\ (R^2 = 0.2660,\ P\ \text{model} = 0.0050)$$

$$\hat{y}\ (\text{June}) = -203.12336 + 0.10949 * \text{year}\ (R^2 = 0.1304,\ P\ \text{model} = 0.0459)$$

$$\hat{y}\ (\text{July}) = -259.60625 + 0.13850\ \text{year}\ (R^2 = 0.1199,\ P\ \text{model} = 0.0357)$$

Where, $\hat{y}$ (m) = water temperature (month)

Table 8. The data sets analysis results for linear trend fitting: intercept, slope, R^2 (goodness-of-fit) and P > F (model probability) for water temperature. Model: $\hat{y} = a_1 + a_2 * year$, where only the statistically significant *(P < 0.05)* results are presented here.

Original 4f (Et. Kaupa 1) data set averaged/ observed data 1974 - 2017				
Yearly averaged monthly water temperature (1974 - 2017)	**Intercept (a_1)**	**Slope (a_2)**	**R^2**	**P > F**
February (only 10 years of data)	653.31373	-0.32290	0.6137	0.0073
March (only 28 years of data)	-453.26039	0.22876	0.2660	0.0050
June (only 31 years of data)	-203.12336	0.10949	0.1304	0.0459
July (only 37 years of data)	-259.60625	0.13850	0.1199	0.0357
Yearly averaged monthly Chl-*a* (1974 - 2017)	**Intercept (a_1)**	**Slope (a_2)**	**R^2**	**P > F**
May (only 14 years of data)	-719.47951	0.36341	0.5401	0.0028
June (only 29 years of data)	-773.07902	0.39101	0.4685	<.0001
July (only 36 years of data)	-390.57200	0.19874	0.2671	0.0013
August (only 23 years of data)	-226.52421	0.11656	0.1747	0.0472
September (only 11 years of data)	-753.02839	0.38007	0.4454	0.0249
December (only 9 years of data)	-719.59573	0.36407	0.6187	0.0119

The relationships between water quality and air temperature were investigated by checking the correlation and multiple regression between water and air temperature. Air temperature does not directly affect most parameters of water quality that are influenced by climate change. However, there is a clear direct relationship between air temperature and water temperature, as shown in the next multiple regression result.

Air temperature and water temperature: positive coefficients for the best-fit regression line were found for air temperature and water temperature. As shown in Figure 12, in the presentation of the supplementary materials of Publication II, air temperature explains 80% (R-square (R^2) = 0.8044) of the water temperature in the analyses. This result is expected because both variables explain the same variable, the temperature. Comparing various multivariate regression formulas, it was found that for all the combined variables, there are differences between the original observed data and the prepared time series data.

These results show that the changes in water quality parameters are due mainly to changes in air temperature influenced by global warming or climate change. It was found that the presence of climate change in the area could not be confirmed for each month. This might be due to the brevity of the period in which the data was collected and seasonal variations. Based on theory and world expectations, the effect of climate change is very real in most parts of the world. This was seen in the analysis. As shown, the air temperature changes for April and July and the water temperature changes in February, March, June and July were statistically significant, as presented in Tables 7 and 8.

3.4 Risks of climate change effects on renewable energy resources and their utilisation impacts on the environment

Contribution to:

Research question 3 (RQ3)

''What are the risks of climate change to renewable energy resources, and how severe are they? What is the nature and magnitude of the risks of renewable energy use and production to the environment?''

Main reference:

Publication III and Girgibo (2022)

RQ3 was answered in the risk analysis study, whose main elements were the identification, estimation and evaluation of risks.

Risk identification: is described in detail in Girgibo's (2022) report. There are two flavours of risks analysed: 1) Climate change risks to renewable energy and 2) Risks of renewable energy use and production to the environment. The lists of all risks identified can be found in Publication III and Girgibo (2022). The novelty of the renewable energy risk analysis study consisted of addressing climate change effects on renewable energy. Thus, the researcher calls this the uncharted territory of climate change and renewable energy studies.

Risk estimation: the detailed estimations of risks for geothermal energy resources, bioenergy and biomass resources and solar-based energy resources can be found in Publication III. Among all types of renewable energy resources, only wave energy risks were not analysed. The estimation of the risks was largely similar to that of Holma et al. (2018), validating the results of Publication III. The main results of the evaluation portion of this risk analysis study are summarised in the following paragraph.

Risk evaluation: Table 9 presents a summary of evaluations and comparisons between the risk analysis results for different renewable energy types. In addition, it presents the least and the most affected or affecting renewable energy types for the two risk analyses conducted in this research. Among the risk of climate change effects on all renewable energy resources, the least affected was ground heat source energy and the most affected was field biomass energy. These evaluation decisions were made based on the generalisation of the estimation results and by comparing with total average summed risk values, in addition comparisons and evaluations conducted within each renewable energy resource type. Regarding climate change risks to geothermal energy resources, the least affected was ground heat source energy and the most affected was the water heat exchanger. In terms of climate change effect risks to bioenergy and biomass energy resources, the least affected were algae resources and the most affected was field biomass energy. In terms of the risks of climate change effects to solar-based energy resources, the least affected was solar energy/solar collectors and the most affected was offshore wind energy.

Regarding the use and production risks of renewable energy resources to the environment, the least influential was solar energy/solar collectors and the most influential was field biomass energy. For geothermal energy resources, the least influential was asphalt/concrete covered areas as a heat source and the most influential were sediment heat energy resources. Among bioenergy and biomass energy resources the least influential was biogas from different sources and the most influential were field biomass energy resources. Field biomass energy was found to be the riskiest among all renewable energy resources to the environment, as well as having the highest risk from climate change effects. For solar-based energy resources, the least influential was solar energy/solar collectors and the most influential was ground/onshore wind energy. The best energy resources, those that were least affecting the environment and were least affected by climate change, were solar energy/solar collectors and ground heat sources, respectively.

Table 9. The best and the worst average risk levels of renewable energy resources (compared and checked by the average risk estimates total sum for each energy resource).

	Risks of climate change effects to the renewable energy		**Use and production of energy resources risks to the environment**	
Renewable energy resources	**Least affected**	**Most affected**	**Least Influential**	**Most Influential**
Geothermal energy resources	Ground heat sources	Water heat exchanger	Asphalt/concrete covered areas as heat sources	Sediment heat energy
Bioenergy and biomass energy resources	Algae	Field biomass energy	Biogas from different sources	Field biomass energy
Solar based energy resources	Solar energy/ collector	Wind energy/offshore	Solar energy/collector	Wind energy/ground
Comparing all energy resources	*Ground heat source*	*Field biomass energy*	*Solar energy/collector*	*Field biomass energy*

Based on the overall evaluation, Figures 17 and 18 were created based on the total average risk estimate values. As stated in Table 9, among the climate change effect risks to renewable energy, the most affected type of energy is field biomass energy and the least affected were the ground heat sources. See Figure 17.

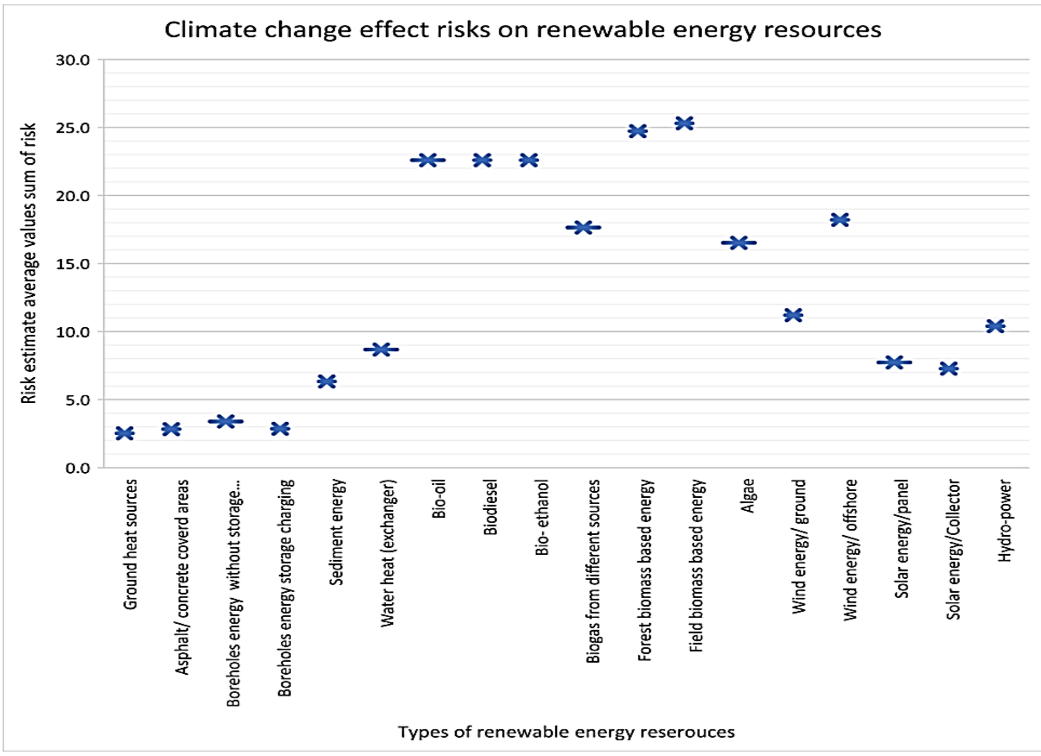


Figure 17. The graph shows the sum of the average risk estimate level of the climate change risks to all renewable energy resources.

As stated in Table 9, among the risks due to use and production of renewable energy resources risks, the most influential is field biomass energy and the least is solar energy/collectors (Figure 18).

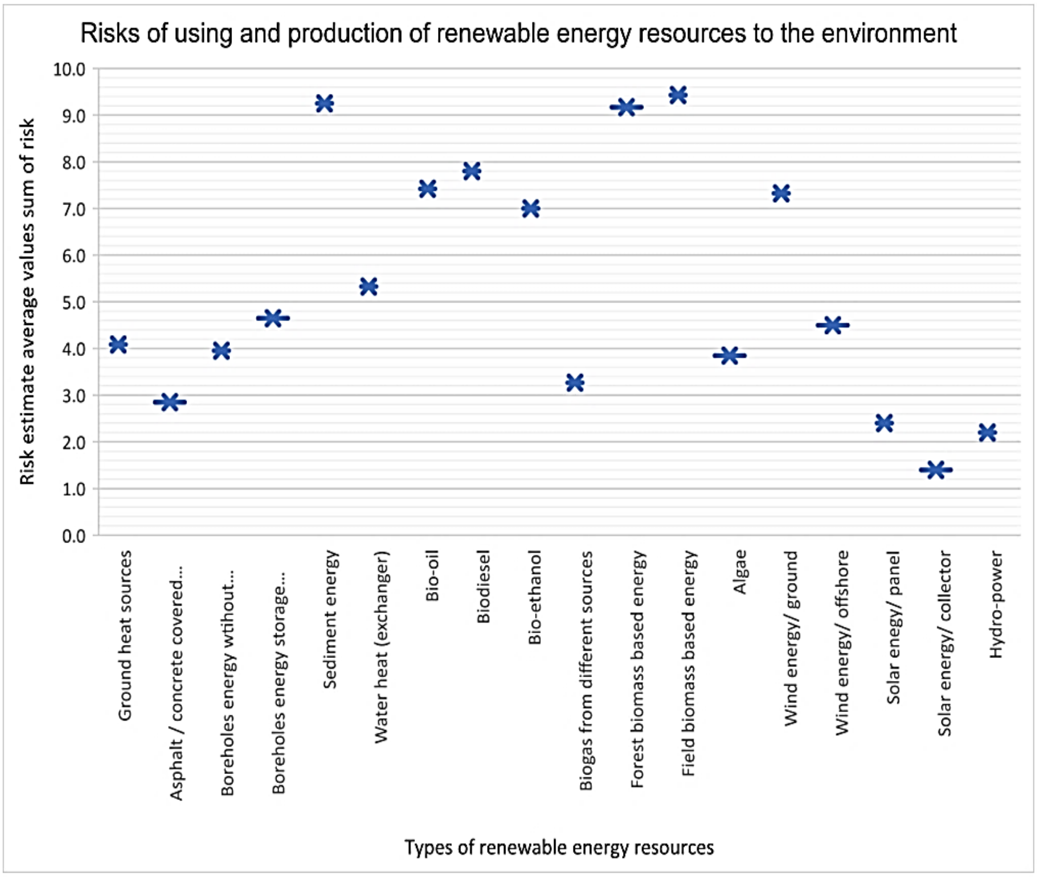


Figure 18. The graph shows the sum of the average risk estimate level of the risks to the environment due to use and production of all renewable energy resources.

As described in the previous paragraph, all except a few results of Publication III are similar to those of Holma et al. (2018). This validates that the analysis of Publication III is correct and reliable. The process of identifying and analysing risks related to renewable energy represents a major step for future extensive risk analysis of renewable energy using a significant number of expert opinions. It is important to impel and safeguard renewable energy development and implementation at the regional level. Energy law and risk management play a key role in the entire process (Girgibo 2022). Renewable energy is a means of achieving sustainable energy. It helps in combating and mitigating climate change. Further, it can help a better, safer world for future generations. Thus, though the risks of renewable energy to the environment or from climate change may be minor, it is important to analyse them to safeguard the use of renewable energy as an environmentally safe, sustainable energy resource.

3.5 Statistical Investigation of Climate Change Effects on the Utilisation of the Sediment Heat Energy

Contribution to:

Research question 1 (RQ1)

''What are the future coastal energy solutions? Do sediment heat energy production and other seaside energy systems use climate change to their advantage, and if so, in what seasons?''

Main reference:

Publication IV and Girgibo et al. (2023)

RQ1 was addressed here through studies that were reported in Publication IV and Girgibo et al. (2023). The detailed results can be stated as follows: The sediment energy production study was conducted using data collected from the Suvilahti area at two sites (the Ketunkatu site and the Litto-oravankatu site). Suvilahti, a suburb of the city of Vaasa in western Finland, was the first area to use seabed sediment heat as the main source of heating for a large number of houses. At the Ketunkatu site, the mean sediment temperature data for February and May show an increase in line with the year of sampling. The standard deviation of January's data shows an increase in variation with increasing years. On another hand, the standard deviation level for September shows a decline with increasing years (Figure 4 and result descriptions of Publication IV). No clear increase or decrease pattern can be seen in the data from the Litto-oravankatu site.

Statistical analyses show that save for a few months, there are statistically significant Pearson's correlations between month temperature and distance from the shore towards to the centre of the water body. June, July, August, and September versus distance correlations were found to be negative for the Ketunkatu site (Table 1 of Publication IV). During these months, as the distance from the shore increases, the temperature declines significantly. A similar finding was also found in October 2016 for the same site. The rest of the months show positive correlation. The negative correlation was because the nearer to the shore an area is, the less water cover it has, and the more heat travels to the sediment from water and sunlight. Therefore, if areas are close to the shore in sunny months, the sediment temperature is higher. Table 1 of Publication IV shows Pearson's correlations between the sampling months temperature of the year and depth/distance at Suvilahti, Ketunkatu in the city of Vaasa. In Liito-oravankatu (Table 2 in Publication IV), all the Pearson's correlations for August and July were found to be negative, except in August 2016 and July 2014. In addition, only June 2014 showed negative correlations. All the analysed correlations between sediment heat in a month (temperature) versus distance were found to be statistically significant. It was noted that the correlations between monthly temperature and distance are quite specific to the location. Furthermore, since the sampling points were in the same water body, this indicates a high location specificity. However, one can generalise the results, since the months with sunny weather show somewhat negative correlations, whereas the rest of the months show positive correlations.

In sunny weather, the greater the distance from the shore, the colder the sediment becomes because it is covered by more water. However, the warming of the sediment temperature increases if it is a greater distance from the shore in winter. In this way, the temperature changes behave more like the conditions seen in a geothermal context. Similar conclusions have been drawn regarding winter months in previous studies conducted in our research group, one of which showed that a significant positive correlation exists between air and water temperatures. It is obvious that the air temperature, as well as the sunlight irradiance, influences the water temperature. Figure 19 shows the scatter plot matrix for all the correlation plots presented between the month's temperature of the year for 2013 and the distance for both sites. According to our data, the best distance for sediment heat energy production is between 100 m and 190 m from the shore, confirming the findings of Dr Anne Mäkiranta. However, this seems to depend on the month in which the data are collected, and in winter months there seems to be a constant increase in sediment temperature as distance from the shore increases.

The forecasts made might not be representative because of a shortage of data. To conduct true long-term forecasting in any kind of modelling requires hundreds of years of data, which is not available in our area. However, this smaller dataset can represent the future situation to some extent. The forecast results presented in the current IPCC (2021) report show roughly similar results. The air temperature is predicted to increase significantly after the year 2041, based on the data on mean air temperature between 1959 and 2019 from the Vaasa Airport weather station collected by the Finnish Meteorological Institute (FMI). Similar weather station data predictions of snow depth show a significant decline in 2033. The main cause of these expected changes is global warming. Consequently, these changes affect the water temperature, leading to changes in sediment temperature and heat energy production. This means that climate change effects could be advantageous for energy production in the summer seasons. The snow cover serves as insulation for the sediment energy build-up, but in the future, when there is no snow cover, the sediment energy might decline. Furthermore, the warming of winter weather may have different consequences in winter sediment energy production. To date, even if it is cold in winter, the sediment temperature has been positive, but this temperature is expected to decline due to snow melting caused by increases in winter temperature.

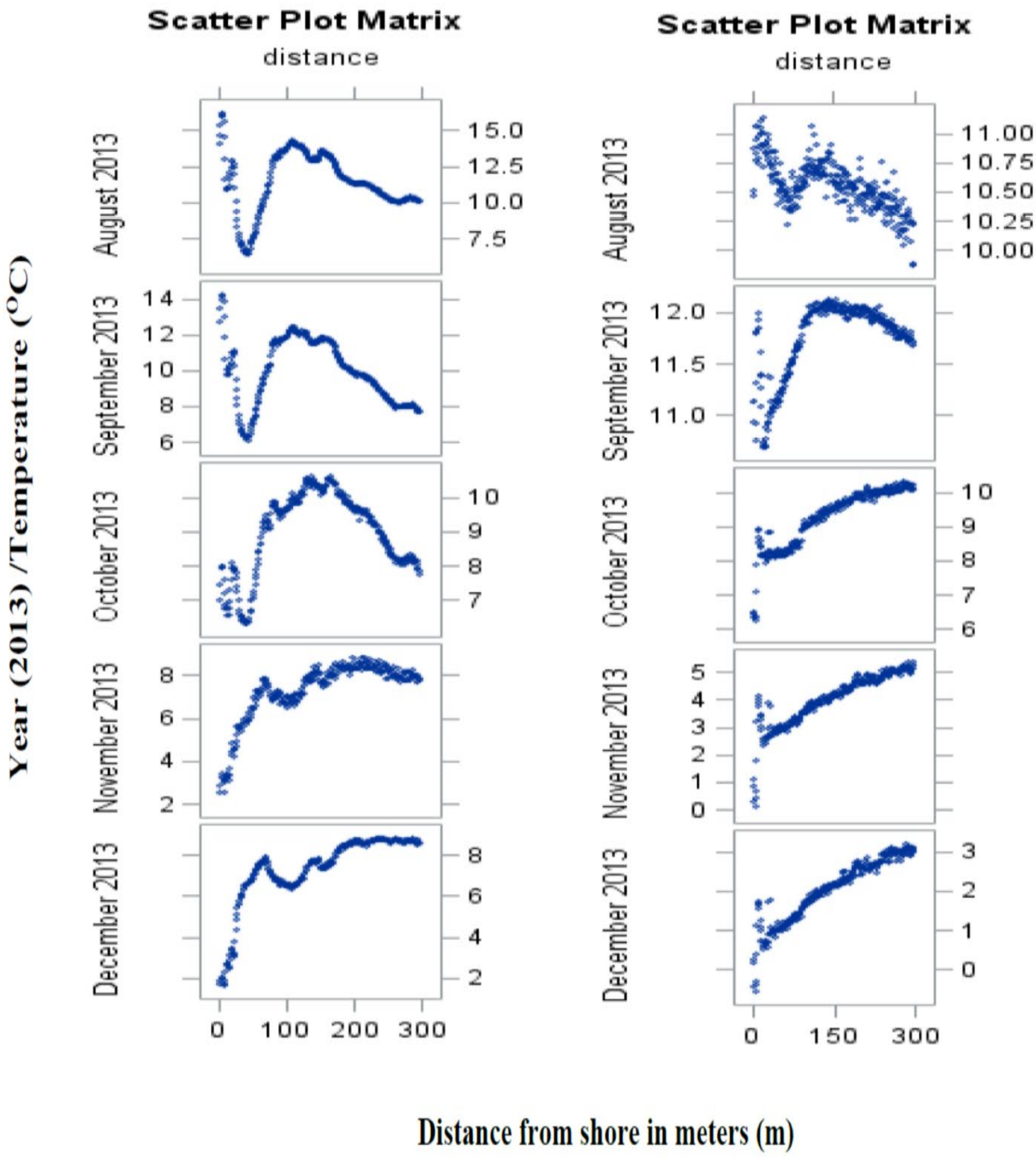


Figure 19. Scatter plot matrix showing temperature for the different months of the year in 2013 versus distance for both sites at Suvilahti in the city of Vaasa. Ketunkatu (left) and Liito-oravankatu (right).

The reliability and validity of quantitative research papers can be examined by conducting factor analysis regarding construct validity (Drucker-Godard et al. 2011). Therefore, a factor analysis was conducted for both sediment energy sampling sites to validate the analyses that were conducted. No clear trends were noticed, except that the data of winter and summer months tend to cluster separately in Ketunkatu. For the Liito-oravankatu site, everything seems to follow a normal distribution pattern, depending on the month and the site specifications.

It was found that sediment heat energy production uses climate change effects to its advantage, especially in the summer. There are forecasts of air and water temperature increases, leading to an increase in sediment temperature with a two-month time lag. Therefore, the air temperature and solar irradiance increases caused by climate change are expected to increase the water temperature. An increase in water temperature causes further increases in sediment temperatures in summer. In winter, ice and snow cover act as insulation for sediment heat energy production and sediment temperature. However, due to a decline in winter snow cover, colder winter air might reduce sediment heat, especially on shallow shores, which could lead to a decline in heat energy production from sediment in winter. On the other hand, in summer, sediment heat energy production has and will, continue to use climate change effects to its advantage.

For other seaside energy solutions, such as groundwater energy utilisation (GEU), the effects of climate change depend on how deep the groundwater is located, the type of water flow present in a specific area and the seasons (Girgibo et al. 2023). To understand the climate change effects on GEU and other seaside solutions, further studies for each solution must be conducted.

3.6 Quantitative and qualitative result comparisons and interpretation and land uplift relations

Contribution to:

Research question 4 (RQ4)

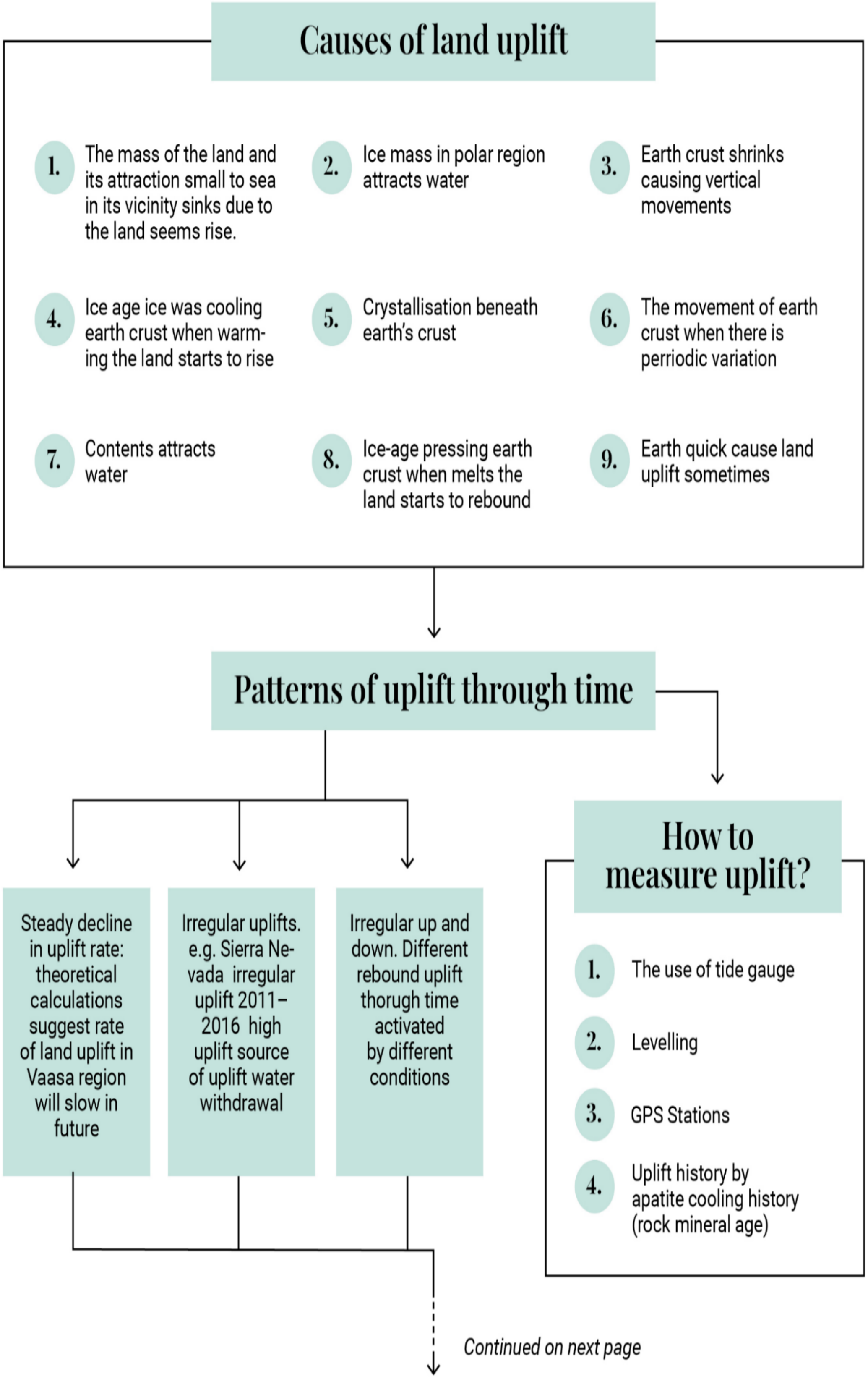
‘’ Why and to what extent does the land uplift phenomenon happen and what are its consequences? How do qualitative data support the quantitative statistical data analysis in the case of land uplift and other effects?”

Main reference:

Publications I – IV; Girgibo (2021); Girgibo (2022) and Girgibo et al. (2022) and Girgibo et al. (2023)

To address the first section of RQ4, a land uplift study was conducted and published by Girgibo et al. (2022). To answer the land uplift question section, a conceptual framework was developed, as presented below. The framework chart summarises all the causes, patterns, consequences, empirical procedures and other issues related to land uplift. Figure 20 shows the conceptual framework chart developed by Girgibo et al. (2022), which answers the first section (land uplift) of the RQ4. This publication also demonstrates that in the future, land uplift effects are expected to continue to overcome sea level rise in the vicinity of the city of Vaasa, in Finland and Sweden (Nordic) and the Baltic Sea. However, in most of the world, sea-level rise be higher, at least in shore areas. On other hand, in the far future, sea level rise will be higher than land uplift based on theoretical calculation made for the region around the city of Vaasa. For more information, see the detailed analysis of the results of land uplift in Girgibo et al. (2022).

The development of the conceptual framework began by identifying the causes and effects of land uplift, as shown in Figure 2 of Girgibo et al. (2022). There are at least nine different causes or sources of land uplift [see Section 1.1.1.1 and Figure 20 in this dissertation and Girgibo et al. (2022)]. The next step was identifying the patterns of land uplift and their possible consequences. From several publications, it was found that land uplift has at least nine possible consequences and three different possible patterns [see framework chart (Figure 20) below and Girgibo et al. (2022)]. At this point, the measuring methods were identified and included in the framework chart development. Finally, the procedure used in the theoretical data calculation was integrated as the empirical aspect of the framework chart developed. For the land uplift section of RQ4, the main result is the framework chart developed, which can be seen in Figure 20.



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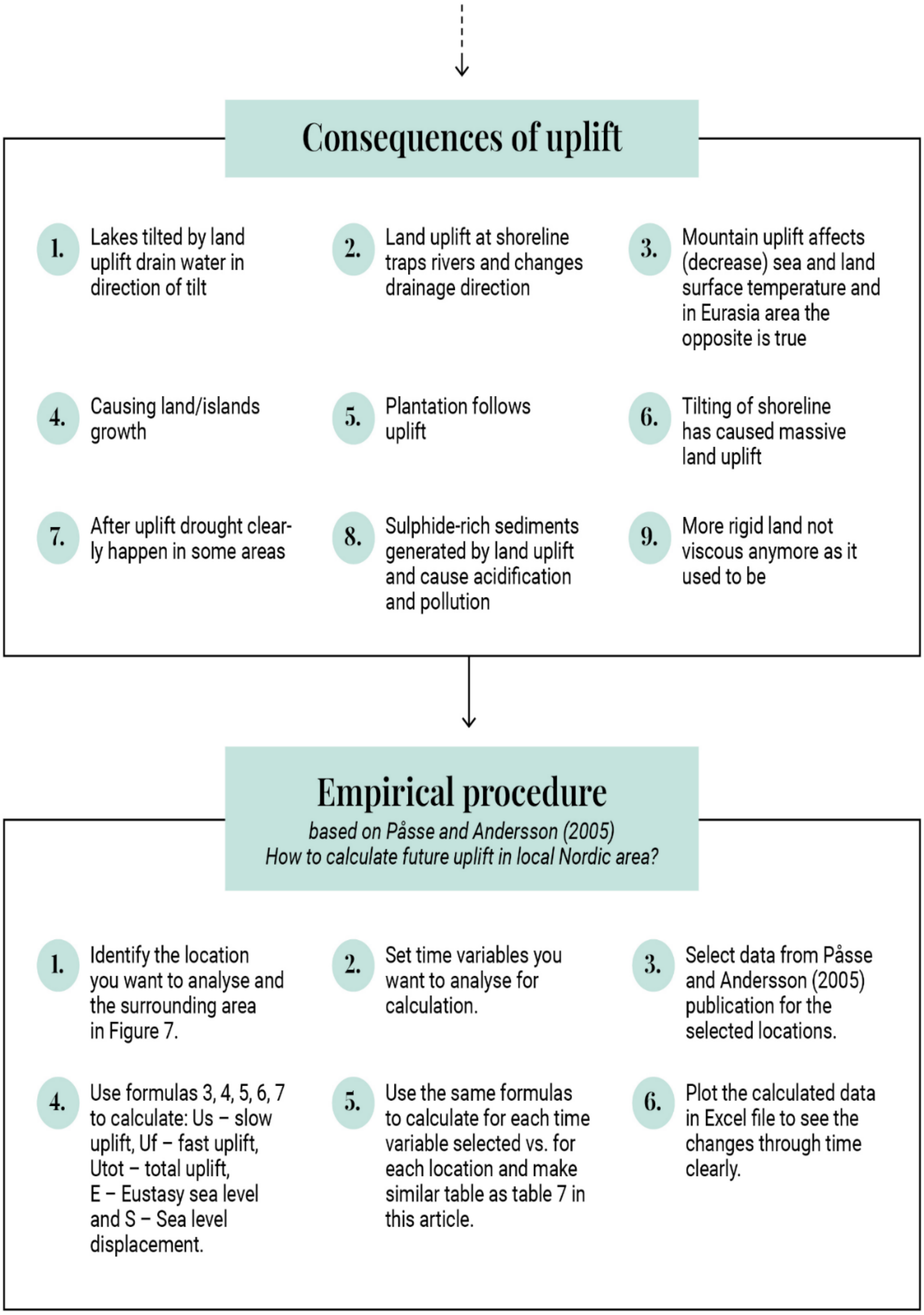


Figure 20. The conceptual and theoretical framework of land uplift: causes, measurement methods, patterns, consequences of uplift and how to calculate future uplift in the local area. For formulas, figures, and table numbers indicated in the framework chart, refer to Girgibo et al. (2022).

According to Girgibo et al. (2022) and as shown in Figure 21, data gathered from various sources show many differences between the expectations for the global situation and for the local Vaasa region. Land uplift is expected to be higher than sea level rise in Vaasa and the surrounding areas of the Baltic Sea, Finland and Sweden, which is not the case for the world as a whole. The sea-level rise for the world must be multiplied by 100, so it is clear that unlike in the four specific study areas (the Baltic Sea, the Vaasa region, Finland and the Nordic area), the expectation for the general world situation is that sea level rise will vastly surpass any land uplift. If all of the Antarctic ice melts, this is expected to lead to widespread flooding, such that even in the Nordic area sea level rise will exceed land uplift.

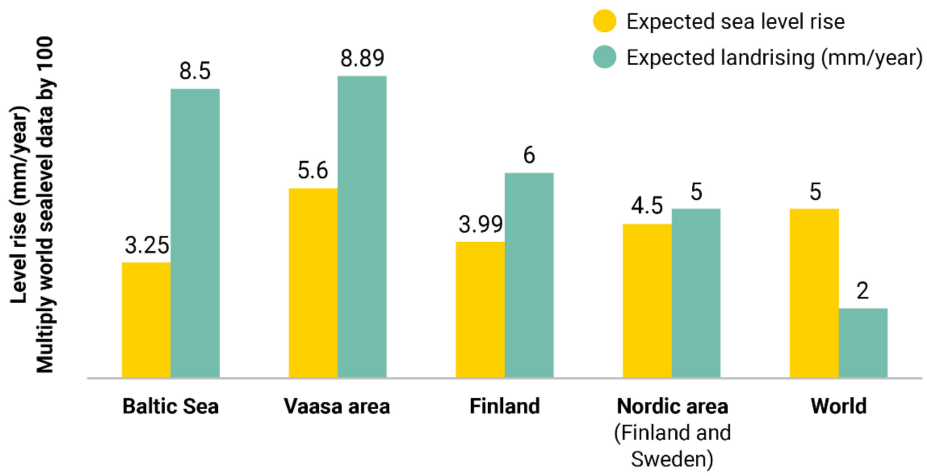


Figure 21. Sea-level rise and land uplift: forecasts of annual rates, based on central estimates.

The section of RQ4 related to mixed methods investigations was addressed by summarising the main results in Table 10 in Appendix 3 for comparison purposes. Generally, it was found that qualitative studies support or complement quantitative studies, as shown in Table 10 in Appendix 3. The manner in which one qualitative study supports another quantitative study is shown in depth in Table 10 in Appendix 3 and in the discussion section while answering RQ4. This study can be proof of the importance of using mixed methods studies instead of only quantitative or qualitative studies. Even though using mixed methods can require longer research time and a great deal of time devoted to developing multidisciplinary expertise, the results show that this additional effort is worth it.

4 DISCUSSIONS

4.1 Discussions of the topics and research gaps

Land uplift effects have been present in Nordic nations for about 10,000 years. In the current century, climate change effects were noticed and its effects were displayed in our environment. Because of climate change, sea level rise has started to appear in the local area. Knowing what to expect in the present and future is important to the local community and other groups. The relationship between climate change, land uplift and sea level rise is complex and the outcome differs from place to place (Girgibo et al. 2022). According to Nordman et al. (2020), in the Vaasa region, land uplift is expected to dominate sea-level rise. Similar findings were confirmed from literature data in Girgibo et al. (2022). It is important to consider sea level rise when calculating land uplift changes.

The future forecast for land uplift in the region is 8.77–9 mm/yr, though in the far future, these expectations might show a decline. If humans do nothing about climate change, the temperature will continue to increase and there will be much more flooding in most parts of the world, including the city of Vaasa. Based on calculations using the formulas from Påsse and Anderson (2005), it is expected that the far future land uplift will decline compared with the present time, as well sea-level rise. It is even possible that in the far future, sea level rise will be higher than land uplift in the Vaasa region (Girgibo et al. 2022). Combined forecasts of land uplift and climate change in the local area are one of the research gaps addressed in this research. This is because filling this gap is important. Local effects can catch residents by surprise if not analysed in depth. Therefore, they must know what to expect in the future.

According to Publication I, the difficulties noticed in the Kvarken archipelago include the following: (1) Oil is expensive due to the additional cost of transportation to islands by boat. (2) There are difficulties in installing borehole energy storage systems because the islands are usually rocky. (3) Sediment energy is not viable, at least not near the city of Vaasa (Kvarken Archipelago), because there are many rocks at the bottom of the sea. (4) Island energy production is more expensive than in other areas. (5) Land uplift shifts the harbour over time so that, for example, a 'water heat exchanger' will non-functional after many years of use because the 'water heat exchanger' will no longer be in seawater if it is not installed deep in seawater at the time of installation. These difficulties were based on the 'Drop in Sea' project outcomes and other discussions.

Energy diversification is important and is at the heart of implementing strategies to overcome climate change problems. Seaside areas and islands are sensitive to climate change, especially sea-level rise and flooding. Even though in Finland, especially within the borders of the city of Vaasa, land uplift is higher than sea-level rise, (Girgibo et al. 2022 and Nordman et al. 2020), the area is also affected by the sea-level rise to some extent. In addition to climate change effects, there are other difficulties and challenges present in utilising energy resources in coastal areas, as presented in the above paragraph. Seaside renewable energy resources can use climate change effects as support for shallow geothermal-energy (seaside energy solutions) production. For seaside energy solutions heat/cooling production, the main resource available due to climate change effects is the change in water temperature. Some seaside renewable energy solutions, such as sediment heat energy production and water heat exchangers, benefit from water temperature changes, at least in some seasons. To see these changes, it was necessary to study the effect of climate change (air temperature) on water systems, mainly regarding their water quality parameters.

Climate change effects as an advantage for energy solutions is one of the new ideas presented in this research and Publication I. This is not only about combating climate change and mitigating it, but also using changes due to climate change to our advantage. One example is using increased water temperatures to extract heat with water heat exchangers. The reason why filling this gap is important and interesting is that insofar as climate change effects are present in our environment, we must use them to our advantage. This is one innovative way of solving the problem: by using the consequences of the problem to help create solutions. Introducing the new type of energy solutions, which uses climate change as an advantage to climate change combating is the research gap addressed in Publication I. The water heat exchanger is a new solution that uses water bodies as an energy source. This technology uses water temperature increases due to climate change to its advantage. The coastal solutions represent one kind of gap in the field as well, since there has not been much study in this area. Therefore, this research helps to fill the gap in information and technology in seaside energy solution types and uses. Adressing the lack of combating climate change with renewable energy solutions and adaptation measures in local seaside areas by the education sector and local community is important as well.

It is important to investigate climate change (mainly air temperature change) effects on water resources and water quality Kvarken Archipelago. This is because how climate change has affected the Kvarken Archipelago remains unclear [Publication II and Girgibo (2021)]. Climate change is expected to influence the study area, the Kvarken Archipelago near the city of Vaasa, Finland (Araújo et al.

2011). The effect of climate change is displayed mainly through weather pattern changes with seasonal variations. Among these changes, air and water temperatures are expected to rise (Kupiainen et al. 2019). Seasonal fluctuations and variations are expected to change for most weather conditions over time (Saranko et al. 2020).

One of the gaps in Rankiene et al. (2016) is that they only identified the phosphorus and nitrogen flux from climate and land use. However, this study tried to look beyond phosphorus and nitrogen changes: the research uses all the available data on water quality parameters that were available from ELY-Keskus, the environmental control centre for the Kvarken area. The data was collected starting from 1962 at the earliest and most of the data started was collected in other locations from 1974. The clear analysis of the effects of climate change (air temperature change) on water quality and what effects are expected in the future due to climate change in naturally maintained areas such the Kvarken archipelago is one of the research gaps that are addressed (Publication II). Addressing this gap helps us to see the exact effects of air temperature change on water quality without being influenced by human pollution and disturbance. The reason why filling this gap is important and interesting it is a new area of research, which is hardly addressed in depth in the local non-polluted area.

Renewable energy resources are very essential in combating climate change. However, there are environmental impacts during their use and production or collection. Climate change effects generate significant risks to renewable energy resources. Risks to renewable energy from climate change effect and renewable energy risks to the environment were addressed in Publication III and Girgibo (2022). Risk can be defined as the possibility of a hazardous event occurring that will have an impact on the achievement of objectives (Misra 2008). Usually, risk causes negative impacts. Decision making is also affected by risk severity and characteristics (Misra 2008). Risk can be environmental, economic, technological or social (Borgheshi and Gaudenzi 2013). In terms of environmental risk, this can include the possibility that the natural environment becomes more polluted and inadequate for the survival of its ecosystems. In economic terms, risk can be the loss of money. Technology risk can be the loss of a sufficient means of gaining the product from the environment. For instance, due to a technology shortage, the energy that can be gathered may be reduced dramatically. Technological advancements are essential for improving efficiency and the economics of renewable energy processes and restricting CO_2 growth (Olabi and Abdelkareem 2022). In terms of social risk, this could include a loss of a suitable living environment or social status. For example, climate change causes a risk to our only living planet, which in turn can be a risk to social survival.

The risks of renewable energy use and production to the environment have been touched upon by Holma et al. (2018). In Publication III and Girgibo (2022), in addition to addressing the above risk, the research tried to bring a new dimension, the risk of climate change to renewable energy resources. The reason that filling this gap is important is that the risk of climate change to renewable energy resources brings a new awareness of climate change risk and creates more initiative and awareness for people to actively combat climate change.

Sediment energy is seaside renewable energy because the thermal energy of the sediment mainly originates from the Sun (with seasonal storage and loss) (Publication IV). A minor portion is from the Earth's own geothermal energy. The combination of solar energy and geothermal energy as an energy source is called geo-energy. Sediment energy benefits from the solar and water temperature changes, at least in summertime. Mäkiranta et al. (2016) confirmed correlations between the air temperature and the sediment temperature in the heat carrier liquid temperature after two months. This means if there is temperature increase in even a few months (April and July) (Publication II results), sediment heat production will increase at least after two months of lag.

To some extent, CO_2 emissions reduction is addressed in this research. The gap is that most studies did not suggest some of the energy solutions addressed here. For example, the new solutions suggested here are a water heat exchanger, sediment energy, GEU (Groundwater energy utilisation), wave energy, asphalt energy and boreholes. This is important in knowing the exact solutions to use in coastal areas. Additionally, the development of sediment heat energy by using climate change as an advantage was first suggested in Publication I and confirmed by Publication IV.

4.2 Answering the research questions and result discussions

In this section, the main research questions are answered and discussed. First, the researcher answered all the sub-research questions in each research question and then discussed the answers. Afterwards, the next research question was answered in the same way.

Research question 1 (RQ1)

> What are the future coastal energy solutions? Do sediment heat energy production and other seaside energy systems use climate change to their advantage, and if so, in what seasons?

<u>Answers</u>: The current and future possible seaside renewable energy solutions identified in Publication I were water heat exchangers, sediment heat energy production, wave energy, asphalt energy resources, GEU (groundwater energy utilisation), wind turbines, KNBNNO-material and solar systems. Most of these solutions use air temperature change and climate change effects to their advantage to enhance the production of heating and cooling energy depending on the seasons. Detailed descriptions of these seaside energy solutions were presented in Publication I and to some extent in Girgibo (2021).

The heat extraction rate from the sediment heat-collection pipes was determined to be 40–50 W/m [Aittomäki (2001) and Mäkiranta (2020)]. Based on Publication IV, the air temperature and solar irradiance increases caused by climate change effects are expected to increase the water temperature. An increase in the water temperature causes further increases in sediment temperatures in summer, but the pattern is site specific and dependent on installation depth. In winter, ice and snow cover act as insulation for sediment heat energy production and sediment temperature. However, a decline in snow cover in winter means that the low temperature of the winter air might reduce the sediment heat, especially on shallow shores. Thus, this could lead to a decline in heat-energy production from sediment in winter. In summer, sediment heat energy production has used and will continue to use climate change effects to its advantage (Publication IV). Most seaside energy solutions, e.g., the water heat exchanger, are expected to use climate change effects to their advantage. This is because most seaside solutions for heat production depend on water temperature changes. The use of groundwater for heating and cooling can be affected by climate change depending on its depth, seasonal variations and water flow patterns (Girgibo et al. 2023).

<u>Result discussions</u>: Most of the currently used and future seaside energy solutions can benefit from climate change, at least in some seasons. Thus, using climate change effects to our advantage leads to adaptation and combating and mitigating climate change. One cares about seaside renewable energy solutions because they provide addition low-emission energy resources for harbours and islands. They may even involve lower costs and less travel; for instance, travelling by boat to get oil to be used in islands is intensive in these aspects. In addition, land uplift causes difficulty in traveling to islands by boat because rocks appear from the bottom of the water bodies. Thus, one must find new seaside renewable solutions that can be easily available and used instead of fossil fuels. In short, the issue of combating and mitigating climate change with possibly lower costs and using available renewable energy resources in all parts of the world comes into the picture.

Publication II showed that air temperature is increasing in April and July. As well, the water temperature decreases in February and increased in March, June and July. All water and air temperatures were found to be statistically significant in these months. Therefore, this is sufficient to prove that there is an increase in water temperature and consequently sediment temperature over time in some months. The heat production from sediment will increase in the summer because the water and sediment temperatures are expected to increase in summer. In Publication IV, it was found that sediment heat production will benefit from climate change effects (air temperature increase), at least in summer. All in all, this sediment heat production increase is expected to manifest in the coming years, based on the expected air temperature effect in water systems (Publication II) and sediment heat production (Publication IV).

Research question 2 (RQ2)

> What are the changes in water quality due to air temperature change effects? Why have long-term water quality parameters and meteorology changed over time due to climate change? If they have not, why are there no changes to them?

Answers: Based on Publication II (refer to all the Tables in Section 3.3 and Table 4 in Section 2.4.1 of this dissertation) findings there are clear changes in weather data and water quality data, probably because of climate change, mainly air temperature changes. Based on the correlation analysis of weather data and water quality parameters, the air temperature showed a significant correlation with water temperature (Pearson's correlation coefficient = 0.89691, $P < 0.0001$). The air temperature increased in April [R^2 (goodness-of-fit) = 0.2109, $P = 0.0009$] and July ($R^2 = 0.1207$, $P = 0.0155$) which as expected has indirectly increased the chlorophyll-*a* level (e.g. increasing in June, with slope = 0.39101, $R^2 = 0.4685$, $P < 0.0001$), an indicator of phytoplankton growth and abundance in the water systems. The water temperatures were expected to decrease in February ($R^2 = 0.6137$, $P = 0.0073$) and increase in March ($R^2 = 0.2660$, $P = 0.0050$), June ($R^2 = 0.1304$, P model = 0.0459) and July ($R^2 = 0.1199$, P model = 0.0357). These are the main changes found in air temperature and water quality (water temperature and chlorophyll-*a*).

The main reasons for these changes in water quality and long-term weather data are global warming and solar irradiance increases. These explanations are based on the theory and explanations of climate change effects, e.g. books by the IPCC (2007, 2013, 2014, 2019 and 2021). In this research analysis of Publication II, the full parameters were not used to indicate the exact effect of climate change. This is because of insufficient data over time for all variables. However, the air temperature suggests that there probably are effects of climate change in the

Kvarken Archipelago, at least for some months. The water quality as measured by the variables water temperature and chlorophyll-*a* changes because of air temperature increases. This can be proven for water temperature because of the strong Pearson's correlation coefficients between water and air temperatures (Pearson's correlation coefficient = 0.89691, P < 0.0001). The investigation into explain the path by which water temperature and solar irradiance affect chlorophyll-*a* concentration was not successful. The researcher believe that air temperature affects water temperature, and water temperature and solar irradiance affect the chlorophyll-*a* indirectly and to some extent directly. This could not be proven because of the multicollinearities between the water quality parameters in the data. Different methods, including structural equation modelling (SEM), could not be used in these data because of the multi-collinearities and non-normality of the data.

Result discussions: The results show that there are changes in weather and water quality parameters over time. What is new here is that these changes in the three parameters of air temperature, water temperature and chlorophyll-*a* concentrations are month specific. It is important to see these results because it shows that even Kvarken Archipelago or other protected areas are expected to have changed due to climate change. It is important to combat and mitigate climate change because even naturally protected areas are affected by it. Knowing that there are changes in water temperature helps us analyse how we can use these changes to our benefit. Even if in these analyses there is no clear confirmation of climate change effects on all parameters, but rather mainly on air temperature, there is enough evidence that changes are happening near the city of Vaasa including the Kvarken Archipelago. Similar studies of water quality data were conducted by Räike et al. (2020) and Kauppila (2007).

Research question 3 (RQ3)

> What are the risks of climate change to renewable energy resources, and how severe are they? What is the nature and magnitude of the risks of renewable energy use and production to the environment?

Answers: The climate change risks identified in Publication III and Girgibo (2022) were: Extreme weather phenomena, wind speed, storms (wind speed and lightning), local or temporal air temperature increase, global warming, melting of ice in Greenland and polar areas and melting of permafrost in Siberia, increases in greenhouse gases (GHGs), precipitation (rain) increase, severe drought (no rain), sea level rise, water temperature increase, high waves, decreased ice thickness in seas and lakes (no ice in the sea), the sufficiency of bioenergy, the cost of bioenergy, the effect of land uplift, new plants (invasive species), new insects (invasive species), new trees with growing areas to the north and insects in the forest with two generations in summer. More detailed information and explanations about the identified risks and the steps can be found at Girgibo (2022).

Among geothermal energy resources, the water heat exchanger was highly affected and the ground heat source was the least affected by the risks of climate change. Among bioenergy and biomass energy resources, field biomass energy was the most affected and algae were the least affected by climate change effects. From the solar-based energy resources, wind energy/offshore was the most affected and solar energy/collectors was the least affected by climate change effects. Comparing all energy resources, it was found that climate change effects cause the most risks for field biomass energy and affect ground heat sources the least. The detailed results and values can be found in Publication III.

For renewable energy use and production risks to the environment, Publication III used similar risks to those Holma et al. (2018) identified: climate change; ozone depletion; acidification; tropospheric ozone formation; particulate matter formation, including public health effects; eutrophication; toxicity; the impacts of biodiversity; soil depletion and soil quality; water use and water footprint; land use, including land area as a resource; lowering of the groundwater level [this groundwater risk identified was not included in Holma et al. (2018)]; the depletion of abiotic resources, such as metals, minerals and fossil fuels; radiation; plant pests and disease; and effects on birds and other animals. These similar identifications helped us to compare our results those of Holma et al. (2018). After comparing our results with Holma et al. (2018), fairly similar results were found, validating our risk analysis research and results. More detailed information and explanations of the identified risks and the steps can be found at Girgibo (2022).

Among geothermal energy resources, sediment heat energy had the most effects and the use of asphalt- or concrete-covered areas as a heat source had the least effects on the environment. Among bioenergy and biomass energy resources, field biomass energy had the most and biogas from different sources had the least. From the solar-based energy resources, wind energy/ground had the most effects and solar energy/collectors the least. Comparing all energy resources, field biomass energy had the most environmental impacts and solar energy/collectors the least. The detailed results and values can be found in Publication III.

Result discussions: Girgibo (2022) describes the risks identified, their definitions and explanations in detail. The evaluation shows that among geothermal energy solutions, both water heat exchangers (the most affected by the risks of climate change effects) and sediment heat energy (the most effects on the environment) were among the main results. These seaside energy solutions are of primary interest to this doctoral research. This makes Publication III important to this research, in addition to the other results given, and opens a path to ensuring that renewable energy solutions become as risk-free as possible. Risks to and from renewable energy resources seem minimal, but these results should not be ignored. The analyses and results of Publication III massively assist in regional renewable energy implementations and management.

Research question 4 (RQ4)

> Why and to what extent does the land uplift phenomenon happen and what are its consequences? How do qualitative data support the quantitative statistical data analysis in the case of land uplift and other effects?

Answers: There are at least nine different causes of land uplift identified (see Section 1.3.3 and Figure 20 for the framework chart). Among the possible causes of the land uplift are the melting of ice, which was compressing the Earth's crust during ice age time in northern Europe and is the land uplift cause present in the city of Vaasa. The consequences of land uplift identified for framework development were: 1. Lake tilted by land uplift drain water in direction of tilt; 2. Land uplift as shoreline traps rivers and changes drainage direction; 3. Mountain uplift affects (decreases) sea and land surface temperature, though in Eurasia the opposite is true; 4. Land/island growth; 5. Natural plantation growth follows uplift; 6. Tilting of shoreline has caused massive land uplift; 7. After uplift drought occurs in some areas; 8. Sulphide-rich sediments are generated by land uplift and cause acidification and pollution; and 9. Land becomes rigid and less viscous.

It was shown how qualitative studies support the quantitative statistical data analysis given in detail in Table 10 (Appendix 3). Some support of qualitative studies for the data analysis studies (quantitative) can be described as follows. Quantification of risks and evaluations (Publication III, qualitative and quantitative study) shows the most and the least affecting and affected renewable energy, including seaside renewable energy resources such as sediment heat energy production which was used in the data analysis study (Publication IV, quantitative study). Current and future seaside renewable energy solutions were identified (Publication I, qualitative study). Among those, the data collected on sediment heat energy production were analysed (Publication IV, quantitative study). Land uplift causes difficulties for the installation of seaside energy solutions, as noticed in the islands of the Kvarken Archipelago (Girgibo et al. 2022, qualitative study). This is used as an explanatory theory for sediment heat energy (Publication IV, quantitative study) and in risk analysis estimations (Publication III, qualitative and quantitative study). Groundwater utilisation (GEU) is one type of energy that has potential to be considered as a seaside renewable energy resource. See, for instance, the suggestion of GEU use in the city of Vaasa region (Girgibo et al. 2023, qualitative study). This supports answering RQ1 and explaining the background in Publication I, qualitative study and Publication IV, quantitative study.

Water expansion due to the increased water temperature leads to additional sea level rise [Girgibo et al. (2022) and Girgibo (2021, water quality change expectations background study), qualitative studies]. Theoretical explanations through data analyses of climate change effects on water quality were provided (Publication II, quantitative study). Climate change causes various risks to most renewable energy resources and even may lead to conflicts between nations that share a single river (Publication III, qualitative and quantitative study). The research helped in understanding and theorising about climate change effects on water quality analysis (Publication II, quantitative study). Water temperature increases could be advantageous to heat energy production (Publication I, qualitative study). For instance, sediment heat energy production used water temperature rise due to climate change to its advantage at least in the summer (Publication IV, quantitative study). Climate change effects can affect groundwater and its heat/cooling energy production, depending on how deep the groundwater is located, seasonal variations and the water flow pattern of the area (Girgibo et al. 2023, qualitative study). This helps to some extent in showing a practical analysis of climate change effects on water quality (Publication II, quantitative study).

<u>Result discussions</u>: The results show how a mixed methods investigation produces sophisticated analyses through qualitative studies supporting quantitative ones. This shows the importance of using mixed-method investigations instead of only qualitative or quantitative ones. In supporting one another, they interleave with each other to help generalise the findings. It is important to acknowledge that mixed method investigations require a great deal of devotion and more time. This can be considered one of their limitations.

4.3 Hypotheses confirmations/falsifications

In this section, the confirmations or falsifications of hypotheses are given.

H_0 (null hypothesis)

> Climate change does not affect weather patterns or water quality parameters. Moreover, there is no correlation between weather parameters and water quality parameters.

The null hypothesis is falsified because it was found that there are changes in air temperature in April and July (see Table 7). Water temperature and chlorophyll-*a* also changed (see Table 8), at least in some months. There were several statistically significant correlations found, as presented in Table 4. This also falsifies the second part of the null hypothesis.

Hypothesis 1 (H_1)

> There is a climate change effect on temperature variation and weather patterns at minimum. The temperature is expected to increase in future environmental and meteorological data. Consequently, there is a possible relationship between long-term water quality and meteorological data. Moreover, it is possible to see local climate change effects.

In this research, it was confirmed that hypothesis 1 is true and that there are future changes expected in the water quality and weather data. There are changes in water quality variables and air temperature over time, at least in some months. Supporting one of the hypotheses of Girgibo’s (2021) report that states that phytoplankton is expected to be higher in the future, it was found through water quality data analysis that Chlorophyll-*a* (an indicator of phytoplankton growth) is expected to be higher in the future, at least in some months. This confirms that there are relationships between air temperature change effects and water quality (mainly water temperature and chlorophyll-*a*) to a considerable degree with both direct and indirect effects. These changes were shown in local area data analysis.

Hypothesis 2 (H_2)

> The efficiency of seaside renewable energy solutions (e.g. sediment heat production) helps to combat, mitigate and adapt to climate change.

Hypothesis 2 is confirmed, hence, the potential of heat production through sediment heat energy in summer is expected to increase. This means it will help in combating, mitigating and adapting to climate change. In terms of adaptation to climate change, hence it was found that sediment heat energy production used the effect of climate change to its advantage, at least in the summer. Therefore, this means that the heat production from sediment will adapt to the changes in climate and benefit from it. In addition, this both falsifies and confirms one of the hypotheses of Girgibo's (2021) pre-literature literature review, which has two parts. It was stated that the potential of energy will decrease (this was falsified, since it was expected to increase depending on the seasons at least for sediment heat energy production), and that the surrounding temperature will increase due to global warming (this was confirmed to be true in the weather and water temperature data analysis).

Hypothesis 3 (H_3)

> Land uplift will continue without declining due to climate change and ice road availability will decrease due to an increase in temperature and ice melt. Moreover, land uplift in the Vaasa region will increase in the far future.

Hypothesis 3 was also confirmed to be true. This is because according to Girgibo et al. (2022), it was found that land uplift will be higher even if there is an expectation of sea level rise. The ice road is also expected to decline. This is based on the findings of forecast modelling; as presented in Publication IV and IPCC (2021), the snow depth is expected to decrease and water temperature to increase. This means that ice road build-up will decline to some extent in the future, perhaps even dramatically. According to the calculation of the land uplift forecast (Girgibo et al. 2022), land uplift is expected increase for quite some time with yearly increases becoming smaller and smaller. However, after thousands of years land uplift will reach its minimum and sea level rise will exceed it. This will occur if current climate change continues as it is, affecting the sea-level rise. Again, supporting the pre-literature review (Girigibo 2021) report hypothesis stating that land uplift will continue to increase whether there is climate change or not, it was confirmed that land uplift in Nordic areas is still expected to increase in the future. Specifically, in the city of Vaasa region, it is expected that land uplift will be higher than the sea level rise in this area, unlike at the global level [Girgibo et al. (2022) and Nordman et al. (2020)]. Thus, land uplift will win out in the city of Vaasa for some periods.

Hypothesis 4 (H_4)

> The ice thickness is decreasing because of melting, so it will be possible to use wave energy or other energy resources in the future.

Hypothesis 4 was also confirmed, mainly theoretically. Based on the findings of forecast modelling, as presented in Publication IV, Publication II and IPCC (2021), snow depth is expected to decline and water temperature to increase. This means that the thickness of the ice will decrease, and less ice will be present on the shores. This will lead to the possibility of a future increase in the use of wave energy or other energy resources. There is no experimental evidence of this at the current time, except theoretical explanations based on the expected snow depth and water temperature changes.

Hypothesis 5 (H_5)

> Due to the CO_2 increase in the atmosphere, solar radiation and the temperature increase, as a result of climate change, the growth of phytoplankton and algae will be much higher in the future. Moreover, the O_2 level will decline.

Regarding Hypothesis 5, one part is confirmed and the other falsified. The confirmation was that the growth of phytoplankton and algae will increase in the future. Evidence for this is that chlorophyll-*a* is expected to rise in some months, with the results presented in Tabel 8 in Section 3.3 and Publication II (e.g. in June the trend is increasing, will slope = 0.39101, R^2 = 0.4685, $P < 0.0001$). The expectation that the O_2 level will decline is falsified. According to further data analyses conducted and in the data analysis report (the full report is unpublished, but some results were published in Publication II and Publication IV), it was found that the dissolved oxygen level in water shows no clear increase. This hypothesis was proposed because the water temperature is expected to increase in the future causing a decline in the dissolved oxygen level in the water. The colder the water temperature, the higher the amount of oxygen dissolved in it. The hypothesis of the expectation of a decline in oxygen level is falsified because no decline was noticed; rather, it continued at a steady level.

Hypothesis 6 (H_6)

> Risk analysis shows the possible risks. Further, it is possible to identify and estimate certain risks in renewable energy resources due to climate change and the risks of renewable energy use and production to the environment.

Hypothesis 6 was confirmed because by the overall results of Publication III. As shown in the results of Publication III and Girgibo (2022), the risk analysis shows that most possible risks were identified, estimated and evaluated for both the risks to renewable energy resources due to climate change and risks of renewable energy use and production to the environment.

5 CONCLUSIONS

5.1 Conclusions of the research

One of the main contributions of this research is in studying relationships through a study of different disciplines and topics. Thus, it helps in creating a sophisticated view of natural phenomena and seaside renewable energy solutions. The relationships between *energy and climate change (air temperature change)* were investigated in this research. The conclusions of the whole research are as follows:

1. IPCC states by the day of 20.03.2023 that, ‘there is only a 7-year window period to reduce 50% of carbon emissions’ (EnergyWeek at the City of Vaasa seminar discussions on 21.03.2023). If so, there is a must massively to adopt renewable energy at the regional level worldwide.

2. During this period with the Russian war on Ukraine having caused an energy crisis in Finland and the EU, in the wake of the COVID-19 pandemic, it is important to focus on the use of local renewable energy to overcome the shortage in energy production and the energy market.

3. The main conclusion was that renewable energy can be used efficiently for regional development. The research and development of renewable energy is a way to improve resources and spur use of these energy resources. Using small and diverse solutions in local areas, such as replacing energy usage with RE solutions, will reduce climate change worldwide if adapted over time.

4. Developing nations like those nations in Africa can bypass the use of fossil fuel energy by creating and implementing renewable energy production systems and infrastructure. Therefore, they contribute to mitigating climate change and meet local energy needs. This will help to overcome their energy and electricity shortage, towards better national development strategies.

5. One key conclusion is that seaside renewable energy is mainly due to shallow geothermal energy and that most of the solutions use climate change effects to their advantage in some seasons, as was confirmed for sediment heat energy production, at least in summer. This is an example of the connection between the use of climate change effects as a heat energy source and the water resources at the installation location.

6. The water exchanger was 1.12 kW more effective than a typical borehole heat exchanger. This is an important finding, suggesting water heat exchangers are

much more power capacity in comparison with deep (200 m) boreholes generally.

7. The means of energy production are expected to increase, but heating demand might also be expected to decrease due to climate change. The ice thickness is expected to decline, which can lead to fewer ice roads in the future and benefit wave energy to some extent.

8. The Kvarken Archipelago area was not affected severely by external and other pollution sources. It was concluded that the quality status of all sampling points (using the standard of SYKE Finland's water quality status) was found to be at least at the ok or passable level.

9. There are statistically significant Pearson correlations between chlorophyll-*a* and all of TP, Secchi depth, month and turbidity. Also, air and water temperatures show a statistically significant Pearson correlation. Further, trend analysis shows anomalies in past and future trends. Generally, it shows that in the future, air and water temperature and Chl-*a* are expected to rise and snow depth levels to decline.

10. The presence of air temperature changes in April (R^2 = 0.2109, P = 0.0009) and July (R^2 = 0.1207, P = 0.0155). One explanation for the presence changes only in April and July and lower R^2 levels can be because of the length in the data collection period. Changes in water quality variables (Chl-*a* and water temperature) were found in some months.

11. The research concludes that there might be direct and indirect effects of the likely increase in air temperature on water quality in the Kvarken Archipelago, in particular by causing water temperature and chlorophyll-*a* concentration to increase at least in some months.

12. The results of the risk analyses show similar results to the previous studies. It was also of note that among the geothermal resources, the water heat exchanger was the most negatively affected by climate change. Sediment heat energy had the most negative effects on the environment, among all geothermal energy resource types.

13. The risk analysis study addressed the new ground of climate change and renewable energy. Even if the risks of renewable energy on the environment or from climate change are low, it is important to analyse these risks to safeguard the use of renewable energy as an environmentally safe, sustainable energy resource.

14. Sediment heat energy production was site-specific and depended on installation depth. Sediment heat energy production uses climate change effects to its advantage, especially in summer. In winter, ice and snow cover act as insulation for sediment heat energy production and sediment temperature. However, due to the decline in snow cover in winter, sediment heat production might be reduced due to winter air. This is because there is no longer any snow cover to protect against cold air temperatures, especially on shallow shores.

15. Negative correlations were present between sediment temperature per month and distance from the shore in sunny months and positive correlations were present in winter months. In addition, sediment temperature seems to build up after a 30–50 m distance from the shore, depending on the shallowness of the water body. Starting from October, the decline in sediment heat temperature at 30–50 m could occur due to heat uptake for household use. The best distance for sediment heat energy production in summer is between 100 and 190 m (sediment temperature record distance from the shore), depending on the month. This confirms the previous research result from the University of Vaasa's research estimations.

16. Groundwater energy utilisation (GEU) was suggested for use in the city of Vaasa. This is an ideal option, which can be environmentally friendly free energy if used with care. However, it might require experimental validations before real installation for use.

17. Sea level rise and even flooding, increase in volume, turbulence, and velocity are expected to occur in the waters of Raippaluoto.

18. The inevitable conclusion is that future sea level rise will exceed any land uplift in most areas of the world. Sea level rise might not affect the local Vaasa area and land uplift will be higher than sea level rise. In the far future, both land uplift and sea level will decline dramatically based on the theoretical calculations results found and presented. Moreover, if the current climate change effects continue, the sea level rise will be higher than land uplift.

19. Mixed methods analysis shows support by qualitative studies for quantitative ones. It is important to use mixed methods because this will give better results and a way of looking at a topic in various aspects. It also overcomes the shortcomings of any one type of method such as qualitative or quantitative ones.

5.2 Recommendations

These are the recommendations of this research: 1. It is important to use the effects of climate change to combat it and mitigate its causes and further consequences. 2. The use of water heat exchanger equipment for heating and cooling can greatly benefit society. 3. Climate action is necessary to protect Kvarken Archipelago's species and ecosystems. 4. The risk analysis findings are crucial. These results help in the implementation and management of renewable energy in regional energy development. 5. Further study in developing a sophisticated framework chart and other theoretical calculations on the topic of land uplift is important. 6. An international community should care for and protect freshwater resources, such as groundwater, even if the research group's field of study is in a different area. 7. All humans have to bear in mind the needs of future generations, where they have as much right as we have to enjoy and drink water, and thus find better ways to maintain and keep groundwater clean for today, tomorrow, and for the use of future generations. 8. All in all, a mixed methods investigation delivers a better understanding, especially in multi-disciplinary research.

5.3 Implications of the context/practitioners and field study

1. It is very important to use the effects of a problem as an advantage to address it, such as by using the effects of climate change on heat production, primarily present in seaside renewable energy resources, to mitigate and combat climate change.

2. Identifying the expected exact air and water temperature effects in the area can help researchers to base their work on these finds instead of using the generalised averaged global temperature. This will minimise errors for future researchers in the environment of the Kvarken Archipelago and the city of Vaasa.

3. The whole process of identifying and analysing risks related to renewable energy was an important step. This will help conduct future extensive risk analysis on renewable energy with a significant number of expert opinions. Energy law and risk management play a major role in the whole process of renewable energy risk analyses.

4. New policies must focus their deployment and implementation not only on protecting the environment but also on reducing and stopping the causes of climate change and air temperature changes.

5.4 Areas of further research

- Expanding renewable energy knowledge to Africa through the LEAP-RE project using the ''Energy Village Concept'' (Work package 14 in the LEAP-RE project).

- The researcher's future research topic will be how all climate change effects have affected the ecosystem and representation within the Kvarken Archipelago. Expanding the study to include other parameters of climate change, such as precipitation patterns and snowfall levels.

- It is possible to expand the risk analysis to deep analyses of the risks of renewable energy with wider expert views, to focus on future working areas and do more multidisciplinary research.

- Experimentation in renewable energy and more testing of renewable energy types, mainly seaside renewable energy solutions, can use climate change effects to their advantage. Including sediment heat and energy production in different water systems or several years of collected data will provide sophisticated findings.

- Further study can be directed towards the development of a sophisticated framework chart and other theoretical calculations that focus attention on the effects of land uplift. Further theoretical calculations to forecast far-future changes in land uplift are essential for comparison with this study's results and to confirm changes at sites elsewhere in the world.

- A deeper and more focused study must be conducted to identify the expected future patterns of the Baltic Sea Gulf-Stream effects.

- In addition, a case study in flooding in other parts of the world is a further future study area.

References

Aittomäki, A. (2001). Lämpöpumpplämmitys [only in Finnish]. Somen lämpöpumppuyhdistus SULPU ry. Finland: Tampere.

Araújo, M. B.; Alagador, Diogo; Cabeza, Mar; Nogués-Bravo, David and Thuiller, Wilfried (2011). Climate change threatens European conservation areas. *Ecology Letters* (2011) 14: 484–492 pp. [Cited 3 Mar. 2020]. Available from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3116148/.

Armitage, P. and Blackburn, J. (2010). Historical Land use and faunal community - Historic land use and the influence of catchment characteristics of faunal communities of small streams, Dorset, UK. *Freshwater Forum* 28 (2010), 5-25 pp. Dorset, UK: Center of Ecology, Hydrology, and Freshwater Biological Association.

Arola, T. (2015). *Groundwater as an Energy Resource in Finland.* Dissertation. Helsinki, Finland: University of Helsinki, Department of Geosciences and Geography. ISBN: 978-951-51-1343-6 (pbk.) and 978-951-51-1344-3 (PDF).

Arrhenius, Svante (1896). On the influence of carbonic acid in the air upon the temperature of the ground. *Philosophical Magazine and Journal of Science*, Series 5, Volume 4, April 1986, 237-276 pp.

Aslani, A (2014). *Evaluation of Renewable Energy Development in Power Generation.* Dissertation. Vaasa, Finland: University of Vaasa. ACTA WASAENSIA 300.

Aslani, A., Helo, P., Feng, B., Antila, E., and Hiltunen, E. (2013 a). Renewable energy supply chain in Ostrobothnia region and Vaasa city - Innovative framework. *Elsevier journal: Renewable and sustainable energy reviews* 23 (2013), 405-411 pp. [Cited 14 June 2017]. Available from https://doi.org/10.1016/j.rser.2013.03.012.

Aslani, A., Naaranoja, M. and Wong, K.-F. V. (2013 b). Strategic analysis of diffusion of renewable energy in the Nordic countries. *Elsevier journal: Renewable and sustainable energy reviews* 22 (2013), 497-505 pp. [Cited 15 June 2017]. Available from https://doi.org/10.1016/j.rser.2013.01.060.

Aslani, A., and Wong, K.-F. V. (2013 c). Analysis of renewable energy development to power generation in the United States. *Elsevier journal: Renewable energy* 63 (2014), 153-161 pp.

Banks, D. (2008). *An Introduction to Thermogeology - Ground Source Heating and Cooling*. Blackwell Publishing Ltd. ISBN: 978-1-4051-7061-1 (hardback: alk. Paper).

Banks, D. (2012). *An Introduction to Thermogeology – Ground Source Heating and Cooling*. 2nd edition. Wiley-Blackwell Publishing Ltd. ISBN: 978-0-470-67034-7 (hardback: alk. Paper).

Belouafa, S. et al. (2016). Statistical tools and approaches to validate analytical methods: methodology and practical examples. *International Journal of* *methodology and quality Engineering*, 8, 9 (2017). [Cited 10 May 2021]. Available from http://dx.doi.org/10.1051/ijmqe/2016030.

Bernhoff, H.; Sjöstedt, E. and Leijon M. (2005). Wave energy resources in sheltered sea areas - A case study of the Baltic Sea. *Renewable Energy 31(2006),* 2164-2170 pp. [Cited 21 March, 2018]. Uppsala, Sweden: Uppsala University. Available from http://dx.doi.org/10.1016/j.renene.2005.10.016.

Bill, N. S.; Mix, H. T.; Clark, P. U.; Reilly S. P.; and Jensen, B. J.L. (2018). A stable isotope record of late Cenozoic surface uplift of southern Alaska. Earth *and Planetary Science Letters* 482 (2018) 300 – 311 pp. [Cited 24 Jan. 2018]. Available from https://doi.org/10.1016/j.epsl.2017.11.029.

Borghesi, A. and Gaudenzi, B. (2013). *Risk Management: How to Assess, Transfer and Communicate Critical Risk.* Springer-Verlag Italia. ISBN: 978-88-470-2531-8 (eBook).

Breilin, Olli et al. (2004). The Geology of the Kvarken Archipelago - report is an appendix (appendix 1) to the application for nomination of the Kvarken Archipelago to the World Heritage list (Ollqvist & Rinkineva-Kantola 2004). Geological Survey of Finland, 2004, 47 pp. [Cited 08 June 2021]. Available from https://tupa.gtk.fi/julkaisu/erikoisjulkaisu/ej_044.pdf.

Brinberg, D. and McGrath, J. E. (1985). *Validity and the Research Process*. SAGE Publications, Inc. ISBN: 0-8039-2302-1.

Caesar, L. et al. (2018). Observed fingerprint of a weakening Atlantic Ocean overturning circulation. *Nature* 556, pages191–196(2018). [Cited 08 March 2021]. Available from https://doi.org/10.1038/s41586-018-0006-5.

Clason, C. C., S. L. Greenwood, N. Selmes, J. M. Lea, S. S. R. Jamieson, F. M. Nick, and P. Holmlund (2016). Controls on the early Holocene collapse of the Bothnian Sea Ice Stream. *J. Geophys. Res. Earth Surf.* 121, pp. 2494–2513. [Cited 21 May 2020]. Available from https://doi.org/10.1002/2016JF004050.

Climate institute (2010). *Oceans and Sea Level Rise*. Climate Institute.

Collins et al. (2013). *IPCC 2013 (Chapter 12) – Long-term Climate Change: Projections, Commitments and Irreversibility*. pp. 1029 – 1136. Cambridge, United Kingdom and New York, USA: Cambridge University Press.

Cook, S. L. S. (2006). Explaining Burnout: A Mixed Method Investigation of Information Technology Workers. Dissertation. Capella University.

Creswell, John W.; Clark, Vick L. Plano (2007). *Designing and Conducting Mixed Method Research; Chapter 7 -: Choosing a Mixed Method Design*. Thousand Oaks (CA): SAGE cop. 2007. ISBN: 978-1-4129-2792-5.

Creswell, John W.; Clark, Vick L. Plano (2011). *Designing and Conducting Mixed Method Research*. Second Edition. Los Angeles (Calif): SAGE cop. 2011. ISBN: 978-1-4129-7517-9.

Çuhac, Caner; Mäkiranta, Anne; Välisuo, Petri; Hiltunen, Erkki; Elmusrati, Mohammed. (2020). Temperature measurements on a solar and low enthalpy geothermal open-air asphalt surface platform in a cold climate region. *Energies*, 2020, 13, 979. [Cited 19 Nov. 2020]. Available from https://doi.org/10.3390/en13040979.

Dasgupta, Susmita and Meisner, Craig (2009). *Climate Change and Sea Level Rise: A Review of the Scientific Evidence*. Environment department papers, Climate Change Serious, 118 pp. Washington, U.S.A.: The International Bank for Reconstruction and Development/THE WORLD BANK.

Dirks, James A. et al. (2014). Impacts of climate change on energy consumption and peak demand in buildings: A detailed regional approach. *The Elsevier Journal: Energy*, Vol. 79 (2015), 20-32 pp. [Cited 8 June, 2017]. Available from https://doi.org/10.1016/j.energy.2014.08.081.

Drucker-Godard, C.; Ehlinger, S. & Grenier, C. (2011). *Validity and Reliability – In: Doing Management Research*. (Book Chapter). London, UK: SAGE Publication Ltd. pp. 196 – 220. [Cited 17, May 2021]. Available from https://dx.doi.org/10.4135/9781849208970.

Dytham, Calvin (2011). *Choosing and Using Statistics - A Biologist's Guide*. Third Edition. ISBN: 978-1-4443-2843-1 (ePDF).

EEA report (2018). *European Environment Agency – Renewable Energy in Europe -2018- Recent Growth and Knock-on Effects*. Luxembourg: Publications Office of the European Union, 2018. ISBN: 978-92-8498-0442.

Ekman, M. (1995). Postglacial uplift of the Åland Islands, and the world's oldest preserved sea level gauge. *Small publications in Historical Geophysics,* No.1, pp. 1-15. Åland Islands: Summer Institute for Historical Geophysics.

Ekman, M. (1996). A consistent map of the postglacial uplift of Fennoscandia. *Terra Nova*, vol. 8, no. 2, pp. 158-165. [Cited 14 Sept. 2018]. Available from https://doi.org/10.1111/j.1365-3121.1996.tb00739.x.

Ekman, M. and Mäkinen, J. (1996). Recent postglacial rebound, gravity change and mantle flow in Fennoscandia. *Geophys. J. Int.* (1996) vol. 126, 229-234 pp. [Cited 8 Sept. 2020]. Available from https://doi.org/10.1111/j.1365-246X.1996.tb05281.x.

Elgin, Dallas J. (2014). Examining the Role of Resources, Beliefs, and Behavior in the Policy Process: A Study of Colorado Climate and Energy Politics and Policy. Dissertation. USA: University of Colorado.

Energy and climate (2014). *Energy and Climate Roadmap 2050: Report of the Parliamentary Committee on Energy and Climate Issues on 16 October 2014*. Finland's Ministry of Employment and Economy Publication. Energy and the Climate 50/2014. ISBN: 978-952-227-906-4 (Web publication).

Environment.fi (2019). The Bay of Bothnia [online]. [Cited on 21 March 2019]. Available from World https://www.ymparisto.fi/en-

US/VELMU/VELMU_research_projects/FINMARINET/Target_areas/Bay_of_Bothnia.

EURACHEM-FINLAND (1996). Quality assurance of analytical and clinical chemistry glossary.

Fan, M. and Shibata, H. (2015). Simulation of watershed hydrology and stream water quality under land use and climate change scenarios in Teshio River watershed, norther Japan. *Elsevier journal: Ecological Indicators 250* (2015), 79-89 pp. [Cited 09 Aug. 2019]. Available from http://dx.doi.org/10.1016/j.ecolind.2014.11.003.

Final Report (2011). The Project 'Drop in Sea': The Equity-Sufficient Integrated Hybrid-Energy Solutions and a Meeting- Concept Research and Development Program. Vaasa, Finland: University of Vaasa. Project number: 123116, J. No 398/3560-2011.

GeoPipe (2016). GePipe company official web page [online]. [Cited on 21 March 2018]. Available from https://www.geopipe.fi/en-GB.

Girgibo, N. (2021). *The Effect of Climate Change on Water and Environment Resources in Kvarken Archipelago Area.* University of Vaasa Reports 20. 90 pp. 2016 – 2021. Vaasa, Finland: University of Vaasa, Tritonia, library. [Cited on 11 Feb. 2021]. Available from http://urn.fi/URN:ISBN:978-952-476-941-9.

Girgibo, Nebiyu and Mäkiranta, Anne. (2021). Sediment Heat Energy Production Expected to Use the Climate Change Effect to its Advantage. *Proceedings of the Conference on Sustainable Development of Energy, Water and Environment Systems*, Dubrovnik, 10.10.-15.10.2021, SDEWES2021.0946. ISSN: 1847-7186, ISSN (online): 1847-7178. pp. 590.

Girgibo, Nebiyu. (2022). *Identifications of renewable energy risks and risk management review.* University of Vaasa Reports 36. 46 pp. Vaasa, Finland: University of Vaasa, Tritonia, library. [Cited on 02 Jan. 2023]. Available from https://urn.fi/URN:ISBN:978-952-395-056-6.

Girgibo, Nebiyu; Lü, Xiaoshu; Hiltunen, Erkki; Peura, Pekka; Yang, Tong; and Dai, Zhenxue (2022). A conceptual framework for the future of sea-level rise and land uplift changes in the Vaasa region of Finland [Published]. *SCIREA Journal of Geosciences*. Vol. 6, No. 1, 2022, pp. 23 - 57. [Cited on 12 June 2023]. Available from https://doi.org/10.54647/geosciences17154, https://eprints.mdx.ac.uk/id/eprint/34968, https://research.aalto.fi/files/83599904/17154.pdf.

Girgibo, Nebiyu; Lü, Xiaoshu; and Yao, Zhitong (2023). The potential of using groundwater as a heating/cooling energy source in the Vaasa city region of Finland. *EWRA: Water Utility Journal*. Issue 30 – 31 (2022). [Cited on 28 Mar. 2023]. Available from http://www.ewra.net/wuj/issue_30-31.htm.

Girgibo, N. et al. Case study on flooding in world severely affected places: USA (Miami, Florida) and Bangladesh. [Forthcoming].

Girgibo, N. et al. Causes and effects of climate change literature review. [Forthcoming].

Girgibo, N. et al. Land uplift freamworks chart development theortical background. [Forthcoming].

Girgibo, N. et al. Theoretical background for Finland, Kvarken Archiplageo area water quality analysis: a systematic literature review. [Forthcoming].

Girgibo, N.; Taskinen, J. and Choo, J. M. Age-, size- and sex-specific variation of morphology and biomass of the freshwater mussel Anadonta anatina (Bivalvia). [Forthcoming].

Google.com: dictionary (2017 – 2023). Used search term [Define: search term], [Online]. [Cited throughout the dissertation]. Available from www.google.com.

Grant, M. A. and Bixley, P. F. (2011). *Geothermal Reservior Engineering: Second edition*. Academic Press: Elsevier Inc. ISBN: 978-0-12-383880-3.

Greenwood, S. L., Clason, C. C., Nyberg, J., Jakobsson, M. & Holmlund, P. (2017). The Bothnian Sea ice stream - early Holocene retreat dynamics of the south-central Fennoscandian Ice Sheet. *Boreas*, Vol. 46, pp. 346–362. [Cited 21 July. 2020]. Available from https://doi.org/10.1111/bor.12217>. ISSN 0300-9483.

Hannah, L. (2011). *Climate Change Biology*. Burlington, USA: Elsevier Ltd. 402 pp. ISBN: 978-0-12-374182-0.

Harrison, Roger (1972). *Statistics and Reliability: Technology Foundation Course Unit 10*. The open university press, T100 10. SBN: 335 02509 9.

Heffron, R. J. (2016). The global future of energy law. *I. E. L. R., Issue 7 (2016) Thomson Reuters (Professional) UK Limited and Contributors*. [Cited 17 Aug. 2021]. Available from https://www.researchgate.net/publication/311913288.

Heffron, R. J.; Hussein, H. I.; Yang, C-H.; and Sun, N. (2017). The global future of energy law: 2017 review. *International Energy Law Review (I.E.L.R), 2017, 8,* 291-302.

Heinsalu, A. (2001). *Diatom Stratigraphy and the Palaeoenvironment of the Yoldia Sea in the Gulf of Finland, Baltic Sea*. Turku, Finland: Department of Geology, University of Turku. ISBN: 951-29-1895-1.

Helsel, D. R. and Hirsch, R. M. (2002). *Statistical Methods in Water Resources*. USA: Technical of Water-Resources Investigation of the United States Geological Survey – 04-A3, Hydrologic Analysis and Interpretation. [Cited 10 Sep. 2020]. Available from http://water.usgs.gov/pubs/twri/twri4a3/.

Hietikko-Hautala, Tiina (2012). *The Kvarken Archipelago World Heritage Sites: Echoes of the Ice Age*. Vaasa, Finland: Central for Economic Development Transport and the Environment for South Ostrobothnia (ELY-Keskus). pp. 159. ISBN: 978-952-257-095-6.

Hiltunen, E.; Linko, L.; Hemminki, S.; Hägg, M.; Järvenpää, E.; Saarinen, P.; Simonen, S.; and Kärhä, P. (2011). *Laadukkaan mittaamisen perusteet (basics of high-quality measurements).* Publication J4/2011. MIKES (Mittatekniikan keskus) and Metrologian Neuvottelukunta. Print at: Multiprint Oy, Vantaa, Espoo, 2011. ISBN: 978-952-5610-75-8.

Hiltunen, E., Martinkauppi, J. B., Mäkiranta, A., Rinta-Luoma, J. and Syrjälä, T. (2015a). Seasonal temperature variation in heat collection liquid used in renewable, carbon-free heat production from urban and rural water areas. *Agronomy Research*, vol. 13 (2), 485-493 pp.

Hiltunen, E., Martinkauppi J.B., Zhu, L., Mäkiranta A., Lieskoski, M. and Rinta-Luoma, J. (2015b). Renewable, carbon-free heat production from urban and rural water areas. *Science direct: Journal of cleaner production,* vol.153 (2017) 379 – 404 pp. [Cited 25 Aug. 2020]. Available from https://doi.org/10.1016/j.jclepro.2015.10.039.

Hiltunen, E. (2016). *Report on - Maailmanperintöportti / Natura 2000.* 13 pp. Unpublished. Vaasa, Finland: University of Vaasa, Technical Faculty, Electrical Engineering and Energy Technology Department.

Hiltunen, E.; Girgibo, N.; Shandiz. M. H., Martinkauppi, B.; Mäkiranta, A.; Nieminen, J. (2017). *Report on - Maailmanperintöportti Merten Talo: Esityksiä energiaratkaisuiksi (27.04.2017).* 17 pp. Unpublished. Vaasa, Finland: University of Vaasa, Technical Faculty, Electrical Engineering and Energy Technology Department.

Hirsch, R. M.; Slack, J. R. and Smith, R. A. (1982). Techniques of trend analysis for monthly water quality data. *Water Resources Research,* Vol. 18. No. 1. 107-121 pp. (February 1982).

Holma, A., et al. (2018). Environmental impacts and risks of the national renewable energy targets – A review and a qualitative case study from Finland. *Elsevier: Renewable and Sustainable Energy Reviews* 82 (2018) 1433 – 1441 pp. [Cited 15 March 2019]. Available from
http://dx.doi.org/10.1016/j.rser.2017.05.146.

Houshialsadat, S. M. (2013). The Role of the Persian Gulf's Natural Gas Reserves for the European Union's Energy Security. Dissertation. Durham: Durham University.

Huck, Schuyler W. (2012). *Reading Statistics and Research: 6th Edition*. Boston, USA: Pearson Education, Inc. ISBN-10: 0-13-265909-3 and ISBN-13: 978-0-13-265909-3.

Huggins, Robert A. (2016). *Energy Storage - Fundamentals, Materials and Applications*. AG, Switzerland: Springer International Publishing. 509 pp. ISBN: 978-3-319-21238-8 and ISBN (eBook): 978-3-319-21239-5.

Huttula, T. (2012). Physical changes of water systems - ice formation in lakes. [Course material]. Lecture given in Jyväskylä University at Department of biological and environmental science, Jyväskylä, Finland.

Huttunen, I., et al. (2015). Effects of climate change and agricultural adaptation on nutrient loading from Finnish catchments to the Baltic Sea. *Elsevier: Science of the Total Environment* 529 (2015) 168-181 pp. [Cited 18 June 2018]. Available from http://dx.doi.org/10.1016/j.scitotenv.2015.05.055.

IEA (2020). *Report on – Energy Technology Perspectives 2020*. International Energy Agency (2020).

IPCC (2007). *Climate Change 2007- The Physical Science Basis*. New York, USA: Cambridge University Press. 996 pp. ISBN: 978-0-521-88009-1.

IPCC (2013). Climate Change 2013 - The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. New York, USA: Cambridge University Press, Cambridge. 1535 pp. ISBN: 978-1-107-05799-9.

IPCC (2014). Climate Change 2014 - Synthesis Report, c/o World Metrological Organization (WMO). Geneva, Switzerland. 151 pp. ISBN: 978-92-9169-143-2.

IPCC (2019). *Special Report on the Ocean and Cryosphere in a Changing Climate* [Eds.: H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem, J. Petzold, B. Rama and N. Weyer].

IPCC (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group - I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR6 WGI).

ISO 31000 (2015). *ISO 31000 - Risk Management - A Practical Guide for SMEs*. 21 pp. Geneva, Switzerland: ISO Copyright Office. ISBN: 978-92-67-10645-8.

James, E. A. and Slater, T. H. (2014). *Writing Your Doctoral Dissertation or Thesis Faster*. California, USA: SAGE publications, Inc. ISBN: 978-1-4522-7415-7.

Kanoshina, I., Lips, U. and Leppänen, J.-M. (2003). The influence of weather conditions (temperature and wind) on cyanobacterial bloom development in the Gulf of Finland Baltic Sea. *Harmful Algae* 2(2003), 29-41 pp.

Kanoshina, I., Lips, U. and Leppänen, J.-M. (2003). The influence of weather conditions (temperature and wind) on cyanobacterial bloom development in the Gulf of Finland Baltic Sea. *Harmful Algae* 2 (2003), 29-41 pp.

Kattilakoski, Iikka-Matti (2017). *Bi-Directional Distributed Thermal Response Test (TRT)*. Master's thesis. Vaasa, Finland: University of Vaasa, Degree Programme in Electrical and Energy Engineering, Energy Technology.

Kauppila, Pirkko (2007). Phytoplankton quantity as an indicator of eutrophication in Finnish coastal waters - Application within the Water Framework Directive. Dissertation. Helsinki, Finland: Finnish Environmental Institute; Monographs of the Boreal Environment Research 31. ISBN: 978-952-11-2898-1.

Kirk, J. and Miller, M. L. (1986). *Reliability and validity in qualitative research.* Qualitative research methods series 1. SAGE Publications Inc. 87 pp. ISBN: 0-8039-2560-3.

Korhonen, J. (2019). *Long-term changes and variability of the winter and spring season hydrological regime in Finland.* Dissertation. Helsinki, Finland: University of Helsinki. Report series in Geophysics No. 79. pp. 82.

Koivisto, R., Mäkiranta, A. & Hiltunen, E. (2019). Reliable renewable hybrid energy solutions. In: Digital proceedings: Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES): 14th Conference on sustainable development of energy, water and environment systems: October 1-6, 2019 Dubrovnik, Croatia, (pp. 1-12).

Kruger, P. (2006). *Alternative Energy Resources - The Quest for Sustainable Energy.* Published by John Wiley & Sons, Inc., Hoboken, New Jersey. 248 pp. ISBN: 10:0-471-77208-9.

Kupiainen, K. J. et al. (2019). Climate impact of Finnish air pollutants and greenhouse gases using multiple emission metrics. *Atmos. Chem. Phys.*, 19, 7743–7757, 2019. [Cited 30 Oct. 2020]. Available from https://doi.org/10.5194/acp-19-7743-2019.

Kvarken Archipelago and Merten Talo (2016). The web page of the Kvarken Archipelago and web page of Merten Talo [online]. [Cited 26 Jun. 2017]. Available from http://www.kvarkenworldheritage.fi/visit-kvarken/; http://mertentalo.fi/start/ and https://highcoastkvarken.org/fi/etusivu/.

Kyoto protocol (1998). Kyoto Protocol to the United Nations Framework Convention on Climate Change. United Nation.

Kääriäinen, E. (1953). On the recent uplift of the earth's crust in Finland. *Fennia* 77, N:o 2. Helsinki: printed by Tilgmann.

Kääriäinen, E. (1966). *The Second Levelling of Finland in 1935-1955.* Helsinki: Valtioneuvoston kirapaino.

Lowrie, William. (2007). *Fundamentals of Geophysics.* Second edition. 393 pp. Cambridge, UK: Cambridge University Press. ISBN-13 978-0-511-35447-2.

Löfman, J. (1999). *Site Scale Groundwater Flow in Hästholmen.* Helsinki, Finland: Posiva Oy. Posiva, 99–12 pp. ISBN: 951-652-067-7.

Martinkauppi, J. B.; Mäkiranta, A.; Kiijärvi, J. and Hiltunen, E. (2015). Thermal behavior of an asphalt pavement in the laboratory and in the parking lot. *Hindawi Publishing Corporation. The Scientific World Journal.* Volume 2015, Article ID 540934, 7 pages. [Cited 17 Aug. 2020]. Available from http://dx.doi.org/10.1155/2015/540934.

Martinkauppi, Birgitta; Mäkiranta, Anne; Hiltunen, Erkki. (2016). PCA analysis of distributed temperature sensing data from an asphalt field. *In: 5th International*

Conference on Renewable Energy Research and Applications (ICRERA), 20 -23, nov. 2016, Birmingham, UK.

Martinkauppi, J.B., Syrjälä, T., Mäkiranta, A., & Hiltunen, E., (2020). A preliminary test for using a borehole as cool storage. *In: 14th Conference on sustainable development of energy, water and environment systems: October 1-6, 2019 Dubrovnik, Croatia.* [Cited 26 Nov. 2020]. Available from https://vb.ktk.lt/object/elaba:48702254/48702254.pdf.

Mcnamara, Kim H. (2008). Fostering Sustainability in Higher Education: A Mixed-methods Study of Transformative Leadership and Change. Dissertation. Antioch University.

Meriläinen, J.J. (1988). Meiobenthos in relation to macrobenthic communities in a low saline, partly acidified estuary, Bothnian Bay, Finland. *Annales Zoologici Fennici,* Vol. 25, No. 4 (1988), pp. 277-292.

Meyers, L. S., Gamst, G. and Guarino, A. J. (2009). *Data Analysis Using SAS Enterprise Guide.* Cambridge, UK: Cambridge University Press. ISBN-13: 978-0-511-60184-2 (ebook – Adobe Reader).

Misra, K.B. (2008) Risk analysis and management - An introduction. *In: Misra K.B. (eds) Handbook of Performability Engineering.* 667 – 681 pp. Springer, London. [Cited 29 Mar. 2020]. Available from https://doi.org/10.1007/978-1-84800-131-2_41.

Mngumi, Julius W. (2016). Perception of Climate Change, Environmental Variability and the Role of Agricultural Adaption Strategies by Small-scale Farms in Africa - The Case of Mwanga District in Northern Tanzania. Dissertation. Scotland, UK: University of Glasgow.

Mousdale, D. M. (2010). *Introduction to Biofuels.* pp. 429. Florida, U.S.A: CRC Press and Taylor & Francis Group. ISBN: 978-1-4398-1207-5 (Hardback).

Mäkinen, J. and Saaranen, V. (1998). Determination of post-glacial uplift from the three precise levellings in Finland. *Spring-Verlag: Journal of Geodesy* (1998), Vol 72, 516-529 pp.

Mäkiranta, Anne (2013). *Distributed Temperature Sensing Method – usability in Asphalt and Sediment Heat Measurement.* Master's thesis. Vaasa, Finland: University of Vaasa, Degree Programme in Electrical and Energy Engineering, Energy Technology.

Mäkiranta, A., Martinkauppi, J. B., and Hiltunen, E. (2016). Correlation between temperature of air, heat carrier liquid and seabed sediment in renewable low energy network. *Agronomy Research* vol. 14 (S1), 1191-1199 pp.

Mäkiranta, A., Martinkauppi, J. B., and Hiltunen, E. (2017). Seabed sediment – a natural seasonal heat storage feasibility study. *Agronomy Research* vol. 15 (S1), 1101-1106 pp.

Mäkiranta, A., Martinkauppi, B., Hiltunen, E., & Lieskoski, M. (2018). Seabed sediment as an annually renewable heat source. *Applied Sciences*, Vol. 8(2), 290. [Cited 20 Aug. 2020]. Available from https://doi.org/10.3390/app8020290.

Mäkiranta, A. and Hiltunen, E. (2019). Utilizing asphalt heat energy in Finnish climate conditions. *Energies*, 2019, vol. 12, 2101. [Cited 17 Aug. 2020]. Available from https://doi.org/10.3390/en12112101.

Mäkiranta, Anne (2020). *Renewable Thermal Energy Sources: Sediment and Asphalt Energy Applications in an Urban Northern Environment*. Doctoral Dissertation. Vaasa, Finland: University of Vaasa, School of Technology and Innovations, Department of Electrical Engineering and Energy Technology, Energy Technology. Acta Wasaensia 454. [Cited 04 March 2021], Available from http://urn.fi/URN:ISBN:978-952-476-935-8.

Nakomcic-Smaagdakis, B. B. and Dragutionovic, N. G. (2016). Hybrid renewable energy systems application for electricity and heat supply for residential building. *University of Novi Sad: Siberia*. [Cited 21 March 2020]. Available from https://www.researchgate.net/publication/283194224.

National Research Council (2010). *The Power of Renewables: Opportunities and Challenges for China and the United States.* Washington, DC: The National. Academies Press. [Cited 02 August 2021]. Available from https://doi.org/10.17226/12987.

Nordman, M.; Peltola, A.; Bilker-Koivula, M.; and Lahtinen, S. (2020). Past and future sea level changes and land uplift in the Baltic Sea seen by geodetic observations. *International Association of Geodesy Symposia*. Springer, Berlin, Heidelberg. [Cited 22 Dec. 2020]. Available from https://doi.org/10.1007/1345_2020_124.

NSL-National land survey of Finland (2020). National land survey of Finland: Land Uplift, [Online]. [Cited 21 July 2020]. Available from https://www.maanmittauslaitos.fi/en/research/interesting-topics/land-uplift.

O'Cathain, A.; Murphy, E. and Nicholl, J. (2007). Why, and how, mixed methods research is undertaken in health service research in England: Mixed method study. *Research article: BMC Health Service Research* 2007, 7:85, 11 pp. England: BioMed Central Ltd. [Cited 9 July. 2017]. Available from http://www.biomedcentral.com/1472-6963/7/85.

Okko, M. (1967). The relation between raised shores and present land uplift in Finland during the Past 8000 Years. *Annales Academie Seientiarum Fennicae, Series A, III. Geologica- Geographica* 93. Helsinki: Geological Survey of Finland.

Olabi, A.G. and Abdelkareem, M. A. (2022) Renewable energy and climate change. *Renewable and Sustainable Energy Reviews* 158 (2022) 112111. [Cited 10 May 2022] Available from https://doi.org/10.1016/j.rser.2022.112111.

O'Sullivan, K. C. (2012). Power Control: A Multiphase Mixed Methods Investigation of Prepayment Metering and Fuel Poverty in New Zealand. Dissertation. New Zealand: University of Otago.

Pakkala, T. A. (2023). *Climate change effect on freeze-thaw load in Finland*. Tampere Univeristy, Tampere, Finalnd. [Cited 27 October 2023]. Available from https://prod-aaudxp-cms-001-app.azurewebsites.net/media/qvjfrn35/303_nsb2023_scientificpaper_camerareadypaper_color.pdf.

Paris Agreement (2015). The Paris agreement summary: climate focus client brief on the Paris agreement III. *Climate Focus*, (28 Dec. 2015), 6 pp.

Pastuszak, M. et al. (2018). Reduction of nutrient emission from Polish territory to the Baltic Sea (1988-2014) confronted with real environmental needs and international requirements. *Oceanological and Hydro biological Studies*. Vol. 47: Issue 2. [Cited 8 Aug. 2020]. Available from https://doi.org/10.1515/ohs-2018-0015.

Patterson B. J. (2013). A Mixed Methods Investigation of Leadership and Performance in Practice-based Research Networks. Dissertation. Iowa city: University of Iowa.

Paudel, I., et al. (2018). Water quality changes seasonal variations in root respiration, xylem CO_2, and sap pH in citrus orchards. *Elsevier: Agricultural Water Management* 197 (2018) 147 – 157. [Cited 21 Aug. 2018]. Available from https://doi.org/10.1016/j.agwat.2017.11.007.

Pawlak, J.F. and Leppänen, J.-M. (2007). Climate change in Baltic Sea – HELCOM thematic assessment 2007. *Baltic Sea Environmental Proceedings No. 111*. Helsinki Commission, Baltic Marine Environment Commission. ISSN 0357-2994.

Pearl, Judea (2009). *Causality - Model, Reasoning and Influence*. New York, USA: Cambridge University Press. ISBN: 978-0-521-89560-6.

Pearl, J. and Mackenzie, D. (2018). *The Book of Why: The New Science of Cause and Effect*. New York, USA: Hachette Book Group. ISBN: 978-0-465-09760-9.

Peura, P. (1999). From Ideology to Company Practice – The Origin of Operational Patterns through Social Selection. In: Werther, W. Jr., Takala, J. & Sumanth, D.J. (eds.), *Productivity & Quality Management Frontiers – VIII*. Bradford: MCB University Press. pp. 386–403.

Peura, P. (2013). *From unlimited growth to sustainable energy: The origin of operational patters by means of social selection*. Dissertation. Vaasa, Finland: University of Vaasa. ACTA WASAENSIA 279. Industrial management 28. pp. 188.

Peura, P. (2013). From Malthus to Sustainable Energy – Theoretical orientations to reforming the energy sector. *Renewable and Sustainable Energy Reviews* 19 (C) 309–327. [Cited 08 April 2021]. Available from http://dx.doi.org/10.1016/j.rser.2012.11.025.

Peura, P., Inkinen, M. & Alasaarela, E. (1994). The three stages of automatic monitoring of waterbodies. *Aqua Fennica* 24, 1: 69-82 pp.

Peura, P. and Hyttinen, T. (2011). The potential and economics of bioenergy in Finland. *Journal of Cleaner Production* 19 (9–10) 927–945. [Cited 27 May 2021]. Available from http://dx.doi.org/10.1016/j.jclepro.2011.02.009.

Peura, P., Kuittinen, H., Knuckey, L., Goodall, L. & Dinya, L. (2014). Implementing Sustainable Energy – Four case studies. *International Journal of Sustainable Economy (IJSE),* Vol. 6, No. 1, 2014. [Cited 10 June 2021]. Available from http://dx.doi.org/10.1504/IJSE.2014.058516.

Peura, p. & Sevola, P. (1992). Acidification mosaic of small lakes. A study on 81 lakes in the Kvarken, Gulf of Bothnia (Finland and Sweden). *Aqua Fennica* 22,2: 153-171 pp.

Peura, P.; Voutilainen, O., and Kantola, J. (2022). From garbage to product and service systems: A longitudinal Finnish case study of waste management evolution. *Waste Management*, Volume 140, pp. 143-153, [Cited 26 April 2022]. Available from: https://doi.org/10.1016/j.wasman.2022.01.025.

Phdungsilp A. (2015). Modeling Urban Energy Flows at Macro and District Levels-Towards a Sustainable Urban Metabolism. Dissertation. Stockholm, Sweden: KTH Royal Institute of Technology.

Pirilä, P. (2000). Climate change - Socioeconomic Dimensions and Consequences of Mitigation Measures. Helsinki, Finland: EDITA Ltd. 392 pp. ISBN: 951-37-2926-5.

Poutanen, M. and Steffen, H. (2014). Land uplift at Kvarken Archiplago and High Coast UNESCO World Heritage area. *Geophysica* (2014), 50(2), 49-64 pp. Masala, Finland and Gävle, Sweden: Finnish Geodetic Institute and Lantmäteriet.

Princiotta, F. (2011). *Global Climate Change - the Technology Challenge*. Springer Science + Business Media. 420 pp. ISBN: 978-90-481-3152-5.

Påsse, T. and Andersson, L. (2005). Shore-level displacement in Fennoscandia calculated from empirical data. *Gff*, vol. 127, no. 4, pp. 253-268. [Cited 13 Nov. 2018]. Available from https://doi.org/10.1080/11035890501274253.

Rahmstorf, S. (2007). A semi-empirical approach to projecting future sea-level rise. *Science (ww.siecnemag.org)* 19 January 2007 Vol. 315, 368-370 pp.

Rankinen, K., Keinänen, H. and Cano Bernal, J.E. (2016). Influence of climate and land use changes on nutrient fluxes from Finnish rivers to the Baltic Sea. *Agriculture, Ecosystem and Environment: Science Direct* 216 (2016) 100 - 115. Elsevier publications. [Cited 20 Feb. 2019]. Available from http://dx.doi.org/10.1016/j.agee.2015.09.010.

Räike, Antti; Taskinen, Antti and Knuuttila, Seppo (2020). Nutrient from Finnish rivers into the Baltic Sea has not decreased despite water protection measures. *The royal Swedish academy of science (KUNGL VETENSKAPS AKADEMIEN): Ambio, pp. 1-15*. Published at Springer. [Cited 18 Sept. 2019]. Available from https://doi.org/10.1007/s13280-019-01217-7.

Saranko, O. et al. (2020). Impacts of town characteristics on the changing urban climate in Vantaa. *Science of the Total Environment* 727 (2020) 138471. [Cited 27 Oct. 2020] Available from https://doi.org/10.1016/j.scitotenv.2020.138471.

SAS Institute Inc. (2014). *SAS/ETS® 13.2 User's Guide: the ARIMA Procedure*. E-book. Cary, NC: SAS Institute Inc.

Saunders, M; Lewis P. and Thornhill A. (2016). *Research Methods for Business Students*. Seventh Edition. Essex, England: Pearson Education Limited. ISBN: 978-1-292-01662-7.

Savin-Baden, M. and Major, C. H. (2013). *Qualitative Research: The Essential Guide to Theory and Practice*. USA and Canada: Routledge. 561 pp. ISBN: 978-0-415-67478-2 (pbk).

SFS GUIDE 99 (2010). *International Vocabulary of Metrology (VIM)*. Basic and general concepts and related terms.

Shrestha, S., Babel, M. S. and Pandey, V. P. (2014). *Climate Change and Water Resources*. Boca Raton, FL, USA: Taylor & Francis group, LLC. 365 pp. ISBN: 978-1-4665–9466-1.

Siegel, A. E. (1998). *Statistics and Data Analysis - An Introduction*. USA: John Wiley & Sons, Inc. 518 pp. ISBN: 0-471-87659-3.

Smith, P. N. (2002). Observations and simulations of water-sediment heat exchange in a shallow coastal lagoon. *Estuaries,* Vol. 25 No. 3, pp. 483-487 (2002). [Cited 13 Jan. 2021]. Available from https://doi.org/10.1007/BF02695989.

Sohail, H. et al. (2022). Low temperature, cold spells, and cardiorespiratory hospital admissions in Helsinki, Finland. *Air Qual Atmos Health* 16, 213–220 (2023). [Cited 27 October 2023]. Available from https://doi.org/10.1007/s11869-022-01259-z

Sokka, L. et al. (2016). Environmental impacts of the national renewable energy targets – A case study from Finland. *Renewable and Sustainable Energy Reviews* 59 (2016) 1599–1610 pp. [Cited 19 May 2021]. Available from http://dx.doi.org/10.1016/j.rser.2015.12.005.

Sukhatme, S. P. (1996). *Solar Energy - Principles of Thermal Collection and Storage*. 2nd Edition. New Delhi, India: Tata McGraw-Hill. 426 pp. ISBN: 0-07-462453-9.

Svensson, Nils-Olof (1991). Postglacial land uplift patterns of south Sweden and the Baltic Sea region. *Terra Nova*, vol. 3, no. 4, pp. 369-378. [Cited 5 July 2018]. Available from https://doi.org/10.1111/j.1365-3121.1991.tb00165.x.

SYKE (2003). *SYKE (Finnish Environmental Institute) - Water Quality of Lakes, Rivers and Sea areas in Finland in 2000 – 2003* [Online]. Syke.fi. [Cited 27 Aug. 2020]. Available from https://www.syke.fi/download/noname/%7B98588B25-E678-4DE2-8006-6CCBACC3F273%7D/30089.

Thomas, Blake H. (2016). Benefits, Barriers, and Opportunities for Renewable Energy Outreach in Extension: A Mixed-methods Needs Assessment. Thesis. Utah: Utah State University.

UNESCO (2009). *Climate Change and Water - An Overview from the World Water Development 3 - Water in a Changing World*. Report. 23 pp. Colombia, Perugia, Italy: The United Nations World Water Assessment Programme [Cited 4 April 2017]. Available from http://unesdoc.unesco.org/images/0018/001863/186318e.pdf.

UNGC-United Nation Global Compact (2009). Climate Change and the Global Water Crisis: What Businesses Need to Know and Do. Report 11 pp.

Vestøl, Olav (2006). Determination of postglacial land uplift in Fennoscandia from leveling, tide-gauges and continuous GPS stations using least squares collocation. *Springer-Verlag: J Geod* (2006) Vol. 80: 248–258 pp. [Cited 4, Aug. 2017]. Available from http://dx.doi.org/10.1007/s00190-006-0063-7.

Vestøl, Olav et al. (2019). NKG2016LU: a new land uplift model for Fennoscandia and the Baltic Region. *Springer: Journal of Geodesy* (2019) Vol 93: 1759-1779 pp. [Cited 06 Oct. 2020]. Available from https://doi.org/10.1007/s00190-019-01280-8.

Von et. al. (2011). Investments in Liberalised Electricity Markets and the Low-Carbon Energy Transition: A Mixed-method Analysis of the German Case. Dissertation. Berlin, Germany: Technical University of Berlin.

Water-Quality (2008). Water Quality: A Filed-Based Water Quality Testing Program for Middle Schools and High Schools. Manual. Boston, USA: Massachusetts Water Resources Authority.

Westerlund, A. and Tuomi, L. (2016). Vertical temperature dynamic in Northern Baltic Sea based on 3D modelling and data from shallow-water Argo flats. *Journal of Marine Systems: Science Direct* 158 (2016) 34 - 44. Elsevier publications. [Cited 26 May 2020]. Available from http://dx.doi.org/10.1016/j.jmarsys.2016.01.006.

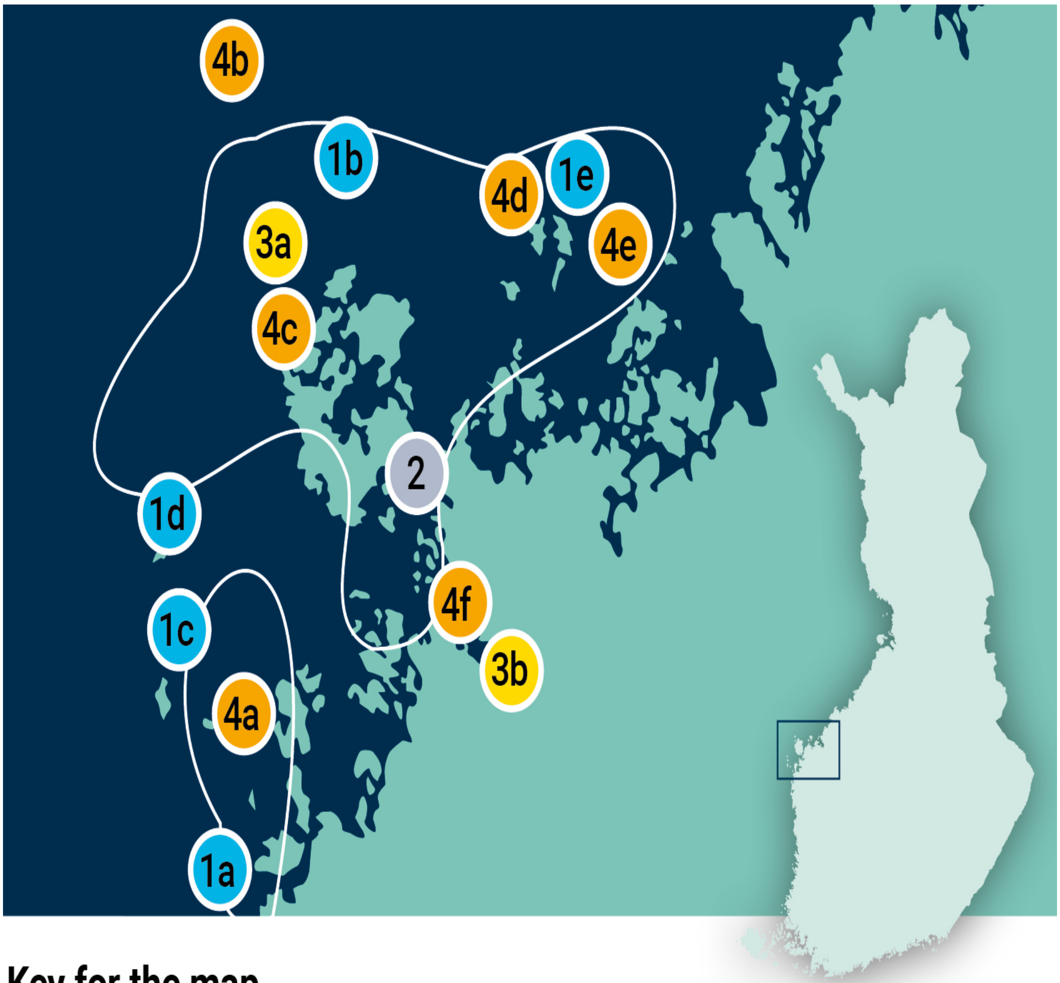
Wetzel, R. G. (2001). *Limnology- Lakes and River Ecosystems*. Third edition, 1006 pp. California, USA: Elsevier Science (USA). ISBN: 0-12-744760-1.

Ylhäisi, J. S. et al. (2010). Growing season precipitation in Finland under recent and projected climate. *Journal of Natural Hazards and Earth System Science* 10, 1563-1574, 2010. [Cited 02 Oct. 2019]. Available from https://doi.org/10.5194/nhess-10-1563-2010.

Appendices

Appendix 1

The map shows: ‘Drop in sea’ project sites, installation location (Merten Talo), weather stations and water sampling locations on map of the Kvarken Archipelago in Finland.



Key for the map

1 ‘Drop in sea’ project sites – 1a: Molpehällorna, 1b: Valsörarna, 1c: Rönnskär, 1d: Norrskär, 1e: Mickelsörana, 1*: Various farm and small houses for sale

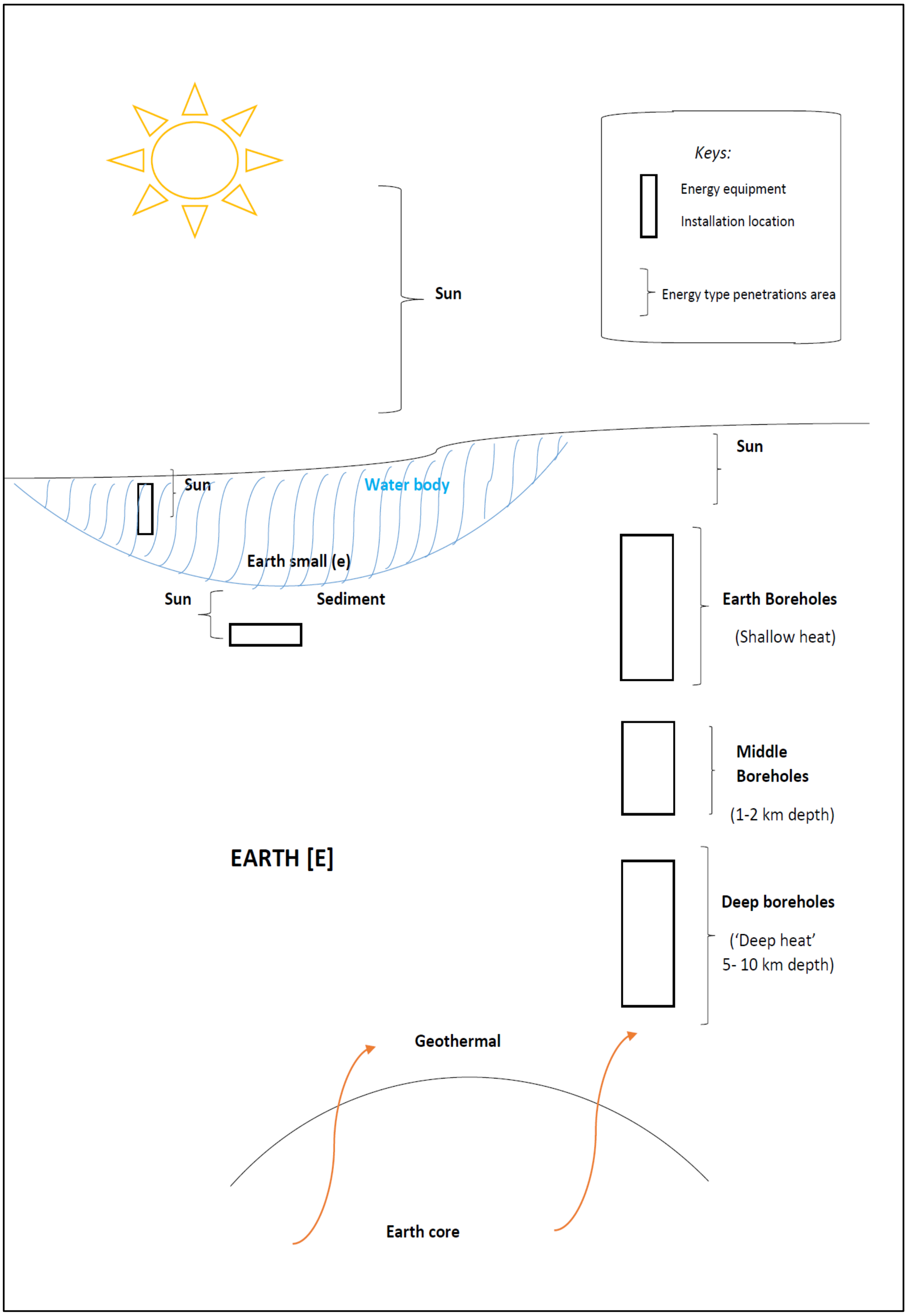
2 Merten talo (Raippaluoto installation site)

3 3a: Valassaaret and 3b: Vaasa airport weather stations

4 Water sample locations from ELY-Keskus – 4a: Vav-11, 4b: F16, 4c: Valsörgloppet, 4d: Vav-7, 4e: Vav-19 and 4f: Et. kaupunginselkä 1

Appendix 2

Schematic showing a possible geothermal-energy solution for installation near the seaside or bodies of water (e.g. near a lake or sea) (from Publication I).



Appendix 3

Table 10. This table presents a summary of the interpretations of the results of the mixed-method investigation for comparison. The table shows specific relationships and comparisons between the different publications, results, topics and research questions (RQs).

Topics → / **Methodology**	**Publication, topics of articles and RQs answered**	**Seaside renewable energy resources and sediment heat energy production**	**Air temperature change effects on water resource**	**Risks of renewable energy and from renewable energy on the environment**	**Land uplift and sea-level rise relationships**
Quantitative studies	**RQ 2 and RQ4 answered** **Publication II and Girgibo (2021)** Air temperature change effects on water quality	The water temperature increase is advantageous for coastal energy production, e.g. sediment heat energy production.	Water quality parameters are affected directly and/or indirectly. Chl-*a* and water temperatures are expected to increase in certain months.	Renewable energy causes a limited number of risks to water systems e.g., in terms of water footprint and/or causing pollution during the construction of energy solutions.	Water expansion due to water temperature increase and sea-level rise affects land uplift rise.

	RQ 1 and RQ4 answered **Publication IV** Sediment heat energy production analysis	Sediment heat energy uses climate change effects to its advantage, at least in summer.	Air temperature increases cause increased water temperatures, which is advantageous for sediment energy production in summer.	Sediment heat energy production installations affect water systems by causing point source pollution.	Land uplift causes difficulties in the installation of seaside energy solutions, e.g. water heat exchangers must be installed in a deeper location not too close to shore.
Qualitative studies	**RQ 4 answered** **Girgibo et al. (2022)** Land uplift and sea-level rise	Land uplift causes difficulty in the installation of seaside energy solutions in the islands of the Kvarken archipelago.	The main change is caused by the relationship of land uplift with sea-level rise. Climate change causes sea-level rise, whereas water expansion due to increased water temperature leads to additional sea-level rise.	Land uplift causes risks, at least in the Kvarken Archipelago, by causing islands not to be accessible by boat, since due to land uplift, underwater rocks rise to the surface.	Framework chart developed; land uplift will decline in the far future and sea-level rise will be higher than land uplift. In the near future, land uplift will continue to be higher than sea-level rise in the city of Vaasa.

	RQ 3 and RQ4 answered **Publication III and Girgibo (2022)** Risk analysis on renewable energy	Quantification of risks and evaluations show the most and the least affecting and affected renewables, including seaside renewable energy resources	Climate change causes various risks to most renewable energy resources and even conflicts between nations that share one river e.g., conflicts between Ethiopia, Egypt and Sudan due to the Nile River water level decline.	Both the risks of climate change for renewable energy (new contribution) and the risks of the use and production of renewable energy to the environment were analysed.	Land uplift causes risks to renewable energy installations and delivery to islands.
	RQ 1 and RQ4 answered **Publication I** Seaside renewable energy resources	Current and future seaside renewable energy solutions were identified. Among those, data collected about sediment heat energy production were analysed.	A water temperature rise could be advantageous to heat energy production, e.g. sediment heat energy production used water temperature rise due to climate change to its advantage, at	There are environmental risks associated with the use and production of seaside energy solutions. For instance, sediment heat energy production site causes point source pollution to	Land uplift causes risks to some seaside renewable energy solutions. For instance, if water heat exchangers are installed too close to shore, the water heat exchanger will no longer be

			least in summer.	water systems.	underwater in the far future.
	RQ 1 and RQ4 answered **Girgibo et al. (2023)** The potential of using groundwater as a heating/cooling energy source in the Vaasa City region of Finland	Groundwater utilisation (GEU) is one type of potential coastal renewable energy resource, e.g. the suggestion of GEU use in region around the city of Vaasa.	Climate change effects can affect groundwater and heat/cooling energy production, depending on how deep the groundwater is located, seasonal variations and the water flow pattern of the area.	Underground construction for energy production or other purposes causes risks to groundwater quality and quantity. Valuing groundwater is important.	Sea-level rise due to climate change can affect the water flow pattern to groundwater. This will affect heat/cooling energy production.

climate MDPI

Review

Seaside Renewable Energy Resources Literature Review

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Abstract: This review paper describes seaside renewable energy resources. The motivation and need behind this work are to give background literature on the use of climate change effects as a resource support for shallow geothermal-energy (seaside energy solutions) production. This leads to combating and mitigating climate change by using its effect to our advantage. As a part of my literature review as a report series, this report gives some background about seaside energy solutions relating to water quality and climate change. This review paper addresses all aspects of renewable energy. The methodology implemented in this review paper and other series was a systematic literature review process. After searching and collecting articles from three databases, they were evaluated by title, abstract and whole article then synthesized into the literature review. The key conclusion is that seaside renewable energy is mainly shallow geothermal-energy and most of the methods use climate change effects to their advantage such as sediment heat energy production. The main recommendation is to use the effects of climate change to combat and mitigate its causes and further consequences. The overall conclusions are built on the relationships between different aspects of the topics. The paper contributes a precise current review of renewable energy. It is the last part of a series of four review papers on climate change, land uplift, water resources, and these seaside energy solutions.

Keywords: seaside energy; renewable energy; climate change; energy storage; energy transitions

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1. Introduction

Energy is defined as the ability to do work. Moreover, "energy is the convertible currency of technology" [1]. Protecting the environment from greenhouse gas emissions caused by energy production can be achieved by replacing fossil fuel energy with renewable energy resources. A broad definition of renewable energy sources from the environmental movement that started in the 1960s includes "any energy source that is 'alternative' to 'conventional' fossil (and, for some, nuclear) fuels" [2]. Based on this book, this definition includes geothermal energy, which is not a renewable resource because it takes hundreds to thousands of years for the heat to be extracted from the geothermal deposits. Sustainable development is an important aspect of energy demand stabilization. Renewable energy resources not only help in achieving sustainability or declining emissions but also in utilizing the available energy resources in local areas. They might even be less expensive and more efficient resources for what is needed. Hybrid renewable energy systems are more cost-effective and energy-efficient over time.

Energy is essential. Without energy, the entire fabric of society as we know it would crumble with time [1]. If energy is this important and we cannot live without it, making it environmentally friendly and sustainable is essential. A well-known solution to achieve this goal is replacing our energy with renewable energy resources. Based on Dincer's [1] explanations, global warming is not the only environmental problem with energy supply and use. Other concerns include air pollution, acid precipitation, ozone depletion, forest destruction, and emissions of radioactive substances, to mention a few. As described in the climate change section of this literature review, the main cause of GHGs is fossil fuel usage.

Replacing these fossil fuel energy resources with renewable energy is necessary, there is no question about it.

Seaside energy solutions can be replaced by renewable energy by improving the diversity of usage of renewable energy in all aspects in different locations, including the city of Vaasa's renewable energy installation locations. This issue is important because the city of Vaasa's location does not seem to be addressed in comparison to the city's use of renewable energy. Even if the use of renewable energy in cities is limited and it represents much more of the population in developed nations than in undeveloped nations. Sustainable development is intimately related to renewable energy resources and utilization [1]. This means that planning and addressing sustainable development and environmental protection can be achieved by implementing renewable energy resources on a massive scale. Other types of integrated development methods are essential for improving those renewable energy resources with high operating costs [3].

Electricity, bioenergy, hydrogen and hydrogen-based fuels with net zero emissions would replace the vast majority of fossil fuels [4]. Renewable energy implementation on massive scales can be achieved over time through policy development, as seen in the EU. This issue is very important; hence, nations or people intend to use old fossil fuel energy resources because they are used to them. Research and development of renewable energy is a way to improve the resources and initiate people's use of these energy resources. People are aware of, to some extent, the research development, at least in Finland. This awareness makes our job easy because people having environmental awareness encourages them to use renewable energy more often, as noticed throughout history. At the University of Vaasa, there has been a study going on for a few decades now on those contributions towards renewable energy, which are very high. As seen in the following paragraphs, the use and improvement study of Nordic renewable energy will be mentioned and shows the base of the research on which it is built.

Renewable Energy Implementation in Nordics

This sub-section of the introduction delivers the renewable energy implementation in Nordics as part of history and shows the research on which it is built. The sub-section also shows the implementation and connection of mitigation strategies for climate change in the EU after the agreements of world protocols. The EU commission has strategies for implementing world agreements in its nations. The EU's commitment is to reduce greenhouse gas (GHG) emissions from 85% to 90% below 1990 levels by 2050 [5]. One of the most active groups of nations in the EU for adapting climate change, mitigating and combating it in different ways, is the Nordic nations.

Nordics are implementing the diverse capacity of renewable energy (RE) to be an energy source for their countries. The usage of renewable energy increased from 1973 to 2009 in Nordic nations, with higher diversity of renewable energy implemented by Finland and Sweden [6]. The replacement of fossil fuels for energy production is not only to be in the Nordics, but it is an example for others to follow. The various encouragements include a subsidy to replace house windows to increase energy efficiency in Sweden; tax minimization in Nordic countries for those that use RE; CO_2 reduction policy, as well as other points and encouragements that help society and business companies to work and use RE much more [6,7].

The dimensions of policy-making in Nordic countries (NCs) are sustainability, self-sufficiency and balancing trade-offs. The objective of diffusion RE policy in NCs includes: (1) energy efficiency; (2) economic efficiency; (3) CO_2 reduction; and d) energy security and diversification [6]. These next descriptions, classifications and explanations are mainly based on [6,7].

Energy efficiency: Means using the maximum output, reducing waste to a minimum and minimizing energy usage. Energy use in NCs is very high due to the following reasons: (1) the presence of winter; (2) high standard of living; (3) high consumption intensity (higher industry energy consumption); and (4) larger distance between houses (few people but dispersed throughout the nations).

Economic efficiency: Maximum output from a given amount of input or minimizing input while obtaining enough output. There are two types of efficiency related to diffusion RE in Nordics:

Technical efficiency: By implementing the lowest possible cost obtaining an efficient output by using the possible techniques and environmental possibilities. For example, in Finland, the use of heaters on wind turbine blades during winter to avoid the freezing problem. Consequently, the current project instruments, such as water heat exchangers, are considered technical efficiency improvements.

Allocative efficiency: To allocate resources and knowledge to maximize the result for the user. For example, there are different types of electricity offering companies in NCs delivering green or normal electricity. Customers can choose what they want.

CO_2 reduction: This is to reduce the usage of fossil fuels to minimize pollution or emission reduction. By allocating technologies and using clean/carbon-free energy sources (renewable energy resources as this research is doing). A lot has been achieved in NCs in different nations with the introduction of climate strategies/greenhouse emission strategies for future efforts; for example, in Denmark and Norway.

Energy security and diversification: As the solution to climate change is expected to deliver, the use of energy diversification is important, and it is at the heart of implementing strategies. The best examples are Finland and Sweden, the two countries with the most diverse type of energy production methods implemented [6] (Figures 1–3). The new water heat exchanger and the previous sediment heat energy production introductions can help increase the diversification of renewable energy solution types in seaside implementations.

Using the above-mentioned dimensions and objectives will lead to sustainable energy efficiency where green energy or RE is the focus. The idea of the "Drop in sea" project, the Merten Talo projects at the University of Vaasa, and their usage of the water body for heat exchangers was the way to satisfy this policy. Moreover, we need to use RE as a solution to the climate change problem and adapt to climate change/use it as an advantage. The solutions to the climate change problem are diverse and locally based. They say "a lot of spider tread together can hold a lion" or in other words ''unity is strength". The use of small and diverse solutions in local areas such as replacing energy usage with RE solutions and others will solve climate change worldwide if adapted over time. This study also satisfies and tries to address the need for a CO_2 reduction policy in NCs.

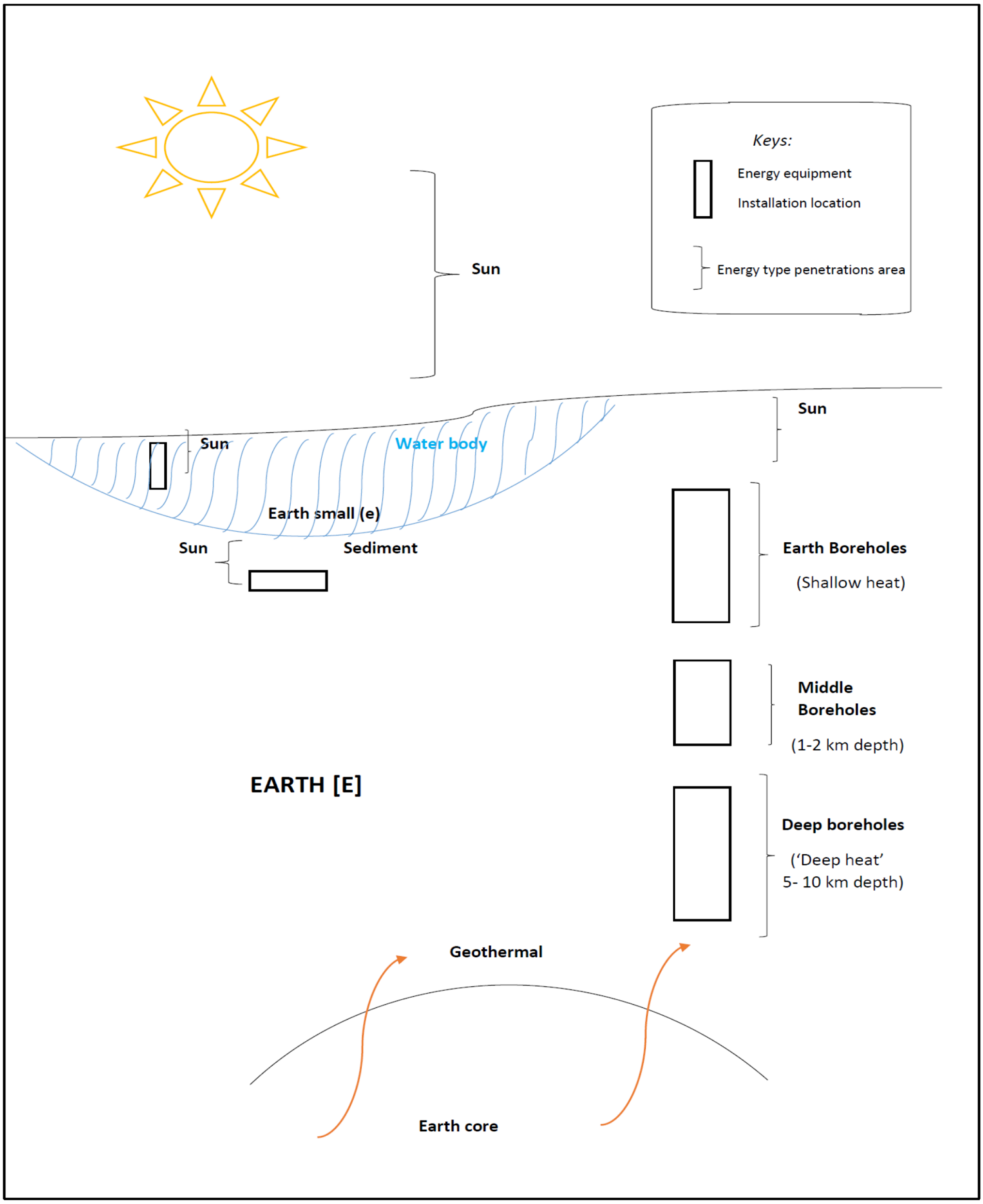

Figure 1. Sketch figure showing possible geothermal-energy solution for installation near seaside or water body areas (e.g., near a lake or sea).

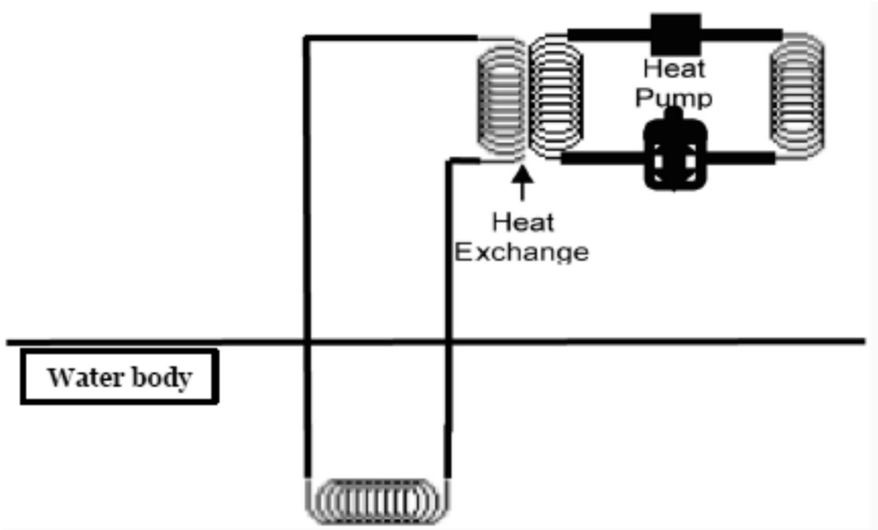

Figure 2. In closed loop geothermal heat pump system, in this picture in our installation, seawater was utilised as a heat source (modified from [8]).

Figure 3. The water heat exchanger that was planned to be installed in Merten Talo is connected to the tubes (of the heat pump in the home), which are insulated. The red wire is the temperature sensors (Picture taken by Anne Mäkiranta during installation process 18 October 2018).

Based on this goal, Finland's National Energy and Climate Strategy is increasing its share of renewable energy sources [5]. The Vaasa region has been active in energy solutions implementations and studies. Renewable energy is one of the focuses, and the seaside energy solutions study was the focus of this paper. One of the main ideas was implementing different resources for a particular area in the Vaasa region. The energy demand and supply differ from place to place due to climate change. Some places require more energy, others might face less energy demand, and some might experience more cooling demand than heating, as noticed in Midwest U.S.A. discussed by [9]. The same or relative situations are expected to vary place to place in Finland as well. The conclusion of [10] reports that except for heating demand, for the remaining methods of energy production, 50% of them increase at a minimum of 6% in the climatological potential of wind power and a maximum of 21% in the climatological potential of peat production.

The objective of this review paper is to review the seaside renewable energy solutions and present them in one figure. Moreover, we aim to connect all aspects of renewable energy to the energy transition caused by climate change towards sustainable development. As well as giving background literature from the past, current and future renewable energy projects conducted at the University of Vaasa, these projects are representative types; thus, they can be adapted and expanded to other locations such as Africa.

The contributions of this review paper are: illustrating the seaside geo-energy renewable resources in one figure (Figure 1 in this paper); suggesting and showing the expansion of local seaside renewable energy implementation to local areas and other worldwide locations to facilitate combating and mitigating climate change; showing possible future renewable energy solutions in seaside areas and suggesting seaside renewable energy solutions for local area use and gives background literature for seaside renewable energy and their connection to climate change, water resources and land uplift.

The novelty of this study is seeing a problematic effect as an advantage to overcome the problem by itself. In other words, using the effects of climate change to our advantage and using them to generate seaside renewable energy resources to combat and mitigate it.

2. Seaside Renewable Energy Resources

2.1. Possible Types of Seaside Energy Solutions

The cost of energy on islands is higher compared to other areas. Regional differences exist in using different renewable energies [11]. Here, we focused on seaside renewable energy resources. The main types of energy sources in seaside locations are renewable energy, mainly water-based and borehole systems. Both are the geo-energy types of resources located near water bodies. Figure 1 shows the possible geo-energy solution for installation near seaside or water body areas. This is one of the main contributions of this review paper. In water bodies, there can be installation of water heat exchange. At the bottom of the waterbody are possibilities for installations of sediment energy. Nearby to the water body, there can be different depths of borehole systems: 1. shallow borehole; 2. middle deep borehole (1–2 km depth) and; 3. deep borehole ("deep heat" 5–10 km depth). This study emphasizes water heat exchangers, shallow boreholes, and sediment energy suggested in seaside areas such as the Merten Talo project site. The main solutions that were planned to be installed first were water heat exchangers and borehole systems. However, the water heat exchanger has to be lifted after installation because of a disagreement between the Merten Talo project owners and the University of Vaasa.

Seaside areas and islands are sensitive to climate change, especially sea-level rise and flooding. Even though in Finland, especially in the city of Vaasa borders, land uplift is higher than sea-level rise, the area is also affected by the sea-level rise to some extent. In addition to climate change effects, there are other difficulties and challenges present at the seaside for utilizing energy resources.

2.2. Seaside Difficulties and Challenges for Energy, Especially on Islands

The difficulties noticed in the Kvarken archipelago were based on the "Drop in Sea" project outcomes and other discussions: (1) The cost of oil is expensive due to the additional cost bought transportation to islands by boat. (2) Difficulties to install borehole energy storage systems because the islands are usually rocky. (3) Sediment energy is not visible, at least not near the city of Vaasa (Kvarken Archipelago), because there are many rocks at the bottom of the sea. (4) Island energy production is more expensive than in other areas. (5) Land uplift shifts the harbor over time so that installing, for example, a "water heat exchanger" is disrupted after many years of use because the 'water heat exchanger' is not in seawater anymore if it is not installed deep in seawater at the time of installation.

2.3. The Possible Future Renewable Energy Solutions in Seaside Areas

This seaside renewable energy solution uses climate change as an advantage. Climate change is a change in the current climate mainly due to CO_2 emissions in the late 20th century. Some say climate change is a hoax, but I am not in those groups. The group I belong to is those who believe climate change is real and that a need for action by the entire population is essential. Knowing that there is controversy among different people, even scholars are showing how much people overlooking evidence. The report by the IPCC group is enough to not only make us believe but also act to create solutions and save the future world climate for the next generation. One way to do that future work would be to adopt renewable energy solutions. For example, in the ethylene industry, new technology (EOD-Ethylene oxide dehydration) can substantially reduce energy and GHG emissions [12]. Implementing various energy solutions in any potential polluting industry can provide great results in reducing global emissions from industries.

Girgibo [10] presents renewable energy resources that use climate change as an advantage by answering the following question. What energy usage methods may be used to extract renewable energy in the Merten Talo area? The possible seaside renewable, advantageous energy alternatives in the Merten Talo Project area would be: UTES (underground thermal energy storage), a water heat exchanger in the sea, ATES (aquifer thermal energy storage), wind energy, BTES (borehole thermal energy storage), solar energy, GEU (groundwater energy utilization) and asphalt energy. Sediment energy can benefit from global warming, but it was not found suitable to be installed at the Merten Talo project site. However, here in the city of Vaasa, Suvilähti area, sediment energy has been installed and experimented with by our renewable energy research group members.

Shrestha et al. [13] said that global warming technology innovations could minimize GHG. In addition, according to [14], some of the solutions to combat climate change are using and installing renewable energy resources as widely as possible. Doing so benefits us and helps save the world from climate change problems. There are various choices for the use of renewable energy, among them, the ones explained in this paper are the new methods for seaside areas. These include water heat exchangers, sediment energy, wave energy and deep wave energy, asphalt energy, GEU (groundwater energy utilization) and BTES (borehole thermal energy storage systems), wind turbines, KNBNNO-material and solar systems.

2.3.1. Water Heat Exchanger

The development of renewable energy that can be used as seaside energy solutions has been progressing in the University of Vaasa renewable energy research group with promising experiments and publications. For example, these publications show a new way of looking and thinking about renewable energy utilization: Refs. [15–17] in sediment energy, ref. [18,19] in asphalt energy, ref. [20] in biofuel energy at University of Vaasa renewable energy research group. The installed water heat exchanger's main principle is shown in Figure 2. However, in the picture, the ground was replaced by a seawater heat source in our case.

Currently, water heat exchanger renewable energy utilization is continuing to make promising progress at the University of Vaasa. It provides a way to source new and innovative renewable energy resources from our environment that can possibly be utilized as seaside energy solutions. The main energy source for water heat comes from the sun and earth, called geo-energy, as shown in Figure 1 at the beginning of the seaside renewable energy resources section. The hot carrier fluid, mainly water, can be stored in bedrock batteries for different times or seasons of usage. This water heat exchanger was installed and removed from Merten Talo shown in the next picture (Figure 3). It is a new type of water heat exchanger that has been used only a few times in Sweden and now in Finland. According to the description given during installation, the water heat exchanger is safe for the environment. It is made from Polyamide-100 (PA-100) plastic-type, with thermal conductivity of 0.40.3 ($W\ m^{-1}\ K^{-1}$). It will not build ice inside even in (-2 °C) and is approximately 109 m long when stretched from the circular structure (see Figure 3) to parallel length. Figure 3 shows the water heat exchanger installed in Merten Talo connected to the tubes (of the heat pump), which are insulated (picture taken on 18 October 2018). Moreover, Figure 4 shows this water heat exchanger inside the seashore at Merten Talo. Table 1 shows the water heat exchange installed with a potential supplier, the GeoPipe water heat exchanger product list given below [21].

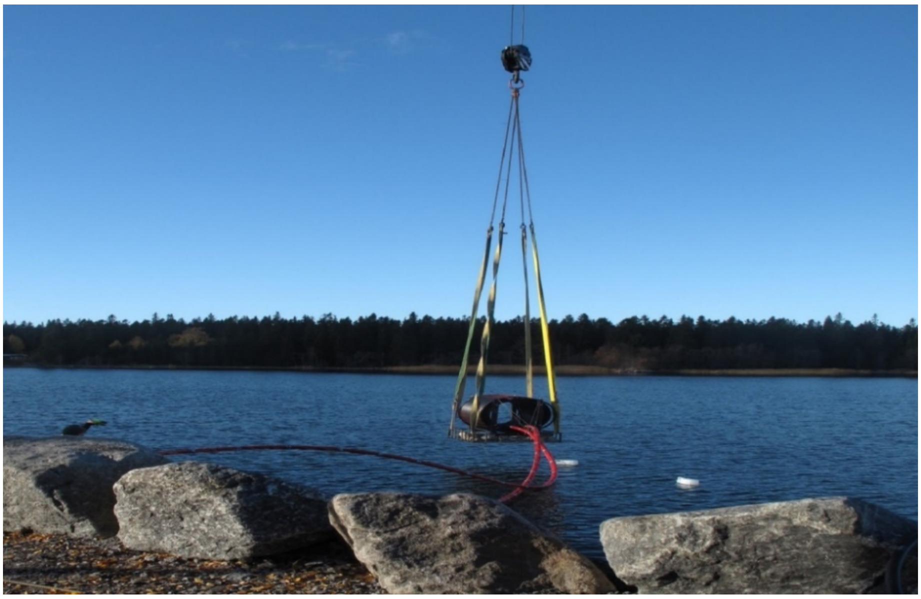

Figure 4. The water heat exchanger being put inside the sea shore at Merten Talo (Picture taken by Anne Mäkiranta during installation process 18 October 2018).

Table 1. Shows a potential supplier of the GeoPipe water heat exchanger product list [21].

Descriptions of Water Heat Exchanger	Size (mm)/Energy Production Capacity in (kW)
Water heat exchanger	9.6 kW
Length	1450 mm
Diameter about	1300 mm
Installation depth minimum	3000 mm
The ice margin is about	600 mm
Water level variation of about	1000 mm
The diameter of the exchanger is about	1300 mm
Heat pump	13 kW

Distribute temperature sensing (DTS) wire was also installed along with a water heat exchanger. The red wire circled the water heat exchanger is a DTS wire (see Figure 3). Temperature measurement is distributed along the wire, which can be used for several kilometers [22]. Light emitted along the wire and the ratio between anti-stokes and stokes scattered light spectrum gives the temperature; location can be found by measuring the round trip by computer (Figure 6 of ref. [22] Figure 14 and explanations and of ref. [23]). It was installed to record the temperature of the water near the water heat exchanger to study the process. Anne Mäkrianta studied the DTS technology use in asphalt and sediment energy in depth in our research group (the University of Vaasa, Renewable energy research group) [22].

In Hiltunen et al. [16], they discussed different types of ground source heat systems. Among those, the open and closed loop lake or sea water heating systems were described. The installed water heat exchanger is a closed loop water heating system where the heating carrier flood circulates in a closed loop. The open loop systems use the lake or seawater described by [16]. This article seems to be the starting paper for the installation plan and buying the water heat exchanger from the Geo-pipe Company. Banks [24] also described these methods to some extent. The other description of [16] was that the installation has to be 3–4 m deep to avoid the risk of ice buildup in the system. Because of this risk, this system is said to be sensitive to damage. In the Merten Talo installed water heat exchanger, there is no ice buildup risk which was not expected because the water exchanger was installed around an 8–12-m-deep section of the nearby seawater. It was also mentioned that 2–3 m deep below the surface of the water is the depth to obtain heat from the waterbody [8].

After the installation of the water heat exchanger at the Merten Talo project site, disagreement started between Merten Talo project leaders and the University of Vaasa. Therefore, the water heat exchanger has been lifted and brought to the University of Vaasa to be used in the Meri-campus project. Hence, the Merten Talo project leaders would not like to connect the water heat exchanger to the heat pump on the site. The climate energy causing water temperaturee to increase is creating an opportunity to use water heat exchange much more in the future as seaside energy solutions.

According to an internet search and our contacts, there is no literature material for our type of water heat exchanger. On the other hand, other water heat exchangers have been studied in many nations. Two examples are [25], a simulation and experiment study in earth water heat exchanger for cooling can be noticed which was conducted in India at a soil depth of 3.5 m and [26] simulation study on U-tube underground heat exchanger is another example. The [25] study shows an inverse correlation between the pipe length and the earth water heat exchanger. In addition, they noticed that in this water heat exchanger, when the mass flow rate increased from 0.008 kg/s to 0.05 kg/s, the performance decreased and what they had proposed seemed to work better than other literature studies they looked at Jakhar [25] and his team found that an earth water heat exchanger with a 60 m pipe length would be sufficient to cool from 48.5 °C to 25.5 °C per existing photovoltaic cooling system. Compared to our water heat exchanger installed in Metern Talo, which has a pipe length of more than 100 m, it is visible for sufficient heat production and cooling purposes. It was found by [25] that the property of the earth heat exchanger does not affect its performance. This result might be the case for our water heat exchanger too.

In the Jakhar et al. [25] study, they had varied burial depth, pipe material, pipe length, pipe diameter and mass flow in their experiment. They found out the burial depth variation was high with a small depth, but when it goes deeper, i.e., a depth of 3.5 m, the temperature variation is small. This fact is true for all earth soil because the temperature profile becomes constant after some depth without being influenced by the weather conditions. On the other hand, when considering our water heat exchanger, the sea depth profile varies from time to time based on weather (such as air temperature) conditions. The property of material does not show in Jakhar's study on earth water heat exchanger performance, and other studies show similar findings on the property of the material. Increasing pipe length increases performance (meaning decreasing temperature, which is what they look for), which decreases with increasing mass flow. Increasing pipe diameter benefits the performance (temperature decrease) in the long run, but the economic factor increased in their study with increasing diameter. Increasing mass flow rate increases the outlet temperature, according to their text; this is because with increasing the flow rate fluid, the contact time to soli, which cools it, decreases significantly. In their study, simulation was also used to compare with reference earth water heat exchangers found to have better performance and the use of them for cooling purposes by a concentrating photovoltaic system.

On the other hand, in Yang et al. [26] simulation study, they used the user interface tool-pdetool of MatLab software to simulate temperature distribution in the soil near the underground heat exchanger (on adjacent borehole systems). They used a two-dimensional model based on MatLab's column heat source theory. The borehole system, a groundwater heat pump, uses the solar energy stored in summer and extracted in winter based on this study description. Their experimental result revealed that the energy efficiency ratio (EER) could rise to 4 by using a hybrid system with the highest value. They described that EER decreases less and less with running time, and the average EER was 2.28. According to this study, figures presented the temperature distribution in simulation increases for both single and multiple boreholes with increasing running periods. In addition, multiple boreholes had a slightly higher temperature distribution level in the same sunning period than that of the single borehole, which is obvious because the adjacent boreholes support each other in temperature difference in multiple boreholes. A water heat exchanger might be advantageous by taking heat energy from the sea and building much more suitable living temperatures near it. It is ideal for creating an experiment by varying burial depth, pipe material, pipe length, pipe diameter and mass flow. Other studies, such as [27], studied the solar pond heat and mass transfer in salinity gradient, which limited the use of the seaside solutions proposed in this work.

2.3.2. Sediment Heat Energy

The sediment energy heat source is from geo-energy, as shown in Figure 1 at the beginning of the seaside renewable energy resources section. '' 'Sediment energy' is renewable: the heat energy of the sediment layer comes mainly from the sun, and only a minor part is from the Earth's geothermal energy" [15,28]. It is important to notice what energy is available in each location and the combination of sun and geothermal energy as an energy source called 'Geo-energy'. The method of collecting the sediment heat is by installing pipes at the bottom sediment and by circulating heat extracting liquids. The heat carrier fluid can be stored in bedrock batteries. Based on Likens and Johnson [29], the major sources of heat available to the bottom sediments of a lake are (1) solar energy (seasonal storage and loss) and (2) geothermal energy. The same article stated that the flux of solar energy is 4 to 5 orders of larger magnitude than the flux of geothermal heat on a normal land surface. However, in sediment, the geothermal heat source is more significant than solar heat because it is covered by water.

Hiltunen et al. [15] publication shows the potential of sediment renewable carbon-free energy for heat production in the local area. The use of solid, organic sediment layer at the bottom of water bodies and heat carrier liquid; is one of the new ways investigated and shown by our university of renewable energy group, which is carbon-free. The sediment energy can be used for cooling in summer and heating in winter, as shown on the Suvilahti shore in the city of Vaasa, Finland [15,16,28,30]. Mäkiranta et al. [17] further study the correlation between temperatures of air, heat carrier liquid and seabed sediment in the renewable, low-energy network. In their investigation, they confirmed that the air temperature, water temperature (after two months), and sediment temperature indicated by carrier fluid had both Pearson's and Spearman's rank positive correlations.

A further study on seabed energy in annual renewable heat sources conducted in our renewable energy group in the past at the University of Vaasa has been published [31]. The results in this study demonstrate that collecting the heat energy does not cause permanent cooling of the sediment, and the energy is sustainable. Air temperature influences the water and sediment temperatures [31]. This point is important in our climate change and water quality analysis. Hence, one of the results of that analysis shows that global warming causes air temperature to increase, and it causes an increase in the water temperature. Thus, water quality is influenced by water temperature change. It is important to notice on the other side of the city of Vaasa is not the sampling point for water quality data. The conclusion of Mäkiranta et al. [31] was that sediment heat is a potential energy source in the city of Vaasa, and the depth has to be kept at least 3 m downward from the sea bottom. They also noticed that ''the value of the maximum sediment temperature per month was calculated as an average of temperatures at a distance of 280–300 m from the shore." [32]

presents both sediment energy and asphalt energy studies results in combination, which was experimented within the city of Vaasa, Finland.

Golosov and Kirillin [33] studied two lakes from Russia and Germany for their sediment conductivity based on the model that uses lake water temperature without any data on sediment thermal property. This approach seems very useful for sediment-heat energy analysis—the model, at least some parts, can be found online freely according to their description. Lake sediments play an interesting and appreciable role in heat transfer and exchange between lakes and the lower atmosphere (ground earth) based on the suggestion in most lakes [33]. In addition, they stated that the model could be used effectively to estimate the effects of climate change on lakes, and can be used to analyze the backward effect of lakes on the climate system. The benefits of near-bottom temperature (at leak sediment boundary) include crustal for the activity of the benthic community and biochemical process, which is especially important in ice-covered lakes and is the major heat source in those periods controlling various important processes [33].

According to Likens and Johnson's [29] article, the heat stored in the bottom sediment of a lake can be an important source of heat during the winter. Depending on the lake type, the mixing and penetration of the sun to the bottom of the lake differ. For example, in the meromictic lake used in [29] experiment, the low or non-mixing conditions of the lake water cause fewer annual temperature fluctuations in deep water. In addition, in that particular lake water (Stewart's Dark Lake), due to the high concentration of humic colloids or colored materials, the solar radiation penetration is low. This result shows that the sediment-water energy that builds up from geothermal and solar depends on the type of water bodies. Solar energy is predominant for the overall heat budget of a lake [29]. Mixing circulation patterns in the lake and direct solar energy through direct isolation can heat and/or cool the bottom water of a lake, from the same article descriptions. Moreover, direct heating from solar energy is influenced by how deep the lake water is. Shallow water lakes can heat up easily on their water body and at the bottom.

The sediment heat budget becomes more significant as the average depth of a lake decreases and is nearer the shores than in deep water [29]. Smith [34] found that yearly differences in the measurement of water-sediment heat exchange can show the difference in temperature value due to different time (year) recordings, making it difficult to compare them. Some studies show that activities and construction in a water body can affect the water quality for some periods. The construction of sediment heat can affect water quality as well. This can be considered one kind of risk to the environment caused by renewable energy use and production. Past conference papers of Ostrobothnia indicated that constrictions in water areas influence water quality parameters. Sediment energy is one of the important types of seaside energy solutions. Its use is important with further developments.

2.3.3. Wave Energy

Tide waves can be generated from the attraction between the moon and earth, as stated by [35]. The tidal wave is the energy source for wave energy production. The method to collect it is by using different mechanical systems above and under the tidal wave. See [10,36] for the types of equipment used. The electrical energy produced in small mechanical turbines can be stored in batteries. Open oceans have much more tidal waves than seas. The tide of the northern Baltic Sea might not be significant, only 1–2 cm [37]. However, from a wave energy production perspective, the Baltic Sea is a promising water body having an economic potential of 24 TWh of energy [38].

The Baltic Sea can contribute to future renewable energy production by wave energy [10]. In addition, the tide wave energy can be collected in several ways, as described in [10]. For more descriptions and discussion of wave energy, see this publication. The collected energy can be transferred to electricity by using different types of turbines and can possibly be stored in batteries. According to Heino [36], the environmental effect of wave energy is that it might enhance the ecosystem by creating shelter so seaweed, branches, and other invertebrates can flourish. In addition, there is the possibility of using fishing nets in the area to increase the abundance of fish. It generates some noise, which is a frequency of 50 Hz, but the noise is not much louder than the ocean water noise. The foundations of the wave equipment can create artificial reefs, which enhance biomass for several sessile or motile organisms. On the other hand, wave energy devices are a potential treatment for marine birds. Direct negative impacts include the risk of collusion (such as underwater collisions), disturbance, and redirecting during construction and operation.

The wave climate affects the wave energy converter, which can be a global influence or local condition [39]. Moreover, to maximize the wave energy converter's power absorption, the local wave climate must be considered. A wave energy converter's annual power production depends on the power matrix of the wave energy converter and the local wave climate [39]. Tuning the wave energy converter to the local sea wave state frequency is essential in energy production from wave energy. According to Rajasree et al. [40], climate change affects the current wave pattern. It is good to see the future predictions of wave data. In addition, they suggest that predicting the shoreline shift, erosion, and accretion over a specified time is traditionally performed based on past wave data. An experiment conducted on the shoreline of India by [40] found that sea waves will increase in the future. Due to this increase, there is a substantial increase in the volume of annual sediment transport in the future on the Indian shoreline. This result might be more or less the same for most parts of the world's shorelines. Because of climate change, the overall wind speed and sea level rise is increasing. This result means these increases can substantially increase wave power, causing sediment transport from shores.

According to Rajasree et al. [40], the result of erosion on the shoreline of India is continuous erosion with an annual average rate of -1.46 m/yr maximum and the average maximum is -2.21 m/yr. In India, on the shoreline under study, there is three times more sediment transport. On the other hand, the wave height increases annually. It was found that in the past, the wave height maximum was 0.016 m/yr, but in the future, it is predicted to be 0.042 m/yr. This result is a good global data example of a substantial wave height increase in the future. This study was performed by using Geo-referencing low-resolution satellite imaging analysis. There is a difficulty, as seen in this article, that a shortage in storm effects can make one unable to ageist the wave analysis. To include the climate change effects, it is possible to increase the numerical wave model empirically by a certain amount [40]. According to the same article, different references indicate that the occurrence of waves and their intensity (magnitude) would change (probably increase) over time for the entire world.

Girgibo [10] and Heino [36] describe the different types of wave energy production and equipment. Heino [36] explains the types of equipment used in wave energy production. Among the different types of wave energy equipment, the hexagonal types are much more efficient [38]. These developed equipment and methods can generate a useful amount of energy in seaside areas. In addition, the newly developed deep-water wave energy utilization system [41] can help extract more energy from deep sections of the sea and ocean. Such developments help us use more wave energy in the future. The seaside or deep-water areas can now generate wave energy efficiently. The advantages of climate change, mainly freeing up seas from ice, can help generate more wave energy in the future. Wave energy is one of the main types of energy production methods in the seaside, along with sediment energy and water heat energy production. There has been some progress in wave energy compared to water heat exchanges and sediment energy. Therefore, utilizing wave energy can be highly recommended.

2.3.4. Asphalt Energy Resources

Asphalt and sediment energy is noteworthy to be used even in northern climate countries such as Finland [32]. The main source of energy for asphalt is solar energy and, to some extent, geothermal energy. The way to collect the asphalt heat is by installing heat carrier liquid under the asphalt at different depths. Asphalt energy can be stored in bedrock heat battery systems [42]. There are increasing studies about asphalt energy, including at the University of Vaasa [18,43].

Further depth analyses and experiments were conducted in different seasons and the asphalt energy potential is published in our university [19]. They concluded that there is a potential for heat energy to be gathered from asphalt layers in Finland in most months except wintertime. Çuhac et al.'s [44] publication further explored and improved the asphalt heat measurements at the University of Vaasa. According to Çuhac et al.'s [44] findings, provided that the night losses can be properly handled, their result implies that the asphalt layer could potentially collect up to 670 kWh/m^2.

2.3.5. GEU (Groundwater Energy Utilization)

The presence of heat convection can facilitate groundwater usage as GEU (groundwater energy utilization), and conduction from bedrock heated by magma or other possible heat sources mainly generated heat from magma [45]. The heat source is geothermal energy. There might be an exceptional possibility that the sun can affect it if is not too deep and located not more than 10 m from the surface of the earth. The method to collect heat from it can be by withdrawing from one groundwater, then using the heat and then dumping the cold water in other locations [46]. The heat is exchanged in the land to other liquids in the heat exchanger, and the warmed liquid can be stored in bedrock batteries.

Grant and Bixley [45] described the fact that the various conditions of fluid or rock heat development and accumulations in groundwater and aquifers could facilitate their chance to be a source of heat for the local community. This kind of source is used as a source in many areas of the world, such as Iceland. The book shows the connection between groundwater and aquifer with geothermal reservoir engineering. Such a geothermal reservoir might not be available here in Vaasa, even in most parts of Finland. However, it gives a side view of the possibility in other nations, e.g., Iceland. The idea of using GEU in Vaasa was recommended based on the graph [5] presented in his dissertation.

On the other hand, according to Watzlaf and Ackman [8], flooding mines, which can be found in many regions of the world, are a cost-effective option for heating and cooling using geothermal heat pump systems. This fact is important because operational costs are much lower than that of conventional heating and cooling (costs of using mine cooling system is less than 50 % conventional one) options, as the same article mentioned. However, how far the mines are from the city or living towns is also a good question to raise when considering this system for heating and cooling, which is a renewable energy source. Based on the groundwater access, land availability and drilling cost, a ground source heat pump can be designed in various styles [8]. Using heat pumps as an underground water heat source, a mine water heat source, or a water heat exchanger makes gaining heat energy much more efficient. The two common ground source heat pumps are closed and open loop systems [8].

The GEU (Groundwater Energy Utilization) system is ideal for utilizing climate change effects as an advantage and can be one of the relations between water resources, climate change and energy. GEU is an open-loop system where the groundwater will be pumped to the surface. Then, thermal energy will be transferred to energy systems, and the cooled water will be pumped back to aquifers [5]. This system can be used for cooling and heating as ATES (aquifer thermal energy systems). UTES refers to underground thermal energy storage systems where heat accumulated by the earth's soil is used as a heating source, based on Girgibo [10], and it is one of the solutions recommended in that paper.

This system comes in two versions; ATES and BTES [10]. ATES refers to aquifer thermal energy storage systems where aquifer water circulates in tube heat exchangers, where heat is exchanged into liquid or air, and where cooled water is dumped in another aquifer. The cool water is kept in the new aquifer until it recharges for the next circulation. BTES are systems that heat liquids such as water in boreholes, pump the liquid to the surface heat, exchange it for another medium then pump it back to the same boreholes to heat up. These systems (especially GEU) are useful because they can adapt to climate change, such as global warming, which causes an increase in temperature. All systems use renewable energy sources, in this way, they contribute to CO_2 emission reduction and avoid leaks of oil to aquifers. This study shows that the effect of climate change or global warming is possible to be used as an energy source and warmer water resources (such as aquifers).

The main source of BTES is geothermal energy. The heat is collected by keeping hot water in the ground at a constant temperature or warming up the heat, transferring liquids into the borehole. It acts as the heat storage system for water or other heat carrier liquids. Because the winter conditions make some areas of the soil below zero, there is a need to use carrier liquid. Some studies have been conducted in our department at the University of Vaasa on borehole systems, such as in [47,48]. Boreholes also act as cold storage for cooling purposes. One example of this was the study and publication by [49] about a preliminary test for using a borehole as cool storage. This study was also performed by the University of Vaasa in Renewable energy research group members. Their study shows that the borehole can be used for cool storage and loaded into the borehole similarly to heat. One of the constraints of building decentralized energy storage is reducing the cost of in-ground heat storage [48]. In addition, Haq and Hiltunen [48] stated that ''to increase the temperature of the ground heat storage concerning the injection power, the volume of the ground heat storage needs to be increased''. Mostly gneiss and granite without volcanic activity is Finland's bedrock property [23].

2.3.6. Wind Turbines

The wind energy conversion system converts the wind kinetic energy into electric energy or another form of energy [50]. The source of energy is the kinetic energy in the wind. The kinetic energy in the wind is collected by the wind turbine, which can be a horizontal axis wind turbine (HAWT) or a vertical axis wind turbine (VAWT). The electrical energy produced in wind turbines can be stored in batteries or other storage systems. Wind turbines were first commercialized in Denmark in the 1980s, and this nation is the global leader in this technology [51]. There are various advantages to VAWT over HAWT. The different aspects of VAWT were studied by two dissertations here at the University of Vaasa [52,53]. The use of vertical wind turbines is encouraged to be used in rush windy conditions. The world-wind conditions are expected to change in the future in most areas and decline in their strength. However, some areas might benefit from the cause of climate change [10]. The suggestion that can be made to VAWT for seaside resources is its ability to be used in windy rush areas and its capacity to be used for local electricity production even if the energy amount is low in the current VAWT studied at the University of Vaasa.

Wind turbines can be installed onshore or offshore. Offshore wind energy can be a suitable energy source in a seaside area. This suggested type of renewable energy in seaside energy solutions by my studies. Wind power is higher usually in water bodies than in lands. This fact benefits the production of energy from offshore wind turbines. However, the installation and running of offshore wind energy production can be difficult, and the cost is also high compared to inland wind energy production.

2.3.7. KNBNNO-Material

KBNNO and KNBNNO do not differ significantly from each other. The production of KBNNO ($[KNbO_3]_{0.9}[BaNi_{1/2}Nb_{1/2}O_{3\text{-}\delta}]_{0.1}$) material by the PLD (pulse laser deposition) method was developed for the first time [54]. This finding leads to the University of Oulu finding KNBNNO material [55]. According to the news, the KNBNNO material can produce electricity from motion, light, and heat. This result was hailed as a completely new finding in the area of energy collection. Girgibo [10] described that the applications of this material are in watches, mobile phones, textiles, shoes, replacing batteries, and sidewalk areas. Energy can be gathered from the motion created by walkers and sunshine simultaneously. The cost now for a piece of material the size of a coin can be only a few cents, and additional costs are expected from manufacturing, labor and electricity [10]. More information can be found about this material in the articles of [54,56] and the report [10].

2.3.8. Solar Systems

Kneifel [57] showed in their study that using solar Photovoltaics (PV) in households had a significant increase in energy efficiency, embodied energy (greater contribution) and lifetime cost management. This result was consistent with other publication results. It was planned first in the Merten Talo project, but unfortunately, the solar PV panels were not installed because of disagreements among the project leaders. However, the use of solar energy is important, whether solar thermal energy or Photovoltaics (PV). The main source of energy is the sun's radiation. It can be collected as heat by solar thermal energy systems or Photovoltaics (PV) to produce electricity from the sun's energy. Thermal solar energy can be stored in bedrock boreholes, and PV electricity production can be stored in batteries. Both these systems were planned to be implemented in the Merten Talo project. Solar energy is one of the main energy resources that will benefit from global warming due to the effects of climate change. A combination of solar and wind energy for charging electric vehicles was recommended by [58]. More descriptions of this combination can be found in the recent report published by Girgibo [10].

3. Sustainable Development

Generally, energy resources are necessary for an adequate amount but are not a sufficient requirement for development in society [1]. To generate energy, sustainable renewable energy resources are great options. Converting waste to energy and biofuels are also considered sustainable energy resources [1]. The same article also stated that sustainability is very concerned with environmental protection, which is important because humans all want to overcome environmental pollution as much as possible as long as we live on our planet, the only living place we have. As this study tried to show in the climate change literature review report series, a large amount of environmental impact is generated from energy. Therefore, it is important to convert our energy resources to renewable energy. Dincer [1] stated that there is a clear and strong relationship between energy efficiency and environmental impacts. For the same products or services, increased energy efficiency is associated with less resource utilization and pollution. Understanding and working on renewable energy efficiency is important in gaining more energy and environmental protection.

All renewable energy resources are not inherently clean [1]. Therefore, it is important to choose better renewable energy resources and advance those renewables that generate pollution to decrease their pollution. This study's main energy solution proposed, the 'water heat exchanger', is completely pollution free, which is important in future shoreline areas, where the water depth (>4–5 m) is sufficient enough to install it depending on the size of the water heat exchanger. Going back to Dincer's [1] discussion, decentralizing energy resources will help users to use both positive and negative externalities of energy consumption. In addition, it discussed that the small equipment is easier in its availability because it is easy to design in a short amount of time and use quickly, providing greater adaptability.

Some of the important aspects of renewable energy resources and technology in helping sustainable development are [1]: (1) Less environmental impact and diversity of their sources helps reduce the environmental impacts. (2) Renewable energy resources cannot be depleted, unlike other non-renewable energy resources such as fossil fuels and uranium. (3) The centralized systems might not require renewable energy resource usage, which is why they are more potentially useful in urban use. This factor helps reduce pollution, and it furthers climate change. The use of renewable energy is encouraged to be used worldwide widely to some level to secure sustainable development. However, there are other factors that influence sustainable development. Dincer [1] stated some of these factors are: (1) public awareness, (2) information, (3) environmental education and training, (4) innovations energy strategies, (5) promoting renewable energy resources, (6) financing, and (7) monitoring and evaluation tools. See the article of [1] for further description of these points.

Climate change is a driving source for renewable energy resource transitions. The driving forces of renewable energy rapid deployment are: declining cost, pollution and climate change, renewable energy targets, technology innovation, corporate and investor action and public opinion. Among the reasons why energy transition is happening, climate change is one of the main ones. More studies for a 100 % transition to renewable electric systems by 2050 were made, and the cost for transition capital expenditure is a maximum of 25.5 trillion € [59].

3.1. Efficiency and Challenges for Future Energy Solutions

Energy efficiency and savings are very important aspects of climate change mitigation. Energy efficiency has been acknowledged globally, and the EU ambitiously established the Energy Efficiency Directive 2012 [60]. The report also stated that efficient energy and saving it are key premises for the climate and energy policy. Therefore, focusing on energy efficiency, storage and saving is very important to all aspects of mitigating climate change. Using less energy than before refers to energy efficiency, whereas giving up entirely a system that requires energy defines energy savings [60]. The cost of new technology comes into the picture when considering energy efficiency. Because most savings with energy efficiency comes with new technologies, which require additional costs [60]. Energy efficiency is expected to contribute to CO_2 emissions reduction by 40% in 2070 [4]. Therefore, it is very important to also focus on energy efficiency.

Based on IEA [4], energy contributes to lower CO_2 emissions in two ways: (1) Reducing total energy use and (2) placing downward pressure on upstream supply systems. Energy efficiency increment in households by choosing various parameters and sealing insulations (3) referenced below: Sweden increases household efficiency by insulation sealings in windows and doors [6], Sukhatme [61] book for basics of how to use solar in household efficiency and ventilation without air conditioning systems and [57] house building energy and emission efficiency. Kneifel et al. [57] stated that when considering energy efficiency application, it is important to consider the effect on operating and embodied carbon emissions. In their study, life-cycle energy is not quite proportional to life-cycle carbon, which is consistent with other discoveries. There is some difficulty in studying energy-related emissions in considering embodied emissions.

Moreover, life-cycle energy and life-cycle carbon emissions are driven mainly by operating energy. It was also stated in this article that, in terms of the technology and economics perspective, it is difficult to change from net-zero operation flows to net-zero life cycle flows in their experimental site investigation. All in all, increasing the efficiency of energy production and use can help reduce much of the emissions. Therefore, it is very important to address efficiency in new projects or renewable energy installations and use.

3.2. Energy Storage

A part of the renewable energy system is energy storage, which is one of the main issues. This includes short-term periods and seasonal storage systems. The book from Huggins [62] gives a depth of knowledge in energy storage systems. It is worth looking at his book to understand the concept of energy storage: fundamentals, materials and applications. Here, only a few energy storage types are presented, mainly thermal energy storage systems.

3.2.1. Thermal Energy Storage Systems

In thermodynamics, the inertial energy present in the system due to temperature is Thermal Energy. According to Hauer et al. [63], a thermal energy system (TES) is a technology that stores thermal energy so that the stored energy is used in later periods. The thermal energy is possibly stored by heating or cooling a later storage medium for heating and cooling applications and power generation. There are three kinds of TES systems as stated by [63]. (1) The sensible thermal storage system (STES) which is based on storing thermal energy by heating or cooling a liquid or solid medium (e.g., in our case, ice thermal storage system for cooling [64]). The compressed air energy storage system [65] and ATES (aquifer thermal energy system) for heat or cool thermal storage in aquifers) [66]. (2) Latent heat storage using phase change materials or PCMs (e.g., forming a solid state into a liquid state [67] for buildings). (3) Thermochemical storage (TCS), using chemical reactions to store and release thermal energy (e.g., in our case cryo-adsorptive hydrogen storage tank) [68].

3.2.2. What Are the Possibilities of Thermal Energy Systems? What Is the Best Technology and Why?

Among the three explained kinds (STES, PCMs and TCS) of thermal energy storage systems in the above section, some options are chosen. From the STES, the possible solutions for us can be: (1) ATES (aquifer thermal energy systems) for cooling and heating depending on the season; (2) borehole storage systems; (3) the ice thermal storage tank for cooling; (4) advanced adiabatic-compressed air-energy storage system (AA-CAES). There was a non-choice made among the PCM system, but the cryo-adsorptive hydrogen storage tank was chosen from the TCS system. These listed technologies are some of the best and most applicable in the area of large industries and commercial buildings.

The best choice for us is ATES for both cooling and heating. Then, the other options are used.

ATES (Aquifer thermal energy storage system) [10,66,69,70]: This is the first type of UTES (underground thermal energy storage system) where it uses aquifer as heat storage. An aquifer is defined as the underground water storage between rocks and land faults. It can function without the connection of the water table (unconfined aquifer) and with a connection to the water table (confined aquifer). The hot water can be pumped from an aquifer and then dumped in another location after heating or cooling. Then, dumped or allocated aquifer water can be used as another circulation when it gets recharged. In winter, the aquifer temperature is higher, so it can be used as a heater; in summer as a cooler.

This approach is mainly utilized for heating and cooling households but is also applicable for industrial use. The only limitation is that the location has to have a geological formation of aquifers. At least in the city of Vaasa, there are some groundwater and aquifers. It is believed that in the city of Vaasa, the use of GEU (groundwater energy utilization) is ideal [5]. Therefore, the use of ATES is possible, and it is one of the energy solutions proposed in my research to adapt to climate change water temperature increase in groundwater and aquifers if they are nearby the land surface. As land depth increases, the ground temperature becomes constant and is hardly affected by climate change. ATES is renewable and minimizes CO_2 emissions. Consequently, it helps the community utilize renewable energy to combat climate change.

Borehole storage systems [24,69]: The other proposed solution for energy storage and generation. It is a type of UTES (Underground thermal energy storage system). Activated by installing at least a 2 m deep pipe which is circulated under soli for heat absorption from the ground to liquid then pumped to surface then used. The circulated liquid can be water or other heat carrier solutions with or without water. The pipe installations can be in different patterns; there are some energy-saving types of installations that save money, space, and heating time. The uses of borehole systems are mainly ideal for heating, but ATES can be used both for heating and cooling in different seasons, as mentioned in Section 1 (See [24,69] books for further reading). Borehole heat storage was installed in the Merten Talo project. Borehole systems have been tested to be used as cool storage in our renewable energy research group at the University of Vaasa.

Ice thermal storage tank for cooling [64]: This is a system that can be used combined with other parts in plants for cooling (see Figure 1 in [64]). Built-in ice storage is ideal for IST (ice storage tank). The hybrid option of the TES system of water-phase transition, solid-melting liquid, and liquid freezing solid accomplish energy-efficient control. At the time of off-peak electricity hours, the ice is built and stored in tanks. Then, at high-peak electricity time, it can be utilized for cooling, saving energy for cooling purposes. A sophisticated routine can be used to achieve higher savings on power and cost. The energy conversion rate is high; hence, it can minimize electricity use at high-peak times.

Advanced adiabatic-compressed air energy storage system (AA-CAES) [65]: The method works by storing compressed air deep, e.g., in salt reservoirs when the electricity is at its peak, underground after passing through on compressor and tightly insulated tanks in a tube. The stored temperature underground is around 40 °C. Then, when grid electricity is in shortage, for example, there is no wind for wind energy turbines, the compressed unground air can be pumped back to rotate the turbine after heating. This method can generate and supply the grid electricity shortage when needed. The usage can be, for example, in food and agriculture industries when electricity shortage can be used to generate electricity. Hence, if it can store the overload electricity power, its energy conversion rate is great.

Cryo-adsorptive hydrogen storage tank [68]: The storage system where it can store hydrogen, metal-hydride, and liquid-hydrogen through adsorption. The renewable energy source hydrogen can be used to produce electricity, heat, and a well-run car. Cryo-adsorptive hydrogen storage is useful because of its high capacity in low pressure. Storing hydrogen in pressure requires much space and higher pressure, which is a costly and risky situation. However, the new solutions, metal-hydride hydrogen and cryo-adsorptive, can minimize this risk of high pressure and cost to some level.

3.2.3. State-of-the-Art Promising Features

Here, the most promising features are described by the same list as above. The state of art means the newly developed mechanisms and installations for all chosen types of TES (thermal energy storage systems). (See also [67] about state-of-the-art thermal energy storage PCM (phase change materials) for buildings).

ATES: The most promising future is the combined heating and cooling systems in the same installation for the building. Hot water is pumped from one aquifer and dumped in another in one direction. In winter, the ice coverage preventing the heat from escaping to the surroundings causes much warmer water underground in aquifers as well. In summer, the utilized and dumped cold water can be pumped and used for cooling purposes in the opposite direction-descriptions and illustrations presented in [46], unpublished report, and groundwater report.

Borehole storage system: The solenoid tube structure is the most energy and space-saving tube installation method. This method will save space for installation, and depth and energy efficiency also increases [69]. The installation method is the best way to do it in our case as well.

IST-ice storage tank: In Wu et al. [64] paper, the authors suggest using three combined IST storages along with other parts. The combined central plant systems are one air handling unit, one heat exchanger, one chiller plant, different pipe configurations and four pumps for circulating along with these three IST storages. This structure can be considered state of the art from this paper's suggestion. However, the latest ideas and combinations can be gathered in the future.

Advanced adiabatic-compressed air energy storage system (AA-CAES): This case is based on the latest literature [65]. Among the options listed, the best and most advanced option can be chosen as state-of-the-art. AA-CAES is one of the options in the reference. There is also a solar-AA-CAES method, but the most efficient one is the poly-generation CAES system. State of the art can be chosen from those options described.

Cryo-adsorptive hydrogen storage tank: The combined storage of hydrogen and metal-hydrides can minimize the usage of space and pressure capacity, but the problem with this technology is that the hydrides are much more expensive. However, it is said that hydrogen is an ideal source of energy. For example, 3000 cars' suspension power is needed to lift 300 L and 500 bar compressed hydrogen in a tank. Therefore, lots of energy is stored in a tank. Cryo-adsorptive hydrogen storage has a high storage capacity at low pressure.

Both hydrogen metal-hydrides storage and cryo-adsorptive hydrogens storage tank can be considered state of the art for this technology.

3.2.4. Energy Efficiency and Cost of Thermal Energy Systems (TES)

The possible energy efficiency, cost, power and storage period are listed below. We hope Table 2 can show a partial view of the described type of TES. More and more efficiency profiles and other lists can be collected from different resources, but here, half of the boxes are filled from five different pieces of literature.

Table 2. Thermal storage system typical parameters (compiled from [63–66,68]).

TES Systems	Chosen System	Capacity (KWh/t)	Power (MW)	Efficiency (%)	Storage Period (h, d, m)	Cost (€/KWh)
STES	Sensible (hot water)	1050	0.00110	5090	d/m	0.110
	Ice thermal storage system	~3.5	-	-	h/d	0.11
	Advanced adiabatic-compressed air energy storage system (AA-CAES)	-	2	6065	h/d	-
	Borehole storage	-	-	-	d/m	-
	ATES (Aquifer thermal storage system)-Hot	-	0.2512.5	-	d/m	-
	ATES-cold	-	7	-	d/m	-
PCM	PCM	50,150	0.0011	7990	h/m	1050
Chemical reaction	Chemical reaction	120,150	0.011	75,100	h/d	8100
	Cryo-adsorptive hydrogen storage tank	-	-	-	h/d	-

3.2.5. What Can Be Implemented Here in the City of Vaasa and for Industries?

The application of ATES and borehole energy storage systems seems ideal for Vaasa. It is known that the city of Vaasa is one of the potentials for GEU (Ground energy utilization), according to [5]. Therefore, plenty of groundwater resources in the area means we can implement this method without geological problems for Vaasa. The other solutions described need innovation and thinking to install them for industries. For example, ideally, ice tank storage can be very useful in dairy industries where there is a much higher need for cooling, freezing and chilling mechanisms for milk production. Other industries such as meat production also require cooling systems for meat storage. Using TES can save energy and provide more energy when there is a shortage in industrial sites.

Heating and cooling can be necessary all over in industries for heating in wintertime and cooling in summer to stabilize room temperature for food and agricultural products, e.g., keeping vegetables in food and agriculture factories. Some industries, mainly food industries, require freezing and chilling. IST-ice storage tanks can provide this freezing and chilling. ATES and borehole storage systems can combine projects (the Merten Talo and other new thermal energy system projects) hand-to-hand. This study focused on community renewable energy utilization increase and sustainability by minimizing climate change and using climate change effects as an advantage (e.g., water and ground temperature increase at the time and in the future), but not for industrial applications as described in this paragraph.

4. Projects as an Application in Installing Seaside and Renewable Energy Solutions (Projects: 'Drop in Sea', 'Merten Talo', and Future Work at 'Energy Village in Africa')

Next, the descriptions of the three projects: 'Drop in the sea', 'Merten Talon' and 'Energy village in Africa' are presented. These projects plan and/or implement renewable energy resources mainly to combat climate change and to utilize local energy resources.

4.1. "Drop in Sea": The Project of Renewable Energy Installation on Islands of the Archipelago

Here, the 'Drop in Sea' project is described [71]. This project took place in Kvarken Archipelago and was interested in real estate and managed by Metsähallitus, private single-family houses and farms in Central Finland. Drop in the sea is the Vaasa Energy Institute and the University of Jyväskylä joint venture. The Vaasa Energy Institute managed the project, and the Levön Institute was attended by the Faculty of the University of Vaasa, Novia University of Applied Sciences, Vaasa University of Applied Sciences and an expert in Metsähallitus. The purpose of the project was to develop a hybrid model service concept for energy self-sufficiency, the implementation of which would be decentralized and constitute several destinations for smart packaging management. The island destination is coastguard and pilot stations, mainly used as tourist destinations. The project was funded by the Mainland Finland Rural Development Programme 2007–2013. The actual time the project is performed is a one-year transfer from the original 1 January 2011 and up to 31 December 2014. The project used less money than was provided by the fund. This project was a very good initiative that helps the islands of Kvarken Archipelago to be self-sufficient by using renewable energy resources. Such projects are very important in encouraging the local areas to utilize renewable energy resources and become self-sufficient, securing or overcoming the energy shortage and minimizing the cost of other fossil fuel energy sources such as oil for heating.

4.2. Merten Talo Project about the Installation of Renewable Energy Solutions on a Local Site

''Merten Talo" means ''House of the sea" in English, which is a nice name presenting the use of the nearby sea as an energy resource, other renewable energy resources and building and introducing an exhibition center for the UNESCO World Heritage site. The Merten Talo project site is located at Raippaluoto, an island in the western Finland archipelago on the shore of Vaasa. The next paragraphs are presented to highlight some of the installations and buildings for the exhibition center.

The first step toward renewable energy installations was the initial plan and proposal of the possible solutions to the project leaders. Some of the solutions proposed were: water heat exchanger, borehole systems, heat pump, solar photovoltaics and solar thermal connected to boreholes for storage and asphalt energy. The overall idea was a solar system (photocell) combining boreholes, solar collectors, and water heat exchangers as heat and light sources for household use for exhibition and restaurant buildings. However, the only renewable solution left on the site is borehole systems and a heat pump. The water heat exchanger was installed and then had to be uninstalled because of financial shortage issues for the controlling system to be installed. ''One of the most important issues for the continued growth of most renewable options is their relative cost" [11]. This statement is seen in this project. The water heat exchanger controlling system cost was high, so the project leaders did not allow it to be used on that site. The solar energy systems were not installed even if they were proposed in the proposal. Asphalt energy and sediment heat energy production was not possible to install because the area is very rocky, so it is not suitable to use asphalt energy near the doors.

The current site is very good as an exhibition center. The ability to see what is present in the UNESCO World Protected Heritage Site is clear now. It will surely increase the number of local citizens and national and international tourists to the protected heritage site, the project's main idea in terms of the exhibition center. In addition, it is expected to facilitate business activity in the local city and area.

The University of Vaasa renewable energy research group was an active member of this project. One renewable energy installation was a water heat exchanger in the sea. However, this equipment has been lifted and returned to the University of Vaasa for another project. The water heat exchanger uses the sea water temperature for heating or cooling purposes. Figure 5 shows the water temperature on Raippaluoto shore. This temperature is expected to rise with the continuation of climate change effects. Thus, the water heat exchanger uses climate change to its advantage. The next Figure 5 shows the temperature profile of the Merten Talo sea shore.

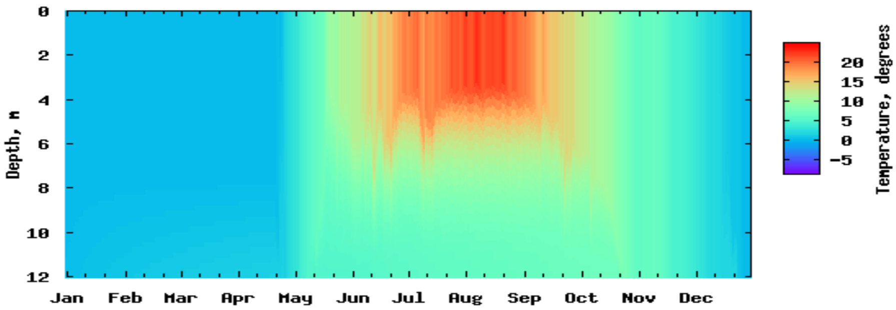

Figure 5. The temperature profile of Merten Talo sea shore (Latitude (−90–90): 63 and Longitude (−180–180): 21) was made by an online model called Flake Global lakes model [72].

The Merten Talo project suggestions, installations and possible experiments were presented in the Results section. The Merten Talo project is the main project that this study considers an installation site and it is a site for this whole doctoral study analyses. The water quality sampling points were designed to be around the Merten Talo project site at the Kvarken Archipelago of the city of Vaasa. The analysis of water quality and climate change can show the effect of climate change on water quality in a naturally protected area. Thus, we can discriminate the effect of pollution in the analysis because the sampling area is naturally kept enough to avoid human interference or pollution.

4.3. LEAP-RE Project Only one Work Package (WP14) on 'Energy Village Concept in Africa' (Current and Future Continuation of Research Work)

The full name of the whole Horizon 2020 project is Long-Term Joint Europa Union (EU)-Africa Union (AU) Research and Innovation Partnership on Renewable Energy (LEAP-RE). Work package number 14 is our section where the "Energy Village (EV)" concept in Africa is implemented. The partner countries in this work package 14 are Finland, Ethiopia, Kenya, Botswana and Uganda. The main work package objective is: to further develop the Energy Village concept and test it in developing nations together with project partners, to create 16–20 energy self-sufficient villages in the target countries and to create an Africa-wide network of energy village experts who can utilize the method in their countries. These objectives and the overall work package initiates a smooth transition to zero-emission energy resources in Africa.

The University of Vaasa started to work on the Energy Village concept in 2003. There have been different kinds of projects implementing Energy Villages in Finland, including the EU-funded project ASPIRE project 2006–2009. These projects targeted work on around 30 energy villages mainly in Finland. The Energy Village idea is to create energy self-sufficient villages which produce their energy from local renewable energy sources + for sale. Renewable energy resources can be Photovoltaic (PV), wind, water, bioenergy . . . etc. Moreover, the energy applications are in all energy vectors: traffic fuels, electricity and heat. In addition, the idea is to take villagers into the development process in the beginning and work together with them to ensure a smooth process and create local income and welfare: work for the people, money spent for energy ''stays" in the village, rural welfare and vitality and less coal and oil to be burnt. The working time of the project is 4 years (June 2021–May 2025).

The main expected results are: to modify and create a set of tools to serve Energy Village-concept utilization in developing countries; to test the created tools and establish Energy Village in target countries (Kenya, Uganda, Ethiopia and Botswana); to create an Africa-Wide Network to utilize the Energy Village concept and; to identify and suggest tools and options to the barriers and obstacles that need to be removed and the drivers and opportunities that will need to be supported. There are four main tasks in this work package 14 (Energy Village concept). Those are (1) The Energy Village concept and methodology. (2) The development of sustainable energy communities. (3) The Energy Village-wide network, and (4) Policies and recommendations.

''After establishing a vision of the future, governments need to continuously track progress and assess the impact of the adopted measures to deliver net-zero emissions, and to re-prioritise efforts as necessary along the way'' [4]. This statement of IEA is a very important message, especially for developing nations involved in the Energy Village concept work package in terms of this project. This is because if there is no continuation in the energy villages established and if they are not replicated it will be difficult to see a concrete result in combating climate change and making the energy of the village self-sufficient. Therefore, the local governments and leaders must follow the steps described in Figure 6. Figure 6 shows the governing process for a strategy toward net-zero emission [4] and this is similar to the steps that must be used in the Energy Village project.

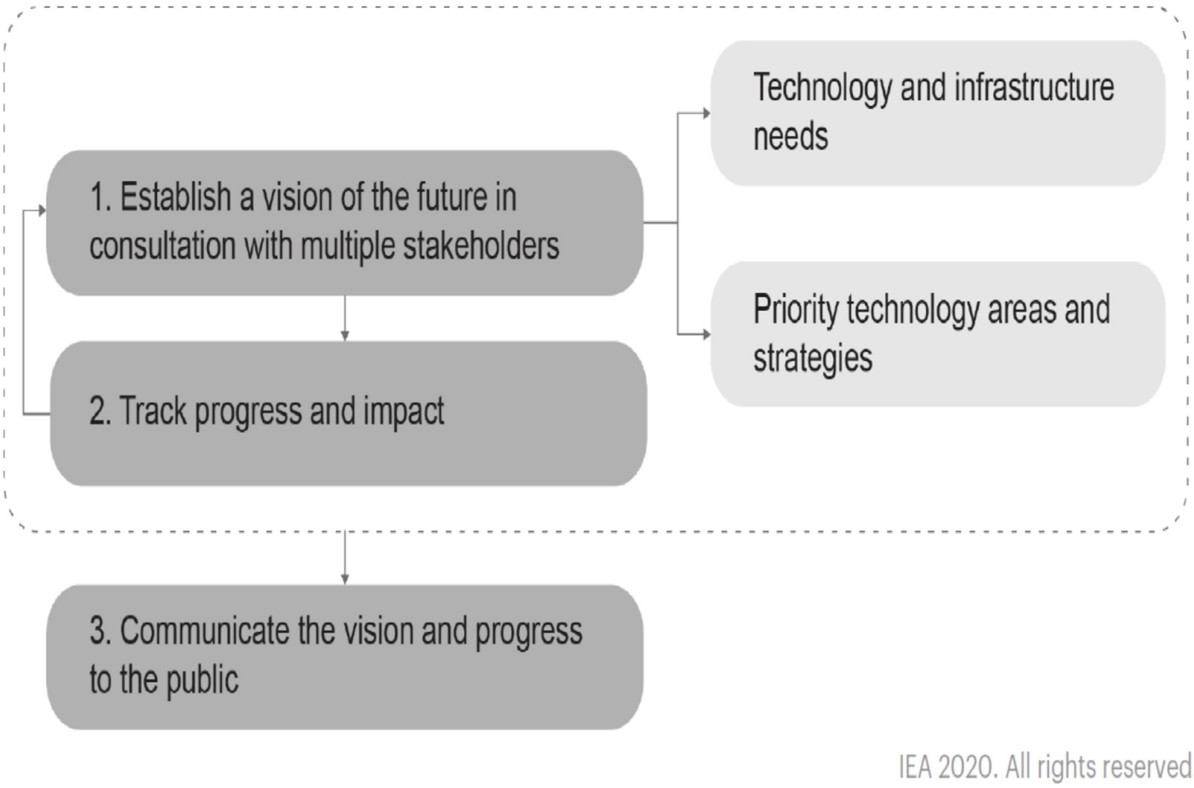

Figure 6. Governing process for a strategy towards net-zero emission [4] and this is similar steps must be used in Energy Village projects.

In the above figure, step one is mainly the work package 14 or 'Energy Village concept' works. The second and third steps had to be developed and adapted by local authorities and the government.

The LEAP-RE Project work package 14 or 'Energy Village concept' project implementation had anticipated possible risk types. These are lack of availability/openness in the data for the definition of Energy Villages; not enough social intervention or lack of agreement in villages in the definition process of roadmap and vision; proactive participation of local inhabitants and private property owners and; interoperability and scalability issues of the ICT tools. These expected risks are planned to be solved throughout the project implementation process.

5. Methodological Lit and Research Gaps Addressed

5.1. Methodological Lit

The databases used in this literature review report series 1 up to 4 were: Scopus, Google scholar, science direct Elsevier journals, Nature Journal, and Google search engine. Scopus, Google scholar and Google search engines are not limited only to specific journals. For example, Scopus has more than 25,000 journals and Google sources are unlimited and it is not known how many journals it can find. These databases provided a lot of search results for some search words. The search words or descriptors used vary for the four topics of this literature review chapter. The main search descriptors used searches were listed as follows.

For the climate change literature review, there were more than 29 descriptors used in the search process the main ones were: climate change, green emissions, flooding, sea level rise, global warming, energy solutions for climate change, metrology change/fluctuations, the relevance of climate change, climate change relevance on energy management, climate change effect on energy sections, temperature variation in climate change, climate change and Finland, and climate change and city of Vaasa were some of them.

For the seaside energy solutions literature review, the main descriptors were: renewable replacement in islands; challenges on using renewable in islands, islands and climate change, islands difficulties, efficiency management in islands, and energy solutions effect on energy sectors on islands.

For the renewable energy resources literature review, the main descriptors used for searching those were: water heat exchanger, GEU (groundwater energy utilization), vertical wind turbines, Borehole thermal energy storage system (BTES), wave energy, challenges with renewables, the efficiency of renewable resources on seaside area, the most economic renewable energy resources, the best renewable resource, climate change risk on renewable energy, renewable energy risk to the environment, renewable energy effect on energy sectors, energy opportunity due to climate change, and renewable energy as combating climate change.

For land uplift, the main descriptors used for searching those were: Land rising and climate change connection, measurement of land uplift, compensation in land uplift, land uplift phenomena in Europe, Land uplift in Vaasa region, Kvarken land uplift, and inclinations in land uplift.

For metrology, a few descriptors used for searching those were: Parameters of metrology, climate change and metrology, patterns in metrology, the study of metrology change and time serious study in metrology.

For water quality, a few descriptors used in the searching process were: Climate change and water quality and water resources and climate change.

For road in ice and the Gulf stream, some descriptors used in the searching process were: Road in ice: ice road availability, ice melting effect, sea ice and climate change, the land rising and sea ice, the decline in ice level and energy opportunity due to climate change wave energy.

For the Gulf Steam: Gulf Steam in Bothnia, Gulf steam forecast, future condition of Bothnia Gulf Stream, coldness in land due to Gulf Stream and Gulf Steam and global warming.

The searching process was very intense and took a lot of time. In this process, more than 380 articles were downloaded in only the main searching time. After a while, there was searching due to the process of the 'snow bowl method'. However, the literature process does not use all of these articles in the full article reading process because of time-limited and unrelated research areas. There were three main steps in the searching process: (1) Defining the parameters of search by the language of publication, subject area, sector and subsector, geographical area, publication period and literature type. (2) Defining my search terms and building relations between them. The main method used in the second step were: brainstorming and relevance tree building. (3) Searching from online databases for full text, abstracts and indexes.

Rational selection and additional searching were performed by seeing relations between different publications. To some extent 'The snow bowl method' was used, meaning that finding one article and looking at the references for other sources led to finding other articles. The same procedure continued until there was no relevant article present in the last article reference. The method used in the literature was the systematic literature review analysis process. In this process, Booth et al. [73] describe procedures utilized as much as possible. The process involved a search for possible articles, followed by a selection of articles using a multi-stage evaluation process. This started with evaluation based on title, then evaluation based on abstract, then evaluation based on a reading of the whole article. That was followed by all the literature review process for four topics of literature review. These are Climate change, land uplift, water resources and seaside energy solutions. Figure 7 was taken from [74] to show the procedure used in systematic literature rereview for the land uplift framework chart development process as an example for one of the topics (land uplift). Similar procedures were used for the rest of the literature review reports.

Figure 7. A synthesis of research addressing land uplift, sea-level rise and their relationship. Chart showing the flow of the literature search and evaluation procedure. N = number of articles and books used for synthesis [74].

The criteria ultimately used to select a source to use were the relations between the title, abstract and/or full text and the topic that is intended to be reviewed. This means first we check the relation between the title and the topic to be reviewed if there is a clear relationship it will be taken to the next step. If no relation exists the article will be discarded. If a relation between title and topic exists, then the next step will be checking the relation between abstract and topic. If there is a relationship that exists it will pass to the next step to full-text relation checking. If no relation exists then the article will be discarded. In the last step, the full text and topic to be reviewed will be checked, and if there is a relation, it will be used in the literature review. If not, the article will be discarded. These were the steps used by criteria of the relation between the topic to be reviewed and different sections of articles/papers.

5.2. Ethical Issues

Hence, this work is not related to human contact and does not use humans as a data source which limits the ethical concerns of the study. The main ethical issue is a human concern about how to combat climate change and how to motivate them towards participation to combat it. The other ethical issue can be related to a literature review by avoiding plagiarism and recognizing all the work of others appropriately. This might be the main reason that references were included after all sentences that were not the idea of the author. All concerns of ethics are applied in this work not only in the literature review but in other sections of the whole study.

5.3. Analysis of the Gap in the Literature

Climate change effects as an advantage for energy solutions. This is one of the new ideas presented in this dissertation. Not only combating climate change and mitigating it but using changes due to climate change to our advantage. One example is using the increased water temperature in water bodies to extract heat with the water heat exchanger. The reason why filling this gap is important and interesting is because as far as climate change effects are present in our environment we have to use it to our advantage. This is one innovative way of solving the problem by using the consequences of the problem towards creating solutions. Introducing the new type of energy solutions, which uses climate change as an advantage for climate change combating is the research gaps. The water heat exchanger is a new solution for using water bodies as an energy source. This technology uses water temperature increases due to climate change to its advantage. The seaside solutions can represent one kind of gap in the field as well. There has been much study in the area of seaside solutions. Therefore, this study helps to fulfil the gap in information and technology in seaside energy solution kinds and uses. The lack of combating climate change with energy solutions and adaptation measures in local seaside areas by the education sector and local community is important as well. CO_2 emission reduction is addressed.

There are suggestions about energy solutions for CO_2 reduction in both books of [14,75]. The gap is that they did not suggest some energy solutions addressed here. For example, the new solutions suggested here are: a water heat exchanger, sediment energy, GEU (Groundwater energy utilization), wave energy, asphalt energy and boreholes. This is important and interesting in knowing the exact solutions to use in seaside areas. Land uplift and climate change combined forecasts in the local area. The reason why filling this gap is important and interesting is because the local effect can be surprising to locals if it is not analyzed in depth. Therefore, they know what to expect in the future. Additionally, the development of sediment heat energy by using climate change as an advantage is also suggested first in this paperwork and confirmed by [28].

One of the gaps in Rankiene et al. [76] article is that they only identified the phosphorus and nitrogen flux from climate and land use. However, this study tried to see behind phosphorus and nitrogen changes; we use all the available data on water quality parameters that are available from ELY-keskus, where they are the control center for the Kvarken area, the data was taken since 1962 at latest and most of the data started to be taken in other locations from 1974. Clear analysis of the effect of climate change on water quality and what kind of effects are expected in the future due to climate change in naturally kept areas such Kvarken archipelago is one of the research gaps that is not addressed. Addressing this gap helps us to see the exact effect of climate change on water quality without being influenced by human pollution and disturbance. The reason why filling this gap is important and interesting is because it is a new area of research, which is hardly addressed in depth in the local non-polluted area to identify the exact effect of climate change only.

The risks of renewable energy use and production to the environment have been touched on by [77]. In my studies, in addition to addressing the above risk, I tried to bring a new dimension, which is the risk of climate change to renewable energy resources. The reason why filling this gap is important and interesting is because the risk of climate change in renewable energy resources brings an eye-opening view of climate change risk and creates more initiation and awareness of people to actively combating climate change.

5.4. Related Works

The University of Vaasa renewable energy research group works on (1) Alireza Aslani's [78] PhD study performed on Nordic Renewable utilization and evaluation of renewable energy studies; (2) Pekka Peura's [79] PhD dissertation shows a start and development of sustainability and somehow the Energy Village concept and; (3) Anne Mäkiranta's [32] PhD dissertation about renewable energy solutions: sediment energy and asphalt energy had an influence and are the best-related works in our research group to my study. These dissertations contributed to this study on energy solution sources, Nordic renewable utilization ideas and sustainability guidance. Climate change studies were used and the most influencer-related work was IPCC studies [80–84] and TAR (third assessment report) which used quantitative evaluation. Risk analysis has one main contributor and related work of [77] on renewable energy risks to the environment. Land uplift had similar discoveries performed by [85], an article in land uplift and sea-level rise relation in the Vaasa area. Additionally, [86] studied Kvarken archipelago land uplift. Renewable energy was influenced by the related PhD study on the GEU (groundwater utilization) study by Arola [5].

Data analyses on climate change and water quality (limnology) areas background literature have been related and influenced by several wide ranges of resources. These are (1) Kauppila's [37] PhD study on water quality. (2) Räike et al.'s [87] water analysis study. (3) Korhonen's [88] PhD study in snow patterns in water systems. (4) Huck's [89] data analysis background book. (5) Helsel and Hirsch's [90,91] data analysis background book. (6) Hirsch et al.'s [91] trend analysis article. (7) Wetzel's [92] limnology book as the background of water science. (8) Fan and Shibata's [93] example of analysis between water quality land use and climate change scenarios. (9) Rankinen et al.'s [77] influence of climate and land use change on nutrient fluxes from Finnish rivers to Baltic sea. (10) Huttunen et al.'s [94] analysis of the effect of climate change. (11) Paudel et al.'s [95] water quality change in seasonal variation in root respiration. (12) Pearl's [96] what causality means source. (13) Ylhäisi et al.'s [97] precipitation analysis in Finland and. (14) Peura and Sevola's [98]) acidification in lakes of Kvaken archipelago in the Gulf of Bothnia (Finland and Sweden). These books, dissertations, articles and papers have been the main related documents in the area of my study.

5.5. Issues of Policy

Influencing Finland's energy policy by 2030, Finland plans for over 50% of all energy consumption to be shared from renewable energy. Moreover, 100% renewable energy is aimed at Finland in 2050, which is a more ambitious vision [99]. As described in Haukkala [99], it is important to ask who are the actors in the coalition and their core beliefs to analyze their impact on policy.

According to Haukkala [99], in Finland, the core motivation for energy transition is (1) concern for nature and care for the environment and (2) the need to find a new energy source to replace the use of fossil fuels. The Finnish green-transition coalition shares a vision that the whole countries run by renewable energy and includes NGOs and other clean energy organizations. These members might differ in opinions such as on the use and buildup of nuclear energy in Finland. Influenced by which type of energy use in companies will win, the same was noticed in Switzerland. The energy transition can take decades and should be accelerated due to the need for climate change mitigations. Policy in Finland is influenced somehow by green-transitions coalitions and the change in the community's view of renewable energy use. In addition, the green-transition coalition's impact weakened because of divergent views on the actual energy transition and its relations [99].

Based on Yao et al. [12], analyzing the life-cycle energy environmental impacts of emerging technology and promoting sustainable chemical production is critical. This is because policymakers can receive such assessments with useful insight for future technology and investment development. The framework developed in the ethylene industry by [12] can be used by researchers, environment/energy analysis, and by policymakers to evaluate various aspects of decisions.

According to IEA [4], effective policy toolkits must be built around five core areas to support clean energy transitions: (1) Tackle emissions from existing assets. (2) Strengthen markets for technologies at an early stage of adoption. (3) Develop and upgrade infrastructure that enables technology deployment. (4) Boost support for research, development and demonstration. (5) Expand international technology collaboration. These are the core areas of facilitating useful policy developments toward combating climate change by replacing fossil fuels with renewable energy resources.

Directorate-General [100] presents the 2020 vision of the EU concerning saving energy. They presented in this report the policy initiation and action plan for energy efficiency and saving. Directive 2002/91/EC [101] gives the policy on the energy performance of buildings. As stated in this policy: the objective of this directive was to promote the improvement of the energy performance of buildings within the community accounting for local indoor and outdoor climate conditions. Directive 2006/32/EC [102] policy aims to ''improve energy end-use efficiency which also contributes to the reduction in primary energy consumption, to the mitigation of CO_2 and other greenhouse gases emissions and thereby to the prevention of dangerous climate change. The aims of this directive are not only to continue to promote the supply side of energy services but also to create stronger incentives for the demand side".

Green paper [102] sketched out the bare bones of a long-term energy strategy in the EU. It is very scary that only 6% (including 2% just for hydroelectricity) of EU energy consumption is projected to be by 2030 based on [102]. There should be a lot of work on the use and policy developments towards using renewable in the EU and the whole world. The EU is still dependent on oil, natural gas is rising, coal and solid fuels dependency is expected to decline in the future and nuclear-expected phaseout in some nations, but some are still using it and even building new facilities in 2000 [103]. Supporting the need for energy in the EU, renewable energy is very essential to the security of the energy supply in Europe. However, these efforts can only become reality if they are supported by real policies of demand geared toward rationalizing and stabilizing energy consumption [103]. Hence, renewable energy must not be neglected because it is the only source of energy in which the EU has a certain amount of room to maneuver in supply [103].

Climate change and the establishment of a progressively integrated energy market are the new two factors that recently emerged during consideration for the future of European energy supply, especially options for its diversification [103]. The same paper says that to combat climate change, Europe has to set an example to the rest of the world by setting a strong policy aimed at reducing gas emissions as well as reducing oil dependency and transport energy efficiency because the biggest or 84% of CO_2 emissions in the EU is from transport. Thus, it is an important step in making a road to combating climate change. However, to tackle climate change, an ambitious policy should not endanger economic development [103]. SAVE and ALT-ENTER directives are important and must be initiated again in the future further even though they are implemented inefficiently in the EU in the past [103].

6. Conclusions

The relation between renewable energy and seaside energy solutions in this literature review report series is addressed. Seaside energy solutions were mainly proposed as renewable energy resources. This creates connections between seaside energy solutions and renewable energy resources. The most effective renewable seaside energy solutions were proposed and some installed. Among those, sediment heat energy production and water heat exchangers were the main solutions in this study.

Seaside energy solutions installed in water resources were appreciated and expected to use climate change effects on the water temperature increase to our advantage (sediment heat energy and water heat exchanger). Creating the connection between climate change effects as a heat energy source and water resources at the installation location. Using the climate change effects to our advantage leads to adaption, combating and mitigating climate change. Towards land uplift, their connection is renewable energy installation as seaside solutions faced difficulties because of land uplift. By causing the shoreline to increase towards the too deep sea and travel to islands become inaccurate by boat because the sea water becomes too shallow. The main conclusion of the overall literature series 1 up to 4 is that renewable energy can be used efficiently for the development of a region and even by using climate change effects to our advantage. This is a new way of solving problems by using the created climate change effects as a source of renewable energy production such as by using a water heat exchanger and/or sediment heat production.

The future direction is expanding the renewable energy knowledge and example projects to other nations such as Africa. For example, implementing the Energy Village concept in Africa by using the LEAP-RE project work package 14. The key conclusion of this review paper is that seaside renewable energy is mainly geo-energy and most of them use climate change effects to their advantage, such as sediment heat energy production. The main recommendation is to use the effects of climate change to combat and mitigate its causes and further consequences. The overall conclusions build on the relationships between different aspects of the topics. The paper contributes a precise current review of renewable energy. The novelty of this study is seeing a problem effect as an advantage to overcome the problem by itself. In other words, using the effects of climate change to our advantage and using it to generate seaside renewable energy resources to combat and mitigate it.

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References

1. Dincer, I. Renewable energy and sustainable development—A crucial review. *Renew. Sustain. Energy Rev.* **2000**, *4*, 157–175. [CrossRef]
2. Kruger, P. *Alternative Energy Resources—The Quest for Sustainable Energy*; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2006; p. 248. ISBN 10:0-471-77208-9.
3. Kamboj, A.; Chanana, S. Optimization of cost and emission in a renewable energy microgrid. In Proceedings of the 2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES), Delhi, India, 4–6 July 2016.
4. IEA. *Report on—Energy Technology Perspectives 2020*; International Energy Agency: Paris, France, 2020.

5. Arola, T. Groundwater as an Energy Resource in Finland. Ph.D. Dissertation, University of Helsinki, Department of Geosciences and Geography, Helsinki, Finland, 2015.
6. Aslani, A.; Naaranoja, M.; Wong, K.-F.V. Strategic analysis of diffusion of renewable energy in the Nordic countries. *Renew. Sustain. Energy Rev.* **2013**, *22*, 497–505. [CrossRef]
7. Aslani, A.; Helo, P.; Feng, B.; Antila, E.; Hiltunen, E. Renewable energy supply chain in Ostrobothnia region and Vaasa city—Innovative framework. *Renew. Sustain. Energy Rev.* **2013**, *23*, 405–411. [CrossRef]
8. Watzlf, G.R.; Ackman, T.E. Underground mine water for heating and cooling using geothermal heat pump systems. *Mine Water Environ.* **2006**, *25*, 1–14. [CrossRef]
9. Beecher, J.A.; Kalmbach, J.A. Climate change and energy. In *U.S. National Climate Assessment Midwest Technical Report*; Great Lakes Integrated Science and Assessments (GLISA): Ann Arbor, MI, USA, 2012; p. 15.
10. Girgibo, N. The effect of climate change on water and environment resources in the Kvarken Archipelago Area. In *University of Vaasa Reports 20*; University of Vaasa: Vaasa, Finland, 2021; p. 90. ISBN 978-952-476-941-9.
11. Gross, R.; Leach, M.; Bauen, A. Progress in renewable energy. *Environ. Int.* **2003**, *29*, 105–122. [CrossRef]
12. Yao, Y.; Masanet, E. Life-cycle modelling framework for generating energy and greenhouse gas emissions inventory of emerging technologies in the chemical industry. *J. Clean. Prod.* **2018**, *172*, 768–777. [CrossRef]
13. Shrestha, S.; Babel, M.S.; Pandey, V.P. *Climate Change and Water Resources*; Taylor & Francis Group, LLC: Boca Raton, FL, USA, 2014; p. 365. ISBN 978-1-4665–9466-1.
14. Hannah, L. *Climate Change Biology*; Elsevier Ltd.: Burlington, VT, USA, 2011; p. 402. ISBN 978-0-12-374182-0.
15. Hiltunen, E.; Martinkauppi, J.B.; Mäkiranta, A.; Rinta-Luoma, J.; Syrjälä, T. Seasonal temperature variation in heat collection liquid used in renewable, carbon-free heat production from urban and rural water areas. *Agron. Res.* **2015**, *13*, 485–493.
16. Hiltunen, E.; Martinkauppi, J.B.; Zhu, L.; Mäkiranta, A.; Lieskoski, M.; Rinta-Luoma, J. Renewable, carbon-free heat production from urban and rural water areas. *J. Clean. Prod.* **2017**, *153*, 379–404. [CrossRef]
17. Mäkiranta, A.; Martinkauppi, J.B.; Hiltunen, E. Correlation between temperature of air, heat carrier liquid and seabed sediment in renewable low energy network. *Agron. Res.* **2016**, *14*, 1191–1199.
18. Martinkauppi, J.B.; Mäkiranta, A.; Kiijärvi, J.; Hiltunen, E. Thermal behaviour of an asphalt pavement in the laboratory and in the parking lot. *Sci. World J.* **2015**, *2015*, 540934. [CrossRef]
19. Mäkiranta, A.; Hiltunen, E. Utilizing asphalt heat energy in Finnish climate conditions. *Energies* **2019**, *12*, 2101. [CrossRef]
20. Zhu, L.; Hiltunen, E.; Antila, E.; Zhong, J.; Yuan, Z.; Wang, Z. Micro-algal Biofuels flexible bio-energies for sustainable development. *Renew. Sustain. Energy Rev.* **2014**, *30*, 1035–1046. [CrossRef]
21. Hiltunen, E.; Girgibo, N.; Shandiz, M.H.; Martinkauppi, B.; Mäkiranta, A.; Nieminen, J. *Report on—Maailmanperintöportti Merten Talo: Esityksiä Energiaratkaisuiksi (27.04.2017)*; University of Vaasa, Technical Faculty, Electrical Engineering and Energy Technology Department: Vaasa, Finland, 2017; p. 17.
22. Mäkiranta, A. Distributed Temperature Sensing Method—Usability in Asphalt and Sediment Heat Measurement. Master's Thesis, University of Vaasa, Degree Programme in Electrical and Energy Engineering, Energy Technology, Vaasa, Finland, 2013.
23. Kattilakoski, I.-M. Bi-Directional Distributed Thermal Response Test (TRT). Master's Thesis, University of Vaasa, Dctionalegree Programme in Electrical and Energy Engineering, Energy Technology, Vaasa, Finland, 2017.
24. Banks, D. *An Introduction to Thermogeology—Ground Source Heating and Cooling*, 2nd ed.; Wiley-Blackwell Publishing Ltd.: Oxford, UK, 2012; ISBN 978-0-470-67034-7.
25. Jakhar, S.; Soni, M.S.; Gakkhar, N. Performance analysis of earth water heat exchanger for concentrating photovoltaic cooling. *Energy Procedia* **2016**, *90*, 145–153. [CrossRef]
26. Yang, W.; Li, S.; Zhang, X. Numerical simulation on heat transfer characteristics of soil around U-tube underground heat exchangers. In Proceedings of the International Refrigeration and Air Conditioning Conference, West Lafayette, IN, USA, 14–17 July 2008; p. 896. Available online: http://docs.lib.purdue.edu/iracc/896 (accessed on 11 September 2022).
27. Boudhiaf, R.; Baccar, M. Transient hydrodynamic, heat and mass transfer in a salinity gradient solar pond: A numerical study. *Energy Convers. Manag.* **2014**, *79*, 568–580. [CrossRef]
28. Girgibo, N.; Mäkiranta, A.; Lü, X.; Hiltunen, E. Statistical investigation of climate change effects on the utilization of the sediment heat energy. *Energies* **2022**, *15*, 435. [CrossRef]
29. Likens, G.E.; Johnson, N.M. Measurement and analysis of the annual heat budget for the sediment in two Wisconsin lakes. *Limnol. Oceanogr.* **1969**, *14*, 115–135. [CrossRef]
30. Mäkiranta, A.; Martinkauppi, J.B.; Hiltunen, E. Seabed sediment—A natural seasonal heat storage feasibility study. *Agron. Res.* **2017**, *15*, 1101–1106.
31. Mäkiranta, A.; Martinkauppi, J.B.; Hiltunen, E.; Lieskoski, M. Seabed sediment as an annually renewable heat source. *Appl. Sci.* **2018**, *8*, 290. [CrossRef]
32. Mäkiranta, A. Renewable Thermal Energy Sources: Sediment and Asphalt Energy Applications in an Urban Northern Environment. Ph.D. Dissertation, University of Vaasa, School of Technology and Innovations, Department of Electrical Engineering and Energy Technology, Energy Technology, Vaasa, Finland, 2020.
33. Golosov, S.; Kirillin, G. A parameterized model of heat storage by lake sediments. *Environ. Model. Softw.* **2010**, *25*, 793–801. [CrossRef]

34. Smith, P.N. Observations and simulations of water-sediment heat exchange in a shallow coastal lagoon. *Estuaries* **2002**, *25*, 483–487. [CrossRef]
35. Lowrie, W. *Fundamentals of Geophysics*, 2nd ed.; Cambridge University Press: Cambridge, UK, 2007; p. 393. ISBN -13-978-0-511-35447-2.
36. Heino, H. *Utilization of Wave Power in the Baltic Sea Region*; Finland Future Research Center (FFRC), University of Turku: Turku, Finland, 2013; ISBN 978-952-249-272-2. Available online: https://www.utu.fi/fi/yksikot/ffrc/julkaisut/e-tutu/Documents/eBook_9-2013.pdf (accessed on 11 September 2022).
37. Kauppila, P. Phytoplankton Quantity as an Indicator of Eutrophication in Finnish Coastal Waters—Application within the Water framework Directive. Monographs of the Boreal Environment Research 31. Ph.D. Dissertation, Finnish Environmental Institute, Helsinki, Finland, 2007.
38. Bernhoff, H.; Sjöstedt, E.; Leijon, M. Wave energy resources in sheltered sea areas—A case study of the Baltic Sea. *Renew. Energy* **2006**, *31*, 2164–2170. [CrossRef]
39. de Andres, A.; Guanche, R.; Vidal, C.; Losada, I.J. Adaptability of a generic wave energy converter to different climate conditions. *Renew. Energy* **2015**, *78*, 322–333. [CrossRef]
40. Rajasree, B.R.; Deo, M.C.; Sheela Nair, L. Effect of climate change on shoreline shifts at a straight and continuous coast. *J. Estuar. Coast. Self Sci.* **2016**, *183*, 221–234. [CrossRef]
41. Yle News. Sukeltajan Keksinnöstä Hiotaan Vientituotetta—Wärtsilä Alkaa Toimittaa Suomalaisia Aaltovoimaloita Maailmalle/The Diver's Invention is Blown into Export Product—Wärtsilä Starts Delivering Finnish Wave Power Plants to the World. 2017. Available online: https://yle.fi/uutiset/3-9871175 (accessed on 10 September 2022).
42. Haq, H.M.K.U.; Martinkauppi, B.; Hiltunen, E. Storing asphalt energy into bedrock heat battery system. *Int. J. Energy Environ.* **2016**, *10*, 137–141.
43. Martinkauppi, B.; Mäkiranta, A.; Hiltunen, E. PCA analysis of distributed temperature sensing data from an asphalt field. In Proceedings of the 5th International Conference on Renewable Energy Research and Applications (ICRERA), Birmingham, UK, 20–23 November 2016.
44. Çuhac, C.; Mäkiranta, A.; Välisuo, P.; Hiltunen, E.; Elmusrati, M. Temperature measurements on a solar and low enthalpy geothermal open-air asphalt surface platform in a cold climate region. *Energies* **2020**, *13*, 979. [CrossRef]
45. Grant, M.A.; Bixley, P.F. *Geothermal Reservoir Engineering*, 2nd ed.; Elsevier Inc.: Massachusetts, CA, USA, 2011; ISBN 978-0-12-383880-3.
46. Girgibo, N. *Report on Groundwater and Aquifers in Vaasa Region: Using Groundwater as Energy Source*; University of Vaasa: Vaasa, Finland, 2022; Volume 67, p. 2014.
47. Haq, H.M.K.U.; Martinkauppi, B.; Hiltunen, E. Analysis of ground heat exchanger for a ground source heat pump: A study of an existing system to find optimal borehole length to enhance the coefficient of performance. *WSEAS Trans. Heat Mass Transf.* **2017**, *12*, 38–47.
48. Haq, H.M.K.U.; Hiltunen, E. An inquiry of ground heat storage: Analysis of experimental measurements and optimization of system's performance. *Appl. Therm. Eng.* **2019**, *148*, 10–21. [CrossRef]
49. Martinkauppi, J.B.; Syrjälä, T.; Mäkiranta, A.; Hiltunen, E. A preliminary test for using a borehole as cool storage. In Proceedings of the 14th Conference on Sustainable Development of Energy, Water and Environment Systems, Dubrovnik, Croatia, 1–6 October 2019.
50. Ali, M.H. *Wind Energy Systems: Solutions for Power Quality and Stabilization*; Taylor & Francs Group, LLC: New York, NY, USA, 2012.
51. Cherp, A.; Vinichenko, V.; Jewell, J.; Suzuki, M.; Antal, M. Comparing electricity transitions: A historical analysis of nuclear, wind and solar power in Germany and Japan. *Energy Policy* **2017**, *101*, 612–628. [CrossRef]
52. Brännbacka, B. Technical Improvements of Wind-side Wind Turbine Systems. Ph.D. Dissertation, University of Vaasa, Vaasa, Finland, 2015.
53. Marmutova, S. Performance of a Savonius Wind Turbine in Urban Sites Using CFD Analysis. Ph.D. Dissertation, University of Vaasa, Vaasa, Finland, 2016.
54. Zhou, W.; Deng, H.; Yang, P.; Chu, J. Investigating of microstructure and optical properties of (K, Ba) (Ni, Nb)O3-δ thin film fabricated by pulsed laser deposition. *Mater. Lett.* **2016**, *181*, 178–181. [CrossRef]
55. Wallenius, D. Yle news (12 November 2017): The Hygrometer Collects Three Types of Energy. *Yle News*, 12 November 2017.
56. Bai, Y.; Siponkoski, T.; Peräntie, J.; Jantunen, H.; Juuti, J. Ferroelectric, pyroelectric, and piezoelectric properties of a photovoltaic perovskite oxide. *Appl. Phys. Lett.* **2017**, *110*, 063903. [CrossRef]
57. Kneifel, J.; O'Rear, E.; Webb, D.; O'Fallon, C. An exploration the relationships between improvements in energy efficiency and life-cycle energy and carbon emissions using the BIRDS low-energy residential database. *Energy Build.* **2018**, *160*, 19–33. [CrossRef] [PubMed]
58. Li, H.; Liu, H.; Ji, A.; Li, F.; Jia, Y. Design of a hybrid solar-wind powered charging station for electric vehicles. In Proceedings of the 2013 International Conference on Materials for Renewable Energy and Environment, Chengdu, China, 19–21 August 2013.
59. Bogdanov, D.; Farfan, J.; Sadovskaia, K.; Aghahosseini, A.; Child, M.; Gulagi, A.; Oyewo, A.S.; Barbosa, L.d.S.N.S.; Breyer, C. Radical transformation pathway towards sustainable electricity via evolutionary steps. *Nat. Commun.* **2019**, *10*, 1077. [CrossRef] [PubMed]
60. Ministry of Employment and Economy. *Energy and Climate Roadmap 2050: Report of the Parliamentary Committee on Energy and Climate Issues on 16 October 2014*; Finland's Ministry of Employment and Economy: Helsinki, Finland, 2014; ISBN 978-952-227-906-4.

61. Sukhatme, S.P. *Solar Energy—Principles of Thermal Collection and Storage*, 2nd ed.; Tata McGraw-Hill: New Delhi, India, 1996; p. 426. ISBN 0-07-462453-9.
62. Huggins, R.A. *Energy Storage—Fundamentals, Materials and Applications*; Springer International Publishing: Cham, Switzerland, 2016; p. 509. ISBN 978-3-319-21238-8/978-3-319-21239-5.
63. Hauer, A. *Thermal Energy System: Technical Brief*; IEA-ETSAP and IRENA: Abu Dhabi, United Arab Emirates, 2013.
64. Wu, C.-T.; Feng, C.-L.; Tsai, Y.-H. Application of an ice thermal energy storage system as ways of energy management in a multi-functional building. *J. Renew. Sustain. Energy* **2015**, *7*, 023107. [CrossRef]
65. Venkataramani, G.; Ramalingam, V. Performance analysis of a small capacity compressed air energy storage system for renewable energy generation using TRNSYS. *J. Renew. Sustain. Energy* **2017**, *9*, 044106. [CrossRef]
66. Seibt, P.; Kabus, F. Aquifer Thermal Energy Storage-Project Implemented in Germany. Available online: http://talon.stockton.edu/eyos/energy_studies/content/docs/FINAL_PAPERS/4A-1.pdf (accessed on 10 September 2022).
67. Sunliang, C. State of the Art Thermal Energy Storage Solutions for High-Performance Buildings. Master's Thesis, Jyväskylä University, Jyväskylä, Finland, 2010; p. 201.
68. Xiao, J.; Yang, H.; Bénard, P.; Chahine, R. Numerical study of thermal effects in cryo-adsorption hydrogen storage tank. *J. Renew. Sustain. Energy* **2013**, *5*, 021010. [CrossRef]
69. Banks, D. *An Introduction to Thermogeology—Ground Source Heating and Cooling*; Blackwell Publishing Ltd.: Oxford, UK, 2008; ISBN 978-1-4051-7061-1.
70. Worthington, M.A. Aquifer Thermal Energy Storage—Feasibility Study Process and Results for District Energy Systems. Conference Presentation. In *IDEA's Annual Campus Energy Conference: Innovation in Clean Energy*; Underground Energy, LLC: Arlington, VA, USA, 2012; p. 37.
71. Final Report. In *The Project ''Drop in Sea": The Equity-Sufficient Integrated Hybrid-Energy Solutions and a Meeting—Concept Research and Development Program*; University of Vaasa: Vaasa, Finland, 2011.
72. Flake. Flake Model for Global Lakes Model. 2019. Available online: http://www.flake.igb-berlin.de/ (accessed on 10 September 2022).
73. Booth, A.; Papaioannou, D.; Sutton, A. *Systematic Approaches to a Successful Literature Review*; SAGE Publications Ltd.: London, UK, 2012; ISBN 978-0-85702-134-2.
74. Girgibo, N.; Lü, X.; Hiltunen, E.; Peura, P.; Yang, T.; Dai, Z. A conceptual framework for the future of sea-level rise and land uplift changes in the Vaasa region of Finland. *SCIREA J. Geosci.* **2022**, *6*, 23–57. [CrossRef]
75. Pirilä, P. *Climate Change—Socioeconomic Dimensions and Consequences of Mitigation Measures*; EDITA Ltd.: Helsinki, Finland, 2000; p. 392. ISBN 951-37-2926-5.
76. Rankinen, K.; Keinänen, H.; Cano Bernal, J.E. Influence of climate and land use changes on nutrient fluxes from Finnish rivers to the Baltic Sea. *Agric. Ecosyst. Environ.* **2016**, *216*, 100–115. [CrossRef]
77. Holma, A.; Leskinen, P.; Myllyviita, T.; Manninen, K.; Sokka, L.; Sinkko, T.; Pasanen, K. Environmental impacts and risks of the national renewable energy targets—A review and a qualitative case study from Finland. *Renew. Sustain. Energy Rev.* **2018**, *82*, 1433–1441. [CrossRef]
78. Aslani, A. Evaluation of Renewable Energy Development in Power Generation. Ph.D. Dissertation, University of Vaasa, Vaasa, Finland, 2014.
79. Peura, P. From Unlimited Growth to Sustainable Energy: The Origin of Operational Patterns by Means of Social Selection. Ph.D. Dissertation, University of Vaasa, Vaasa, Finland, 2013; p. 188.
80. IPCC. *Climate Change 2007—The Physical Science Basis*; Cambridge University Press: New York, NY, USA, 2007; p. 996. ISBN 978-0-521-88009-1.
81. IPCC. *Climate Change 2013—The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: New York, NY, USA, 2013; p. 1535. ISBN 978-1-107-05799-9.
82. IPCC. *Climate Change 2014—Synthesis Report*; World Metrological Organization (WMO): Geneva, Switzerland, 2014; p. 151. ISBN 978-92-9169-143-2.
83. IPCC. *Special Report on the Ocean and Cryosphere in a Changing Climate*; Pörtner, H.-O., Roberts, D.C., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., Mintenbeck, K., Nicolai, M., Okem, A., Petzold, J., et al., Eds.; Cambridge University Press: New York, NY, USA, 2019.
84. IPCC. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group—I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR6 WGI)*; United Nations Environment Programme: Nairobi, Kenya, 2021.
85. Nordman, M.; Peltola, A.; Bilker-Koivula, M.; Lahtinen, S. Past and future sea level changes and land uplift in the Baltic Sea seen by geodetic observations. In *International Association of Geodesy Symposia*; Springer: Berlin/Heidelberg, Germany, 2020. [CrossRef]
86. Poutanen, M.; Steffen, H. Land uplift at Kvarken Archipelago/high-cost UNESCO World Heritage area. *Geophysica* **2014**, *50*, 49–64.
87. Räike, A.; Taskinen, A.; Knuuttila, S. Nutrient from Finnish rivers into the Baltic Sea has not decreased despite water protection measures. *Ambio* **2020**, *49*, 460–474. [CrossRef]
88. Korhonen, J. Long-Term Changes and Variability of the Winter and Spring Season Hydrological Regime in Finland. Report Series in Geophysics No. 79. Ph.D. Dissertation, University of Helsinki, Helsinki, Finland, 2019; p. 82.
89. Huck, S.W. *Reading Statistics and Research*, 6th ed.; Pearson Education, Inc.: Boston, MA, USA, 2012; ISBN 0-13-265909-3/978-0-13-265909-3.

90. Helsel, D.R.; Hirsch, R.M. *Statistical Methods in Water Resources*; U.S. Geological Survey: Reston, VA, USA, 2002.
91. Hirsch, R.M.; Slack, J.R.; Smith, R.A. Techniques of trend analysis for monthly water quality data. *Water Resour. Res.* **1982**, *18*, 107–121. [CrossRef]
92. Wetzel, R.G. *Limnology—Lakes and River Ecosystems*, 3rd ed.; Elsevier Science (USA): San Diego, CA, USA, 2001; p. 1006. ISBN 0-12-744760-1.
93. Fan, M.; Shibata, H. Simulation of watershed hydrology and stream water quality under land use and climate change scenarios in Teshio River Watershed, Northern Japan. *Ecol. Indic.* **2015**, *250*, 79–89. [CrossRef]
94. Huttunen, I.; Lehtonen, H.; Huttunen, M.; Piirainen, V.; Korppoo, M.; Veijalainen, N.; Viitasalo, M.; Vehviläinen, B. Effects of climate change and agricultural adaptation on nutrient loading from Finnish catchments to the Baltic Sea. *Sci. Total Environ.* **2015**, *529*, 168–181. [CrossRef]
95. Paudel, I.; Bar-Tal, A.; Rotbart, N.; Ephrath, J.; Cohen, S. Water quality changes seasonal variations in root respiration, xylem CO_2, and sap pH in citrus orchards. *Agric. Water Manag.* **2018**, *197*, 147–157. [CrossRef]
96. Pearl, J. *Causality—Model, Reasoning and Influence*; Cambridge University Press: New York, NY, USA, 2009; ISBN 978-0-521-89560-6.
97. Ylhäisi, J.S.; Tietäväinen, H.; Peltonen-Sainio, P.; Venäläinen, A.; Eklund, J.; Räisänen, J.; Jylhä, K. Growing season precipitation in Finland under recent and projected climate. *J. Nat. Hazards Earth Syst. Sci.* **2010**, *10*, 1563–1574. [CrossRef]
98. Peura, P.; Sevola, P. Acidification mosaic of small lakes. A study on 81 lakes in the Kvarken, Gulf of Bothnia (Finland and Sweden). *Aqua Fenn.* **1992**, *22*, 153–171.
99. Haukkala, T. A struggle for change—The formation of a green-transition advocacy coalition in Finland. *Environ. Innov. Soc. Transit.* **2018**, *27*, 146–156. [CrossRef]
100. European Commission. Directorate-General for Energy and Transport. In *2020 Vision: Saving Our Energy*; Office for Official Publications of the European Communities: Luxembourg, Luxembourg, 2007; ISBN 92-79-03629-7.
101. European Union. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. In *Official Journal of the European Communities*; European Union: Brussels, Belgium, 2003.
102. European Union. Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC (Text with EEA relevance). In *Official Journal of the European Communities*; European Union: Brussels, Belgium, 2006.
103. European Commission. Towards a European strategy for the security of energy supply. In *Green Paper*; Publications Office of the European Union: Luxembourg, Luxembourg, 2000.

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The air temperature change effect on water quality in the Kvarken Archipelago area

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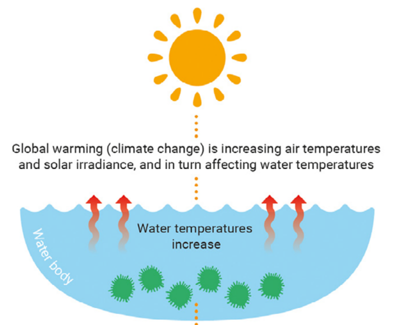
HIGHLIGHTS

- Climate change increase air, water and chlorophyll-a concentration in a few months.
- Climate change effect is seen in air temperature influencing water temperature.
- Water temperature and other parameters influenced chlorophyll-a concentration.
- An indirect effect of air temperature on chlorophyll-a concentration is shown.
- Understanding what kind of changes can be seen in water systems is important.

GRAPHICAL ABSTRACT



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ABSTRACT

The Kvarken Archipelago is Finland's World Heritage site designated by UNESCO. How climate change has affected the Kvaken Archipelago remains unclear. This study was conducted to investigate this issue by analyzing air temperature and water quality in this area. Here we use long-term historical data sets of 61 years from several monitoring stations. Water quality parameters included chlorophyll-a; total phosphorus; total nitrogen; coliform bacteria thermos tolerant; temperature; nitrate as nitrogen; nitrite-nitrate as nitrogen, and Secchi depth and correlations analysis was conducted to identify the most relevant parameters. Based on the correlation analysis of weather data and water quality parameters, air temperature showed a significant correlation with water temperature (Pearson's correlations = 0.89691, $P < 0.0001$). The air temperature increased in April (R^2 (goodness-of-fit) = 0.2109 & P = 0.0009) and July (R^2 = 0.1207 & P = 0.0155) which has indirectly increased the chlorophyll-a level (e.g. in June increasing slope = 0.39101, R^2 = 0.4685, $P < 0.0001$) an indicator of phytoplankton growth and abundance in the water systems. The study concludes that there might be indirect effects of the likely increase in air temperature on water quality in the Kvarken Archipelago, in particular causing water temperature and chlorophyll-a concentration to increase at least in some months.

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1. Introduction

Climate change is expected to influence the study area, the Kvarken Archipelago near Vaasa, Finland (Arau'jo et al., 2011). The effect of climate change is displayed mainly through weather pattern changes with seasonal variations. Among those air and water temperatures are expected to rise (Kupiainen et al., 2019). In addition, the same study states that there are expectations of erosion, flooding, land uplift (unique effect in this area) (Girgibo et al., 2022b), strong wind, weather conditions change, the water level rising, precipitation expected to rise and snow depth to decline. Seasonal fluctuation and variations are expected to change for most weather conditions over time (Saranko et al., 2020). Moreover, the other effect of climate change on water systems is indicated by sea level rise (Girgibo et al., 2022b). The importance of this paper is that the investigation of air temperature change's effect on water quality helps understand what kind of changes can be seen in water systems and in what pattern they appear to some extent.

Water quality continuous monitoring has several parameters. In this paper, we are interested in the following parameters Chlorophyll-a (Chl-a), Phosphorous (TP), Secchi depth, Turbidity and water temperature. Chlorophyll-a, as a measure of phytoplankton biomass, is the most often used indicator for quantifying eutrophication by measuring the trophic status of a water body (Kauppila (2007)). Chl-a in water quality analysis is important and is the centre of most parameters' influence. According to Kauppila (2007), using chl-a for water quality assessment, compared to phytoplankton identification and biomass, is cheap and fast for analysis. On the other hand, she described that phytoplankton biomass and species composition estimate could reveal more aspects of eutrophication than chl-a alone, providing more ecological classification metrics. Phosphorous (TP) usually appears in water due to different pollution sources and/or exported from other areas. The actual TP export to the Baltic Sea has remained the same for several years (Räike et al., 2019). Several rivers have shown a decrease in TP because of the discrepancy between the non-normalized and flow-normalized TP, partially due to various mitigation measures to decrease TP concentrations.

Turbidity is a measure of water's cloudiness or lack of clarity resulting from suspended particles or suspensions Wetzel (2001). In technical terms, turbidity is a measure of how much light passes through water and scatter light produced turbidity, which is caused by suspended solid particles (Water-Quality, 2008). Water turbidity restricts the growth of phytoplankton and light penetration limitations in maxima turbidity conditions Kauppila (2007). The type of particles can be microscopic plankton, stirred-up sediment or organic material, eroded soil, clay, silt, sand, industrial waste or sewage (Water-Quality, 2008). In addition, there are several reasons why bottom sediment may be stirred up. Such as waves or currents, bottom-feeding fish, people swimming or wading, or storm runoff (Water-Quality, 2008). In Kauppila (2007) study, the Secchi depth accounts for 16 to 89 % of the variation in chlorophyll-a in Finnish coastal waters and outer water with small chlorophyll-a concentrations. Secchi disk transparency is the mean depth of the point where a weighted white disk, 20 cm in diameter, disappears in water when seen at the top of the water level and reappears when raising Wetzel (2001).

Seasonal variation can affect the level of Secchi disk depth level. The Secchi disk transparencies observation ranges from a few centimetres in turbid waters to 40 m in rare clear lakes (Wetzel, 2001). There is no direct inverse relationship between Secchi depth data with diffuse light attenuation. On other hand, water temperature influences the aquatic species in water bodies. Water's specific heat and thermal energy properties help species survive more easily because water temperature changes happen more slowly in water systems. Climate change influences the water temperature by producing more sun irradiances and higher air temperatures. Climate change is caused by mainly human influences when using fossil fuels for energy sources in different activities.

Climate change has significant impacts on water quality worldwide. Kernan et al. (2010) investigated freshwater ecosystems and found that the biosphere and hydrology cycle are stitched together by freshwater systems. Freshwater systems are a very vulnerable part of the hydrosphere. Climate change will inevitably upset the schemes of aquatic ecosystems as species become eliminated or new ones move into previous cooler habitats (Kernan et al., 2010). Based on these theories, different water quality variables have been studied to assess the impact of climate change. Liu and Wang (2022) investigated the arctic water quality in different rivers by analyzing the total suspended solids in the rivers. Li et al. (2022) investigated the effect of precipitation and Nitrogen on soil microbes. Winder and Schindler (2005) confirmed the influence of climate change on water systems and their species (see also Choo and Taskinen (2015), and Meerhoff et al. (2007)). de Mour et al. (2017) investigated a eutrophic lake located in Central Brazil during a bloom of filamentous cyanobacteria (*Geilterinema amphibium*) by exploring the changes of Chlorophyll-a (Chl-a) concentrations. Kraemer et al. (2022) studied the water qualities for 344 globally distributed large lakes during 1997–2020 using 742 million chlorophyll-a (chl-a) estimates with 6 satellite sensors. Other selected parameters are total phosphorus, total nitrogen, coliform bacteria thermos tolerant, temperature, nitrate as nitrogen, nitrite-nitrate as nitrogen, and Secchi depth.

Bothnian Bay is located in the Gulf of Bothnia and the Kvarken Archipelago is located inside the area of Bothnia Bay. The Kvarken Archipelago is Finland's World Heritage site designated by UNESCO. The purest water in Finland has been universally acknowledged (Ahmed, 2019). A few studies investigated pollution cofounding factors of climate change impacts, for example, hydraulic engineering and sediment technology constructions ((Girgibo et al. (2022a) and Girgibo (2022)), sediment phosphorus (TP) content (Mäkelä, 1986), phosphorus and nitrate trends Fonsellius (1986) and species conditions (Meriläinen (1984), Begge and Meriläinen (1985) and Meriläinen (1988). TP was found to reflect the intensity of engineering around the Kvarken Archipelago area, although TP content can be elevated by floods (Mäkelä, 1986). The same study reported that the first extensive dredging operation revealed an increase of organic carbon in sediment. Several climate/weather factors can affect the mitigation of total TP pollution. According to Fonsellius (1986), there were increasing total phosphorus and nitrate trends in the Gulf of Bothnia, but the phosphate values in Bothnian Bay are extremely low all year round. Furthermore, part of the phosphate in Bothnian Bay might be arsenic: there is a metal ore-smelting plant on the Swedish side of the bay that has been associated with emissions of arsenic. Nitrate concentrations in Bothnian Bay are usually high (Fonsellius, 1986). No significant changes in phytoplankton and chlorophyll-a during the years 1969–1975 and 1979–1983 have been found in the Gulf of Bothnia (Huttunen et al., 1986). The authors of that study recommended that these years´ measurements can serve as a reference period for future studies. After the 1980s there have been improvements in the water quality. Especially, in the Kvarken Archipelago is an unpolluted area at least since the UNESCO protections (Peura and Sevola (1992), Hietikko-Hautala (2012)). This paper extends these studies by collecting much richer data from 61 years from several monitoring stations to investigate the air temperature change effect on water quality in the Kvarken Archipelago in Bothnian Bay. The objective of this paper is to address the following questions:

– Has air temperature change affected well-protected areas like the Kvarken Archipelago? If so, how have these changes impacted water quality? And what are the consequences of water quality variables such as Chl-a concentrations?
– How does the Chl-a level vary over time due to weather effects influenced by climate change? How do changes in other nutrient levels affect Chl-a?

The answers to these research questions will help identify the exact effects of air temperature change on water quality. This study was undertaken to assess expected changes in water quality using long-term historical water quality and climate data. The analysis methods used were mainly Pearson's correlations, linear and multi-regression. Other supporting analyses method were basic statistics, such as normality of data check, skewness and kurtosis interpretation. Our investigation based on these methods indicates that there is a likely effect of air temperature change in a few months on water quality even in the Kvarken Archipelago area. The significance of the study is showing the effect of air temperature change on water quality in the Kvarken Archipelago in a naturally protected area. This shows that the local effects of climate change might differ from the world's expectations.

2. Methods and materials

Fig. 1 illustrates the flow chart of the analysis methods used in this paper. There had been several analyses were conducted which can be classified into data collection, data selection, preliminary analyses, trend analyses and main analyses. Data collection's various section purposes were answering the research questions, getting useful data, protecting and managing the data during the research lifetime and cleaning data, checking its usability and quality. The limitations and drawbacks of the data collection steps were the limited data type present in the local area, taking a very long time to gather the data, not being able to follow it all the time forced to share our data a few times and data combinations generating short data for the most sampling points. The data selection has two major steps: selecting parameters that reflect the best water quality conditions based on limnology theories and using statistically significant relations. These step limitations can focus only on a few parameters with enough data length and only four relations between Chl-a and water quality parameters; air and water temperature were statistically significant.

The preliminary analyses are required to see the water quality status, check the quality of data, see the changes through time, identify the water quality status, and find out the relationships between parameters. Its limitations were, some summary data show wrong results due to outliers in the data, mean trimming was required to see some correct results and too many analysis results cannot be reported in one article. Trend analyses and main analyses have the purposes of investigating the air temperature change effect on the Kvarken Archipelago, investigating the change in water quality data, finding out whether air temperature change influenced water quality data, checking causality relations and trend analyses. These analysis limitations were short data sets and only air temperature able to be used as an indicator of climate change effect among weather change influencers, little water quality variables were able to be used, and no causality was able to be confirmed.

2.1. Data collection and sampling sites

The Kvarken Archipelago is located inside the area of Bothnian Bay. The Gulf of Bothnia comprises the Åland Sea, the Archipelago Sea, the Southern

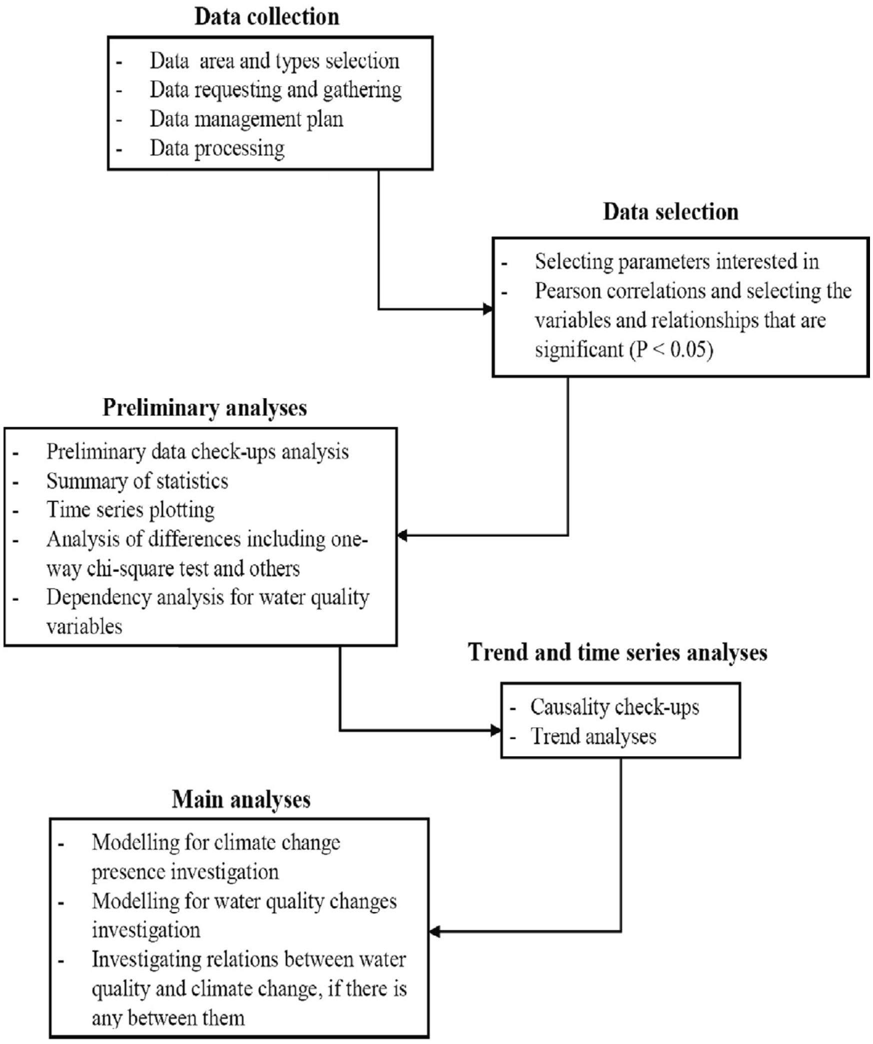

Fig. 1. Flow chart illustrating the analysis methods used.

Quark, the Bothnian Sea, the Quark and the Bothnian Bay (Fonsellius, 1986). The Kvarken Archipelago is a coastal area and archipelago on the east coast of Sweden and the west coast of Finland. The sampling area was around the Kvarken Archipelago in Bothnian Bay, adjacent to the city of Vaasa in western Finland. Fig. 2 illustrates the locations of the six sampling points and the two weather stations for weather data. This study's sampling points are located in Bothnian Bay, close to the Kvarken Archipelago area. The area is far away from the nearest emission sources and relatively unaffected by industrialisation, so its nature is well-preserved (Peura and Sevola, 1992).

Most of the sampling points of water type lie between seawater and inland water mainly these sampling areas are connected to seawater. The analysis standard that was applied was that for seawater, as determined by Suomen Ympäristökeskus (SYKE), the Finnish Environment Institute (Table 2 in supplementary materials). The choice of the seawater standard is logical because all the water samplings are located in seawater. The seawater standard was also applied at the Et. Kaupa 1 (Eteläinen Kaupungin Lahti) site (3f in Fig. 2), even though it is very near to the land. The seawater standard limits are numerically lower, for example in Chl-a than that for inland water. Merten talo (the House of Sea) was a renewable energy installation the project site was presented here because it was a central element for other whole research, which is why the water sampling points builds around it. Now on, Et. Kaupa 1 site is called the 3 f water sampling site. The nearest location 3 f was chosen as a representative sampling site because 1) it is inland water; 2) it has the poorest water quality; 3) it has the longest data compared to the rest of the sampling points; and 4) it has the shortest distance to the weather station. The important reason was that this sampling point was the worst thus any finding can be better than this sampling point result in the same nearby areas. This means any finding from the protected area can be expected to be better so 3 f can show the worst expectations. Other factors can affect the sampling (3f) point. Thus, good exceptions can be found in the protected area, but they cannot be worse than 3 f.

The weather data were gathered from two weather stations over two periods (1959–2011 and 1959–2019) consisting of precipitation amount [mm], snow depth [cm] and air temperature [°C].

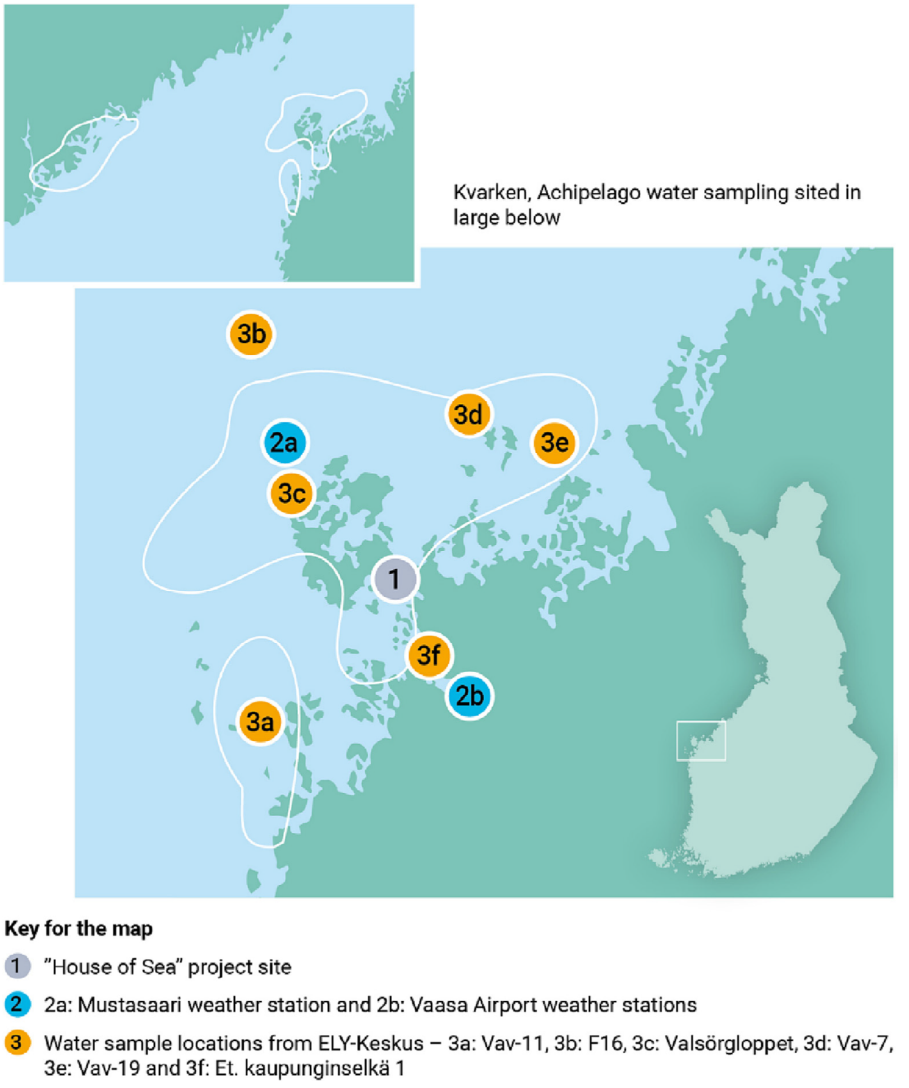

Fig. 2. The map shows the water sampling points, weather stations and the study area. The High Coast/Kvarken Archipelago UNESCO World Protected Site (inside the white line borders). All sampling points near the Kvarken, Archipelago and most inside UNESCO-protected areas (the copyrights of the figure belong to the University of Vaasa, Maria Hällund).

Water quality data were gathered over the period of (1974–2017) including chlorophyll-a [μg/l], total phosphorus, unfiltered [μg/l]; total nitrogen, unfiltered [μg/l]; coliform bacteria thermos tolerant [kpl/100 ml]; temperature [°C]; nitrate as nitrogen, unfiltered [μg/l]; nitrite-nitrate as nitrogen, unfiltered [μg/l], and Secchi depth [m].

The process of sampling in data collection passed through several development processes and specific procedures. No clear sampling procedures are described in the references given to us by ELY-keskus as procedure references. All the collected data qualities were checked and the high-quality datasets from the sampling point 3 f and the Vaasa airport weather station were chosen for analysis. Data processing was done. The two main data processing were removing outlier data and adding missing values were also done during some stages.

2.2. Selections of variables

Pearson's correlation (product-moment correlation) is the data analysis tool to study statistical dependency. The null hypothesis is H_o: the population correlation is zero (= there is no linear relationship). The alternative hypothesis is H_1: the population correlation is not zero. Pearson correlation analysis was conducted between chlorophyll-a and water quality data variables with significant correlations (probability $P < 0.05$), which were chosen to further model the relationships. The chosen water quality and weather variables are total phosphorus (TP), Secchi depth, time (month), turbidity and air temperature vs. water temperature. These selected variables are relevant because they are the basic indicators of changes in water systems and quality. Another reason most of the other parameters were excluded is that while combining the data, only these basic selected variables had enough continuous data to be used in statistical analyses.

2.3. Model eqs

A linear model is performed to test the significance of the temporal changes in the variables:

$$\hat{y} = a_1 + a_{2*}\ \text{year}$$

where, $\hat{y}$ = predicted variable, a_1 = intercept and a_2 = slope.

SAS Enterprise Guide 7.1. the software was used to calculate the *p*-value and $p \leq 0.05$ rejects the null hypothesis that there is no significance between the two variables.

3. Results

3.1. Preliminary analyses results

3.1.1. Descriptions of data and summary of statistics

Table 1 below lists the key water-quality parameters' mean and standard deviation values for all six sampling points. Variations in values are highly influenced by the sampling period, which is very different at each sampling point. Thus, a slight bias may be introduced because we're not comparing the same number of samples for each point. Among the mean values, the TP and most of the nitrogen analyses show higher values for the 3 f sampling point. This might indicate some kind of local pollution or the influence of the nearby city of Vaasa and the surrounding land. Additionally, the standard deviations of sampling point 3 f show much higher values for most parameters. This suggests the sampling point is affected by its surrounding area or incoming pollution sources. The mean values of the parameters in (Table 1) are compared with the SYKE seawater standard (Table 2 in supplementary materials) later in this discussion of the results, but at this point, the most notable observation is the very high turbidity value at the 3 f sampling point.

These data validate the decision to focus in this analysis on a single sampling point to represent all six points. 3 f has the highest mean and standard deviation values (Table 1), so if this sampling point satisfies the water quality standard, the others will be accepted without further analysis. Furthermore, 3 f is more or less inland water (see Fig. 2) and thus may be expected to exhibit poorer water quality indicators than seawater. The SYKE standard (Table 2 in supplementary materials) illustrates the key differences between expected water quality in lakes/rivers and seawater. Therefore, we are using the worst-case scenario by using 3 f as a single representative sampling point and applying the seawater SYKE standard. The logical descriptive way of comparing and choosing the representative sampling point was done during the statistical analyses.

3.1.2. Water quality and weather data (climate change) variation time series plotting

3.1.2.1. Water quality time series plots. The water-quality variables for the 3f sampling point presented in the following time series are chlorophyll-a, nitrite-nitrate-as-N, coliform bacteria and all-weather data variables. These are depicted in Figures (Figs. 1–3 in supplementary materials): time series data for all the weather parameters are presented in other analysis reports.

Chlorophyll-a time series data shows a clear increase through time (Fig. 1 in supplementary material). This might be due to an increase in nutrients and water temperature through time, most probably influenced or even caused by climate change effects. Some anomalies appear in the years 1980, 1982, 1989, 1993, 2008–2010, 2013 and 2015. Fig. 1 in supplementary materials, also presents the chlorophyll-a (μg/l) time series, but with three- and five-point smoothing for the data. These two data-smoothing tools make the increase in chlorophyll-a through time even more apparent. This merits investigation, particularly about the possibility of a causal link to climate change. The Kvarken Climate Change report (Girgibo, 2021) stated that no algae are blooming near Merten Talo (House of the Sea) in the UNESCO heritage area. Nevertheless, there is a clear increase in chlorophyll-a in this area. The 3 f sampling point is 31 km from the House of the Sea project site, so may show different water characteristics. Pastuszak et al. (2018) observed that "eutrophication can happen even in low phytoplankton level waters," so eutrophication may be present in this area, even if there is less Chl-a concentration.

Plots of phosphorus show that this parameter also seems to be increasing through time, with a notable anomaly in the early 1980s. There is a similar anomaly seen in nearly all the graphs of water-quality parameters, which is most probably due to the effect of the 1970 -1980s industrial revolution. The TP level has been growing since 2000, possibly due to the effect of climate change. There is some similarity between the growth of chlorophyll-a and TP through time. This may also show that the TP is affecting the Chl-a concentration. However, the forecast found after this analysis TP is expected to decline over time, but these time-serious data were based on observed data only plotting it manually in excel.

The TN data show many fluctuations and anomalies. The most recent, in 2012, seems less marked than some in the1980s, 1992 and 2004–2006. The TN data do not show a clear incremental increase. However, an increase through time is evident in Figure (Fig. 2 in supplementary materials), depicting nitrite-nitrate-as-nitrogen. Thus, the different nitrogen types exhibit different patterns.

The concentrations of nitrite-nitrate-as-nitrogen begin to show higher values in the years following 1992. The change in this parameter seems to contribute to changes in TN level during the same period. Both nitrite-nitrate-as-nitrogen and TN show higher values in 1996–1998 and 2012–2016: the cause of this is worthy of investigation.

The concentration of coliform bacterium (thermotolerant) has declined over time (Fig. 3 in supplementary materials). This improvement in water quality is most probably due to increased efforts to avoid pollution, especially as the water sampling point is close to the city. This downward trend runs counter to the upward trend of the other nutrients. The climate change effect and water quality improvement are possible explanations for this discrepancy. The highest coliform bacterium concentrations occurred in 1974–1984, a time of rapid industrial development when it was common to dispose of waste in water bodies.

Table 1
Mean and standard deviation values of parameters for all water-sampling points. Sampling point names and numbers (similar names in Fig. 1) were kept in brackets.

Sampling parameters	Mean (M) ± Standard deviation (SD) (range)					
	Et kaupa 1 (3f)	F16 (3b)	Valsörsgloppet (3c)	Vav-7 (3d)	Vav-11 (3a)	Vav-19 (3e)
Average sampling depth	0.784 ± 0.242 (0–1)	0.167 ± 0.375 (0–1)	3.471 ± 1.718 (1–5)	–	–	–
Faecal enterococci (pcs/100 ml)	3.391 ± 7.422 (0–40)	–	–	–	–	–
Oxygen saturation (yes. %)	87.844 ± 19.787 (22 − 123)	102.4 ± 10.574 (91–115)	97.529 ± 5.088 (90–112)	97.118 ± 8.105 (63–132)	97.423 ± 6.504 (65–125)	97.308 ± 6.277 (72–114)
Dissolved oxygen (mg/l)	9.828 ± 1.674 (3.2–13.3)	11.691 ± 1.6 (9.1–14.7)	10.9 ± 1.853 (8.4–14)	11.079 ± 1.904 (8.3–14.6)	11.215 ± 1.671 (7.5–15.3)	11.213 ± 1.496 (7.5–14.6)
Chemical oxygen demand mg / l	–	–	5.58 ± 2.097 (3.9–8.8)	–	–	–
Suspended solids, fine, filtration polycarb. 0,4 μm mg/l	–	–	–	–	–	1.347 ± 0.878 (0.5–3.2)
Suspended solids, coarse (mg/l)	18.291 ± 17.663 (4.4–60)	–	–	–	2.065 ± 0.705 (0.5–3)	1 ± 1 (1)
Chlorophyll a (μg/l)	7.68 ± 5.97 (0.3–36)	3.417 ± 1.963 (2.3–7.4)	1.954 ± 0.905 (0.4–3.1)	2.389 ± 0.781 (0.8–4.3)	2.863 ± 2.227 (0 − 21)	2.791 ± 1.358 (0 − 10)
Total phosphorus, unfiltered (μg/l)	20.89 ± 19.003 (2–218)	7.284 ± 4.024 (1.6–22.6)	11.553 ± 5.048 (4.7–28)	10.647 ± 5.568 (4–50)	14.567 ± 5.336 (6–57)	10.502 ± 6.1 (3–69)
Totalt nitrogen, unfiltered (μg/l)	1118.851 ± 1013.358 (140–6700)	259.839 ± 132.627 (165–1188)	274.118 ± 79.613 (170–420)	308.404 ± 126.153 (170–1300)	281.286 ± 54.943 (110–550)	407.191 ± 219.384 (130–2800)
Coliform bacteria thermotolerant (kpl/100 ml)	11.263 ± 22.861 (0 − 130)	–	–	–	–	–
Water temperature (°C)	11.885 ± 7.414 (− 0.2–24)	8.164 ± 5.553 (− 0.3–17.7)	10.353 ± 7.61 (− 0.2–22.2)	9.445 ± 7.727 (− 0.3–22.2)	8.80 ± 5.65 (− 0.3–21.9)	9.127 ± 5.985 (− 0.3–21.7)
Nitrate as nitrogen, unfiltered (μg/l)	300.793 ± 607.684 (2 − 3100)	1.267 ± 1.176 (0–4)	28.272 3 ± 37.59 (2–110)	83.063 ± 110.651 (5–640)	58.423 ± 54.964 (0–250)	209.52 ± 137.867 (70–630)
Nitrite as nitrogen, unfiltered (μg/l)	1.88 ± 2.403 (0 − 11)	–	–	1.969 ± 0.897 (1–5)	2.756 ± 6.953 (0–61)	2.36 ± 0.7 (1–4)
Nitrite nitrate as nitrogen, unfiltered (μg/l)	456.253 ± 697.891 (2–2900)	41.544 ± 30.975 (1 − 110)	–	56.542 ± 52.105 (2–140)	27.76 ± 42.093 (0–190)	146.622 ± 147.67 (2 − 1000)
Secchi depth (m)	1.295 ± 0.534 (0.2–2.5)	5.25 ± 0.987 (4–7)	4.553 ± 1.305 (0.6–5.8)	3.957 ± 0.933 (2.2–6.5)	3.227 ± 0.971 (0.35–8)	3.721 ± 1.321 (0.4–11)
pH	7.149 ± 0.882 (4.3–8.4)	7.994 ± 0.139 (7.6–8.31)	7.806 ± 0.09 (7.7–8)	7.712 ± 0.234 (6.9–8.2)	7.816 ± 0.225 (6.7–8.4)	7.637 ± 0.271 (6.5–8.1)
Salinity (‰, salinity unit)	3.252 ± 1.15 (0.1–5.1)	3.96 ± 0.45 (3.2–5.41)	3.998 ± 0.527 (3.4–4.88)	3.691 ± 0.402 (3–5.68)	5.014 ± 0.467 (1.82–6.05)	3.301 ± 0.36 (1.06–5.5)
Turbidity (FNU)	5.447 ± 6.417 (0.46–42)	–	0.681 ± 0.315 (0.31–1.7)	0.744 ± 0.321 (0.15–2)	1.726 ± 1.217 (0.1–9.8)	1.407 ± 1.671 (0.1–19)
Conductivity (mS/m)	582.916 ± 184.866 (25.6–880)	–	717.733 ± 84.98 (610–870)	666.667 ± 57.451 (560–830)	891.343 ± 66.039 (680–1060)	605.077 ± 54.595 (210–750)

3.1.2.2. Weather data (climate change) time series plots. All the weather data were gathered from two weather stations: Vaasa airport and Mustasaari.

3.1.2.2.1. Vaasa airport weather station data. The average air temperature at Vaasa airport. From 1959 to 2011 the temperature has been between a maximum of 25 °C in summer and a negative (−) 30 °C in winter. The data do not show any change through the time when plotted in this manner. However, the removal of seasonal cycles reveals additional information. Air temperature can be expected to increase due to global warming, influencing various parameters of water quality. However, the influence of air temperature on water temperature is not clear: it seems that there is a delayed effect. Further investigation is studied later, showing the expected influence of climate change on quality in water bodies.

The rainfall appears to have random fluctuations rather than a pattern, but also shows seasonal fluctuations. Removal of seasonal variations is expected to show other patterns. Such as increments through the time of rainfall in the local area. Some seasons show extremely high precipitations, which is normal. The majority of the data are below 25 mm of precipitation, but with some outliers in at least two seasons´ precipitation. There does not appear to be a clear increase or decrease in rainfall over time. Based on collected data, Girgibo (2021) and forecasts by others point towards the likelihood of increasing rainfall all over Finland in the far future.

In addition to the normal seasonal fluctuations, the snow depth data also seem to show some cyclical events, with greater depth in some decades than in others. The depth was low from 2000 to 2011 but unfortunately, there are no data for this site from the Finnish Metrological Institutes (FMI) for the years after 2011. This time series data does not show a clear decline or increase in snow depth. Other findings are possible after removing the seasonal cycles. Such as the decline of snow depth through time. The other measurements for Vaasa airport weather station (lowest air temperature and highest air temperature) show only the natural fluctuations and so have not been plotted.

3.1.2.2.2. Mustasaari weather station data. Some small increase in average air temperature through time is apparent in the Mustasaari weather station data. However, further analysis must be done after removing the seasonal variations. Such as the increment of air temperature in the local area. The lowest temperature in Mustasaari is between zero and minus 20 °C, whereas in Vaasa airport station the lowest temperature reaches minus 30 °C. The proximity of Vaasa airport weather station to urban areas may be expected to result in higher temperatures than at Mustasaari, but this does not seem true for the coldest temperatures. The coldest temperature at Mustasaari seems to exhibit a decadal cycle, which can be normal natural fluctuations.

The lowest air temperature seems to increase over time at the Mustasaari weather station. However, the highest air temperature appears to show normal fluctuations. The coldest temperatures in this lowest air temperature seem to have a decadal cycle, as was noticed in the average air temperature at Mustasaari. More can be discovered after removing the seasonal cyclic changes in this data. After the removal of seasonal cycles, it is possible to see an increment or decrement in the air temperature in the local area.

The rainfall seems to show natural fluctuations, with occasional severe rainfall. Rainfall is changing over time and some articles state that winter rainfall is increasing in Finland. It should be possible to test this statement by separating winter and summer rainfall data, but the available data was not suitable for this. However, the forecast of air temperature was built by modifying seasonal variations and lags in modelling and this shows a clear increment through time. The snow depth graph from Mustasaari depicts a decrease in recent decades, but with a spike in snowfall in 2019. The snow depth data from both weather stations show a decadal cycle, with this pattern being more clearly exhibited in the data from Vaasa airport.

3.1.3. Water quality status checking by one-way chi-square analysis

3.1.3.1. Comparing the 3f sampling point data with the SYKE standard. Table (Table 2 in supplementary materials) presents the various limits for the parameters used by SYKE (Suomen Ympäristö-keskus/Finnish Environment Institute) to assess the water quality of lakes, rivers and sea areas in Finland (SYKE, 2003).

3.1.3.2. One-way chi-square analysis. One-way chi-square analysis was used to evaluate the data against the SYKE seawater standard. The seawater standard, instead of the lake/river standard, was used because its limits for Chl-a and TP are more stringent, so complying with this also will satisfy the lake water standard. There were around 322 samples taken during the period from 1974 to 2017, equating to an average of at least two samples per year, so these results are sufficient for an adequate representation of the long-term picture.

Figure (Fig. 4 in supplementary materials) shows how the sample results are distributed across the SYKE seawater standard for Chl-a. Of the 322 water samples, 4.04 % were found to satisfy the SYKE's Excellent rating for seawater. However, 320 samples included are replaced by satisfactory level (3) for those sampling periods missing. >50 % of the data is missing value if we assume 34.84 % is the satisfactory sampling period. Almost 204 samples or 74.84 % are represented by satisfactory levels including the missing values. Crucially, only 0.62 % of the samples have a Poor rating (level 5) for Chl-a concentrations. The remaining 33 % - around 100 samples – have either Good or Passable ratings (levels 2 or 3) for Chl-a concentration.

Despite the sampling point 3 f´s proximity to land at this Chl-a level satisfies the seawater standard and is better than lake water quality. Against the null hypothesis of equal cell frequencies, the chi-square value is 616.3851. Degrees of freedom (d.f.) are calculated as k–1 where k is the number of categories. With five categories in the present example, there are four d.f. With four d.f. the chi-square value is likely to occur with a probability (Probability > Chi-Sq) of <0.0001 if the null hypothesis is true, which is statistically significant against the alpha level of $\alpha = 0.05$ (5 % statistical significance). One can therefore conclude that the five possible seawater standards used to classify Chl-a data were not mate equally for Chl-a at the sampling point of the 3 f sampling point. Using the Chl-a concentration as representative of water quality shows that the water is at least in satisfactory condition.

Figure (Fig. 5 in supplementary materials) shows how the samples are ranked against the SYKE seawater standard for TP. Of the 322 samples, 25.78 % are classified as Excellent. However, 320 samples included are replaced by satisfactory level (3) for those sampling periods missing. The missing values do not seem a lot in TP data compared to that of Chl-a data. Most of the other water quality variables were found to be at a good level. Therefore, it is possible to justify that the missing values do not influence the assumption of the data is satisfactory level. Almost 125 samples (40.06 %) are ranked as Satisfactory (level 3), including the missing values. Only 0.62 % of the samples have a Poor rating (level 5) for TP concentrations. The other 180–190 samples are either Good (27.02 %) or Passable (6.52 %).

The null hypothesis of equal cell frequencies, the chi-square value, is 167.814. With five categories in the present example, there are four degrees of freedom (d.f.). With four d.f. the chi-square value is likely to occur with a probability (Probability > Chi-Sq) of <0.0001 if the null hypothesis is true, which is statistically significant against the alpha level of $\alpha = 0.05$ (5 % statistical significance). We can therefore conclude that the five possible seawater standards used to classify TP data were not mate equally for TP at the sampling point of 3 f. The water is at least in satisfactory or passible condition when using TP as an indicator of water quality.

Figure (Fig. 6 in supplementary materials) depicts the frequency of sampling results across the SYKE standard´s three ratings for transparency (Secchi-depth). Excellent quality (level 1) was observed in just 0.62 % of the 322 samples. However, 320 samples included are replaced by satisfactory level (3) for those sampling periods missing. The missing values do seem much in transparency (Secchi-depth) compared to others. Most of the other water quality variables were found to be at a good level. Therefore, it is possible to justify that the missing values do not influence the assumption of the data is satisfactory level. Almost 145 samples (44.41 %) are Satisfactory (level 3), including the missing values. The remaining 54.97 % are classified as Good (level 2).

Against the null hypothesis of equal cell frequencies, the chi-square value is 160.44. With three categories in the present example, there are two degrees of freedom (d.f). With two d.f. the chi-square value is likely to occur with a probability (Probability > Chi-Sq) of <0.0001 if the null hypothesis is true, which is statistically significant against our alpha level of $\alpha = 0.05$ (5 % statistical significance.) We can therefore conclude that the three possible seawater standards used to classify Secchi depth data were not mate equally for transparency (Secchi depth) at the sampling point of 3 f. In other words, the water quality is at least in a satisfactory condition when using transparency (Secchi-depth) as the parameter.

The SYKE standard has only two classifications for turbidity: Excellent (level 1) and Good (level 2). 54.66 % of the samples were ranked as Good: and 45.34 % were rated as Excellent. Against the null hypothesis of equal cell frequencies, the chi-square value is 2.795. There is one degree of freedom with two categories in the present example. With one d.f. the chi-square value is likely to occur with a probability (Probability > Chi-Sq) of <0.0946 if the null hypothesis is true, which is statistically significant. The good quality standard classification was more often than the excellent water quality standard classification for turbidity. In other words, the water quality is at least in good or below conditions when using turbidity as a water quality check-up.

3.1.4. Water quality analysis (additional statistical dependency analysis)

The central variable in this study of water quality data is chlorophyll-a (Chl-a), which is an indicator of the amount of phytoplankton present in water systems. This is influenced mainly by nitrogen and phosphorus. The five relations show a linear relationship at 5 % ($P < 0.05$) statistical significance are: 1. Chl-a and TP; 2. Chl-a and Secchi-depth; 3. Chl-a and month; 4. Chl-a and turbidity; and 5. water-temp and air-temp. The other correlations analysed showed no linear relationship. The summary of these results and relationships is presented in the next Table 2.

3.2. Trend and time-series analyses

The air temperature vs. years is weather data, and this weather data was collected from Vaasa airport weather station from Finnish Meteorological Institute (FMI) database. The sum of temperature per year starting from 1974 to 2010. The basic anomaly observed was similar to the water temperature and Chl-a analysis where 1974 and 1998 years show lower values and the rest show higher values in this bar chart. These two-year anomalies were also observed inline plot chart for observed data. These results show lower values for these two years. This fact means that in these two years,

Table 2
Pearson's correlation summary for water quality variables and weather data from Vaasa airport. The results presented here are statistically significant (rejecting the null hypothesis). (P = probability *($P < 0.05$)*).

	Chl-a	Water temp.
TP	0.55794, $P < 0.0001$	–
Secchi depth	−0.55085, $P < 0.0001$	–
Month	−0.25609, $P = 0.0053$	–
Turbidity	0.43998, $P < 0.0001$	–
Air temperature	–	0.89691, $P < 0.0001$

the air temperature was lower, which is why changes were noticed in the rest of the variables. In the forecasted data there is the expectation of a very high air temperature in the year 2033. This result is also the driver of changes noticed in the other variable charts of forecast data for 2033. The rest of the forecasted years seem to have higher values than the observed data bar chart. The anomaly for the year 2033 is also seen clearly in the line plot for forecasted air temperature data. The seasonal fluctuation was noticed both in observed and forecasted data line plots. These results are expected because both data were not treated for lags and/or seasonal variations corrections. These trend analyses show that there is a clear connection between variables. This result means the data and its analyses were not robust. The air temperature was the driver of all variables, although other variables' contributions influenced some variables.

For Chlorophyll-a (Chl-a) vs years observed and predicted data values show variations and anomalies. Except in 1998, all yearly sums of data from 1978 until 2010 show increments through time with some year fluctuations. The line graph shows an anomaly (decline in the amount of Chl-a). Otherwise, the observed data shows a clear inclination in Chl-a throughout the years. This result shows that higher values are expected in predicted data from June 2022 to February 2042. Thus, one can conclude that all trends for Chl-a vs year show a clear increment through time. The line plot of Chl-a predicted data shows an anomaly in about the year 2033. This year also noticed other analyses that have expected to show a different pattern than the rest of the predicted data. There is nothing real theory about what can happen in the year 2033, but this has shown higher fluctuations in expectation for various variables plot. The years 2023, 2025 and 2037 show some anomalies (inclinations). There are no clear explanations for those years of anomalies too. Generalizing, Chl-a vs year trend analysis, one can say that it shows a clear inclination both in observed data and predicted data.

Water temperature vs year observed data shows a lower amount of sum per year temperature in the years 1974 and 1998. As noticed in the line plot, the water temperature was above 5 °C on average in all the years from 1970 to 2010. The line plot also shows a lower value anomaly for the year 1998. The fluctuates noticed were because of seasonal variation causing the temperature to be positive or negative. The FMI (Finnish Meteorological Institute) website mentioned that the winter of 1998/1999 was average, and on February 11th' there was its largest extent of ice in Bethania bay. The forecasted data shows a continuously higher temperature sum per year than the observed data. In some years, the sum of temperatures was higher in the observed data bar chart. The seasonal variation was seen both in observed and forecasted data. The forecasted data was prepared before lag and seasonal correction in modelling procedures. Therefore, the seasonal variations were also expected to be seen in the forecasted data line plot. The year 2033 anomaly seen in Chl-a vs year line plot chart was not seen in this water temperature vs year line plot chart. It was expected to see similar patterns because they employ similar data sets.

There is less observed data for Snow-depth. It was seen that the Snow-depth values were highest from 1980 to 1989. The collected data was from 1974 to 1995. The forecasted data shows a Snow-depth decline over time. It was seen a significant decline in Snow-depth after March 2028. It is also seen in the forecasted data there is no Snow-depth value starting from 2033.

The industrial revolution in history has influenced water bodies significantly in the past. However, nowadays, its influence has been declining much more significantly. This result shows the growth in environmental protections and better world environment management compared to the past. However, it is not clearly shown in the analyses for TP. This result is because the data collection started in 1974. However, the industrial evolution time was before 1970. This data collection was started probably due to the growth in awareness for controlling pollution in water bodies and the environment. In the bar yearly sum vs year chart of observed data for the TP chart, it was noticed that the highest value is for 1982. The rest show lower values. The line plot also shows a similar pattern. Comparing the observed data charts with the forecasted data charts, one can conclude that there is no clear increment through time. However, there was an anomaly in the year 2023 with the highest bar chart values and line plots for forecasted data. In the line plot for forecasted data, a higher value of TP was observed between 2022 and 2025. The rest show normal fluctuations. Bar yearly sum vs year chart, also shows normal fluctuation, no increment or decrement. Therefore, we have concluded here that there is normal fluctuation to be expected in future values of TP on this site.

If we compared the Turbidity and Secchi-depth charts, it is clear that those years that recorded lower amounts of Turbidity show higher Secchi-depth as expected. The yearly sum for 1990, 2002, and 2006 was higher, as seen in the bar chart. The lowest values were found in 1974 and 1998. This result is probably due to short observed values because Turbidity also showed lower values in these years. However, Secchi-depth also showed lower values; thus, the only explanation can be the shortage of data in these years to show lower values. Similar patterns were observed in other variables of lower values in these years. The line plot for observed data showed the highest values in 1979–1992 and 2007. The lowest values are noticed in this line plot for the years 1981 and 1998. The forecasted data bar yearly sum and line plot show higher values. This result is showing somehow higher values for Secchi-depth in the future. This result is a bit unexpected because the Turbidity data forecast also shows an increment in future. One point to notice was that the Secchi-depth increment forecast is higher than that of the Turbidity forecast. Therefore, there is an expectation of a higher Secchi-depth than Turbidity. Seasonal variations can explain the fluctuation noticed in the forecasted data line plot. The bar yearly sum vs year chart shows higher values in the middle years, and it is the opposite pattern compared to the Turbidity bar yearly sum vs year chart.

Bar yearly sum vs years for observed data shows that the values in the years 1974 and 1998 are low. A similar pattern was also noticed in the other variables for these years. The year 1982 shows the highest Turbidity compared to the rest of the observed data. The line plot for observed data shows a similar pattern as that of the yearly sum bar chart, even though the value was lower because they do not show the yearly sum. The highest values observed in this observed data line plot were in 1977 and 2010. Moreover, the lowest value noticed in this line plot was in the year 1978. There is no clear increment or clear decrement in all of the charts. There is an expectation of many fluctuations, as seen in the forecast. The bar yearly sum vs year for forecasted data shows somehow U shape structure. This result means it has a higher value at the beginning of the forecast years, then declines in the middle and rises at the end of the years. There are no clear explanations for why the bar chart created this shape. A similar pattern is noticed inline plot for forecasted data. The line plot showed a lot of fluctuation. This most probably had been influenced by seasonal variations. The years 2021, 2023 and 2039 showed the highest values seen in the line plot. The opposite result is noticed in Secchi-depth (transparency). Hence, turbidity and Secchi-depth show opposite characteristics of the same water body.

3.3. Main analyses results: linear and multiple regression analyses

3.3.1. Weather data change investigations and descriptions

Climate change in short can be defined as a change in the state of the climate that can be distinguished by statistical tests (Girgibo, 2021). In this paper, the air temperature change effect is investigated in weather data by statistical analyses, which is linear regression. First, we try to show that there is a change in air temperature in near areas of the city of Vaasa for at least a few months. Afterwards, the water quality changes investigations in two main parameters, which are Chl-a and water temperature. Then the relationship between water quality and air temperature is presented.

Air Temperature (weather pattern change): the result shows for seasonally corrected data that the coefficient of determination (R^2) is 0.0181, so only about 1.8 % of the total variation in Air temperature can be explained by this regression model. The percentage of data explained is very low. Its trustworthiness is very questionable.

So, as one-year increases, increases the value of Air temperature is on average by 0.20158 amount. Because the probability of the model is 0.0334 and which is <0.05 (5 % significance level), we can now reject the H_0 for the explanatory variable. R^2 is <2 % of the data explained by this analysis we concluded that there is not enough evidence to confirm the presence of the significant effect of climate change in the area in continuous years at every month together. However, in the Months of April and July, there were statistically significant air temperature changes in the Kvarken Archipelago area. The R^2 for April was 0.2109 or the model explains a 21.09 % increase in Air temperature. For July R^2 was 0.1207 or the model explains a 12.07 % increase in Air temperature throughout the data collection period (see Fig. 3). This means there are changes in air temperature in the months of April and July based on our data sets analysis. The next Table 3 presents the yearly average each month air temperature intercept, slope, R2 and P > F each from 1959 to 2011.

3.3.2. Water quality change investigations and descriptions

The two indicators used for water quality are chlorophyll-a and water temperature investigation results given below. The indirect causality path that is indicated that air temperature influenced the water temperature and further through indirect paths influence the growth and abundance of phytoplankton biomass indicated by chlorophyll-a concentration. However, this indirect causality was not confirmed due to multicollinearity in the data.

Chl-a (Chlorophyll-a) (water quality changes): the result shows for seasonally corrected data that the coefficient of determination (often denoted R^2) is 0.0067, so this regression model can explain only 0.6 % of the total variation in Chl-a. The percentage of data explained is very low. Its trustworthiness is very questionable.

So, as every one-year increase, increases the value of Chl-a on average by 0.04779 amount. Because the *p*-values are 0.2128 and which is >0.05, not statistically significant based on the seasonally corrected data set. We can now accept the H_0 for the explanatory variable. The linear regression model does not exist for each month. However, a statistically significant increase in years was seen in the months of May, June, July, August, September and December (See Table 4 for the results).

Additional data mining shows that the result for chl-a regression is

$$\hat{y} = 9.63156 + 0.03725^{*}\ \text{Phosphorous} - 2.73417^{*}\ \text{Secchi Depth} + 0.06193^{*}\ \text{Turbidity}$$

where, $\hat{y}$ = Chl-a.

Water temperature (water quality changes): the result shows for seasonally corrected data that the coefficient of determination (R^2) is 0.0180, so this regression model can explain only about 1.8 % of the total variation in Water temperature. The percentage of data explained is very low. Its trustworthiness is very questionable (See Table 5 for this result).

So, as one-year increases, increases the value of water temperature on average by 0.10764 amount. Because the *p*-values of the model are 0.0340 and are <0.05 (5 % significant level), we can now reject the H_0 for the explanatory variable. R^2 <2 % of the data is explained by this analysis we concluded that there is not enough evidence to confirm the presence of the water temperature increase in the area each month. However, as the following equations show for February, March, June and July there are statistically significant results. Please see Table 4 for the whole water temperature and Chl-a analysis results, which are statistically significant.

Table 3
The data sets analysis results for linear trend fitting: intercept, slope, R^2 (goodness-of-fit) and P > F (model probability) for air temperature. Model: $\hat{y}$ = a1 + a2*year and only the statistically significant (*P < 0.05*) results are presented here.

Original Vaasa airport data set/ observed data 1959–2011				
Yearly averaged monthly air temperature (1959–2011)	Intercept (a1)	Slope (a2)	R^2	P > F
April (48 years of data in number)	−87.29270	0.04515	0.2109	0.0009
July (49 years of data in number)	−46.31031	0.03144	0.1207	0.0155

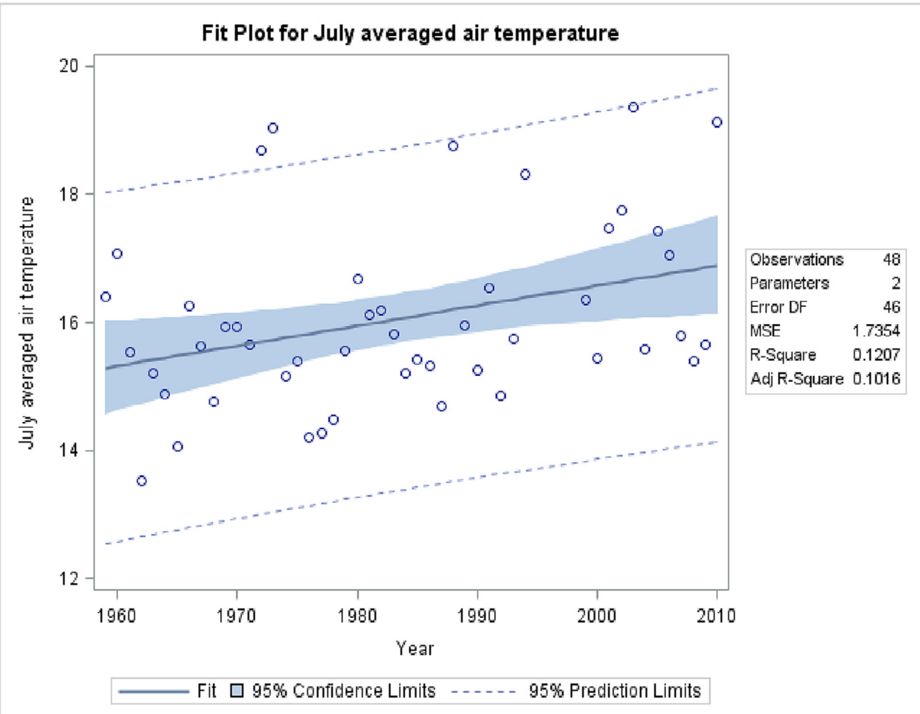

Fig. 3. July averaged per year data with regression line.

Table 4
The data sets analysis results for linear trend fitting: intercept, slope, R^2 (goodness-of-fit) and P > F (model probability) for water temperature. Model: $\hat{y} = a1 + a2*year$ and only the statistically significant at (*P < 0.05*) results are presented here.

Original 3f data set averaged/ observed data 1974–2017				
Yearly averaged monthly water temperature (1974–2017)	Intercept (a1)	Slope (a2)	R^2	P > F
February (only 10 years of data in number)	653.31373	- 0.32290	0.6137	0.0073
March (only 28 years of data in number)	- 453.26039	0.22876	0.2660	0.0050
June (only 31 years of data in number)	−203.12336	0.10949	0.1304	0.0459
July (only 37 years of data in number)	−259.60625	0.13850	0.1199	0.0357
Yearly averaged monthly Chl-a (1974–2017)	Intercept (a1)	Slope (a2)	R^2	P > F
May (only 14 years of data in number)	−719.47951	0.36341	0.5401	0.0028
June (only 29 years of data in number)	−773.07902	0.39101	0.4685	<0.0001
July (only 36 years of data in number)	−390.57200	0.19874	0.2671	0.0013
August (only 23 years of data in number)	−226.52421	0.11656	0.1747	0.0472
September (only 11 years of data in number)	−753.02839	0.38007	0.4454	0.0249
December (only 9 years of data in number)	−719.59573	0.36407	0.6187	0.0119

Also, the pictures for air and water temperature analyses are found in supplementary materials in Figs. 7–11.

The statistically significant monthly ($P < 0.05$ or 5 %) results for water temperature are displayed in the next formulas.

- $\hat{y}$ (February) = 653.31373–0.32290*year (R^2 = 0.6137, P model = 0.0073)
- $\hat{y}$ (March) = − 453.26039 + 0.22876*year (R^2 = 0.2660, P model = 0.0050)
- $\hat{y}$ (June) = −203.12336 + 0.10949*year (R^2 = 0.1304, P model = 0.0459)
- $\hat{y}$ (July) = −259.60625 + 0.13850 year (R^2 0.1199, P model = 0.0357)

Where, $\hat{y}$ (m) = water temperature (in the month).

3.3.3. Relationships between water quality and climate change

The relationships between water quality and air temperature were investigated by checking the correlation and multi-regression between water and air temperature. This relationship is not a direct path for most parameters of water quality influenced by climate change. However, there is a clear direct relationship between air temperature influencing water temperature as shown in the next multi-regression result.

Air temperature and water temperature: Positive relations of regression line best-fit plotting were found for air temperature and water temperature. Fig. 12 in the presentation of the supplementary materials explains 80 % (R-square = 0.8044) of the data in the analyses. This is the result is expected because both variables explain the same variable, which is temperature.

Comparing various multi-regressions formulas, it was found that for all the combined variables, the formulas show differences between original/observed data and forecasted prepared time series data. This article aims to show that these changes in water quality parameters are due mainly to changes in air temperature (see Fig. 12 in the supplementary materials), influenced by global warming or climate change.

It was found that the presence of climate change in the area cannot be confirmed for each month. This might be due to the shortage of the period where the data is collected and seasonal variations. Based on theories and other world areas' expectations the effect of climate change is very real in most parts of the world. This was in air temperature change for the months of April, and July for air temperature and the water temperature in the months of February, March, June and July were statistically significant as shown in Tables 3 and 4.

4. Discussions

It was expected that Chl-a and Secchi depth would have opposing trends, but they both have an upward trend. However, the Secchi depth trend fluctuates and is not a straight upward trend. This probably derives from the Chl-a fluctuations in the original data, and is not clear in this forecast analysis because of seasonal factors and lag removal. The theoretical explanations stated that global warming is accompanied by increasing phytoplankton concentration (chlorophyll-a amount) in current and future water systems. This might show causality relations, but these cannot be proven, for example by using structural equation modelling (SEM). There is multicollinearity between variables, which is one of the limitations of SEM analysis.

Some dependent relations between different water quality parameters and weather data. Dr. Petri Välisuo used Bayesian networks and Pomegranate modelling software to investigate the preliminary relationships within the data. The work used 100 data points, drawn from 2004 to 2018. The arrows shown in Bayesian networks do not show the causality relation according to Pearl and Mackenzie's (2018) causality description book. Our analysis finding indicates that oxygen saturation is dependent on month and temperature; chlorophyll-a is dependent on oxygen and nutrients, and turbidity is dependent on chlorophyll-a and Secchi depth. There is a clear dependency of one parameter on another. The main effect of weather data seems through air temperature affecting ➔ water temperature and this, in turn, affecting ➔other water quality variables. This might show

Table 5
The two data sets analyses result for linear trend fitting, intercept, slope, R^2 (goodness-of-fit) and P > F (model probability). All R^2 results were found to be very low. Model: $\hat{y} = a1 + a2*year$ and bold results are statistically significant (*P < 0.05*).

	3f original data set/ observed data (1974–2017)				3f observed data/seasonally corrected data (1974–1994)			
The whole period of data Model: $\hat{y} = a1 + a2*year$	Intercept (a1)	Slope (a2)	R^2	P > F	Intercept (a1)	Slope (a2)	R^2	P > F
Chl-a	**- 477.836**	**0.24304**	**0.1978**	**< 0.0001**	- 88.73758	0.04779	0.0067	0.2128
Phosphorous	**593.03797**	**- 0.2831**	**0.0255**	**0.0304**	**920.18657**	**- 0.45300**	**0.0559**	**0.0002**
Secchi depth	8.30957	- 0.00346	0.2905	1.57164	1.57164	−0.00005334	0.0000	0.9866
Turbidity	- 12.12905	0.00829	0.0004	0.7904	13.91197	−0.00486	0.0001	0.8821
Water temperature	- 151.44406	0.08183	0.0137	0.0805	**- 202.74471**	**0.10764**	**0.0180**	**0.0340**
Air temperature (1959–2011)	- 155.49392	0.08240	0.0083	0.1685	**- 390.32824**	**0.20158**	**0.0181**	**0.0337**

causality, but that must be proven by other analyses before concluding there is a clear causal relationship between climate change and water quality, through the weather. Chl-a and oxygen saturation; Chl-a and dissolved oxygen; and Chl-a and TN do not show statistically significant linear correlations. They might have some other polynomial correlations or they probably act by affecting other parameters that are important for the growth of phytoplankton.

The figure presented by Pastuszak et al. (2018) shows more relationships between different aspects of a water body. This point is essential in understanding the complexity of using Chl-a as an indicator of phytoplankton concentration, and then further used to evaluate the status of water and eutrophication. Lakes can be eutrophic but still with a low concentration of Chl-a (oligotrophic or mesotrophic) (Pastuszak et al., 2018). However, the water sampling places in this study are not that deep water. Therefore, the statement of Pastuszak et al. (2018) might not be true in our sampling point because they do not show total lake water characteristics. In our data, the average of total phosphorus and total nitrogen in the nearby Vaasa region seems similar to a past analysis by Pitkänen et al. (1986), suggesting a regulated natural habitat has existed in the area for quite some time. The quantity and quality (coastal morphometry, season) and the concentrations in the open sea are the main factors regulating total nutrients in the surface layer of coastal waters (Pitkänen et al., 1986).

One immediate conclusion is that the water quality in all six sampling points is at least at the passable level of the SYKE standard. It is apparent from the summary in Table (Table 1) that water quality at the 3 f sampling point is the worst of the six, and yet it was found that even here the water is above the passable level. It is also clear that rising air temperature is causing an increase in water temperature because they have a strong Pearson's correlation (product-moment correlations). We cannot confirm direct causality relations, but there is a clear influence of increasing air temperature on increasing water temperature, further probably leading to an increase in chlorophyll-a. Plant growth depends on sunshine and temperature. Hence, phytoplankton growth (indicator chlorophyll-a) is influenced by water temperature increase and sun irradiance variations. The time lag found in some analyses shows that expected increases in water temperature and chlorophyll-a levels come sometime (probably days to months of lag) after the air temperature increase. This can be one kind of proof of the influence of air temperature noticed in water quality variables.

Explaining the correlation between water quality and other parameters of the data is shown in Table 2. There were four statistically significant correlations found between Chl-a and other parameters. These parameters include total phosphorus (TP), Secchi depth, month, and turbidity. An additional positive correlation was found between air and water temperature (0.89691, $P < 0.0001$). These correlations do only show the dependency between them, not causality. Hence, water temperature is a water quality that influences most of the other water quality parameters it is easy to see that the air temperature has affected the water quality. Even the path cannot be seen in this paper. Having such a view helps to notice and confirm that air temperature change affects all over the world also in environmentally protected areas and based on our findings only in a few months. It is shown that April and July air temperatures increase statistically significant and the models explain these increments with 12 and 21 % of these months' observed data, respectively (see Table 3). Water temperature for February, March, June and July found statistically significant results.

The correlation analysis between water quality and nearest weather data and within the water quality variables show similar results in nearly all sampling points. Noted exceptions are positive correlations (at the Vav-19 (3e) site) and negative correlations (at the Vav-7 (3d) site) between total phosphorus (TP) and air temperature. Other analysis results seem similar to the pattern of the Et. Kaupa 1 (3f) correlation outcomes. The correlation results obtained at Vaslörgloppet (3c) appear to be untrustworthy because of the limited amount of data gathered by ELY-keskus at this location. All data were not possible to analyse using *t*-test, one-way ANOVA, two-way ANOVA, multi-way ANOVA or ANCOVA due to the fact the data are not normal.

The lack in this study would be not able to use more various methods due to the data being found to be non-normal data. This limits the whole analysis to be based on those analyses that can allow the use of non-normal data. The water system can be affected by various climate change variables including air temperature, precipitation, and snowfall level. One of the limitations of this paper is that only air temperature was considered as an indicator due to a lack of enough data. The importance of air temperature change effect on water quality in this paper investigation is the understanding of what kind of changes can be seen in water systems and this helps how to overcome them through time. Moreover, the significance of the study is showing the effect of air temperature change in the Kvarken Archipelago in a naturally protected area in April and July month. Knowing changes in the weather data and water systems in the Kvarken Archipelago can show how these effects are real even in protected areas and why we must minimize the causes and effects of climate change. This can be done not only by protecting the environment, but also world scale solving climate change causes. As can be seen here even if we protect our local environment, if the world does not work together with the reduced emission sources, these emissions can influence everyone in the world where ever we are. Not only the current generations but the next generations will be affected because of our unfairness towards the environment and its protections.

5. Conclusions

In the preliminary analysis, the summary of statistics showed that the 3 f sampling point is the worst based on comparing it with other sampling points using the mean and standard deviations. This was one of the reasons to choose it as a representative sampling point. It was found that the water quality of sampling point 3 f (the worst) is above the passable level. This and the summary statistics confirm that all sampling water quality statuses based on SYKE standards were at least above the OK level. Showing the protected area was not affected severely by other pollution sources. In dependency analysis, it was found that statistically significant Parsons correlations between Chl-a and (TP, Secchi depth, Month, and turbidity). As well, air temperature shows a statistically significant correlation with water temperature.

Trend analysis shows that there are anomalies in past and future trends. As well, they show that in the future air, water and Chl-a are expected to rise and snow-depth levels to decline. In the main analyses section, the presence of air temperature changes in the months of April ($R2 = 0.2109$ & $P = 0.0009$) and July ($R2 = 0.1207$ & $P = 0.0155$). One explanation to see changes only in April and July months can be because of a shortage in the data collection period. Changes in water quality variables (Chl-a and water temperature) were found in some months. There are strong relationships between air temperature and water quality was shown the relation between air and water temperature.

According to our analysis of large amounts of data, a fairly flat trend (slope = 0.20158) of air temperature increases in the Kvarken Archipelago can be observed for 1974–1994, which is statistically significant. However, this finding explains by this model only 1.81 % of the data. The world's heritage site has been well protected to some level. Still, changes already are visible and have direct effects in this well-reserved area on both the air temperature change vs. year ($\rho < 0.05$) in April and July. Therefore, climate action is an obligation to protect Kvarken Archipelago's species and ecosystems. New policies must focus, be deployed and implement not only on protecting the environment but also on declining and stopping the causes of climate change or air temperature changes. How climate change has affected the ecosystem representation within the Kvarken Archipelago will be our further research topic, including other climate change variables such as precipitation patterns and snowfall levels.

Ethics approval and consent to participate

Not applicable

Consent for publication

All the authors agreed and gave their consent for publication.

CRediT authorship contribution statement

Nebiyu Girgibo – original idea, writing the original manuscript, data gathering, data analysis, reviewing, editing and fund acquisition. Xiaoshu Lü –reviewing, editing, and funding acquisition. Erkki Hiltunen – requesting data, reviewing, editing and funding acquisition. Pekka Peura, and Zhenxue Dai – reviewing and editing.

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Data availability

The data is not available for public use because the research is ongoing, and our research teams would like to continue with this research so we are not willing to share our current data.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

There is no conflict of interest.

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Appendix A. Supplementary data

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References

Ahmed, M., 2019. Medconnection – Finland lifestyle: Water in Finland purest in the world [online]. Cited 17 Jan. 2023. https://mediconnection.fi/en/water-finland-purest-world/.

Arau'jo, M.B., Nogués-Bravo, David, Thuiller, Wilfried, 2011. Climate change threatens European conservation areas. Ecology Letters 14 (2011), 484–492. https://doi.org/10.1111/2Fj.1461-0248.2011.01610.x.

Begge, P., Meriläinen, J.J., 1985. The occurrence of water mites (Acari: Hydrachnellae) in the estuary of the River Kyrönjoki (Bothnian Bay). Annales Zoologici Fennici 22 (2), 123–127. https://www.jstor.org/stable/23734134.

Choo, J.M., Taskinen, J., 2015. Effect of short-term temperature change on cercarial release by Rhipidocotyle fennica (Trematoda, Bucephalidae) from the freshwater bivalve host, Anodonta anatina. Ecological Parasitology and Immunology. 4 6 pp.

Fonsellius, S.H., 1986. The hydrography of the Gulf of Bothnia. Report From the Hydrography Group. 68. Publications of the Water Research Institute, National Board of Waters, Finland.

Girgibo, N., 2021. The effect of climate change on water and environment resources in the Kvarken Archipelago area. 90 pp. 2016 – 2021The University of Vaasa Reports 20. University of Vaasa, Tritonia, library, Vaasa, Finland . http://urn.fi/URN:ISBN:978-952-476-941-9.

Girgibo, N.W., 2022. Seaside renewable energy resources literature review. Climate 10 (10), 153. https://doi.org/10.3390/cli10100153 2022.

Girgibo, N., Mäkiranta, A., Lü, X., Hiltunen, E., 2022a. Statistical investigation of climate change effects on the utilization of the sediment heat energy. Energies 2022 (15), 435. https://doi.org/10.3390/en15020435.

Girgibo, Nebiyu, Lü, Xiaoshu, Hiltunen, Erkki, Peura, Pekka, Tong, Yang, Zhenxue, Dai, 2022b. A conceptual framework for the future of sea-level rise and land uplift changes in the Vaasa region of Finland. SCIREA J. Geosci. 1, 23–57. https://doi.org/10.54647/geosciences17154.

Hietikko-Hautala, T., 2012. The Kvarken Archipelago World Heritage Sites: Echoes of the Ice Age. Central for Economic Development Transport and the Environment for South Ostrobothnia (ELY-Keskus), Vaasa, Finland. ISBN: 978-952-257-095-6, p. 159.

Huttunen, M., et al., 1986. Phytoplankton of the open sea areas of the Gulf of Bothnia – Observations made in the first stage of the Baltic monitoring programme in 1979—1983. Publications 0f the Water Research Institute, National Board of Waters, Finland, No. 68.

Kauppila, P., 2007. Phytoplankton quantity as an indicator of eutrophication in Finnish coastal waters - application within the water framework directive. DissertationMonographs of the Boreal Environment Research 31. Finnish Environmental Institute, Helsinki, Finland 978-952-11-2898-1.

Kernan, M., Battarbee, R.W., Moss, B.R., 2010. Climate Change Impacts on Freshwater Ecosystems. Wiley-Blackwell, Oxford 978-1-4051-7913-3.

Kraemer, B.M., Kakouei, K., Munteanu, C., Thayne, M.W., Adrian, R., 2022. Worldwide moderate-resolution mapping of lake surface chl-a reveals variable responses to global change (1997–2020). PLOS Water 1 (10), e0000051. https://doi.org/10.1371/journal.pwat.0000051.

Kupiainen, K.J., et al., 2019. Climate impact of finnish air pollutants and greenhouse gases using multiple emission metrics. Atmos. Chem. Phys. 19 (7743–7757), 2019. https://doi.org/10.5194/acp-19-7743-2019.

Li, Z., et al., 2022. The influence of increased precipitation and nitrogen deposition on the litter decomposition and soil microbial community structure in a semiarid grassland. Sci. Total Environ. 844 (2022), 157115. https://doi.org/10.1016/j.scitotenv.2022.157115.

Liu, S., Wang, P., 2022. Emerging solute-induced mineralization in Arctic rivers under climate warming. Sci. Total Environ. 851 (2022), 158091. https://doi.org/10.1016/j.scitotenv.2022.158091.

Mäkelä, K., 1986. Variations in dry matter, phosphorus and organic carbon in two Bothnian Bay sediment cores in relation to hydraulic engineering works. Publications of the Water Research Institute, National Board of Waters, Finland, No. 68.

Meerhoff, M.C., et al., 2007. Effects of habitat complexity on community structure and predator avoidance behaviour of littoral zooplankton in temperate versus subtropical shallow lakes. Freshwater Biology 52, 1009–1021. https://doi.org/10.1111/j.1365-2427.2007.01748.x.

Meriläinen, J.J., 1984. Zonation of the macrozoobenthos in the Kyrönjoki estuary in the Bothnian Bay, Finland. Annales Zoologici Fennici 21 (2), 89–104 1984.

Meriläinen, J.J., 1988. Meiobenthos in relation to macrobenthic communities in a low saline, partly acidified estuary, Bothnian Bay, Finland. Annales Zoologici Fennici 25 (4), 277–292 1988.

de Mour, M.E.P., Rocha, L.dos S., Nabout, J.C., 2017. Effects of global climate change on chlorophyll-a concentrations in a tropical aquatic system during a cyanobacterial bloom: a microcosm study. Ambiente & Água - An Interdisciplinary Journal of Applied Science 12 (3). https://doi.org/10.4136/ambi-agua.2014.

Pastuszak, M., et al., 2018. Reduction of nutrient emission from polish territory to the Baltic Sea (1988–2014) confronted with real environmental needs and international requirements. Oceanol. Hydrobiol. Stud. 47 (2). https://doi.org/10.1515/ohs-2018-0015.

Pearl, J., Mackenzie, D., 2018. The Book of Why: The New Science of Cause and Effect. Hachette Book Group, New York, USA 978-0-465-09760-9.

Peura, P., Sevola, P., 1992. Acidification mosaic of small lakes. A study on 81 lakes in the Kvarken, Gulf of Bothnia (Finland and Sweden). Aqua Fennica 22 (2) 153-171 pp.

Pitkänen, H., Niemi, J., Sarkkula, J., Sandman, O., 1986. Phosphorus and nitrogen balance of a coastal bay. Publications of the Water Research Institute, National Board of Waters, Finland, No, p. 68.

Räike, A., Taskinen, A., Knuuttila, S., 2019. Nutrient from Finnish rivers into the Baltic Sea has not decreased despite water protection measures. The royal Swedish academy of science (KUNGL VETENSKAPS AKADEMIEN): Ambio. Springer, pp. 1–15 https://doi.org/10.1007/s13280-019-01217-7.

Saranko, O., et al., 2020. Impacts of town characteristics on the changing urban climate in Vantaa. Sci. Total Environ. 727 (2020), 138471. https://doi.org/10.1016/j.scitotenv.2020.138471.

SYKE, 2003. SYKE (Finnish Environmental Institute) - Water Quality of Lakes, Rivers and Sea areas in Finland in 200 – 2003 [Online]. Cited 27 Aug. 2020Syke. fi. https://www.syke.fi/download/noname/%7B98588B25-E678-4DE2-8006-6CCBACC3F273%7D/30089.

Water-Quality, 2008. Water Quality: A Filed-based Water Quality Testing Program for Middle Schools and High Schools. Manual. Massachusetts Water Resources Authority, Boston, USA.

Wetzel, R.G., 2001. Limnology- Lakes and River Ecosystems. 1006Third edition. Elsevier Science (USA), California, USA ISBN: 0-12-744760-1.

Winder, M., Schindler, D.E., 2005. Climate change uncouples trophic interactions in an aquatic ecosystem. Ecology 85, 2100–2106. https://doi.org/10.1890/04-0151.

Risks of climate change effects on renewable energy resources and the effects of their utilisation on the environment

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Abstract

Renewable energy resources are essential for combating climate change. However, their use, production and collection have environmental impacts. Climate change effects also represent a significant risk to renewable energy resources. The unique contributions were that the risks of climate change to renewable energy resources were addressed, which is addressed rarely before. Climate change (GHGs increase) affects ground heat source; Asphalt/concrete-covered areas and borehole energy about 0.5 risk levels. Toxicity was the main common environmental impact from ground heat source; Asphalt/concrete-covered areas; borehole energy; and sediment heat energy production about 0.7; 0.6; 0.9; and 1.6 risk estimate levels. Bioenergy sufficiency and cost affects bio-oil, biodiesel and bioethanol; biogas from different sources; forest biomass and algae about 2.25; 1.9; 2.4 and 2.3 risk estimate levels, respectively. The most common impact was the impacts on biodiversity form all bioenergy and biomass energy. Extreme weather phenomena affect ground wind energy; offshore wind energy; the solar panel and collector; and hydropower about 2.7; 3.4; 1.3; and 1.2 risk estimate levels, respectively. Ground and offshore wind energy affects birds and other animals about 1.3 and 1.1 risk estimate levels, respectively. Field-based biomass energy is affected by climate change more than other renewable energy resources. Ground heat sources were the least-affected type of renewable energy and the type with the fewest effects on the environment was solar energy/collectors. The water heat exchanger was the most affected and sediment heat energy had the most environmental impacts, among all geothermal energy types. The significance of the study is that aimed to help in making sure renewables are safe for the environment leading and helping renewable energy sustainability by creating attractiveness and awareness of its risk-free facts to society. One of the novelties of the study is that new renewable energy sources included – sediment heat, asphalt heat and water heat exchangers. One of the conclusion is that even if the risks of renewable energy are much lower than those of fossil fuels, they are still significant and cannot be ignored. These findings are crucial for implementing and managing renewable energy in regional development.

Highlights:

- Climate change effects generate significant risks to renewable energy resources.
- Field-based biomass energy has the greatest risks high-level environmental risks.
- Climate change affects ground heat sources the least and to field-biomass the most.
- Ice thickness affects sediment and water heat exchanger at 1.1 and 1.4 risk levels.
- Abiotic resource depletion by the solar panel & collector at 1.1 and 0.5 risk levels.

Keywords: Renewable energy, impacts on the environment, climate change effects, geothermal energy, solar-based energy, bioenergy

Word count: 14995 words

List of abbreviations

CHP	– Combined heat and power
COVID-19	– Coronavirus disease
GHG	– Greenhouse gas
GHGs	– Greenhouse gases
LCA	– Life Cycle Assessment
PBR	– Photobioreactor
PV	– Photovoltaic cells

1. Introduction

Risk can be defined as the possibility of the occurrence of a hazardous event that affects the achievement of objectives [1]. Usually, risk causes negative impacts. Decision-making also is affected by the severity and characteristics of risk [1]. According to Yaghlane et al. [2], risk analyses have become much more important due to the increase in industrial accidents. However, this risk analysis article is not about industrial processes, but rather specific renewable energy resources that are affected by climate change, useful equipment for these resources and the risks of their production to the environment. Risk can be environmental, economic, technological or social [3]. In terms of environmental risk, the loss can consist of a naturally maintained environment becoming more polluted and insufficient for its ecosystems to survive. In economic terms, risk can include the loss of money. Technological risk can encompass loss of methods for producing products from the environment, such as energy available for collection or extraction falling dramatically due to a technology shortage. This is particularly relevant because technological advancements are essential for improving the efficiency and economics of renewable energy processes and for restricting CO_2 growth [4]. Social risk, on the other hand, includes the loss of an ideal living environment or social status. For example, climate change causes risks to our only living planet, which in turn implies risks for effective social survival. The future consequences of risk may be negative (hazard risks) or positive (opportunity risks) or could lead to uncertainty, and the lack (partial or total) of information [3]. Climate change causes uncertainty for our world and its inhabitants.

According to [1], the steps in the risk management process are:

1. Identification of risk in a selected domain of interest;
2. Planning the remainder of the process;
3. Mapping out the social scope of risk management, the identity and objectives of stakeholders, and the basis upon which risks will be evaluated constraints;
4. Defining the framework that will be used in the activity and an agenda for identification;
5. Developing an analysis of risks involved in the process;
6. Mitigation of risks using available technological, human and organizational resources.

Figure 1, which was originally presented in [5], shows a diagram that presents the solutions proposed in the risk management process.

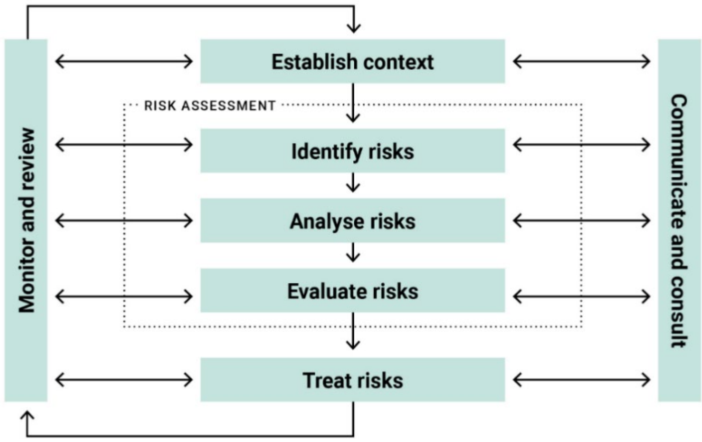

Figure 1. A diagram presenting the solutions proposed for the risk management process. (The diagram was designed by Andrei Palomäki at Studio Andrei. The original source of the picture was [5]).

Risk identification, risk estimation and risk evaluation are the most important steps in risk analysis. Risk identification is a distinct activity, which is a part of the risk assessment process [3]. Furthermore, the full value of the risk identification procedure comes from its comprehensive description of the risks identified [6]. The whole process of risk identification for this research was reported separately in the publication of Girgibo [7]. Risk estimation and analysis were performed by creating two tables: 1. Climate change risks for renewable energy resources, and 2. Risks of renewable energy use and production to the environment. The experts consulted to estimate the risks were mainly from Finland, with the majority from the region of the city of Vaasa, with one from Sweden. They gave their estimations of risks on a scale from 0 (no risks) up to 6 (extremely high-level risks). After collecting these expert evaluations, the average values of all evaluations were calculated. Risk evaluation was carried out in two steps: 1. Eliciting expert opinions [2]: the research used quantitative methods based on expert opinions, meaning that experts were asked to quantify their judgments numerically. 2. The expert opinions are aggregated and averaged. The researchers appreciate the help of the experts who provided their opinions and assigned these opinions a risk level in the risk matrix.

Environmental risk can be defined as the potential or actual risks of various phenomena to the environment and living organisms. These effects can be due to emissions, resource depletion, effluents, wastes, et cetera. The ideas concerning the topic of technological risks brought up during the discussion with senior advisor Dr Pekka Peura were the following. The lack of a systematic means of integrating renewable energy globally is a primary problem in promoting the use of renewable energy technology and resources. Building infrastructure to buttress technology deployment was supported in policy proposals for an energy transition towards net zero emission resources [8]. Environmental uncertainty and carelessness are the main risks associated with the use of renewable energy, in the sense of using environmental resources irresponsibly and eventually depleting them. The risk in Finland would be the end of forestry. The renewable energy market is new, which means there are not as many risks as fossil fuel energy resources, which are more developed. According to

Wing and Jin [9], the sales price in the market is guaranteed by policies for renewable energy resources and grid access. New technology development leads to the obsolescence of older technology, which implies lower efficacy compared with newer versions [10]. Therefore, the early planning of projects using new technologies with renewable energy is risky, since equipment efficiency might develop further, leading into diminished public acceptance of the project and potentially less political support [10]. A major barrier to the use of renewable energy sources are national policies and policy instruments, which also affect costs and technological innovations [11]. In addition, inaccuracy in early planning regarding resource assessment and the supply of renewable energy technology can also create risks [10].

Risk matrices are a useful tool for risk assessment despite their limitations [12]. Therefore, the risk matrix method was supported by other methods in this analysis. On the other hand, the risks of different renewable energy types have been addressed by some publications, including the following: Saner et al. [13] stated that the impact of ground source heat pumps in a life cycle analysis can be represented by CO_2 emission equivalence and that greenhouse gas (GHG) emissions are not the only impact of geothermal energy. Greening [14] published a comprehensive analysis of different types of domestic heat pumps, covering their life cycle environmental impacts and the potential implications for the UK. Johnson [15] showed that the footprint of heat pump refrigerants is a significant greenhouse gas pollution source. In 2012, a quarter of total energy consumption in Finland was due to wood fuel energy production [16]. This shows the importance of bioenergy in Finland. In addition, Energy and Climate [16] state that the growth plan was for 25 TWh shares of Finnish electricity and heat production to come from forest chips by 2020.

According to Repo et al. [17], average emissions per unit bioenergy energy production from Norway spruce stumps decreased by about 20% and bioenergy from branches decreased by about 60% compared with the overall fuel cycle emissions of natural gas, after 50 years. 'The idea of biofuels production from micro algae is not new, but currently, it has received the keenest interests in an effort to combat global climate changes. Most of the studies have been focused on the following aspects: (1) the micro algae culture system, including raceway, photo bioreactor (PBR) and fermenter; (2) collection, screening and classification of micro algae, (3) molecular biology and genetic engineering; and (4) system analysis and resource assessment. The strengths of micro algae–based biofuels as the third-generation biofuels are many' [18]. Solar energy has the lowest impact on total greenhouse gas emissions relative to the national renewable energy targets of Finland [19]. The risks and environmental impacts of renewable resources cannot be ignored even if they appear to be small [19]. There are different types of renewable energy risks: environmental, economic, social and technological. Economic and social risks were not addressed in depth in this study. However, the environmental risks of renewable energy use and production were one of the key contributions in this paper. The number of researchers who have addressed this issue is small. The other area of contribution was that of the risks of climate change to renewable energy resources. These are unique contributions that have not been addressed much in other studies, even compared with the environmental risks of renewable energy. The significance of the study is that aimed to help in making sure renewables are safe for the environment leading and helping renewable energy sustainability by creating attractiveness and awareness of its risk-free facts to society. One of the novelties of this article is that new renewable technologies such as sediment heat energy production, asphalt heat and water heat exchangers were assessed and evaluated in the risk analyses. The research gaps tried to address are in these two areas.

The research questions addressed in this article are: 1. What and how much are the risks of climate change to renewable energy resources? 2. What and how much are the risks of renewable energy use and production to the environment?

2. Methods

The detailed procedures of this research were published in Girgibo [7]. According to Misra [1], there usually are three main stages involved in quantitative risk assessment: risk identification; risk estimation; and risk evaluation. A similar procedure to that planned and used by Holma et al. [20], modified for this paper's expertise meetings, is described below. The method of expert view was chosen because of Holma et al. [20] indication that the process helps to assess risks in the field of renewable energy with professional person knowledge one can quickly identify the associated risks. This was true in this paper's case because the current research found similar results to that of Holma et al. [20] even though both used different expertise to analyse the environmental impacts of renewable energy use and production. Of the experts that provided evaluations, thirteen were from Finland and one from Sweden. These experts were divided roughly equally into three renewable energy resources groups: geothermal energy, bioenergy and biomass, and solar energy. More than 25 experts were contacted, but only 14 were able to deliver their evaluations. The overall data collection time was more than seven months since the first request was sent by email. The construction of the whole experiment and study took more than two years and began in March 2019. Similar evaluations were planned for both risks: 1) Risks to renewable energy resources caused by climate change and 2) risks to the environment caused by renewable energy production and use. Risk analysis was performed by experts, who evaluated the risks on a scale from 0 to 6, from 'no risk' to 'very high risk', as shown in the matrix of the risk analysis table. The scale is as follows: 6 = extremely high risk, 4 = high risk, 2 = medium risk, 1 = low risk and 0 = no risk; empty boxes were coded as zero risk (see Table 1 for similar explanations). All risks analysed in this study are negative risks or threats, not positive risks. However, the procedure consisted of the following steps:

1. Verbal discussions between the organiser group members and others on both types of risks and impacts.

2. Critical stage: determining the impacts and risks, with the overall impacts determined via verbal evaluations.

3. The group members identified both types of risks in identification tables.

4. The new risks identified were added to matrix tables for both risk identifications.

5. Panel discussion was not performed because of COVID-19. All members gave their rankings for the risk matrix tables through email.

6. All table data collected was calculated by the organisers.

7. After the calculation, the experts received the risk analysis result table by email.
8. The organisers requested comments on the final risk table.
9. Modification was carried out according to the comments.
10. The final table of risks will be sent to all experts by email. The result will be used in this article in risk analysis as the result and for further future analysis.

The panel discussion step could not be carried out due to the global coronavirus pandemic, which also affected the Vaasa region. Therefore, most face-to-face contacts were not used, but a few email discussions were conducted. Afterwards, the experts were asked to evaluate the risk analysis matrix and to send their assessments by email to avoid face-to-face contact. The result shows lower values, most between 0 and 1. This was because the result represents average risk level values for experts who replied for specific renewable energy types.

Table 1. Risk estimate levels used in this study.

The risk analysis was carried out by who evaluated the risk level	**Range used for this research in comparison with Holma et al. [20]**	**Definition of range in risk analysis in our research (and in Holma et al. [20])**
6	Greater than 4.0 = Extremely significant	Extremely high risk (Extremely significant)
4	2.0 – 4.0 = Very significant	High risk (Very significant)
2	1.0 – 2.0 = Significant	Medium risk (Significant)
1	0.0 – 0.95 = Somewhat significant	Low risk (Somewhat significant)
0	0.0 = Not significant	No risk (Not significant)

3. Results

3.1. Identification of risks

The whole risk identification process and results of this research were reported separately in the publication of Girgibo [7]. The risks identified and used in the estimation had two classes: 1. Climate change risks and 2. Risks of renewable energy use and production to the environment. In the first category, the risks identified and used in the estimation matrix were extreme weather phenomena; wind speed; storms (wind speed and lightning); local or temporal air temperature increases; global warming; ice melting, including melting of ice in Greenland and polar areas and melting of permafrost in Siberia; increases in greenhouse gases (GHGs); precipitation increase; severe drought; sea level rise; water temperature increases; high waves; the thickness of ice in the sea and lakes, concretely the disappearance of sea ice; bioenergy sufficiency; the cost of bioenergy; the effects of land uplift; new plants in fields (invasive species); new insects in fields (invasive species); new trees in forests, with growing areas to the north and insects in the forest, including two generations in summer.

For the second (renewable energy risks to the environment) the research used similar risks (two new risks added in our research 'lowering of groundwater level' and 'effects on birds and other animals') to those that Holma et al. [20] identified: climate change, ozone depletion, acidification, tropospheric ozone formation, particulate matter formation: public health effects, eutrophication, toxicity, the impacts of biodiversity, soil depletion and soil quality, water use/water footprint, land use (land area as a resource), lowering of groundwater level, abiotic resource depletion (metals, minerals, fossil fuels), radiation, plant pests and disease, and effects on birds and other animals. The easiest definition of toxicity is the quality of being very harmful or rapidly unpleasant. The similarity in these identifications helped us to compare our results with those of Holma et al. [20], as presented in the discussion section of this article.

3.2. Estimation and analysis of risks

In the next subsections, the estimates for the risk levels of and to all types of renewable energy are presented. These results describe the average risk estimate levels based on expert opinions.

3.2.1. Geothermal energy risk analysis

a) Ground source heat

The risks of climate change to ground source heat were the lowest for all the geothermal energy types analysed here. The estimated risk level due to increased greenhouse gases was the highest, at about 0.5. The rest of the risk levels were below 0.5, with most being zero (see Figure 2 for further information). Thus, one can conclude that ground source heat is the most promising among geothermal energy types since it will not be substantially affected by climate change effects.

The risks of the use and production of ground source heat mainly involved soil depletion and effects on soil quality, land use, and the groundwater level. The risk estimates for toxicity and soil depletion and soil quality were about 0.6 and 0.7, respectively. The risk estimates for land use and the groundwater level were 0.6 and 0.5, respectively. The remainder of the risk estimates were below 0.4, with some even being zero. Except for the risks of the use and production of shallow geothermal sources in terms of toxicity, land use, soil depletion and groundwater, the remainder of the risks are among the lowest compared with the other geothermal energy types analysed here (see Figure 3 for a detailed understanding).

b) Asphalt/concrete-covered areas

The highest risks from climate change risks to renewable energy for asphalt/concrete-covered areas came from precipitation (rainfall) effects, with a risk level estimate of about 0.9. The increase in greenhouse gases had the second-highest estimate for asphalt areas, at about 0.5. Extreme weather phenomena, severe drought (lack of rain) and global warming were next, with roughly similar risk estimates of 0.4, 0.4 and 0.3, respectively. The rest of the risk level estimates were approximately zero, or at least below 0.2. The use of asphalt/concrete-covered areas for heat energy production seems to be the most promising strategy, in terms of climate change risks, aside from ground source heat (Figure 2 for detailed results).

The use and production of asphalt/concrete-covered areas for heat energy production have some of the lowest risk level estimates. However, they have the highest estimated risk of producing toxicity, about 0.6. The mid-level risks, at around 0.3, were associated with climate change, particulate matter formation, public health effects, soil depletion and soil quality changes, land use and abiotic resources. The other risks generated by the use and production of asphalt energy were very low and indeed approximately zero (Figure 3). This analysis shows that asphalt heat energy use and production was one of the safest technologies under consideration as an energy resource, in terms of its risks to the environment.

c) Borehole energy

Two types of geothermal borehole energy were analysed: boreholes with and without energy storage. The results are presented in the following sections:

c1. Without energy storage

The climate change risks to geothermal boreholes without energy storage were found to be lower than the risks to geothermal boreholes with thermal energy charging. Among climate change risks, the highest were due to increased greenhouse gases for borehole energy without energy storage, with an estimated risk level of 0.5. Extreme weather phenomenon had a risk level of 0.4 for this energy type. Global warming, the melting of permafrost, increased precipitation and severe drought were estimated as having risk levels around 0.3, with the other risks being lower. In a general comparison between the two borehole types, boreholes with thermal energy charging were estimated to face more risks due to climate change.

Both borehole types have similar environmental use and production risks, based on this study's analysis. The main differences were in soil depletion and soil quality, and in toxicity. The borehole without energy storage charging was estimated to have a lower risk level for soil quality, soil depletion and toxicity levels. Soil depletion and soil quality risks were much lower for the borehole without energy storage charging (see Figure 3 for detailed results).

c2. With thermal energy charging

Among geothermal energy types, the borehole system with thermal energy charging has the third-highest risks due to climate change, while among the risks of climate change, increases in greenhouse gases represent one of the highest risks for the largest number of geothermal resources. In borehole energy with thermal energy charging, the increase of greenhouse gases is estimated to have a risk level of around 0.5. Estimated precipitation increases and extreme weather phenomena had a risk level of about 0.4. Global warming, new plants to the fields and severe drought were about 0.2. The risk levels for the melting of ice and sea level rise were about 0.15. The rest of the risk levels were estimated as below 0.1, with some risk levels even being as low as 0 (see Figure 2 for detailed results).

The use and production of borehole energy with thermal energy charging represents a mid-level risk to the environment compared with the other geothermal energy types analysed here. The risk estimate for toxicity for the borehole system with storage charging was about 0.9. Lowering of the groundwater level was estimated to have a risk level of about 0.7. Public health effects and climate change were estimated at a risk level of about 0.5. The remainder of the risks caused by use and production of borehole systems with energy charging were below 0.5, which is low (see Figure 3 for more detailed observations).

d) Sediment energy

Sediment energy was expected to face the second-highest climate change risks of all geothermal energy types, after the water heat exchanger, which faces the highest risks. The thickness of sea and lake ice has the highest risk, at about 1.1. Next, extreme weather phenomena are estimated to cause a risk level of about 0.9. The increase in greenhouse gases and high waves are estimated to cause risk in sediment energy at a level of about 0.5. Global warming is estimated to have a 0.4 risk level for sediment energy. Storms (wind speed and lightning) and severe drought (absence of rain) both were estimated at a risk level about 0.3. The rest of the climate change risk types were estimated to cause lower than a 0.3 risk level for sediment energy. Some risks associated with climate change even have a risk level of zero for sediment energy (Figure 2).

Sediment energy use and production is estimated to have the highest risks to the environment (Figure 3). Toxicity due to sediment energy has the highest risk level, about 1.6. Land use and abiotic resource depletion are estimated to be caused by sediment energy at a risk level of about 1.0. The risk level of public health effects was about 0.8. Climate change effects, effects on animals, lowered groundwater and particulate matter formation were estimated at about 0.7 or lower. The rest of the risks of sediment energy use and production to the environment are lower than 0.7. The risk levels of use and production of sediment energy to the environment are much higher compared with climate change risks to sediment energy. Similar patterns also were noticed in other renewable energy sources analysed here (Figure 3). The production and use of renewables have low risks compared with non-renewable resources. Therefore, the benefits of renewable energy are much higher than its negative impacts, meaning that the use of renewables helps to safeguard the environment. However, the use and production of any type of energy has risks to the environment.

e) Water heat exchanger

The water heat exchanger has the highest risk due to climate change risks to renewable energy compared the rest of the geothermal energy types that were analysed in this study (Figure 2). The risk estimate levels due to sea and lake ice thickness and extreme weather phenomena were 1.4 and 1.1. These were the highest compared to the other risks to geothermal energy analysed here. The other highest risks for the water heat exchanger are storms, high waves and increases in greenhouse gases, which had risk levels 0.9, 0.7 and 0.7 respectively. The lowest values observed for the water heat exchanger were related to bioenergy and forest risks among climate change risks. It was also noted that land uplift had possible risks around the 0.4 level. This means when the water heat exchanger installed, it must be installed in a deep site. Otherwise, if the heat exchanger is installed near the shore, after several decays the water level might not be high enough to generate sufficient heat. This is because land uplift can cause seawater levels to decline, particularly in shore areas and especially those in Scandinavia, such as the city of Vaasa, Finland (see Figure 2 for further understanding of the results).

The water heat exchanger has some of the lowest renewable energy use and production risks to the environment compared with other geothermal energy types. The highest environmental risks of the water heat exchanger were climate change effects and particulate matter formation, which were both at a risk level of 0.7 (below 1) (Figure 3). Please see the meaning of the risk level numbers in the methods section of this article (Table 1). The lowest values were zero (no risk) (Figure 3). The rest of the environmental risks were between 0.7 and 0.0, which is below 1.0 (low risk). This makes the water heat exchanger one of the safest renewable energy technologies, since it presents little risk to the environment during its use and production stages.

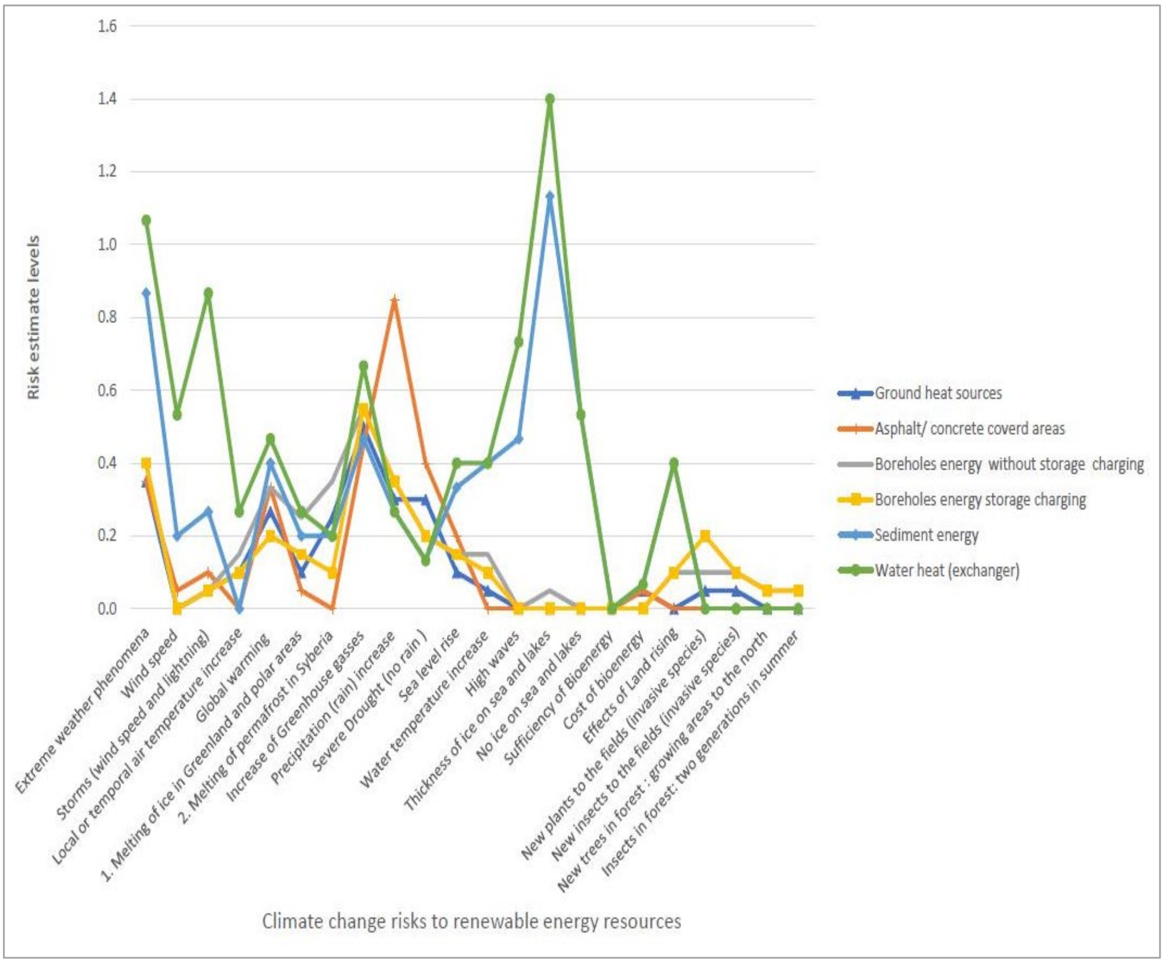

Figure 2. Graph showing risk estimate level of climate change risks to geothermal energy types.

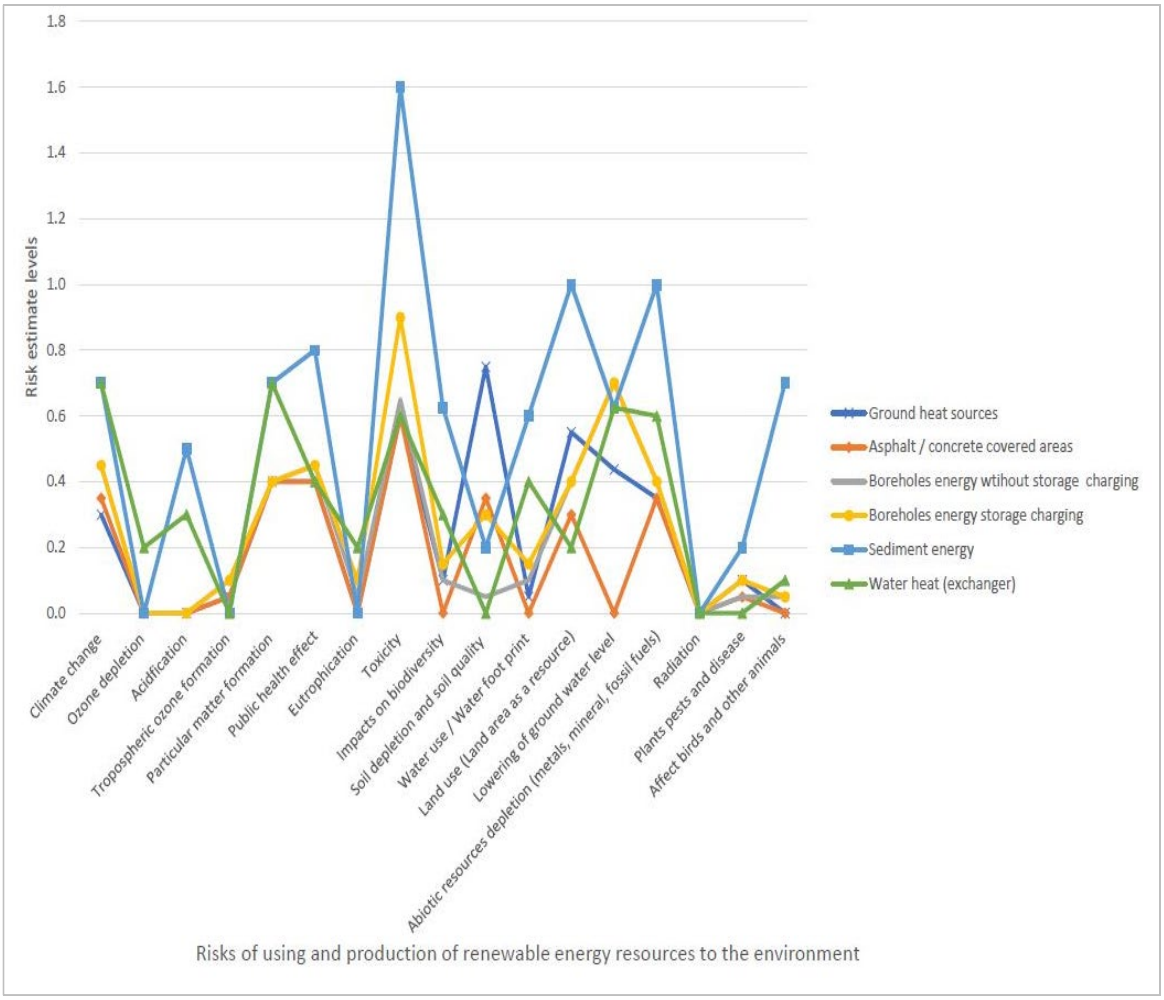

Figure 3. Graph showing risk estimate level of the risks of the use and production of geothermal energy types to the environment.

3.2.2. Bioenergy and biomass risk analysis

a) Bio-oil

Bio-oil, biodiesel and bioethanol had very similar risks due to climate change effects. The bio-oil and biodiesel results are not visible because they are identical to the bioethanol plots (Figure 4). The highest risk level for bio-oil was associated with climate change effect risks to bioenergy sufficiency and costs, with an estimated level of about 2.25. The next highest risk level for bio-oil was 2.0, for risks from extreme weather phenomena, severe drought, invasive plants and insect species. Wind, storm and global warming risks to bio-oil are estimated at about 1.4. The increase in greenhouse gas risks for bio-oil was about 1.25. The rest of the risks from climate change were below 0.8, which corresponds to precipitation. Some were even estimated as zero (Figure 4). Climate change risks for bioenergy and biomass were the second highest among renewable energy types, after solar-based energies.

In terms of the risks of bio-oil use and production to the environment, their impact on biodiversity was the highest at 1.2. For almost all environmental risks of bioenergy and biomass use and production, the impact on biodiversity was the highest. The next highest risk level for bio-oil was 0.6, an estimate level that corresponded to plant pests and diseases, acidification and tropospheric ozone formation. Land use and its effects on birds and other animals were the next-highest risks of Bio-oil, at about 0.4 for both. The remainder of the risks are lower (see Figure 5 for further details).

b) Biodiesel

Climate change risks to biodiesel are similar to those for bio-oil and bioethanol. The highest climate change risk for biodiesel corresponded to the cost of bioenergy, at a risk level about 2.25. The next-highest climate change risk level was about 2, corresponding to extreme weather phenomena, severe drought, bioenergy sufficiency, new plants in the fields and new insects in the fields. Wind speed, storms, and global warming also had a risk level of about 1.4 for the risks of climate change to biodiesel. Next came the effects of increased greenhouse gases, at about 1.25. The remainder of the risk estimate levels were lower than 1 (Figure 4).

The risks of biodiesel use and production to the environment were also estimated. Biodiversity risks from use and production were found to be among the highest for most bioenergy and biomass. The impact of biodiversity was 1.5 for biodiesel. Toxicity due to biodiesel was estimated to have a risk level of 0.8. The next highest risk level was 0.6, corresponding to the risks of acidification, tropospheric ozone formation, particulate matter formation and plant pests and disease generated from biodiesel use and production. Ozone depletion, soil depletion and soil quality and effects on birds and other animals had a risk level of 0.4 for biodiesel. The rest of the risks were estimated as well below the 0.4 risk estimate level (Figure 5).

c) Bioethanol

For climate change effect risks for bioenergy and biomass, the highest risks level for bioethanol corresponded to the cost of bioenergy, at about 2.25. The next-highest risk level estimate was about 2.0, corresponding to extreme weather phenomena, severe drought, new plants in the fields and new insects in the fields. The risks to bioethanol due to wind, storms and global warming were estimated at about 1.4. The risk level for bioethanol due to increases in greenhouse gases was about 1.25. The rest of the risks from climate change were below 0.8, which corresponded to precipitation and more insects in the forest. Moreover, some risks were estimated as zero (Figure 4). It is important to note that bio-oil, biodiesel and bioethanol had the exact same risk level results for climate change effect risks.

Among the risks of the use and production of bioethanol to the environment, the highest risks came from its impact on biodiversity, at about 1.4. The risks of its effects on climate change were about 0.8. Acidification, tropospheric ozone formation and toxicity were the next highest risk levels, at about 0.6. The next-highest risk estimate level was 0.4. This estimate was for ozone depletion, soil depletion and soil quality, plant pests and disease, and effects on birds and other animals. The rest of the risk estimates were below 0.4 (Figure 5).

d) Biogas from different sources

The highest risks to biogas due to climate change were associated with sufficiency of bioenergy, with a risk estimate level of 1.9. Severe drought had a risk estimate level of 1.8 and cost of bioenergy had a level of 1.7, which are among the highest risk estimate levels. Extreme weather phenomena and new invasive insect species in fields are expected to cause risk for biogas from different sources, with risk levels of about 1.6 and 1.4, respectively. New invasive plants in fields and storms are expected to cause risk levels of about 1.25 and 1.1, respectively. Wind speed was about a 0.9 risk estimate level, causing risks to biogas from different sources. The rest of the risk estimate levels are below 0.9 (Figure 4).

The environmental risks of the use and production of biogas from different sources were also estimated by expert opinions. Biogas use and production had among the lowest risk levels compared to other bioenergy and biomass energy types. The highest risk caused by biogas was 0.5, for impacts on biodiversity. Toxicity and its effects on birds and other animals had a risk estimate level of about 0.3. The remaining risks to the environment from biogas were below 0.3, which is quite low (Figure 5).

e) Forest biomass energy

The highest risks were associated with the costs of bioenergy, at a level of 2.4. This is a similar pattern to that seen for other types of bioenergy. Among the climate change risks to forest biomass energy, storms and extreme weather phenomena both had a risk estimate level of about 2.2, which is one of the highest. Severe drought and more insects in the forest with two generations per year had risk estimate levels of almost 2.0. Global warming and new invasive insect species in fields had risk estimate levels of almost 1.5. Increased greenhouse gases and new invasive plants in fields had risk estimate levels of almost 1.2. New trees in the forest with growing areas had a level of 0.8. The rest of the risks caused by climate change effects were at or below the 0.5 risk estimate level (Figure 4).

The use and production of forest biomass energy causes environmental risk as well, and indeed these risk levels were among the highest among bioenergy and biomass energy types. The highest risk estimate for forest biomass energy is 1.8 for impact on biodiversity. Effects on climate change had a risk level of about 1.1. A risk level of around 0.8 was associated with particulate matter formation, plant pests and diseases, and effects on birds and other animals. Land use (land area as a resource) impacts were caused by forest biomass energy use and production with a risk estimate level of 0.6. Toxicity and public health effect risk impacts caused by forest biomass energy were estimated to be around 0.5. The risk level of acidification was around 0.5 as well. Tropospheric ozone formation and eutrophication risks were about 0.3. The risks levels of ozone depletion and abiotic resource depletion (metals et cetera) were around 0.2. The rest of the risks caused by forest biomass energy use and production were about or below 0.2 risk estimate levels. Better observation and comparisons can be seen in (Figure 5).

f) Field biomass energy

Field biomass energy faced risks due to climate change effects. Some risks of climate change to field biomass energy were estimated in this study as well. Severe drought (absence of rain) was the highest risk, estimated at a risk level of around 2.5. Extreme weather phenomena and the cost of bioenergy were both estimated to have a risk level of about 2.3. Storms and sufficiency of bioenergy had a risk estimate level of about 2.1. New invasive insect species in fields caused an estimated risk level of 2.0 for field biomass energy. Wind speed risk was 1.9 and new invasive plants species risk was 1.6. On other hand, global warming was estimated to cause a risk level of 1.4. Insects in the forest (two generations per summer) and precipitation were estimated to have a risk level of 1.1. The local or temporal temperature increase, the increases in greenhouse gas emissions and sea level rise have an estimated risk level of about 1.0. The melting of ice in Greenland and polar areas and the melting of permafrost in Siberia had risk estimate levels of about 0.7 and 0.6, respectively. Growing areas of new trees in the forest in the north had a risk estimate level of about 0.4. Risks due to water temperature and the thickness of ice in the sea and lakes were about 0.3. The rest of the risks caused by climate change effects were below 0.3 and some were even close to 0 (Figure 4).

The use and production of field biomass energy affects the environment. Effects on biodiversity represented the greatest risk of field biomass energy, at about 1.5. Risks to land use (land area as a resource) and climate change were next, at a risk level of about 1.0 and 0.9, respectively. Particulate matter formation and soil depletion and soil quality due to field biomass energy had risk estimate levels of about 0.8 and 0.7. Toxicity had a risk estimate level was about 0.6. Acidification, eutrophication, water use/water footprint, abiotic resource depletion (metal, minerals, fossil fuel and so forth) and effects on birds and other animals were all at a risk estimate level of about 0.5. Tropospheric ozone formation, public health effects, and lowering groundwater levels were around the 0.4 risk estimate level. Ozone depletion and plant pests and diseases were risks at a level of about 0.3. The lowest risk was radiation risk, which has a 0.0 risk estimate level caused by field biomass energy use and production (Figure 5).

g) Algae

For risks to algae because of climate change effects, the cost of bioenergy and sufficiency of bioenergy had risk levels of about 2.3 and 1.9, respectively. Extreme weather phenomena had a risk level to algae of approximately 1.4. Wind speed and storms had a risk estimate level of about 1.2. High waves had a level of about 1.1. Global warming risk was 1.0, severe drought was 0.9, water temperature was 0.9, the thickness of ice in the sea and lakes was 0.8 and local or temporal air temperature was about 0.7. The risk levels due to an increase in greenhouse gases and new invasive insect species in fields were 0.5. The risk levels due to increased precipitation were 0.4, the risk due to melting of permafrost were 0.3, and the risk due to new invasive plant species in the fields was around 0.3 (Figure 4). It was also noted that algae were the least affected by climate change effects among bioenergy and biomass energy types.

Water use/water footprint had the highest risks due to the use and production of energy from algae, at a risk estimate level of about 0.7. Risks at about a 0.4 risk estimate level included eutrophication, impacts on biodiversity and abiotic resources depletion (metals, minerals, fossil fuels et cetera). The risk estimate levels of plant pests and disease and effects on birds and other animals were around 0.3. Acidification and climate change had risk estimate levels of around 0.2. Risks due to toxicity, soil depletion and soil quality, and lowering groundwater levels were estimated at about 0.1. Risks from ozone depletion, public health effects and radiation were all estimated at 0.0.

This concludes the risk analysis of climate change effects on bioenergy and biomass, as well as bioenergy and biomass energy use and production risks to the environment. In the following two figures (Figure 4 and Figure 5) there is more information about the risks of bioenergy and biomass.

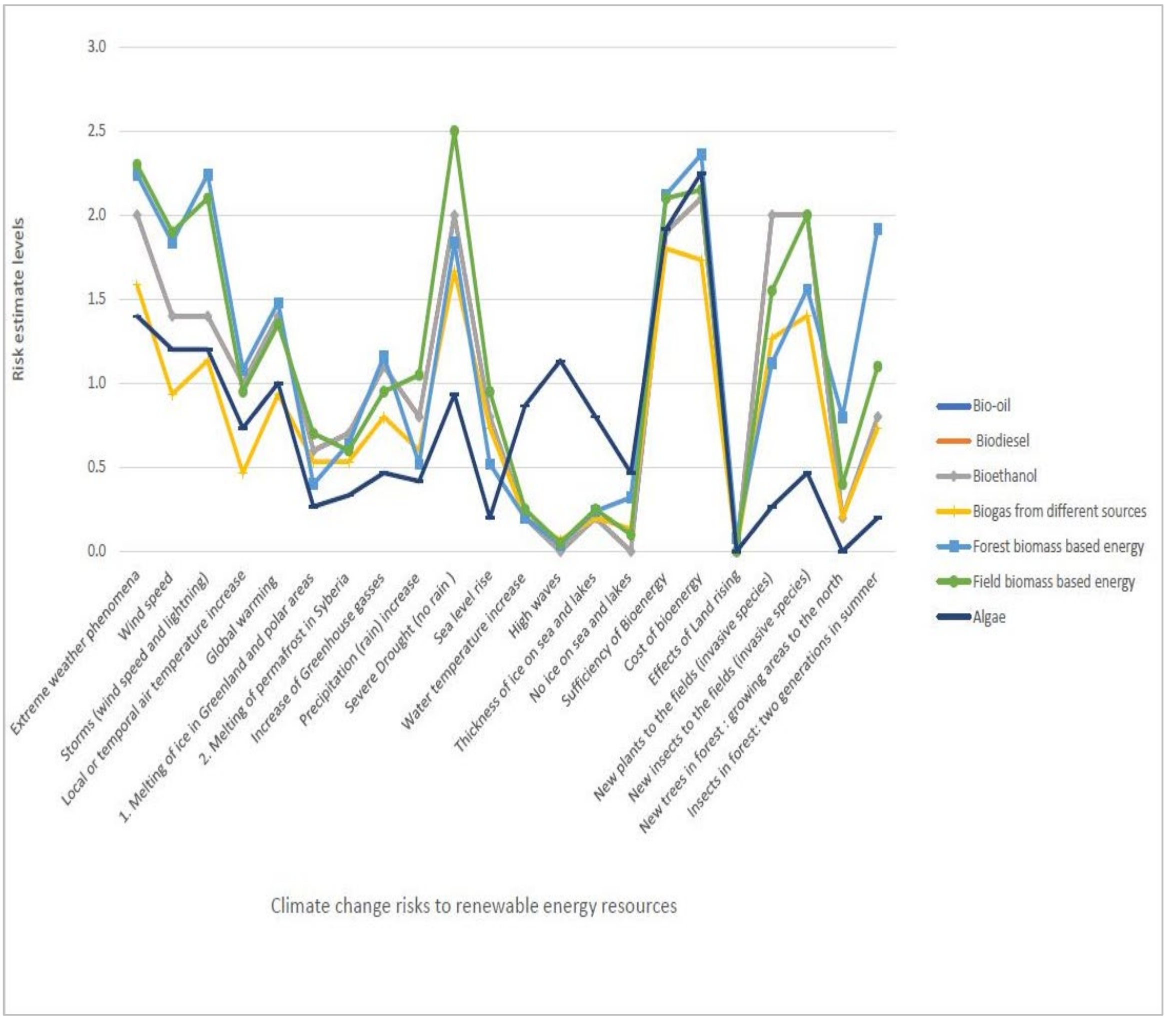

Figure 4. This graph shows risk estimate levels for climate change risks to bioenergy and biomass energy types.

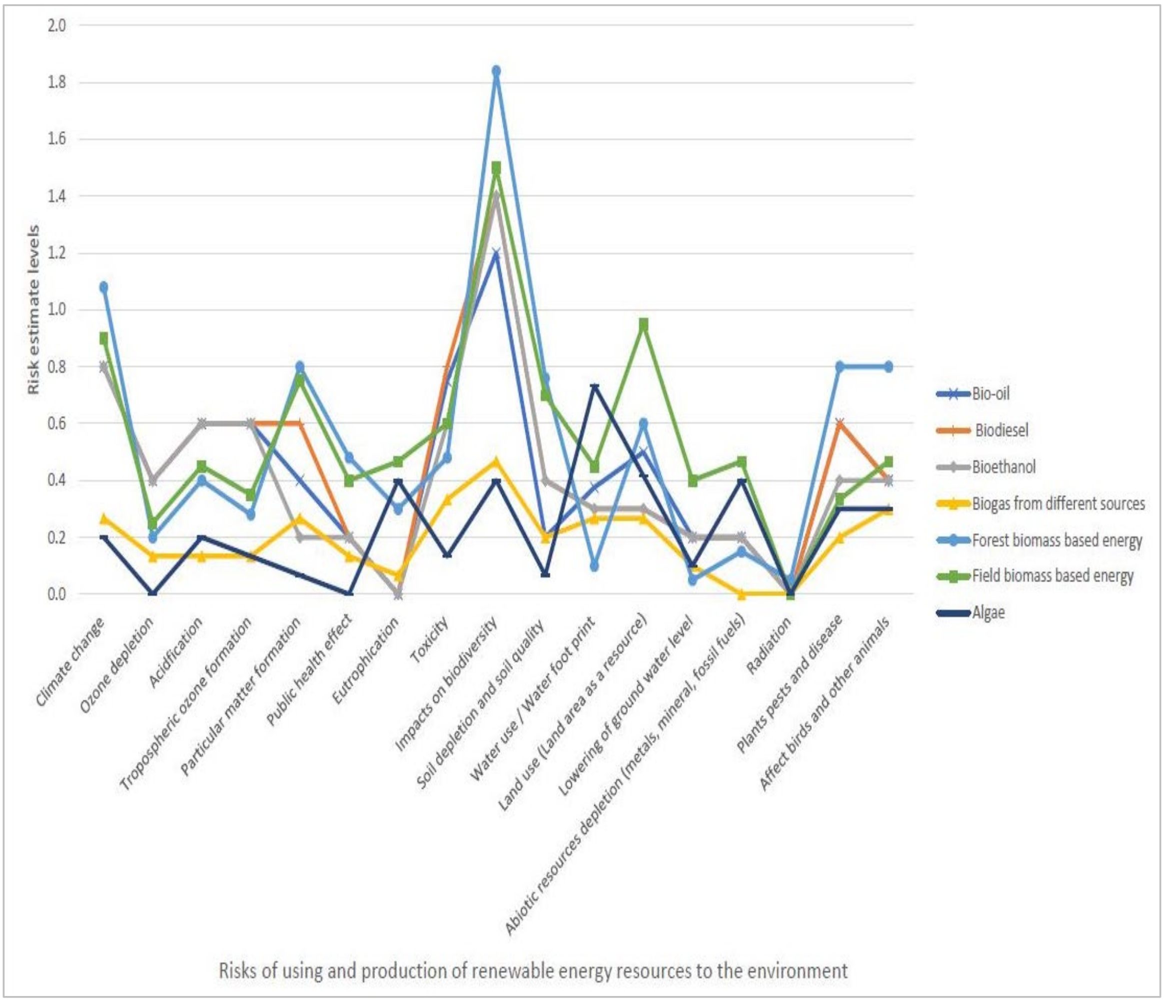

Figure 5. This graph shows risk estimate levels of the use and production risks of bioenergy and biomass energy types to the environment.

3.2.3. Solar energy-based risk analysis

a) Wind energy

There are two types of wind energy to be analysed, ground and offshore wind energy. Both are covered in the following sections.

a1. Ground

Ground wind energy was mainly affected by a few climate change risks: extreme weather phenomena, wind speed and storms with estimated risk levels of 2.7, 2.5 and 2.6, respectively. In these risk types, the estimated risk levels were the second highest among solar based energy types, after offshore wind energy. Local or temporal air temperature risks affected ground wind energy about at a 0.7 risk estimate level, which quite low compared with the previously mentioned risks. Severe drought had a risk estimate level of about 0.6. Further, the rest of the risks generated by climate change effects on ground wind energy are below the 0.5 risk estimate level. Figure 6 presents the rest of the results for risks generated by climate change effects.

Land use (land areas as a resource) represented the highest risks of ground wind energy to the environment at a risk estimate level of about 1.8. Impacts on biodiversity and effects on birds and other animals had risks of about 1.1 and 1.3, respectively. Impacts of ground wind energy on abiotic resource depletion and climate change were around 0.9 and 0.8, respectively. Particulate matter formation and public health effects both had risk estimate levels of around 0.5. Soil depletion/soil quality and water use/water footprint risks were both around 0.2. The rest of the environmental impacts of ground wind energy had zero estimated risk (Figure 7).

a2. Offshore

The highest risks for offshore wind energy were extreme weather phenomena, wind speed and storms, which have risk estimate levels of 3.4, 3.1 and 3.3, respectively. The other high-risk estimates were only for sea level rise and high waves, at levels of 1.6 and 1.8. This is expected because offshore wind energy is mainly installed in open waters. Therefore, any water-related risks also affect this energy source. The next-highest risks are the thickness of ice on the sea and lakes, local or temporal air temperature increases, the melting of ice in Greenland and polar areas, and sea and lake ice thickness, which all had risk estimate levels of about 0.9 or below. The melting of permafrost in Siberia, severe drought, and water temperature increases were about 0.5. Further, the rest of the risks created by the effects of climate change were below 0.5 (see Figure 6 for further information).

There are five main environmental risks of the use and production of offshore wind: effects on birds and other animals, abiotic resource depletion, climate change, impacts on biodiversity and particulate matter formation, which have risk estimate levels of 1.5, 1.1, 0.8, 0.3 and 0.5, respectively. These analyses are important because they clearly show the variation between ground (onshore) and offshore wind energy risks. Similar comparisons can be carried out across all renewable energy analyses. The rest of risks generated by offshore wind energy were at or below the 0.3 risk estimate level. See Figure 7 for further observations.

b) Solar energy

There are two means of using solar energy: solar panel → electricity and collector → heat. The results for both are given in the following sections. These panels and collector types have relatively similar risks and they have similar climate change effects, with only a few differences.

b1. Panel

Among the risks of climate change effects to solar panel energy, the highest risk was estimated for storms, at a risk estimate level of about 1.4. The next-highest risk is due to extreme weather phenomena, at a risk estimate level of about 1.3. Wind speed had a risk estimate level of about 1.1. Increased precipitation and increased greenhouse gases were at the 0.9 and 0.8 risk estimate levels, respectively. Severe drought (absence of rain) and global warming were around the 0.6 risk estimate level. Local or temporal air temperature was around the 0.5 risk estimate level. The rest of the climate change risks to panel solar energy were below 0.5. For more information, see Figure 6.

Solar-based energy types have similar patterns in their use and production risks to the environment. This is true for panel solar energy as well. Among the risks of solar panel energy, abiotic resource depletion has a roughly 1.1 risk estimate level, which is the highest value for the risks of solar panel energy. Land use (land areas as a resource) had risk estimate levels about 0.6. Climate change had risks from solar panel energy of about 0.4. Impacts on biodiversity and soil depletion and soil quality had risk estimate levels of 0.1 and 0.2, respectively. The rest of the risk estimate levels are at or below 0.1, with most being zero. The rest of the results are presented in Figure 7.

b2. Collector

The highest risks of climate change effects on solar energy collector technology were due to storms (wind speed and lightning). The risk estimate level was found to be 1.4 based on the average of the expert opinions. Extreme weather phenomena and wind speed were the next-highest risks for collector solar energy, at about 1.3 and 1.1, respectively. The other risks that were visible for solar collectors were due to precipitation, increased greenhouse gases and severe drought, at risk levels of about 0.9, 0.8 and 0.6, respectively. Global warming had a risk estimate level of about 0.4. Local or temporal air temperature was around a 0.2 risk estimate level. The rest of the climate change effect risks were below 0.2 (Figure 6).

The use and production of collector solar energy has risks. Abiotic resource depletion is the highest risk generated by collector solar energy, at a risk estimate level of about 0.5. Effects on climate change, water use/water footprint effects and land use (land area as a resource) were at risk estimate levels of about 0.4, 0.2 and 0.2, respectively. The rest of the results show that all the other types of risks due to collector solar energy were below 0.2 and most risk estimates generated were zero. For further observations, see Figure 7.

c) Hydropower

Hydropower was found to be one of the solar-based energy resources least affected by climate change effects. Among climate change effects, drought is the highest risk for hydropower, at a risk estimate level of about 1.6. Extreme weather phenomena and global warming were found out have risk estimate levels of about 1.2. Wind speed, storms, melting of ice in Greenland and polar areas, and sea and lake ice thickness all were found out to have similar risk levels, about 1.0. Water temperature increases and heat waves had risk estimate levels of about 0.8 and 0.6. The local temporal air temperature increase, the increase in greenhouse gases, precipitation, sea level rise and the effects of land uplift all affect hydropower at the same level, about 0.2. The rest of the climate change risks included in this analysis were found to have a risk estimate level of 0.0 (the results are presented in full in Figure 6).

Among solar-based energy resources, the use and production of hydropower was one of those that least affected the environment, after solar/collector energy production, based on a comparison of the total sum of the average risk values. The highest risks due to hydropower were determined to be impacts on biodiversity, water use/water footprint, and land use, all with risk estimate levels at about 0.4. Eutrophication, abiotic resource depletion (such as metals), radiation, plant pests and diseases, and effects on birds and other animals were all at about the 0.2 risk estimate level. The rest of the risks of hydropower were zero. For further observations, see Figure 7.

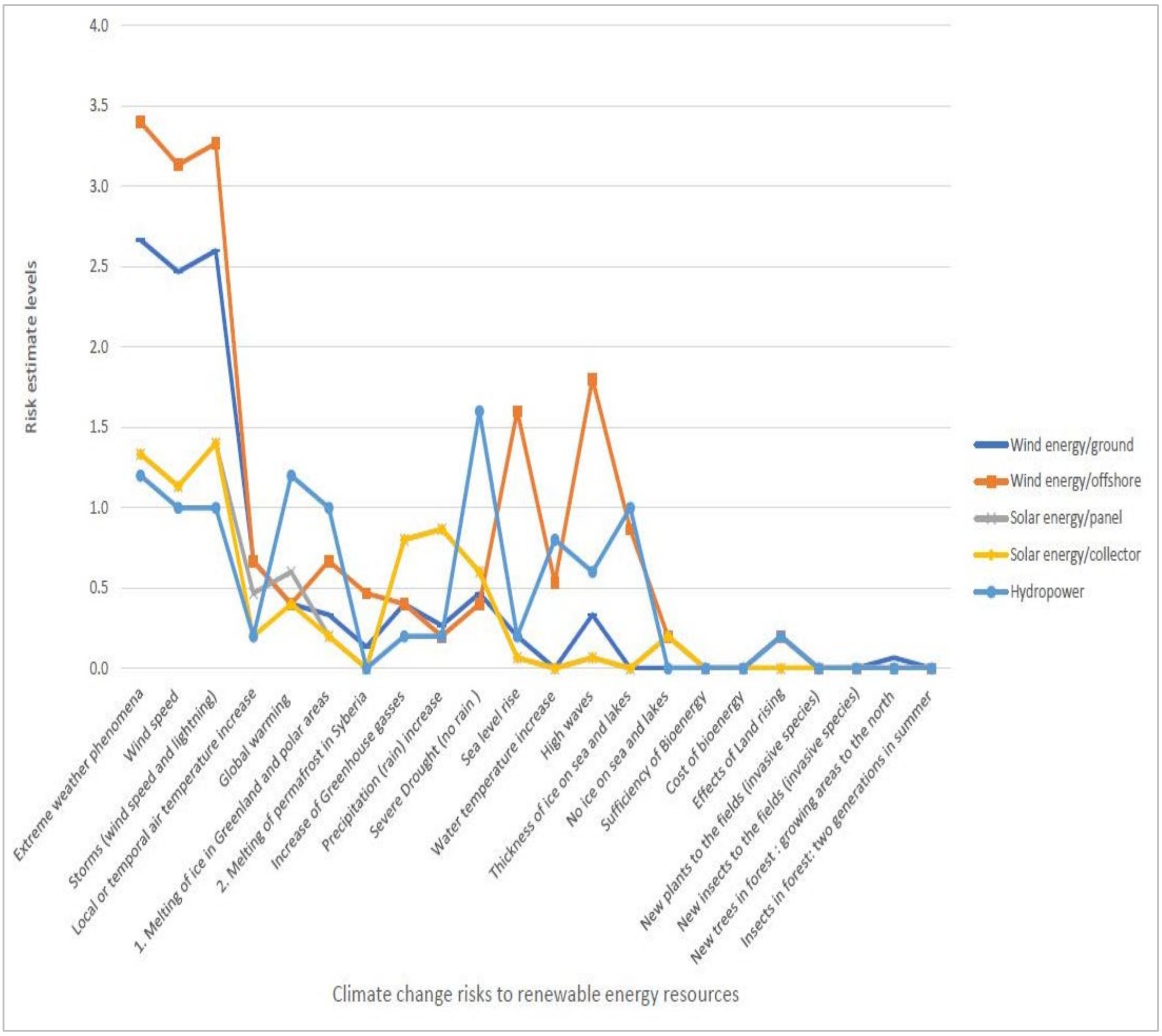

Figure 6. Graph showing risk estimate levels of climate change risks to solar-based energy types.

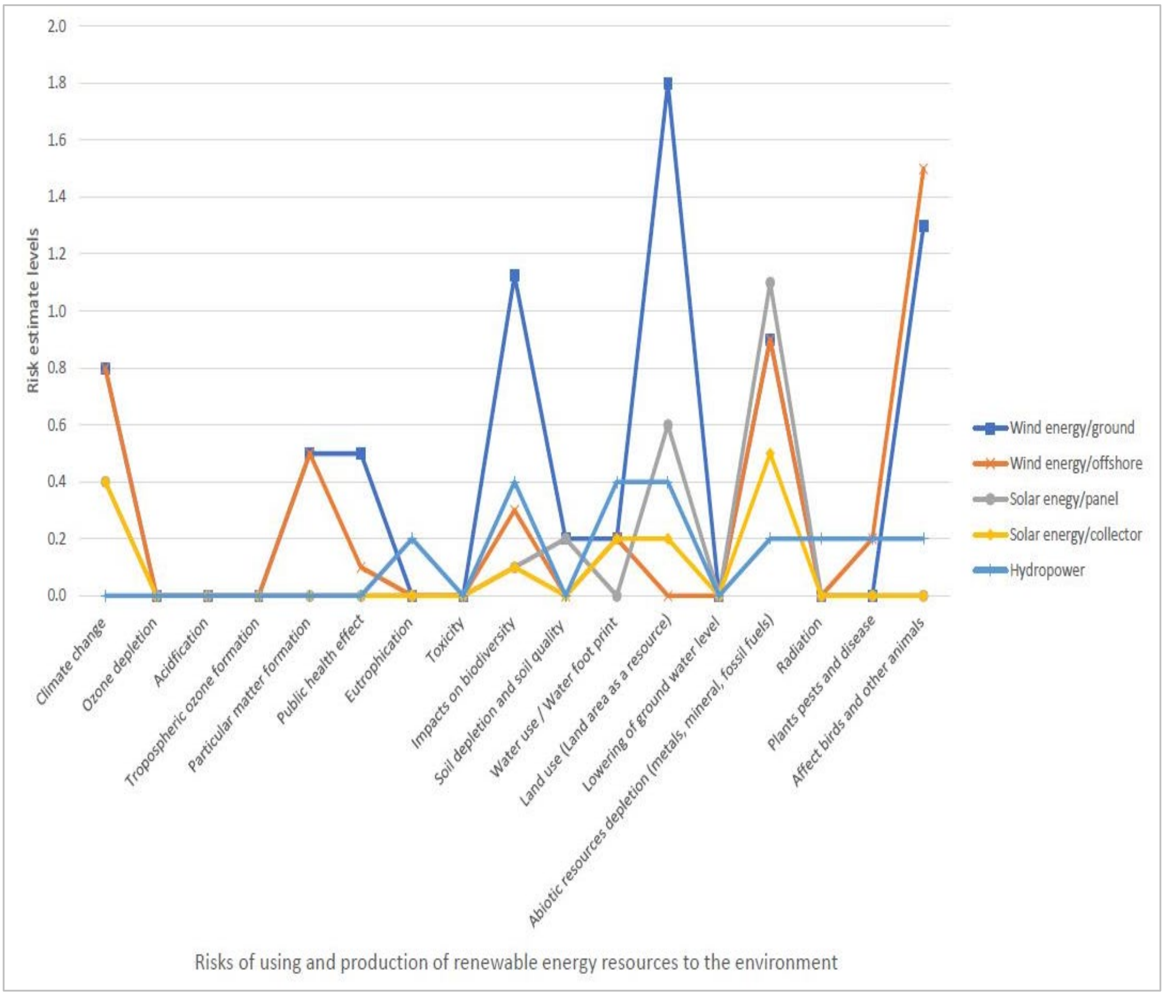

Figure 7. Graph showing risk estimate levels of the use and production risks of solar-based energy types to the environment.

3.3. Evaluations of the risks

Table 2 presents the summarised evaluations and a comparison between the risk analysis results for the different renewable energy types. In addition, it presents the least and most affected or affecting renewable energy types for the two risk analyses conducted in this research study. Regarding the risks of climate change effects on all renewable energy resources, the least affected was ground heat source energy and the most affected was field biomass energy. These evaluation decisions were made based on the generalisation of the result described above and by comparing with the total average summed risk values, as well as comparing and checking within each renewable energy resource types. In evaluating climate change effect risks to geothermal energy resources, the least affected sources were ground heat sources and the most affected were water heat exchangers. Regarding climate change effect risks to bioenergy and biomass energy resources, the least affected were algae resources and the most affected was field biomass energy. Regarding the risks of climate change to solar based energy resources, the least affected were solar energy/collectors and the most affected was wind energy/offshore.

Among the environmental risks due to the use and production of renewable energy resources, the least risky were solar energy/collectors and the riskiest was field biomass energy. Field biomass energy was determined to be the riskiest to the environment among all renewable energy resources, as well having the highest risk due to climate change effects. For geothermal energy resources, the least risky was energy using asphalt/concrete covered areas as a heat source and the riskiest were sediment heat energy resources. Among bioenergy and biomass energy resources, biogas from different sources had the least effects and field biomass energy resources had the most. For solar-based energy resources, the one with the least effects was solar energy/collectors and one with the most effects was ground wind energy. The best energy resources, those that had the fewest environmental effects and were the least affected by climate change effects, were solar energy/collectors and ground heat sources, respectively.

Table 2. Generalising the renewable energy resources with the best and the worst average risk levels (also checked by the average risk estimate total sum for each energy resource).

Renewable energy resources	**Risks of climate change effects to the renewable energy**		**Use and production of energy resources risks to the environment**	
	Least affected	**Most affected**	**Least affecting**	**Most affecting**
Geothermal energy resources	Ground heat source	Water heat exchanger	Asphalt/concrete covered areas as heat sources	Sediment heat energy
Bioenergy and biomass energy resources	Algae	Field biomass energy	Biogas from different sources	Field biomass energy
Solar-based energy resources	Solar energy/collector	Wind energy/offshore	Solar energy/collector	Wind energy/ground
Comparing all energy resources	*Ground heat source*	*Field biomass energy*	*Solar energy/collector*	*Field biomass energy*

Based on the overall evaluation, Figures 8 and 9 were created based on the total average risk estimate values. As stated in Table 2, among the climate change effect risks on renewable energy, the most affected is field biomass energy and the least affected is ground heat source energy. See Figure 8.

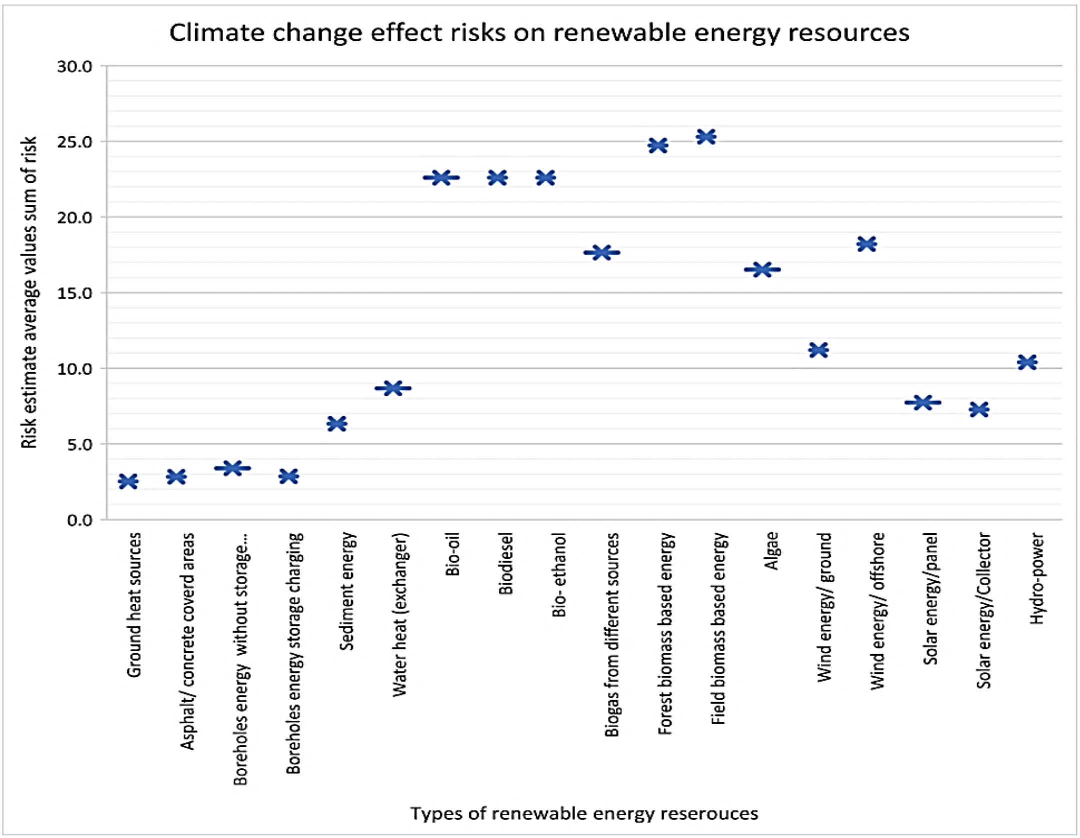

Figure 8. Graph showing the sum of the average risk estimate levels of climate change risks to all renewable energy resources.

As stated in Table 2, among the use and production risks of renewable energy resources, the resource with the greatest effects was field biomass energy and the resource with the lowest effects was solar energy/collectors (Figure 9).

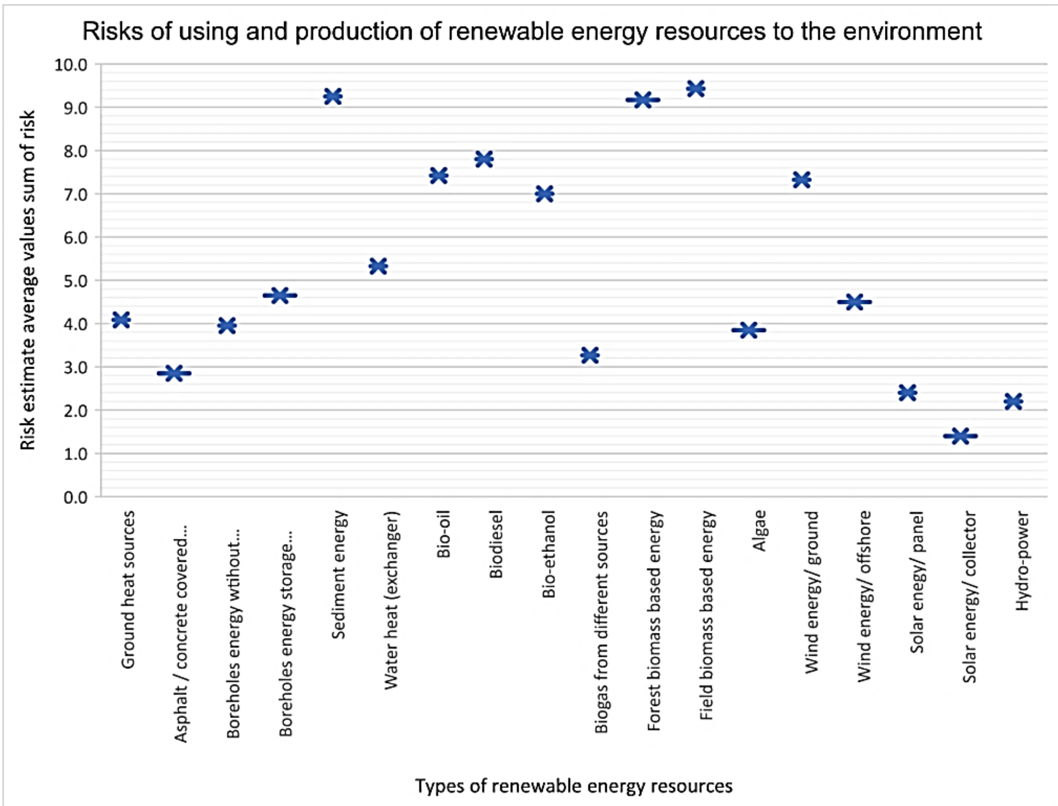

Figure 9. Graph showing the sum of average risk estimates level for the environmental use and production risks of all renewable energy resources.

The following paragraphs present the arguments relative to the validation of the risk analysis process. Risk analysis was performed with a procedure similar to that of Holma et al. [20], namely risk analysis based on data collection through expert evaluations (see for detailed procedures and steps [7]) This method is a well-recognised method in risk analysis. The experts were chosen such that they have in-depth knowledge of at least one of the renewable energy technology types. Having a group of experts for data collection helps gather the best risk information for all types of renewable energy. Therefore, the experts' views measure the existence and magnitude of the risks. The only limitation was that the number of experts was low (14 experts out of 25 who were asked for their risk evaluation), but this number nonetheless is comparable with that of Holma et al. [20], who used 20 experts. This means that our results can indicate the direction for risks and can serve as a starting point for future in-depth investigation into the risks of renewable energy. The method used in this risk analysis also was used by [20]. This method is sufficiently accurate to collect good data on risks and on renewable energy. The experts chosen were knowledgeable about their own specific renewable energy types. It was noted that they could perceive and understand the different types of risks in the renewable energy resource types. The generalisability of the method is such that at least its national-level accuracy was sufficient.

The risk analysis and management concept is suitable for assessing the risks of renewable energy. Its repeatability and reproducibility can be guaranteed if the right types of experts are present. The opinion of one expert might differ from that of another. However, the average results certainly can show similar patterns. The repeatability of the concept in different locations is quite feasible, though it probably will produce different results because of the area specificity of specific renewable energy sources and of their production methods. Different risks to renewable energy due to climate change can be present in different places. Risk analysis of renewable energy resources was mainly built upon a mixed qualitative and quantitative strategy. It is more qualitative, and thus a lack of identification of statistical analysis uncertainties seems certain. Therefore, more uncertainties can be identified by the Type-B error method instead of the Type-A error method. The uncertainties of the risk analysis of renewable energy resources can be identified through the Type-B error method. This concept of risk analysis of renewable energy has uncertainties that can might be generated by the small number of respondents. Thus, it may be difficult to accurately generalise the concepts to a global scale. However, as previously stated, before this concept the analysis was planned to be a starting point for larger risk analysis investigations.

The researchers are aware of the small number of expert respondents for this risk analysis. In addition, the generalised averaged risk estimate levels might be different with larger numbers of expert respondents. The main uncertainties that can be present in risk analysis of renewable energy resources are due to the small number of experts. This is one of the uncertainties that can be identified by the Type-B error method. The researchers attempted to mitigate this problem by comparing our findings with the publication of Holma et al. [20] on risks of the use and production of renewable energy to the environment. The results are similar in most cases. However, climate change effect risks to renewable energy cannot be compared with Holma et al. [20], because they did not study this aspect of risk. The analysis of climate change risks is a new result. Thus, the uncertainties generated by the small number of experts responding to the risk analysis are still present. Both aspects of risk were planned to serve as a starting point for future in-depth analysis of risks to and from renewable energy resources.

4. Discussions

Identifications of risk types in renewable energy were carried out by examining different resources for risk types according to Holma et al. [20], In addition, some experts who participated in this risk analysis also contributed to the risk identification process. The risks identified and used were presented in the results section and in publication of Girgibo [7]. Two risks, which were identified in addition to those from Holma et al. [20], fell under the category of risks to the environment due to the use and production of renewable energy: lowering groundwater and affecting birds and other animals. The risks of climate change effects on renewable energy were all new and not considered in [20]. Those identifications also can be found in the results section. The climate change effects were presented in depth in all IPCC reports (e.g. [21] and [22]). It was believed that all possible risk aspects were addressed to obtain the most possible results.

The estimation and analysis results were presented for all renewable energy types analysed in this research. The first section covered geothermal energy types, including ground heat sources, asphalt/concrete-covered areas, borehole energy (without energy storage and with energy storage charging), sediment energy and water heat exchangers. Among these, the least affected by climate change was ground heat source energy, because it is located underneath the surface of the Earth. Thus, the change due to weather patterns and global warming is very limited. The most affected by climate change are water heat exchangers. This is because the water heat exchangers are installed underwater, and both the water and the exchanger have been affected severely by changes in air temperature and solar irradiance. These evaluations were carried out based on the average total results. Among the risks due to the use and production of renewable energy resource, the riskiest was sediment heat energy. On other hand, it has been found that sediment heat energy uses climate change effects to its advantage, at least in summer [23]. However, the average total result shows that sediment heat production has the largest effects among geothermal energy resources.

The use of asphalt/concrete-covered areas as the heat source was found to have the least effects on the environment. This is because this energy is built under asphalt or concrete layers and even in pre-existing structures. The University of Vaasa has been very active in both sediment heat energy and the use of asphalt/concrete areas as heat sources. Both are new renewable energy technologies. This finding on how they affect the environment helps in planning their implementation and management. Ground heat source energy was also found to have the least effects across all types of renewable energy resources. Thus, this was the best renewable energy technology, since it was also among the least affected. Bioenergy and biomass energy were the other type of energy that was analysed for their risks. Among all types of bioenergy and biomass, field biomass was found to be the most affected by climate change effects and to have the most effects on the environment. Thus, this is one of the riskiest types across all types of renewable energy. The source least affected by climate change was algae and the source with the fewest effects on the environment was biogas from different sources. Climate change effects least affected solar energy/collectors, which also had the lowest environmental effects. This makes it the best technology among solar-based energy resources. However, according to Solaun et al. [24], literature on the climate change impacts of solar sources has received less attention than that on wind or hydropower. Across all renewable energy, the least affecting to the environment was solar energy/collectors. The source that was most affected by climate change effects among solar-based energy resources was offshore wind energy. Ground wind energy was found to have the most effects on the environment among solar-based energy resources. Cronin et al. [25] have critically reviewed the literature on the impacts of climate change on the energy supply system, summarising the regional coverage of studies, trends in the results and sources of disagreement. In their study, they noted that several authors had commented that the negative impacts of climate change on wind and solar generation and infrastructure will be insignificant since the rapid development and relatively short lifetimes of these technologies allow adaptation through technological upgrades and siting.

Comparing our result with those of Holma et al. [20] shows the similarity of the risk estimates in most cases for the risks of the use and production of renewable energy to the environment. However, this does not hold for some risks, mainly in solar energy and hydropower technologies. See Table 3 in the appendix section of this article for these comparisons. The other part of the risk analysis, which consists of climate change effect risks to renewable energy, is a novel contribution of our research. As far as we know, there are no risk analysis publications to compare with this study's result for this topic. After comparing Holma et al. [20] and our results, it was noted differences in the following risk and renewable energy types: The risks due to climate change are different for solar energy and hydropower between Holma's results and our own. The risk of causing climate change due to solar energy was found to be significant or somewhat significant (the risks from [20]), not significant (the risks of Holma et al. [20]), but somewhat significant for our results. Our result was close to not significant risk since the risk level estimate was 0.4. Thus, the accepted result can be taken as not significant across all risks analyses (our results and two of those due to [20]). Among the risks of eutrophication for agriculture fuel, biogas was found to be very significant or significant (the risks from Holma et al. [20] for 2018), significant (the risks from Holma et al. [20] for 2020) and somewhat significant for our results (0.1–0.5 risk estimate level). These results show wide differences across the different analyses. This may be due to differences of opinion between different experts.

Toxicity risks were found differ across different analyses for solar power and hydropower. Toxicity risks from solar power and hydropower were found to be somewhat significant (the risks from Holma et al. [20] for 2018) and not significant in our case (0.0 risk estimate levels). The impacts of biodiversity or aesthetic impacts show a difference for hydropower, being somewhat significant or significant (the risks from Holma et al. [20] for 2018), significant (the risks from Holma et al. [20] for 2020) and somewhat significant (0.4 risk estimate level) for our results. Soil depletion and soil quality, including organic matter, erosion nutrient balance, salinisation and compaction for hydropower were somewhat significant or significant (the risks from Holma et al. [20] for 2018) and not significant (0.0 risk estimate level) for our result. Water use/water footprint for hydropower was somewhat significant or significant (the risks from Holma et al. [20] for 2018), not significant (the risks from Holma et al. [20] for 2020) and somewhat significant (0.4 risk estimate level) for our result, which is close to not significant. Water use/water footprint for all renewables was not significant (the risks from Holma et al. [20] for 2018) and somewhat significant (0.1–0.8 risk estimate levels) for our result. Land use (land area as a resource) risks from wind power were somewhat significant (the risks from Holma et al. [20] for 2018) and significant (wind energy/ground, 1.8 risk estimate level) or not significant (wind energy/ offshore, 0.2 risk estimate level) for our results. Hydropower risk was found to be significant (the risks from Holma et al. [20] for 2018) and somewhat significant (0.4 risk estimate level) for our results. Abiotic resources depletion (materials, minerals, fossil fuel) risks from solar power were significant (the risks from Holma et al. [20] for 2018), not significant (the risks from Holma et al. [20] for 2020) and somewhat significant (solar collector) or significant (solar panel) (0.4 or 1.0 risk estimate levels) for our results. In additions, abiotic resource depletion (materials, minerals, fossil fuel) risks from hydropower were somewhat significant (the risks from Holma et al. [20] for 2018), not significant (the risks of Holma et al. [20] for 2020) and somewhat significant (0.2 risk estimate levels) for our results. These were the only differences noted between the results of this research and those of Holma et al. [20].

The strengths of the study lay in its finding similar results as in the previous studies. Furthermore, this article is probably the first formal contribution to specific risks of climate change effects to renewable energy. The method adopted by this paper contributes to a more holistic understanding the environmental and climate change risks associated with renewable energy resources, in comparison with the existing literature. The limitations of the study that were noted were the low number of experts that participated in the risk analysis and the time taken to collect the data. The unexpected findings included the generalised evaluation, which shows the best and the riskiest types of renewable energy. Thus, generalising the whole analysis shows that field biomass energy had the most effects on the environment and was the most affected by climate change. The main hypothesis was that even though the environmental impacts of renewable energy sources (most technologies) appear small, they cannot be completely ignored [19]. This research emphasises that even if the risks of renewable energy to the environment are low, there are clear risks. In additions, climate change affects renewable energy to somewhat. This is the significance of this study showing the risks of renewable energy in some areas of Finland and for biogas in Sweden. All these studies can serve as a starting point for future research into the risks of renewable energy using broad expertise. In addition, this research result and future results can be easily incorporated into the management of renewable energy regional development.

5. Conclusions

The main finding can be summarised as follows. Geothermal energy risk analysis findings were: ground heat source affected by climate change effects (GHGs) at 0.5 and the rest of the risks from climate change on it were below 0.5 risk estimate level. Ground heat sources affect the environment by causing toxicity; soil depletion/soil quality effects; land use; and lowering groundwater level were between 0.7 to 0.5 risk estimate levels. The rest environmental impacts of ground heat sources were below 0.4 level. Asphalt/concrete-covered areas were affected by precipitation (rain fall); and GHGs increase risk levels about 0.9 and 0.5, respectively. The rest effects of climate change were below 0.5 level. Asphalt/concrete-covered areas have an impact on the environment mainly by causing toxicity about 0.6 risk estimate level. The rest impacts were at 0.3 level or below. Borehole energy storage (with or without thermal energy storage) are affected by climate change and GHGs; and extreme weather phenomena about 0.5 and 0.4 risk estimate levels, respectively. The rest effects of climate change were below 0.4 level. Borehole energy storage impacts on environment are soil depletion/soil quality and toxicity about 0.9 level. The rest are below 0.9 risk estimates level.

The effects of climate change on sediment heat energy production were the sea and lake ice thickness change and extreme weather phenomena about 1.1 and 0.9 risk levels, respectively. The rest effects of climate change on it were about 0.5 level or below. Sediment heat energy production impacts on environment were toxicity; land use and abiotic resources; public health effect; and climate change, effects on animals, groundwater level lowering, and particulate matter formation about 1.6; 1.0; and 0.7 level or lower, respectively. The rest of its impacts on environment lower than 0.7 risk estimates level. The water heat exchanger affected by climate change by sea and lake ice thickness change and extreme weather phenomena were about 1.4 and 1.1 risk estimates levels, respectively. The rest effects on it were below 0.4 level and for land uplift it was 0.4 risk estimates level. Water exchanger impacts on the environment were climate change effects and particulate matter formation about 0.7 risk level. The rest of impacts were below 0.7 risk level and some are at zero (no risk) level.

Bioenergy and biomass energy risk analysis the main findings were: bio-oil, biodiesel and bioethanol face similar risks from climate change effects. The climate change risks on these bioenergy fuels were bioenergy sufficiency and cost and most weather changer along with invasive plants and insect species estimated about 2.25 and 2.0 risk levels, respectively. The rest climate change risks were at

1.4 or below risk levels. Bio-oil impacts on environment were impact of biodiversity; and plant pests and diseases, acidification and tropospheric ozone formation about 1.2; and 0.6 risk levels, respectively. The rest risks of bio-oil on the environment were at 0.4 or below level. For biodiesel impact on environment, the top two were impact of biodiversity and toxicity about 1.5 and 0.8 risk levels, respectively. The rest impacts of biodiesel were at 0.6 or below level. For bioethanol impact on environment, the top two were impact of biodiversity and climate change about 1.4 and 0.8 risk levels, respectively. The rest impacts of bioethanol were at 0.6 or below risk level. Biogas from different sources have the highest risks from the sufficiency of bioenergy; severe drought and cost of bioenergy about risk levels of 1.9; 1.8 and 1.7, respectively. The rest of risks from climate change on biogas from different sources were at 1.6 or below risk levels. Biogas from different sources has the lowest impacts on the environment which were at 0.5 or below risk levels.

Forest biomass energy has the highest risks from the cost of bioenergy; storms and extreme weather; and sever drought and more insects in the forest about 2.4; 2.2; and 2.0 risk levels, respectively. The rest climate change effects on forest biomass energy were at 1.5 or below risk level. Forest biomass energy has impact on environment such as the impact of biodiversity and effects on climate change at 1.8 and 1.1 risk levels, respectively. The rest of its impact on the environment were at 0.8 or below risk levels. Climate change risks on field biomass energy were severe drought; extreme weather phenomena and the cost of bioenergy; and storms and sufficiency of bioenergy about 2.5; 2.3; and 2.1 risk levels, respectively. The rest risks from climate change on it were at 2.0 or below risk levels and even some were close to zero (no risk) level. The highest impacts on the environment from field biomass energy were effects of biodiversity; land use and climate change about 1.5; 1.0 and 0.9 risk levels, respectively. For field biomass energy, the rest impact was at 0.8 or below levels and radiation risk was at 0.0 level. Climate change risks to algae were the cost of bioenergy; the sufficiency of bioenergy and extreme weather phenomena about 2.3; 1.9 and 1.4 risk levels, respectively. The rest risks from climate change on it were at 1.2 or below risk levels. Algae as energy source causes impacts on the environment where the top three risks were water use/water foot print; eutrophication and impacts of biodiversity about 0.7; 0.4; and 0.3 risk estimate levels, respectively. The rest risks from algae as energy were at 0.2 or below levels.

Solar energy-based risk analysis the main findings were: ground wind energy affected by climate change through extreme weather phenomena; wins speed; storm about 2.7; 2.5 and 2.6 risk levels, respectively. The rest risks from climate change on ground wind energy were at 0.7 or below risk levels. Ground wind energy impacts on environment were land use (land areas as a resource); impacts on biodiversity; and effects on birds and other animals about 1.8; 1.1; and 1.3 risk estimate levels, respectively. The rest of its impacts on environment were at 0.9 or below risk level. Offshore wind energy risks due to climate change were extreme weather phenomena; wind speed and storms about 3.4; 3.1 and 3.3 risk estimate levels, respectively. The rest risks on it from climate change were at 1.6 or below risk levels. The environmental impacts of offshore wind were effects on birds and other animals; abiotic resources depletion and climate change at 1.5; 1.1 and 0.8 risk estimate levels, respectively. For offshore wind energy the rest impacts on environment were at 0.5 or below risk levels.

On solar panel energy risks from climate change were storms; extreme weather phenomena and wind speed about 1.4; 1.3 and 1.1 risk estimate levels, respectively. The rest of risks of climate change on the solar panel were at 0.9 or below risk levels. Solar panel energy impacts on environment was abiotic resource depletion has a roughly 1.1 risk estimate level. The rest of the impacts were at 0.6 o below risk levels. Climate change effects on solar energy collector technology were storms (wind speed and lightning); extreme weather phenomena and wind speed about 1.4; 1.3 and 1.1 risk estimate levels, respectively. The rest of risks due to climate change in solar collector technology were at 0.9 or below risk levels. The use and production of solar collector technology impacts on environment were abiotic resource depletion; effects on climate change; and water use/water footprint effects about 0.5; 0.4 and 0.2 risk estimate levels, respectively. For solar collector technology, the rest of impacts on environment were at 0.2 or below risk levels. In addition, most of its risks on environment were zero (no risk). Climate change effects on hydropower were drought; extreme weather phenomena and global warming; and wind speed, storms, the melting of ice in green land and polar areas and sea and lake ice thickness change about 1.6; 1.2; and 1.0 risk estimate levels. The rest of risks of climate change on hydropower were at 0.8 or below risk levels. The environmental impacts of hydropower were biodiversity, water use/water foot print and land use; and eutrophication, abiotic resources' depletion, radiation, plant pests and diseases and effects on birds and other animals were 0.4; and 0.2 risk estimate levels, respectively. For hydropower, the rest of the risks on the environment were zero (no risk).

Most of the risk analysis results show similar findings with the studies by Holma et al. [20] for risks of the use and production of renewable energy to the environment. Thus, this confirms that our results were very trustworthy. The unique contributions were that the risks of climate change to renewable energy resources were addressed, this has not been addressed much in other studies. The significance of the study is that aimed to help in making sure renewables are safe for the environment leading and helping renewable energy sustainability by creating attractiveness and awareness of its risk-free facts to society compared to fossil fuels. One of the novelties of the study is that new renewable energy sources – sediment heat, asphalt heat and water heat exchangers – are considered in this study and their risks are evaluated.

The riskiest renewable energy was found to be field-based biomass energy. It will affect the environment at higher levels, and it will be greatly affected by climate change compared to all renewable energy resources. The renewable energy that was least affected by climate change effects was ground source heat and the energy with least effects were solar energy/collectors. It was also of note that the water heat exchanger was the most affected and sediment heat energy was the had the most environmental effects among all geothermal energy types. It was also highlighted that there are risks to the environment due to renewable energy use and production and that climate change effect risks to renewable energy clearly exist. These risks were quantified in this research. There is a clear need for a more in-depth study utilising more expert opinions. This research contributed insights to the neglected topic of risk related to renewable energy. Even if the risks of renewable energy are small in comparison with fossil fuels, they are nonetheless significant enough that they cannot be ignored. These findings are crucial to the implementation and management of renewable energy in regional energy development.

The limitations of this research were: 1) the low number of experts that participated in the risk analysis, 2) the time taken to collect the data was too long and 3) some energy systems and methods should be added and improved, e.g. PV (photovoltaic cells) battery storage and its analysis by using the LCA (Life Cycle Assessment) method and software's. Future plan of development is that to include a wide number of expertise in larger areas e.g. in several nations and collect the data in the shorter period including the missing energy storage systems. Moreover, develop the method into better well-known methods such as LCA and other software's. In the future, it will be possible to expand the risk analysis by consulting more experts for data collection and performing more multidisciplinary research.

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Statements of declarations

1. The authors declare that they have no known competing financial interests or personal relationships that could appear to influence the work reported in this paper.

2. There is no conflict of interest.

Ethics approval and consent to participate

Not applicable

Consent for publication

All the authors agreed and gave their consent for publication.

Competing Interests

There are no competing interests between the authors, or with the funding organizations.

Author contributions

Nebiyu Girgibo – original idea, writing the original manuscript, data collection, data analysis, reviewing, editing and funding acquisition. Erkki Hiltunen – requesting data, reviewing, editing, and funding acquisition. Xiaoshu Lü – reviewing, editing and funding acquisition. Anne Mäkiranta and Ville Toumi– reviewing and editing.

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Availability of data and materials

The data is not available for public use because the research is ongoing, and our research teams would like to continue with it, so we are not currently sharing our data.

References

[1] Misra, K. B. Risk analysis and management - An introduction. In: Misra K.B. (eds) Handbook of Performability Engineering, 667 – 681 pp. Springer, London; 2008. [Cited 29 Mar. 2020]. Available from: https://doi.org/10.1007/978-1-84800-131-2_41.

[2] Yaghlane, B. B., Simon, C., and Hariz, N. B. Evidential risk graph model for determining safety integrity level. NATO Science for Peace and Security Series - E: Human and Societal Dynamics 2015; 88, IOS Press, pp.204-221, 2011, Use of Risk Analysis in Computer-Aided Persuasion, 978-1-60750-827-4. [Cited 3 June 2020]. Available from: https://doi.org/10.3233/978-1-60750-828-1-204.

[3] Borghesi, A. and Gaudenzi, B. Risk Management: How to Assess, Transfer and Communicate Critical Risk. Springer-Verlag Italia; 2013. ISBN: 978-88-470-2531-8 (eBook).

[4] Olabi, A. G. and Ali Abdelkareem, M. Renewable energy and climate change. *Renewable and Sustainable Energy Reviews* 158; 2022; 112111. [Cited 10 May 2022] Available from https://doi.org/10.1016/j.rser.2022.112111.

[5] ISO 31000. ISO 31000 - Risk Management - A Practical Guide for SMEs. 21 pp. Geneva, Switzerland: ISO Copyright Office; 2015. ISBN: 978-92-67-10645-8.

[6] Piney, C. Risk identification: combining the tools to deliver the goods. Paper presented at PMI® Global Congress 2003—EMEA. The Hague, South Holland, The Netherlands. Newtown Square, PA: Project Management Institute; 2003. [Cited 14 Oct. 2020]. Available from: https://www.pmi.org/learning/library/risk-identification-life-cycle-tools-7784.

[7] Girgibo, N. Identifications of renewable energy risks and risk management review. University of Vaasa Reports 36. 46 pp. Vaasa, Finland: University of Vaasa, Tritonia, library; 2022. [Cited on 02 Jan. 2023]. Available from https://urn.fi/URN:ISBN:978-952-395-056-6.

[8] IEA. Report on – Energy Technology Perspectives 2020. International Energy Agency; 2020.

[9] Wing, L. C. and Jin, Z. Risk management methods applied to renewable and sustainable energy: A Review. Journal of Electrical and Electronic Engineering. Special Issue: Sustainable and Renewable Energies and Systems 2015; Vol. 3, No. 1-1, 2015, pp. 1-12. [Cited 03 Mar. 2021]. Available from: http://dx.doi.org/10.11648/j.jeee.s.2015030101.11.

[10] Gatzert, N. and Kosub, T. Risks and Risk Management of Renewable Energy Projects: The Case of Onshore and Offshore Wind Parks Working Paper, 39 pp. Department of Insurance Economics and Risk Management, Friedrich-Alexander University Erlangen-Nürnberg (FAU); 2016.

[11] Owusu, P. A. & Asumadu-Sarkodie, S. A review of renewable energy sources, sustainability issues and climate change mitigation, Cogent Engineering 2016; 3:1, 1167990. https://doi.org/10.1080/23311916.2016.1167990.

[12] Landell, H. The risk matrix as a tool for risk analysis: How to apply existing theories in practice in order to overcome its limitations. Mater Thesis. Gävle, Sweden: Faculty of Engineering and Sustainable Development, University of Gävle; 2016.

[13] Saner, D. et al. Is it only CO_2 that matters? A life cycle perspective on shallow geothermal systems. Renewable and Sustainable Energy Reviews 14; 2010; 1798 -1813 pp. [Cited 02 June 2021]. Available from http://dx.doi.org/10.1016/j.rser.2010.04.002.

[14] Greening, B. and Azapagic, A. Domestic heat pumps: Life cycle environmental impact and potential implication of the UK. Energy 39; 2012; 205-217 pp. [Cited 09 June 2021]. Available from https://doi.org/10.1016/j.energy.2012.01.028.

[15] Johnson, E. P. Air-source heat pump carbon footprints: HFC impacts and compression to other heat sources. Energy Policy 39; 2011; 1369-1381 pp. [Cited 14 July 2021]. Available from https://doi.org/10.1016/j.enpol.2010.12.009.

[16] Energy and climate. Energy and Climate Roadmap 2050: Report of the Parliamentary Committee on Energy and Climate Issues on 16 October 2014. Finland's Ministry of Employment and Economy Publication. Energy and the Climate 2014. 50/2014. ISBN: 978-952-227-906-4 (Web publication).

[17] Repo, A. Tuomi, M. and Liski, J. Indirect carbon dioxide emissions from producing bioenergy from forest harvest residues. Global Change Biology (GCB) Bioenergy 2011; 3, 107-115 pp. [Cited 14 July 2021]. Available from http://dx.doi.org/10.1111/j.1757-1707.2010.01065.x.

[18] Zhu L. Hiltunen, E., E. Antila, J. Zhong, Z. Yuan and Wang Z. Micro-algal Biofuels flexible bio-energies for sustainable development. Renewable and Sustainable Energy Reviews 2013; Vol. 30, 1035-1046 pp. 2014. [Cited 12 Aug. 2020]. Available from http://dx.doi.org/10.1016/j.rser.2013.11.003.

[19] Sokka, L. et al. Environmental impacts of the national renewable energy targets – A case study from Finland. Renewable and Sustainable Energy Reviews 59; 2016; 1599–1610 pp. [Cited 19 May 2021]. Available from: http://dx.doi.org/10.1016/j.rser.2015.12.005.

[20] Holma, A., et al. Environmental impacts and risks of the national renewable energy targets – A review and a qualitative case study from Finland. Renewable and Sustainable Energy Reviews 82; 2018; 1433 – 1441 pp. [Cited 15 March 2019]. Available from: http://dx.doi.org/10.1016/j.rser.2017.05.146.

[21] IPCC. Climate Change 2013 - The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. New York, USA: Cambridge University Press, Cambridge; 2013. 1535 pp. ISBN: 978-1-107-05799-9.

[22] IPCC. Climate Change 2021: The Physical Science Basis. Contribution of Working Group - I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR6 WGI); 2021.

[23] Girgibo, N.; Mäkiranta, A.; Lü, X.; Hiltunen, E. Statistical Investigation of Climate Change Effects on the Utilization of the Sediment Heat Energy. Energies 2022; *15*, 435. [Cited 03 March 2022]. Available from: https://doi.org/10.3390/en15020435.

[24] Solaun, K. and Cerdá. E. Climate change impacts on renewable energy generation. A review of quantitative projections. Renewable and Sustainable Energy Reviews 116; 2019; 109415: 1-16 pp. [Cited 10 May 2022]. Available from https://doi.org/10.1016/j.rser.2019.109415

[25] Cronin, J., Anandarajah, G. and Dessens, O. Climate change impacts on the energy system: a review of trends and gaps. Climatic Change 2018; 151:79–93. [Cited 12 May 2022] Available from https://doi.org/10.1007/s10584-018-2265-4

Appendix

Table 3. The summarised results for the risks of renewable energy to the environment: impact category, renewable energy and process, and significant category risk (comparison of Holma et al. [20] and the current research results). The dash sign (-) represents those technologies not analysed under the specific column.

The impact category in the assessment	**Renewable energy sources and process**	**Significance category risk for 2018 [20]**	**Significance category risk for 2020 target level [20]**	**Risk estimate levels for our research findings**
Climate change	Solar power	Significant or somewhat significant	Not significant	Somewhat significant (0.4 risk estimate level)
	Agriculture fuel, biogas	Significant and in the case of biogas not significant or somewhat significant	Agriculture - Not significant or rape diesel- somewhat significant Biogas - Not significant or somewhat significant	Somewhat significant for filed biomass (0.9 risk estimate level) and biogas from different sources somewhat significant (0.25 risk estimate level)
	Wind power	Somewhat significant	Not significant or somewhat significant	Somewhat significant (0.8 risk estimate level)
	Geothermal energy	-	Not significant or somewhat significant	Somewhat significant (generalised to all types of geothermal energy, risks were between 0.3 – 0.7 risk estimate levels)
	Hydro power	Somewhat significant or significant	-	Not significant (0.0 risk estimate level)
	Forest energy	Significant	Wood biomass - Significant	Significant or somewhat significant (1.25 risk estimate level)
Ozone depletion	Solar power	Somewhat significant or not significant	Not significant	Not significant (0.0 risk estimate level)

	All renewables	-	Not significant	Not significant to somewhat significant (0.0 – 0.4 risk estimate level)
Acidification	Solar power	Not significant or somewhat significant	Not significant	Not significant (0.0 risk estimate level)
	Agriculture fuel, biogas	Somewhat significant	-	Somewhat significant (0.4 risk estimate levels. Biogas was somewhat significant (0.1 risk estimate level)
	Forest energy	Somewhat significant	-	Somewhat significant (0.4 risk estimate level)
	Geothermal and wind power	-	Not significant or somewhat significant	Not significant or somewhat significant (0.0 – 0.5 risk estimate level)
Tropospheric ozone formation	Solar power	Not significant or somewhat significant	Not significant	Not significant (0.0 risk estimate level)
	Agriculture fuel, biogas	Somewhat significant	-	Somewhat significant (0.1 – 0.6 risk estimate level)
	Forest energy	Somewhat significant	-	Somewhat significant (0.3 risk estimate level)
	Geothermal and wind power	-	Not significant or somewhat significant	Not significant (0.0 risk estimate level)
Particular matter formation: impacts on health and short-term climate effects	Solar power	Not significant or somewhat significant	-	Not significant (0.0 risk estimate level)
	Agriculture fuel, biogas	Somewhat significant	Somewhat significant	Somewhat significant (0.2 – 0.8 risk estimate level)
	Wood burning /forest energy	Very significant	Very significant	-
	District heating plants	Significant	-	-
	Other forest type products/Forest energy	Somewhat significant	-	Somewhat significant (0.2 – 0.8 risk estimate level)

	Geothermal and wind power	-	Not significant or somewhat significant	Somewhat significant (0.4 – 0.8 risk estimate level)
Eutrophication	Agriculture fuel, biogas	Very significant or significant in the case of biogas	Significant	Somewhat significant (0.1 - 0.5 risk estimate level)
	Hydropower	Somewhat significant or significant	-	Somewhat significant (0.2 risk estimate level)
	Forest energy	Somewhat significant	-	Somewhat significant (0.4 risk estimate level)
Toxicity	Solar power	Somewhat significant	-	Not significant (0.0 risk estimate level)
	Agriculture fuel, biogas	Somewhat significant	Somewhat significant	Somewhat significant (0.4 – 0.6 risk estimate level)
	Hydropower	Somewhat significant or significant	-	Not significant (0.0 risk estimate level)
Impacts of biodiversity and/or aesthetic impacts	Solar power	Not significant or somewhat significant	-	Somewhat significant or not significant (0.1 risk estimate level)
	Agriculture fuel, biogas and CHP (combined heat and power) plants	Somewhat significant	Somewhat significant	Significant to somewhat significant (0.4 – 1.8 risk estimate level)
	Wind power	Somewhat significant	Not significant or somewhat significant (Aesthetic and noise)	Somewhat significant to significant (1.2 risk estimate level)
	Hydropower	Somewhat significant or significant	Significant	Somewhat significant (0.4 risk estimate level)
	Geothermal energy/air source heat pump aesthetic impacts	Somewhat significant and (not analysed)	Somewhat significant	Somewhat significant (0.0 – 0.8 risk estimate level)
	Deadwood (forest energy)	Significant	Significant	-

Soil depletion and soil quality, including organic matter, erosion nutrient balance, salinisation and compaction	Agriculture fuel, biogas	Somewhat significant, not significant for nutrient balance	Somewhat significant	Somewhat significant (0.2 - 0.7 risk estimate level)
	Solar power	-	Not significant	Not significant or somewhat significant (0.0 (solar collector) and 0.2 (solar panel) risk estimate level)
	Hydropower	Somewhat significant or significant	-	Not significant (0.0 risk estimate level)
	Forest energy	Somewhat significant	-	Somewhat significant (0.8 risk estimate level)
Water use/water footprint	Solar power	Not significant or somewhat significant	Not significant	Not significant (Solar energy/ panel, 0.0 risk estimate level) or Somewhat significant (Solar energy/ collector, 0.2 risk estimate level)
	Hydropower	Somewhat significant or significant	Not significant	Somewhat significant (0.4 risk estimate level)
	Geothermal power	Somewhat significant or significant	Somewhat significant	Somewhat significant (0.1 – 0.6 risk estimate levels)
	CHP production	Somewhat significant	Not significant	-
	All renewables	-	Not significant	Somewhat significant (0.1 – 0.8 risk estimate levels)
Land use (land area as a resource)	Wind power	Somewhat significant	-	Significant (wind energy/ground, 1.8 risk estimate level) or not significant (wind energy/ offshore, 0.2 risk estimate level)
	Hydropower	Significant	-	Somewhat significant (0.4 risk estimate level)

	Agriculture fuel	Significant	-	Significant (1.0 risk estimate level)
	Biogas	Significant	Not significant or somewhat significant	Somewhat significant (0.2 – 0.3 risk estimate levels)
Lowering of groundwater levels	All renewables	-	-	Between not significant and somewhat significant (0.0 – 0.8 risk estimate levels)
Abiotic resource depletion (materials, minerals, fossil fuel)	Solar power	Significant	Not significant	Somewhat significant (solar collector) or significant (solar panel) (0.4 or 1.0 risk estimate levels)
	Hydropower	Somewhat significant	Not significant	Somewhat significant (0.2 risk estimate levels)
	Geothermal power	Somewhat significant	Not significant or somewhat significant	Somewhat significant up to significant (0.4 up to 1.0 risk estimate levels)
	Wind power	Somewhat significant	Not significant or somewhat significant	Somewhat significant (0.8 risk estimate level)
	All energy that requires infrastructure	Somewhat significant	-	-
	All renewables	-	Not significant	Not significant up to significant (0.0 up to 1.0 risk estimate levels)
Radiation	All renewables	Not significant	Not significant	Not significant (0.0 risk estimate level), somewhat significant (0.2 risk estimate level) for hydropower
Plants, pests and diseases	Agriculture fuel, biogas	Significant, or somewhat significant for Barley and wheat ethanol	Agricultural fuel was somewhat significant and biogas was not analysed	Somewhat significant (0.2 – 0.4 risk estimate levels)
	Forest energy	Somewhat significant	-	Somewhat significant (0.8 risk estimate level)

Effects on birds and other animals	All renewables	-	-	Between significant and not significant (0.0 – 1.4 risk estimate levels)

energies

Article

Statistical Investigation of Climate Change Effects on the Utilization of the Sediment Heat Energy

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Abstract: Suvilahti, a suburb of the city of Vaasa in western Finland, was the first area to use seabed sediment heat as the main source of heating for a high number of houses. Moreover, in the same area, a unique land uplift effect is ongoing. The aim of this paper is to solve the challenges and find opportunities caused by global warming by utilizing seabed sediment energy as a renewable heat source. Measurement data of water and air temperature were analyzed, and correlations were established for the sediment temperature data using Statistical Analysis System (SAS) Enterprise Guide 7.1. software. The analysis and provisional forecast based on the autoregression integrated moving average (ARIMA) model revealed that air and water temperatures show incremental increases through time, and that sediment temperature has positive correlations with water temperature with a 2-month lag. Therefore, sediment heat energy is also expected to increase in the future. Factor analysis validations show that the data have a normal cluster and no particular outliers. This study concludes that sediment heat energy can be considered in prominent renewable production, transforming climate change into a useful solution, at least in summertime.

Keywords: sediment temperature; Pearson's correlations; autoregression integrated moving average (ARIMA) modelling forecast; factor analysis; renewable energy

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1. Introduction

Sediment energy is renewable energy because the thermal energy of the sediment layer mainly originates from the Sun (with seasonal storage and loss). A minor portion is from the Earth's own geothermal energy. The flux in solar energy is from four to five orders of magnitude larger than the flux in geothermal heat on a normal land surface [1–3]. The combination of geothermal energy and solar energy as an energy source is called geoenergy [4]. Sediment heat is usually collected by the pipes that are horizontally installed into the sediment layer, and circulating heat-extracting liquid in the pipes. The temperature profile of the sediment is collected using the Distributed Temperature Sensing (DTS) method [5,6]. A more detailed review and description of the DTS is presented in an IEEE journal publication by Ukil et al. [6]. The seawater battery for deep water applications has been studied by Wilcock and Kauffman [7]. The sediment nutrient contents of total carbon and nitrogen variation due to human activities has been investigated by Wang et al. [8]. On the other hand, Reimers et al. [9] investigated a different way of harvesting energy from Marchine sediment–water interface.

Hiltunen et al. [10] show a potential for sediment renewable carbon-free energy for heat production in the local area. The use of thermal energy from the solid organic sediment layer at the bottom of water bodies via heat-collection pipes, heat-carrier liquids, and heat pumps is one of the new carbon-free ways to produce energy that was investigated by the University of Vaasa. Sediment energy can be used for cooling in summer and heating in winter, as shown in the Suvilahti shallow bay in the city of Vaasa, Finland [1,10,11]. Mäkiranta et al. [12] studied the correlation between the temperatures of air, heat carrier liquid, and seabed sediment in a renewable low-energy network. In their investigation, they confirmed correlations between the air temperature, heat carrier liquid temperature after 2 months, and the sediment temperature. A further study on seabed energy as an annual renewable heat source demonstrated that the collection of heat energy does not cause any permanent cooling of the sediment, and that the energy is sustainable. However, the air temperature influences the water and sediment temperature [13]. Global warming causes an air temperature increase and, in turn, an increase in the water temperature [11]. Further economic feasibility studies show that the collection depth has to be at least 3 m below the sea bottom [13]. Sediment thermal conductivity values have been noted to increase and stabilize in deeper layers. The depth of stable thermal conductivity values was related to the sedimentary environment [14]. Thermal conductivity and thermal diffusivity increase with increasing depth below the seafloor because they are negatively correlated with porosity [15]. On the other hand, these relations are also important in other areas of study, such as climate change and water quality analysis.

Depending on the lake type, the mixing and penetration of the solar energy to the bottom of the lake differs. In the meromictic lake experiment in [2], the low or non-mixing conditions of the lake water caused less annual temperature fluctuation than that observed in deep water. The particular lake water they studied (Stewart's Dark Lake) had a high concentration of humic colloids or colored materials, thus resulting in a low level of solar radiation penetration. This shows that the sediment water energy that builds up from geothermal and solar energy depends on the type of water body [2]. Mixing, circulation patterns in the lake, and direct isolation of solar energy can heat and/or cool the bottom water of a lake. Moreover, direct heating from solar energy is influenced by the depth of the lake water. The water body and bottom sediment of shallow lakes can easily be heated. The results of Guo and Ma [16] also show that the temperature of seawater is evidently influenced by the sediment–water heat exchange, and that tidal sediment was a heat source providing warmth to the seawater. Golosov and Kirillin [17] studied two lakes in Russia and Germany for their sediment conductivity, based on a model that uses lake water temperature without any data on sediment thermal properties. This seems very useful for the sediment-heat energy analysis. Lake sediments play an interesting and appreciable role in heat transfer and exchange between lakes and the lower atmosphere (ground earth) in the majority of lakes [17]. Pivato et al. [18] has also concluded that heat flux at the sediment–water interface is crucial for soil temperature dynamics. Golosov and Kirillin [17] state that their model can be used effectively to estimate the effect of climate change on lakes, and can also be used to analyze the backward effect of lakes on the climate system. Considering the benefits of near-bottom temperature analysis (at the lake sediment boundary), crustal temperatures can be used to monitor the activity of the benthic community and biochemical processes. This is especially important in ice-covered lakes, where this comprises a major heat source in seasonal periods [17]. According to Hamilton et al. [19], time-varying sediment heat flux can especially affect the water temperature in ice-covered water bodies. Heat flows from the sediments to the water column and from the water to the ice, which occurs during ice-cover periods [20].

The sediment heat budget becomes more significant as the average depth of a lake decreases and is more significant nearer the shores than in deep water [2]. Smith [21] found that measurements of water–sediment heat exchange can show differences in temperature values due to the different time of year in which they are recorded, which makes it difficult to compare them. The results of Tsay et al. [22] suggest that the accurate simulation of thermal stratification in shallow transparent lakes requires consideration of sediment heat flux. In addition, some studies show that activities and construction in a water body can affect the water quality for some period of time. The buildup of sediment heat can also affect the water quality, and this can be considered as one kind of environmental risk caused by renewable energy use and production. In previous conference papers concerning Ostrobothnia, it has been indicated that constrictions that take place in the water area influence the water-quality parameters. Sediment energy is one of the important types of seaside energy solutions; therefore, it is important to consider it in the context of further developments.

The objective of this study is to obtain new data on a unique heating and cooling system in order to describe its status and operation, temperature distributions, correlation tests, and dependency analysis. Temperature versus distance measurements can provide data to optimize the size of the installation. The novelty of this study is in its researching a possible connection between climate change and the utilization of seabed sediment heat collection. This would help in the planning of new constructions in the future.

The research questions raised in this study are:

(1) Is there a correlation between different months vs. the distance from shore in sediment temperature? At what distance is the maximum sediment heat energy production possible?
(2) Can climate change be advantageous for using sediment heat energy?
(3) What are the benefits for using sediment heat energy if weather temperatures become warmer in summer and winter?

A research gap is expected to be filled by examining the correlation between distance from shore and sediment temperature variations. The climate change effect can be advantageous for renewable energy production. Furthermore, renewable energy production, which uses climate change advantages, can potentially be used in the fight against climate change.

2. Materials and Methods

2.1. Data Collection Sites, Method, Descriptions and Validations

A housing fair was arranged in Suvilahti, Vaasa, in 2008. New houses were designed to utilize the annually reloaded heat energy from seabed sediment as heating and cooling energy. The energy was mainly generated by the Sun and collected through heat collection pipes filled with heat collection fluid. A unique low-energy network was built to cover the heating and cooling demand of 42 detached houses.

The total length of the Suvilahti seabed sediment heat collection pipeline was about 8 km (12 × 300 m and 14 × 300 m), and it was installed in the solid clay layer, horizontally into the seabed sediment, by a horizontal drilling machine (Figure 1). The position of the pipes was at 3–4 m depth from the sea bottom of the Gulf of Bothnia. Sediment heat is extracted via this heat-collector pipe field in the sediment layer and heat pumps inside the individual houses. The network is also used to cool houses in the summertime.

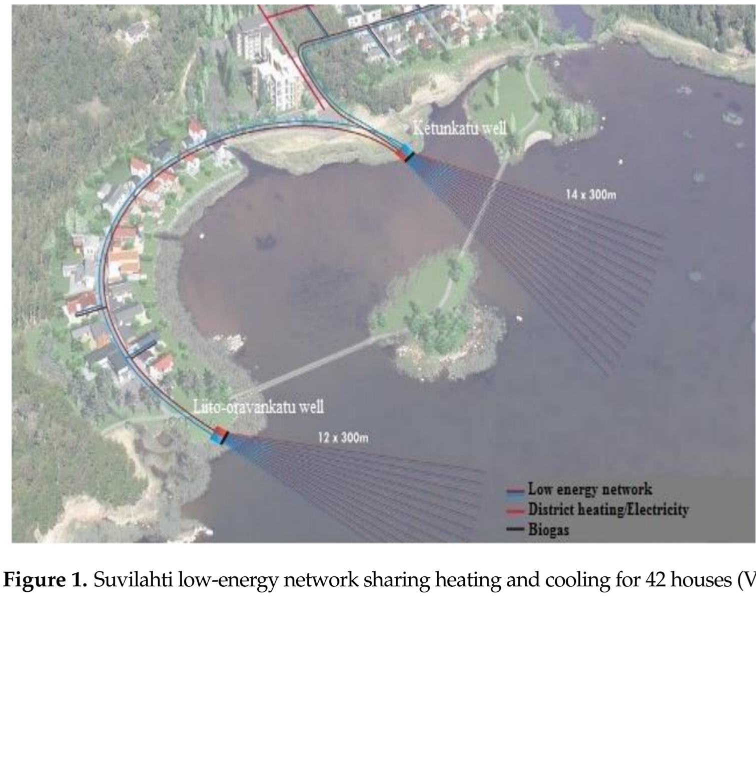


Figure 1. Suvilahti low-energy network sharing heating and cooling for 42 houses (Vaasan Ekolämpö Oy).

Heat carrier fluid runs in the brackets of the pipe on the outer casing gathering thermal energy. When the collection fluid reaches the end of the pipe, it returns to the shore through the middle of the pipe to release thermal energy for the heat pump. After that, the fluid begins the cycle again (Figure 2).

Figure 2. Profile of a Refla heat-collection pipe (A. Mäkiranta 2013).

Sediment temperatures were measured using a distributed temperature-sensing (DTS) method in Suvilahti. A fiberglass cable was used as a linear temperature sensor. The cable was installed on the surface of one heat-collection pipe during the building process of the Housing Fair area. The total length of the cable temperature sensor was 300 m. The measurement device and calibration configurations are shown in Figure 3. Measurements were carried out once per month because of the delay in the air temperature influence on sediment temperature. Sediment heat temperature data used in this analysis were recorded during the years 2013–2016 and for only one month in 2018.

Figure 3. Sensornet Oryx DTS device that can be used even in outdoor conditions.

Mäkiranta [5] has described the distributed temperature sensing (DTS) method and its limitations in her thesis. DTS measurements were calibrated during each measurement with the help of Pt100 (accuracy $\pm$ 0.25 °C) point sensors. A separate patch cable was used to make the connection for calibrations. The patch cable was routed into an ice-bath to ensure the temperature data validity in these double-ended measurements. The sensor cables in the seabed sediment were installed on the outside of the system's heat-collection pipes, which contain the heat carrier fluid. The validity of the sediment temperature data can still be regarded as reasonable due to the fact that the fluid's influence on the surrounding sediment temperature can be expected to be quite small. The forecasted data have limitations in ARIMA modeling. Only 60 years of data were used to predict 40 years forward. This does not satisfy the modeling prediction requirements. However, a similar result to our forecasts was found in IPCC (2021) publications, which is why they are presented. Weather data were collected from the Vaasa airport weather station for the years 1959–2019. The weather data were collected by Finnish Metrological Institute. The water temperature data were taken from water quality data collected by the ELY-keskus (Center for Economic Development, Transport and the Environment) at the Eteläinen Kaupunkiselkä 1 sampling point in the city of Vaasa between 1962 and 2018. The water data were used in autoregression integrated moving average (ARIMA) forecast modeling. However, it is noted that the water sampling point was different from the sediment energy installation point because there is no long-term water quality measurement data that correspond with the sediment energy installation points. The forecasted data have limitations in ARIMA modeling. Only 60 years of data were used to predict 40 years forward, which, again, does not satisfy the modeling prediction requirements. However, it was a similar result to that found in IPCC (2021) publications.

2.2. General Statistical Analysis Method

The analysis was conducted using SAS Enterprise Guide 7.1 software. The statistical analysis conducted in SAS includes descriptive analysis, dependency analysis, autoregression integrated moving average (ARIMA) forecast modelling, and factor analysis. All analyses were conducted using the prescribed software procedures for each tool, and additional detailed information can be found at [23]. However, the general procedure used in the statistical analyses was based on the eight steps of general data analysis procedure (Dytham [24]) described below:

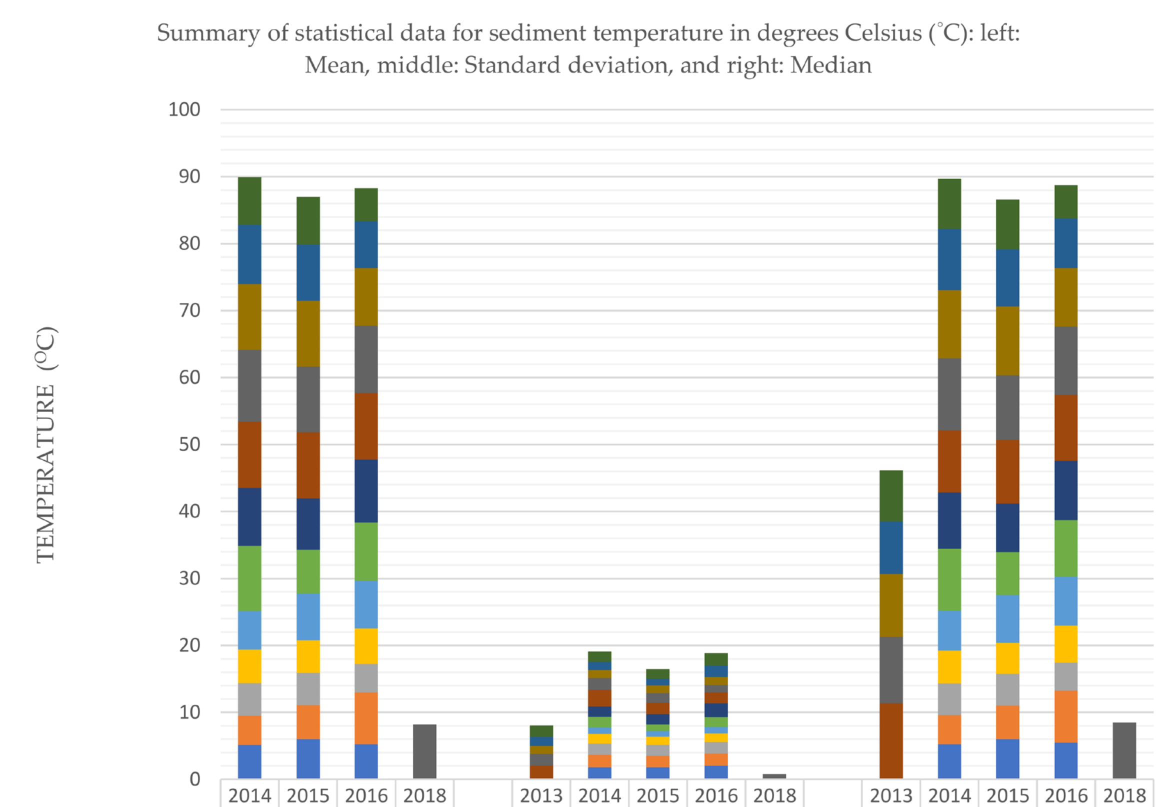
(1) Decide specific points of interest;
(2) Formulate several hypotheses;
(3) Design and choose the necessary data and parameters for analyses;
(4) Collect dummy data to form approximate values based on what was expected to be obtained—some of our original data were used as dummy data during this analysis;
(5) Select appropriate tests;
(6) Carry out the test(s) using the dummy data;
(7) If there are problems, go back to step 3 (or 2); otherwise, proceed to use real data;
(8) Carry out the test(s) using the real data and report the findings and/or return to step 2.

3. Results

3.1. Summary of Statistics

The sediment temperature measurement distances from the shore stretched 0–300 m towards the center of the water body. The normality of the data was checked at the beginning. All of the temperature data were found to be non-normal for all years and months, except for the distributions of distance measurements and in the Suvilahti Liito-oravankatu location for August 2013 and August 2015. Figure 4 shows the 2016 September data measured on 3 October 2016, and the December 2016 data measured on 10 January 2017. The bold highlighted data for Vaasa, Suvilahti, Ketunkatu in Figure 4 shows incremental or decremental increases in the years from 2013 to 2018. No yearly pattern was noticed at Vaasa, Suvilahti, Liito-oravankatu. In Figure 4, the mean sediment temperature data for

February and May show an incremental increase in line with the year of sampling. The January data standard variation shows an increment in variation with increasing years. However, September shows a decline in the standard variation level with increasing years.



	2014	2015	2016	2018		2013	2014	2015	2016	2018		2013	2014	2015	2016	2018
December 7.365	7.114	7.119	4.956	0	0	1.667	1.565	1.463	1.866	0	0	7.659	7.498	7.482	5.014	0
November 7.339	8.852	8.343	6.959	0	0	1.367	1.208	1.004	1.72	0	0	7.825	9.117	8.507	7.404	0
October 9.002	9.789	9.879	8.607	0	0	1.186	1.192	1.1	1.172	0	0	9.374	10.16	10.26	8.738	0
September 9.952	10.74	9.814	10.04	8.22	0	1.804	1.745	1.494	1.083	0.832	0	9.916	10.77	9.686	10.16	8.491
August 11.456	9.873	9.874	9.974	0	0	2.015	2.513	1.724	1.652	0	0	11.37	9.284	9.514	9.868	0
July -	8.667	7.646	9.348	0	0	0	1.558	1.495	2.081	0	0	0	8.38	7.223	8.887	0
June -	9.752	6.581	8.744	0	0	0	1.551	1.003	1.447	0	0	0	9.336	6.432	8.421	0
May -	5.729	6.945	7.129	0	0	0	0.993	0.811	0.961	0	0	0	5.903	7.137	7.302	0
April -	5.045	4.865	5.269	0	0	0	1.446	1.229	1.258	0	0	0	4.922	4.648	5.562	0
March -	4.834	4.877	4.26	0	0	0	1.679	1.624	1.731	0	0	0	4.728	4.738	4.186	
February -	4.365	5.013	7.739	0	0	0	1.844	1.724	1.879	0	0	0	4.368	4.977	7.78	0
January -	5.158	6.025	5.25	0	0	0	1.812	1.815	1.997	0	0	0	5.222	6.025	5.446	0

Figure 4. Summary of statistical data for sediment temperature in degrees Celsius (°C), summarized for whole depths: mean, standard deviation, and median at Suvilahti, Ketunkatu, in the city of Vaasa.

Median values show incremental increases in the months of February and May, and a decrement was noticed in December. The average highest sediment temperature was recorded from June to December in almost all of the recorded years. Medians also show similar results to the average values. January and August standard variation values were among the highest in all of the years recorded in Ketunkatu. Figure 1 shows the summary of statistical data for sediment temperature at the Suvilahti, Ketunkatu site. Here, only the main results are presented. The highest mean and median sediment temperatures were observed in August 2013 at Ketunkatu. July 2016 showed the highest standard variations for this site. The lowest mean and median for sediment temperatures observed at Ketunkatu were seen in February 2014, and the lowest standard deviation was observed in May 2015.

A summary is given of the statistical data for sediment temperature at the Suvilahti, Liito-oravankatu site. Standard variation values from October to December were the highest in all years in Liito-oravankatu. No clear increment or decrement pattern can be seen in the data. The highest average/mean and median sediment temperature values were observed from July to September throughout the years. The highest mean and median sediment temperatures at Liito-oravankatu were observed in September 2014. October 2016 showed the highest standard variations at this site. The lowest mean was seen in January 2014 and the lowest median was in March 2014. The lowest standard deviation was observed in August 2013.

3.2. Dependency Analysis

The correlation uses hypotheses that either confirm or falsify. The null hypothesis is H_0: the population correlation is zero (i.e., there is no linear relationship). The alternative hypothesis is H_1: the population correlation is not zero. If the correlation result is not statistically significant it means the null hypothesis (H_0) is accepted and the alternative hypothesis (H_1) is rejected. If it is statistically significant, then the alternative hypothesis is accepted and the null hypothesis is rejected. Pearson's correlation is an appropriate analysis for this kind of non-ranked data, but to use Spearman's rank correlation, the data must be ranked beforehand.

With the exception of a few months, the results show statistically significant Pearson's correlations in months vs. distances from the shore towards to center of the water body. June, July, August, and September vs. distance correlations were found to be negative (Table 1). During these months, as the distance from the shore increases the temperature declines significantly. A similar finding was also found in October 2016, but the sampling day is closer to September than the middle of October, and is not statistically significant. The rest of the months show positive correlation results. The negative correlation can be explained thus: the nearer to the shore an area is, the less water cover it has and the more heat travels to the sediment from water and sunshine. Therefore, if areas are close to the shore in sunny months, the sediment temperature seems higher. One of the previous studies in our group found that there is clear correlation between air, heat carrier liquid, and sediment temperature with a 2-month lag in the sediment temperature. Thus, the negative correlations noticed in this analysis might represent the effects of previous months air and water temperatures. Table 1 shows Pearson's correlations between the sampling months of the year and increments of depth/distance at Suvilahti, Ketunkatu in the city of Vaasa.

All of the August and July Pearson's correlations were found to be negative, except in August 2016 and July 2014 (Table 2). Moreover, only June 2014 also shows negative correlations. All of the analyzed correlations between sediment heat in month vs. distance were found to be statistically significant. The correlations of both sites in the city of Vaasa (Suvilahti, Ketunkatu (Table 1) and Liito-oravankatu (Table 2)) show different results, meaning that the correlations between monthly temperature vs. distance are very specific to the location. Furthermore, as the sampling points were in the same water body, this indicates a high specificity to the exact location. However, one can generalize the results as the months with sunny weather show somewhat negative correlations, whereas the rest of the months show positive correlations. Table 2 shows the Pearson's correlations between sampling months of the year and increments of depth/distance at Suvilahti, Liito-oravankatu in the city of Vaasa.

Table 1. Pearson's correlations analysis between different months and increment of depth/distance at Suvilahti, Ketunkatu in the city of Vaasa. The first row shows Pearson's correlation results, the second row shows statistical significance, and the third row shows the number of samples in each analysis.

Pearson's Correlation for Month Temperature vs. Distance													
	Distance		Distance		Distance		Distance		Distance		Distance		Distance
distance	1 297	14 January	0.83502 <0.0001 297	14 July	−0.23757 <0.0001 297	15 January	0.83798 <0.0001 297	15 July	−0.36584 <0.0001 297	16 January	0.78473 <0.0001 297	16 July	−0.40112 <0.0001 297
13 August	−0.06398 0.2717 297	14 February	0.85858 <0.0001 297	14 August	−0.4735 <0.0001 297	15 February	0.84782 <0.0001 297	15 August	−0.45013 <0.0001 297	16 February	0.82599 <0.0001 297	August	−0.36077 <0.0001 297
13 September	−0.26751 <0.0001 296	14 March	0.88269 <0.0001 297	14 September	−0.33784 <0.0001 297	15 March	0.861 <0.0001 297	15 September	−0.3517 <0.0001 297	16 March	0.85545 <0.0001 297	3 October 2016	−0.06442 0.2684 297
13 October	0.2583 <0.0001 296	14 April	0.88997 <0.0001 297	14 October	0.07311 0.209 297	14 April	0.92268 <0.0001 297	15 October	0.23263 <0.0001 297	16 April	0.78695 <0.0001 214	26 October 2016	0.56589 <0.0001 297
13 November	0.77142 <0.0001 296	13 May	0.36606 <0.0001 297	14 November	0.67664 <0.0001 297	15 May	0.60669 <0.0001 297	Nove-mber 15	0.66131 <0.0001 297	16 May	0.58907 <0.0001 297	16 November	0.78826 <0.0001 297
13 December	0.81126 <0.0001 296	14 June	−0.21912 0.0001 297	14 December	0.79345 <0.0001 297	15 June	−0.06697 0.2499 297	15 December	0.78921 <0.0001 297	16 June	−0.18148 0.0017 297	December 2016 (10 January 2017)	0.83927 <0.0001 297
												28 September 2018	0.35938 <0.0001 297

Table 2. Pearson's correlations analysis between different months of years and increment of depth/distance at Suvilahti, Liito-oravankatu, in the city of Vaasa. The first row shows Pearson's correlation results, the second row shows statistical significance, and the third row shows the number of samples in each analysis.

Pearson's Correlation for Month Temperature vs. Distance											
Distance		Distance	Distance		Distance		Distance		Distance		Distance
distance	1 297	14 January	0.83861 <0.0001 297	14 July	0.66525 <0.0001 297	15 January	0.94156 <0.0001 297	15 July	−0.61598 <0.0001 297	16 June	0.62211 <0.0001 297
13 August	−0.68564 <0.0001 297	14 February	0.91661 <0.0001 297	14 August	−0.91378 <0.0001 297	15 February	0.95283 <0.0001 297	15 August	−0.38679 <0.0001 297	16 July	−0.88149 <0.0001 297
13 September	0.60053 <0.0001 297	14 March	0.9571 <0.0001 297	14 September	0.56162 <0.0001 297	15 March	0.94234 <0.0001 297	15 September	0.70828 <0.0001 297	16 August	0.66973 <0.0001 297
13 October	0.9159 <0.0001 297	14 April	0.93862 <0.0001 297	14 October	0.92784 <0.0001 297	15 April	0.96703 <0.0001 297	15 October	0.93696 <0.0001 297	3 October 2016	0.9117 <0.0001 297
13 November	0.91276 <0.0001 297	14 May	0.78181 <0.0001 297	14 November	0.95282 <0.0001 297	15 May	0.87094 <0.0001 297	15 November	0.95067 <0.0001 297	26 October 2016	0.94707 <0.0001 297
13 December	0.95347 <0.0001 297	14 June	−0.67468 <0.0001 297	14 December	0.96502 <0.0001 297	15 June	0.80705 <0.0001 297	15 December	0.96568 <0.0001 297	16 November	0.95512 <0.0001 297
										December 2016 (10 January 2017)	0.96501 <0.0001 297
										28 September 2018	0.89186 <0.0001 297

In sunny weather, the further the distance from shore, the colder the sediment gets because it is covered by more water. Thus, it might not get enough heat from the sun, and the water that covers it may also be colder. However, the opposite is true in winter months where the water or snow acts as a cover from the cold air temperature. Thus, this warms the sediment temperature more if there is a greater distance from the shore. In this way, the temperature changes behave more like the conditions seen in a geothermal context. Similar conclusions have been drawn about winter months in previous studies conducted in our research group, and one study showed that a significant positive correlation exists between air and water temperatures. Inherently, it is obvious that the air temperature influences the water temperature, in addition to the sun light irradiance.

The next few figures present Pearson's correlation results for the year 2013 as examples of the general correlation results. Figure 5 shows the negative correlations between August 2013 sediment temperature vs. distance from the shore. The August 2013 temperature declines until almost a 50 m distance is reached from the shore, then rises after 50 m for both locations. Thus, one can say that the water depth level after 50 m seems to become high enough to generate more cover for the sediment so that it receives more heat. It has been noted [6] that within a 0–50 m distance from the shore, flora (reeds, etc.) might affect the temperature. This is generally far enough from the shore that the sediment temperature is also seen to rise, meaning that more heat can be collected at this distance using sediment heat energy collection technologies. However, the water body type influences the distance from the shore depending on how shallow or deep the water body is. Particularly, according to our data, the best distance for sediment heat energy production is between 100 and 190 m from the shore, confirming the findings of Mäkiranta. However, this seems to depend on the month in which the data are collected, and in winter months there seems to be a constant increase in sediment temperature as the distance from the shore increases. In the upper section of Figure 5, the probability result is only at a 1% statistically significant level.

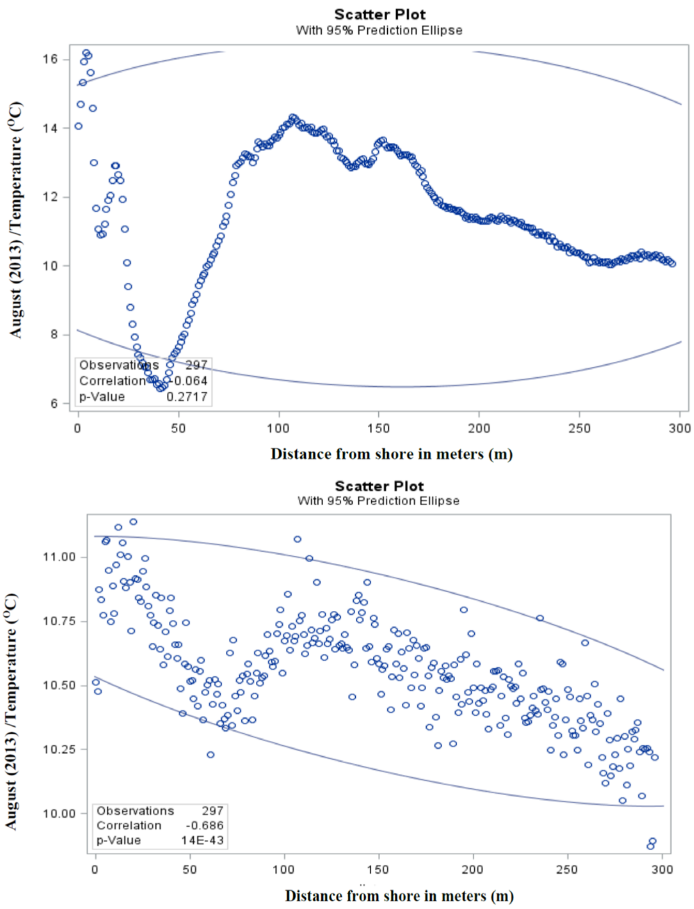


Figure 5. Plot showing Pearson's correlations between August 2013 temperature and distance at Suvilahti, in the city of Vaasa. Ketunkatu (above) and Liito-oravankatu (below). The meaning of p-value = 14E−43 = 14 × 10 $^{-43}$ (below).

Figure 6 shows the September 2013 sediment temperature vs. distance correlations; the two locations have different results, where one is negative, and the other is positive. This can show how area specificity can influence this kind of correlation analysis and the sediment temperature patterns. Otherwise, the changes seen at different distances before and after 50 m are similar.

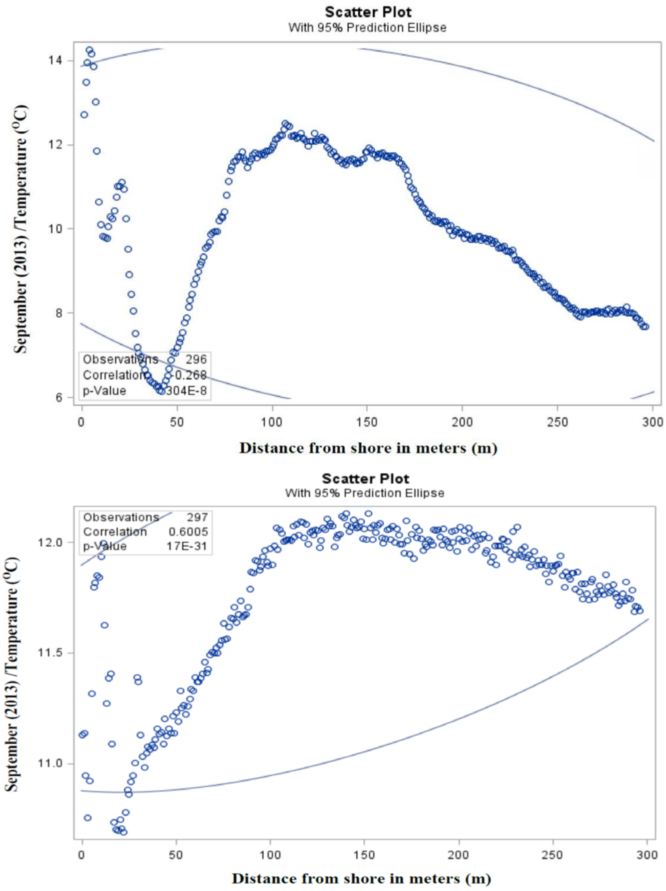


Figure 6. Plot showing Pearson's correlations between September 2013 temperature and distance at Suvilahti, in the city of Vaasa. Ketunkatu (above) and Liito-oravankatu (below). The meaning of p-value = 304E−8 = 304×10^{-8} (above). The meaning of p-value = 17E−31 = 17×10^{-31} (below).

The difference between the results shown in the above two figures can be explained by the correlations between August and September 2013 sediment temperatures in the two locations. As noticed in further analysis, there are clear, statistically significant positive correlations at Ketunkatu. However, in Liito-oravankatu, the August and September 2013 sediment temperature show negative correlations. This can be explained by the specificity of both sediment temperature collection areas. Both locations had similar weather temperatures and are located in relatively close proximity. However, the shallowness of the water body and sediment soil characteristics can explain this to some extent and, as both locations are in the same water body, the sediment soil or sand characteristics are expected to be roughly similar. The October 2013 sediment temperature vs. distance shows positive correlations for both locations (Figure 7). However, the correlation shows much higher values for the Liito-oravankatu location. One can conclude that the location of the Liito-oravankatu installation seems to be deeper compared to the Ketunkatu location. This can be explained by the fact that, at the shore, the October temperature is lower in Ketunkatu than in Liito-oravankatu. In October in Finland, the air and water temperatures are somewhat colder due to the fact that winter is either approaching or has started already. Moreover, the weather change results in sediment temperature changes. Another factor is that, starting at the beginning of October, sediment heat uptake was started by the houses. Thus, the decline in sediment heat temperature at the beginning shore in the winter months could be due to the uptake of heat from sediment for household use.

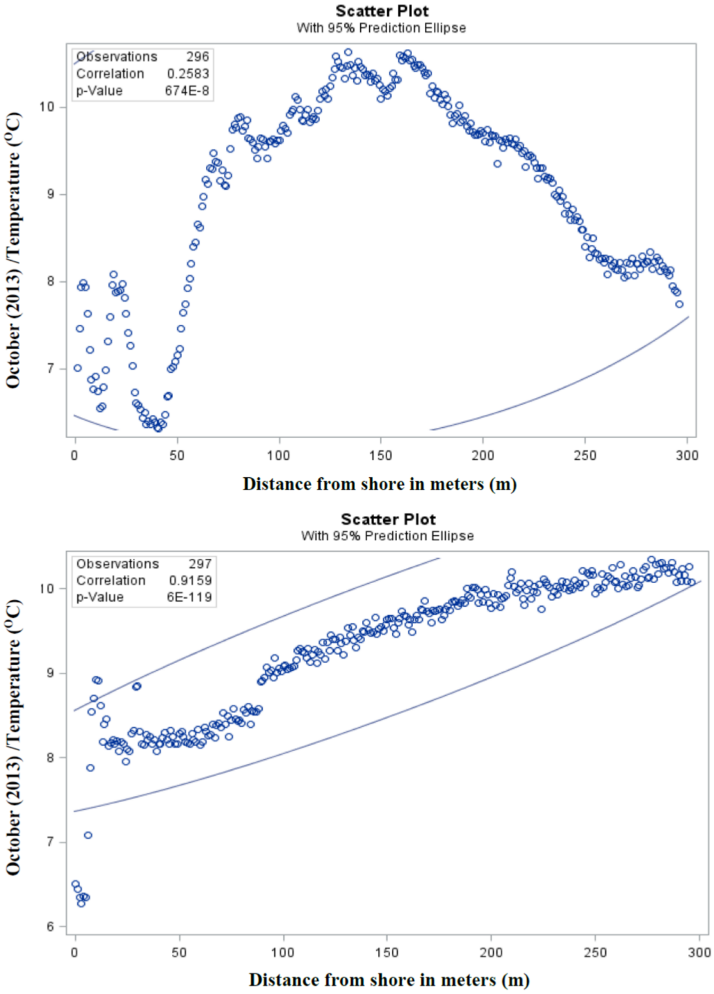


Figure 7. Plot showing Pearson's correlation between October 2013 temperature and distance at Suvilahti in the city of Vaasa. Ketunkatu (above) and Liito-oravankatu (below). The meaning of *p*-value = 674E−8 = 674 × 10^{-8} (**above**). The meaning of *p*-value = 6E−119 = 6 × 10^{-119} (**below**).

Further analysis showed positive correlations at Ketunkatu and negative correlations at Liito-oravankatu for sediment temperature between October and August 2013. In the location of Ketunkatu, as the October 2013 temperature increases, so does the August 2013 temperature. The opposite is true for the Liito-oravankatu location. This can be explained as the Liito-oravankatu installation is deeper, so the October 2013 temperature is lower than August 2013 at a distance of about 50 m. This confirms that the Liito-oravankatu installation location is deeper than Ketunkatu, in addition to the physical observation of the differences in these installation sites. However, other results show that both locations show positive correlations for October and September 2013 sediment temperatures. This is due to the fact that both months' temperatures are somehow similar, at a colder temperature. However, at a specific depth location, the Ketunkatu sediment temperature is lower than that of Liito-oravankatu, which also confirms the depth difference between the two installation locations. Figure 8 shows positive correlations for November 2013 vs. distance for both locations. However, the Ketunkatu site show less linear correlation values compared to those of Liito-oravankatu. This is because the Liito-oravankatu installation is deeper than the Ketunkatu site and, in Ketunkatu, the depth of the water seems to be lower, until it is 50 m distance from the shore.

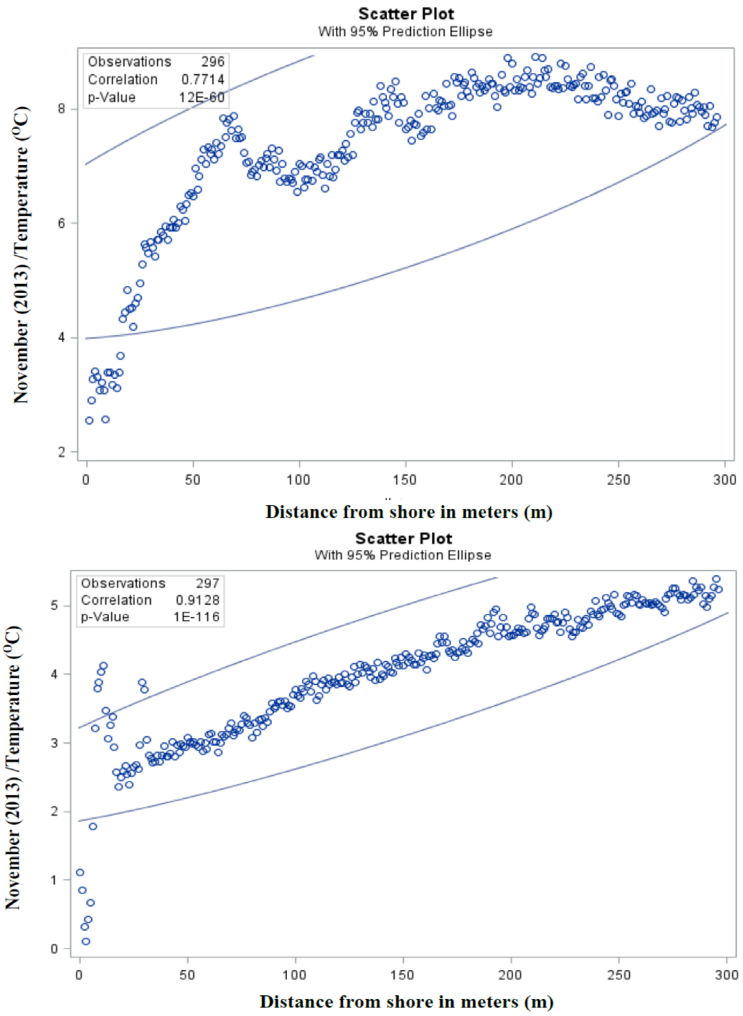
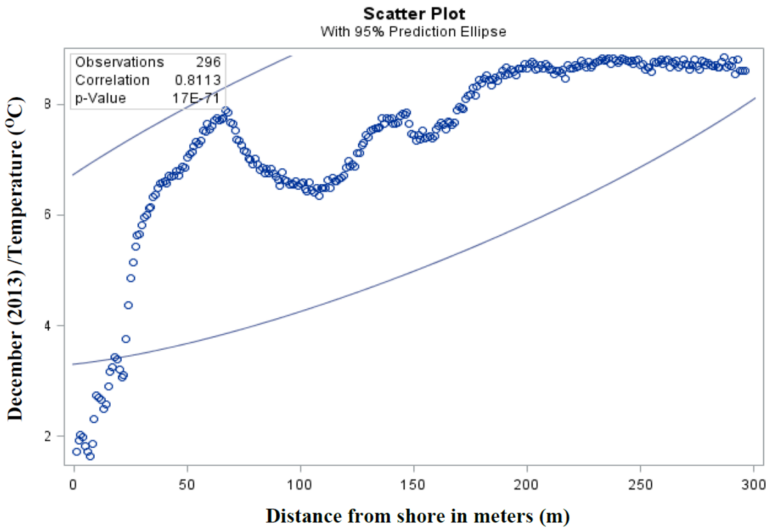


Figure 8. Plot showing Pearson's correlation between November 2013 temperature and distances at Suvilahti in the city of Vaasa. Ketunkatu (above) and Liito-oravankatu (below). The meaning of p-value = 12E−60 = 12 × 10^{-60} (**above**). The meaning of p-value = 1E−116 = 1 × 10^{-116} (**below**).

Other analyses show both sites' Pearson's correlations between November 2013 and August 2013 sediment temperatures, showing negative correlations. This is due to the fact that the different months have different weather temperatures, which affect the sediment heat energy or temperature. However, the Ketunkatu site correlations between November 2013 and August 2013 sediment temperatures are not statistically significant, which means that the presented results are not robust. However, we can accept the Liito-oravankatu site correlations for the same period as they are statistically significant. A similar observation in the Ketunkatu site sediment temperature correlations between November 2013 and September 2013 is not statistically significant, with a positive correlation. However, the Liito-oravankatu site correlations result is statistically significant between November 2013 and September 2013, and show that both the sediment temperatures in November and September were positive, even though the air temperature was negative most of the time. This is because the depth of this site is much deeper than that of the Ketunkatu site. December 2013 vs. distance correlations show similar results to those of November 2013 vs. distance (Figure 8), and Figure 9 shows the December 2013 vs. distance correlations results for both sites. Both sites show positive correlations, which are statistically significant.



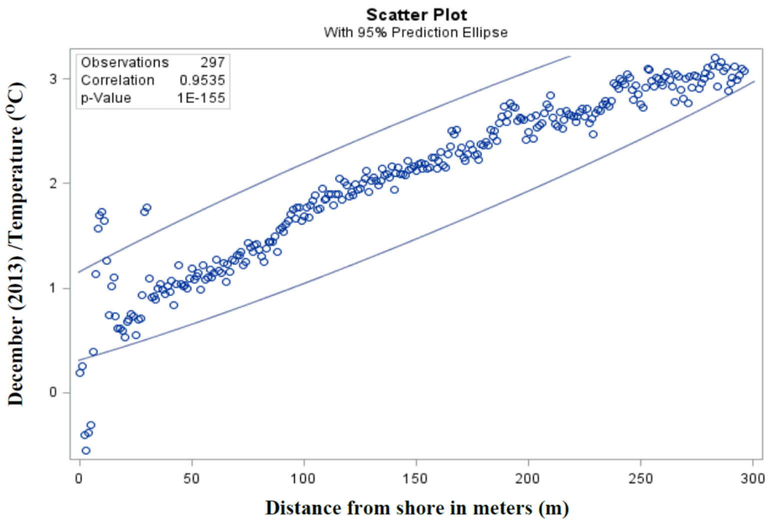


Figure 9. Plot showing Pearson's correlation between December 2013 temperature and distance at the city of Vaasa, Suvilahti. Ketunkatu (above) and Liito-oravankatu (below). The meaning of *p*-value = 17E−71 = 17×10^{-71} (**above**). The meaning of *p*-value = 1E−155 = 1×10^{-155} (**below**).

November 2013 and October 2013 show statistically significant positive correlations. This is because both months' temperatures were very similar; however, the variation in correlation values between the two sites reflects the differences in the site installation depth. There is a positive Pearson's correlation between December 2013 vs. September, October, and November 2013, which is statistically significant. This is because these months have similar air temperatures and cause similar sediment heat temperatures. However, the correlations between December 2013 and August 2013 show a statistically significant negative correlation. This can be explained by the difference between the two months' air temperature levels causing different sediment heat temperatures. Figure 10 shows the scatter plot matrix for all the correlation figures presented between the months of the year in 2013 and distance for both sites.

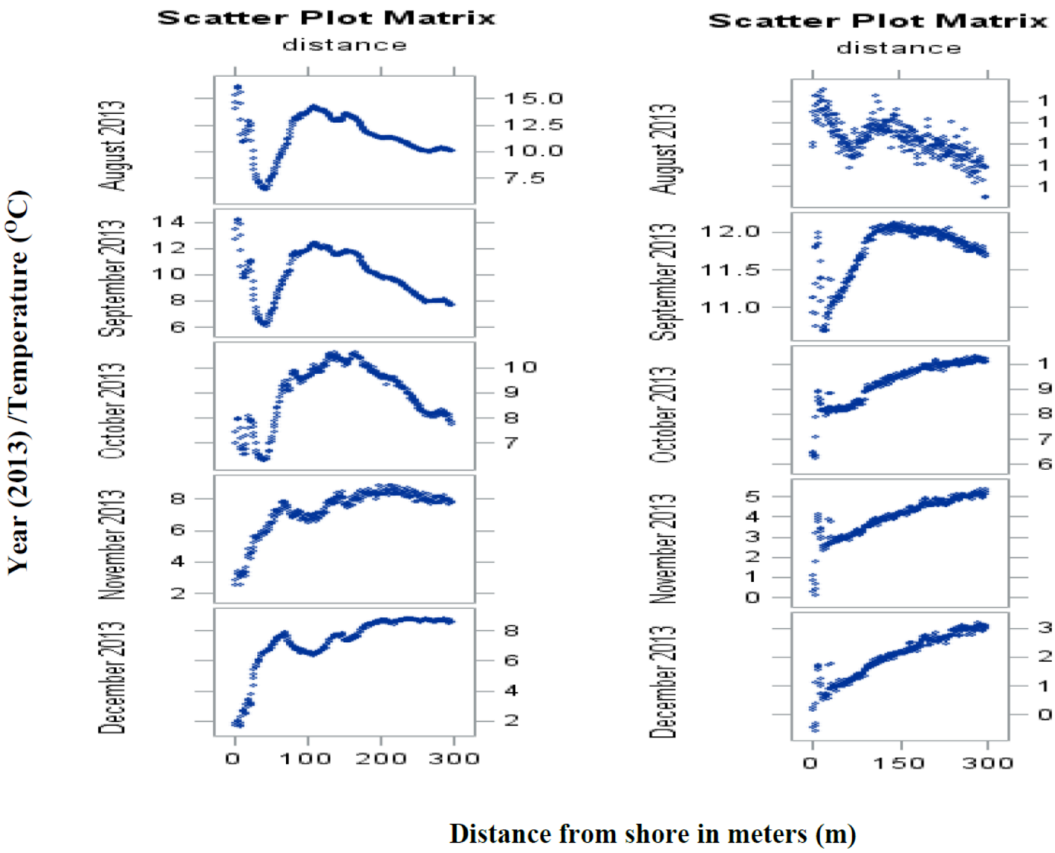
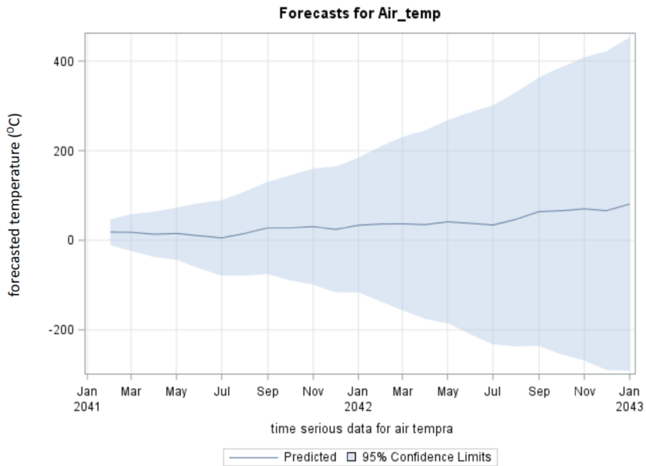


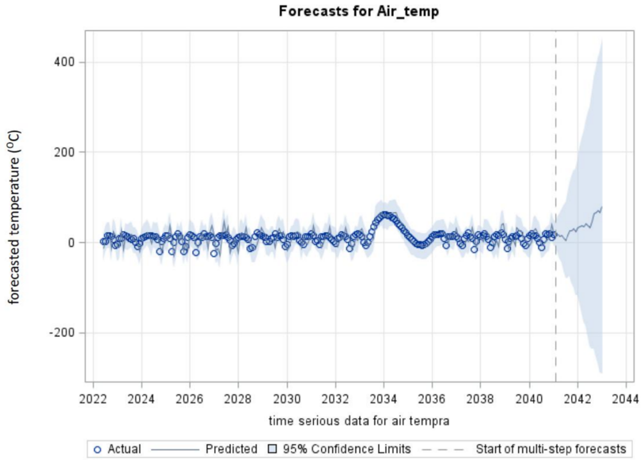
Figure 10. Scatter plot matrix showing the months of the year in 2013 vs. distance for both sites at Suvilahti in the city of Vaasa. Ketunkatu (**left**) and Liito-oravankatu (**right**).

3.3. ARIMA Modeling Forecast

The forecasts presented here might not be representative because of a shortage of data. To conduct a true long-term forecasting (40 years of forecast) in any kind of modelling requires hundreds of years of data, which are not available in our area. However, the smaller dataset can represent the future situation to some degree. The forecast results presented in the current IPCC 2021 report [25] show approximately similar results. As can be seen in Figure 11, the air temperature is predicted to increase significantly after the year 2041, based on the collected data of mean air temperature between 1959 and 2019 from the Vaasa Airport weather station collected by the Finnish Meteorological Institute (FMI). The same weather station data predictions of snow depth (Figure 12) show a significant decline in 2033. The main cause of these change expectations is global warming. Consequently, these changes cause effects in water temperature, leading to changes in sediment temperature and its heat energy production. This means that the climate change effect could be advantageous for energy production is summer seasons. The snow cover is used as insulation for the sediment energy build-up, but when there is no snow cover in the future, the sediment energy in winter might decline. Furthermore, the warming of the winter weather may have different consequences in winter sediment energy production. To date, even if it is cold in winter, the sediment temperature has been positive, but this is expected to decline with snow melting caused by increases in winter temperature.



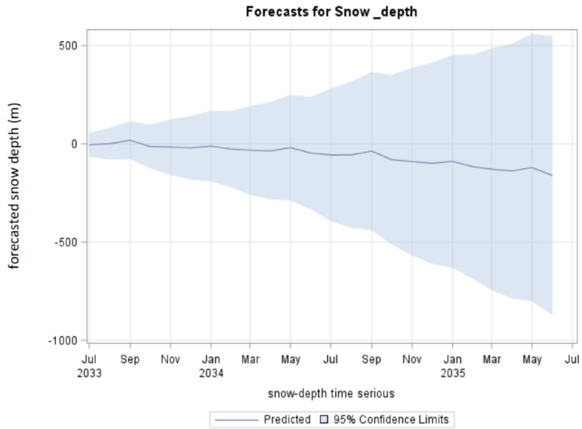
(**a**)



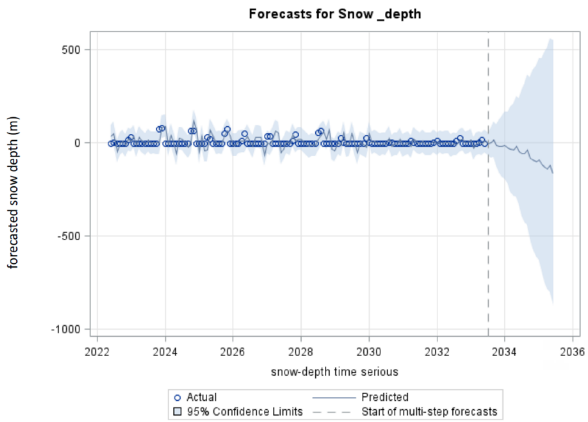
(**b**)

Figure 11. ARIMA analysis for the air temperature forecast over time from the Vaasa airport weather station. In the figure -200 = minus 200. (**a**) shows temperature forecast from 2041 to 2043. (**b**) shows forecast in air temperature from 2022 to 2044.

Our previous research found a positive correlation between air and water temperature, and a positive correlation between water temperature and sediment temperature with a 2-month lag. This suggests that air temperature affected by climate change will affect the water temperature, as well as the sediment temperature. Figure 13 shows how water temperature is expected to increase significantly after the year 2042. This forecast was conducted in a water body near the city of Vaasa at the Eteläinen Kaupunkiselkä 1 water sampling point by the Center for Economic Development, Transport and the Environment (ELY-keskus), and means that the water temperature will also change after the indicated air temperature increase in 2041. Moreover, it is expected this will lead to increases in sediment temperature, given that water temperature and sediment temperature have positive correlations after a 2-month lag. Consequently, energy production from sediment energy is expected to increase in the future, using the effects of climate change to its advantage, at least in the summer. However, in winter, this might be different.

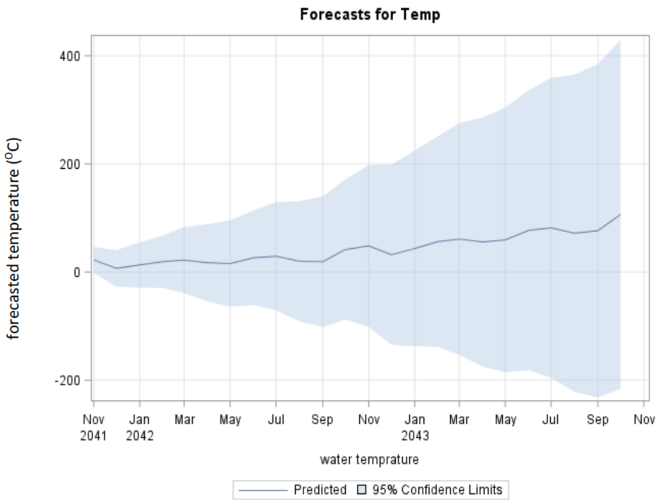


(**a**)



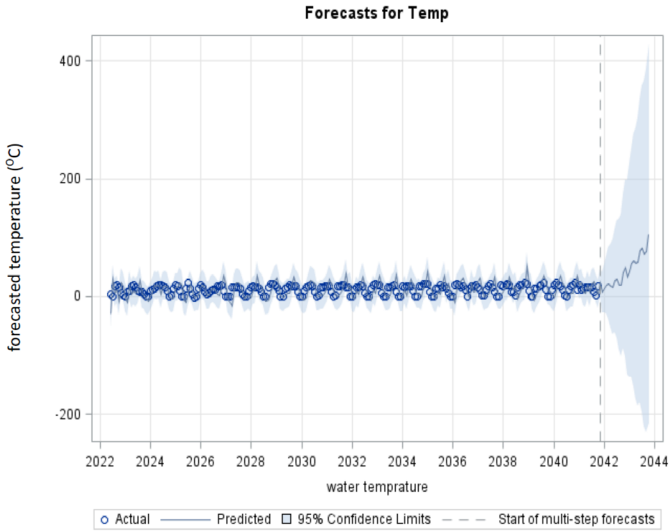
(**b**)

Figure 12. ARIMA analysis for the snow-depth forecast over time from the Vaasa airport weather station. In the figure − 500 or −1000 = minus 500 or minus 1000. (**a**) shows forecast in snow depth since 2033 up to 2035. (**b**) shows forecast in snow depth from 2022 to 2036.



(**a**)

Figure 13. *Cont.*



(**b**)

Figure 13. ARIMA analysis for the water temperature forecast over time at a different location than the sediment energy location (Eteläinen Kaupunkiselkä 1) near the city of Vaasa. In the figure –200 = minus 200. (**a**) shows forecast in water temperature 2041 up to 2043. (**b**) shows forecast in water temperature from 2022 to 2044.

3.4. Validations by Factor Analysis

The reliability and validity of quantitative research papers can be examined with conducting factor analysis, regarding construct validity [26]. Therefore, a factor analysis was conducted for both sediment energy sampling sites to validate the analyses that were conducted in this paper.

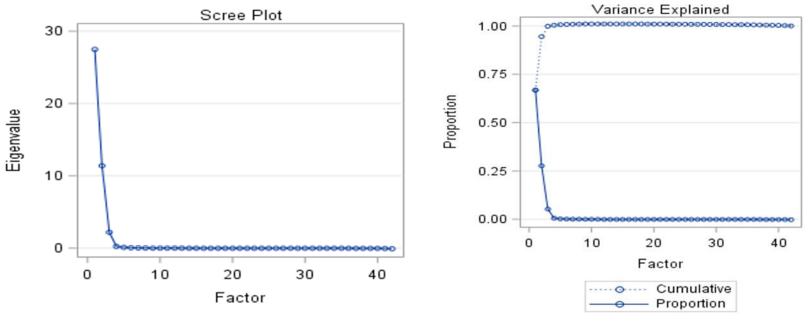
3.4.1. Validations by Factor Analysis for City of Vaasa at Suvilahti, Ketunkatu Site Data

A total of 298 records were read, with 213 used and subject to significant tests (see Table 3). Four factors appear to explain most of the variability in the data, and these are presented in Table 3.

Table 3. Analysis information for factor analysis at the Ketunkatu site.

Input Data Type			Raw Data
Number of Records Read			**298**
Number of Records Used			213
N for Significance Tests			213
Variance Explained by Each Factor			
Factor 1	**Factor 2**	**Factor 3**	**Factor 4**
27.479995	11.382338	2.188676	0.227792

As can be seen in Figure 14, the first four factors account for most of the total data variability. The rest of the factors account only for a very small proportion of the variability and are likely to be unimportant. The first three factors have a variance (Eigenvalues) greater than 1, and one has a variance below 1. Therefore, four factors explain most of the variability in the data.



(**a**) (**b**)

Figure 14. Scree plot (**a**) Eigenvalue vs. factors and (**b**) proportion vs. factors: four factors are retained by the PROPORTION criterion.

Figure 15 shows the score plots, where different factors are used in combination. As can be seen in factor 2 vs. factor 1, there is a cluster for summer and winter month data which explains most of the data pattern. Similar clusters were noticed in plots of factor 3 vs. factor 1 and factor 4 vs. factor 1. However, no outliers were found in the score plots. In addition, most of the data seem to be located in the middle area of the score plots. However, no clear trends were noticed except that the data of winter and summer months tend to cluster separately.

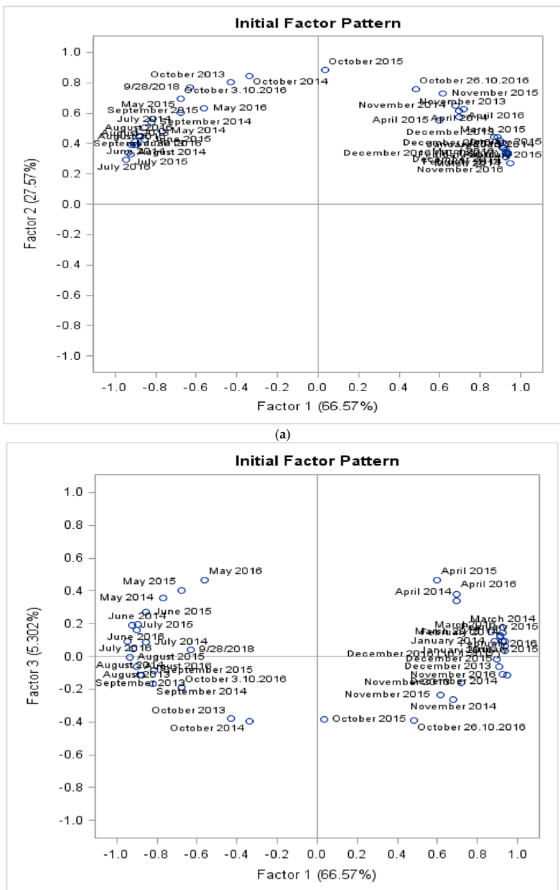
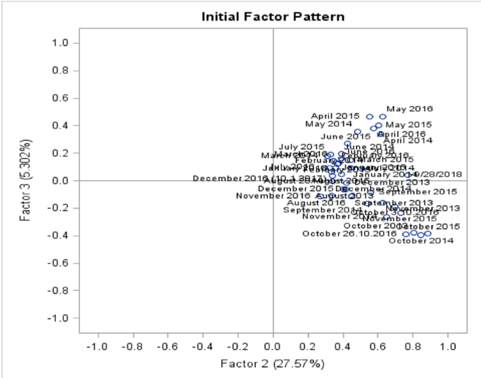
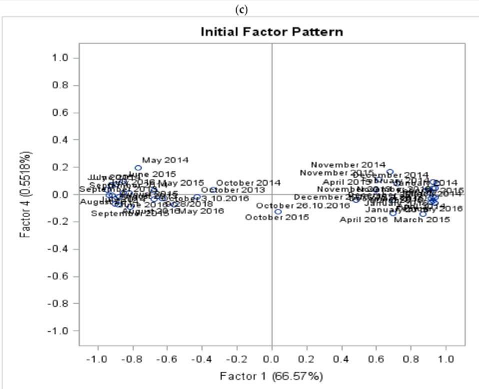


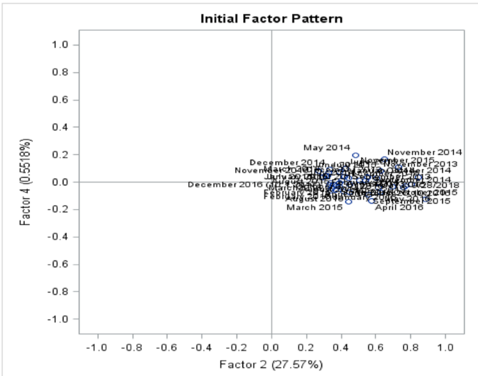
Figure 15. *Cont.*



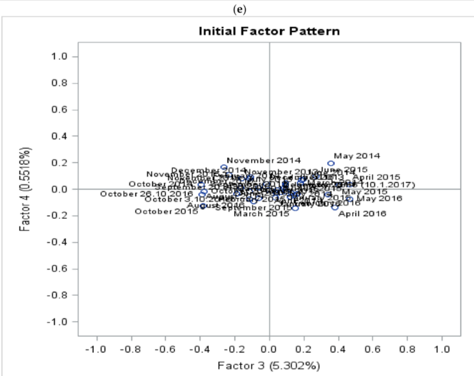
(c)



(d)



(e)



(f)

Figure 15. Six score plots built for four factor combinations at the Ketunkatu site. (**a**) Factor 2 vs. Factor 1. (**b**) Factor 3 vs. Factor 1. (**c**) Factor 3 vs. Factor 2. (**d**) Factor 4 vs. Factor 1. (**e**) Factor 4 vs. Factor 2. (**f**) Factor 4 vs. Factor 3.

The Suvilahti, Ketunkatu site data may explain factors based on the data for Figure 15. Separation between the data of summer and winter months seems to be created by Factor 1. Factor 2 seems spread the data to the upper section of both winter and summer data separately, and/or all the data together. Factor 3 helps to bring all the data to the center of the plots, whereas factor 4 seems to cluster all the data together in separate seasons and/or without seasonal variations. The next factor analysis figures, do not seem clear enough and radiable due to the fact that they were automatically generated from SAS software. It was not possible to modify the figures to a better shape. However, they can show that the general result is representative enough.

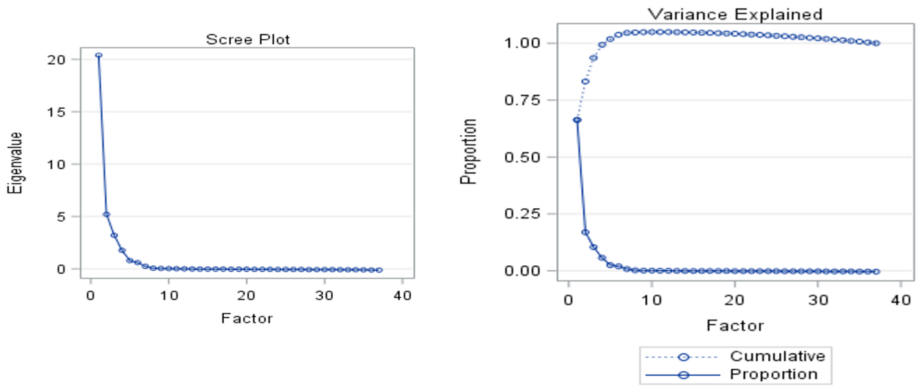
3.4.2. Validations by Factor Analysis for the Suvilahti, Liito-Oravankatu Site Data

A total of 298 records were read, with 297 used and subject to significant tests (see Table 4). Five factors appear to explain most of the variability in the data. These are presented in Table 4.

Table 4. The table presenting the analysis info for facto analysis at site Liito-oravankatu.

Input Data Type				**Raw Data**
Number of Records Read Number of Records Used				298 297
N for Significance Tests				297
Variance Explained by Each Factor				
Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
20.390920	5.198181	3.196084	1.759724	0.773356

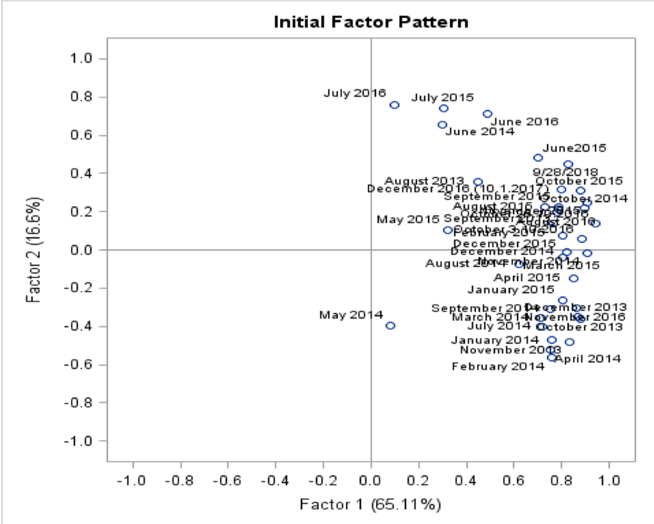
As can be seen in Figure 16, the first five factors account for most of the total variability in the data. The rest of the factors account for only a very small proportion of the variability and are likely to be unimportant. The first four factors show a variance (Eigenvalues) greater than 1, and one shows a variance below 1. Therefore, five factors explain most of the variability in the data (see Table 4).



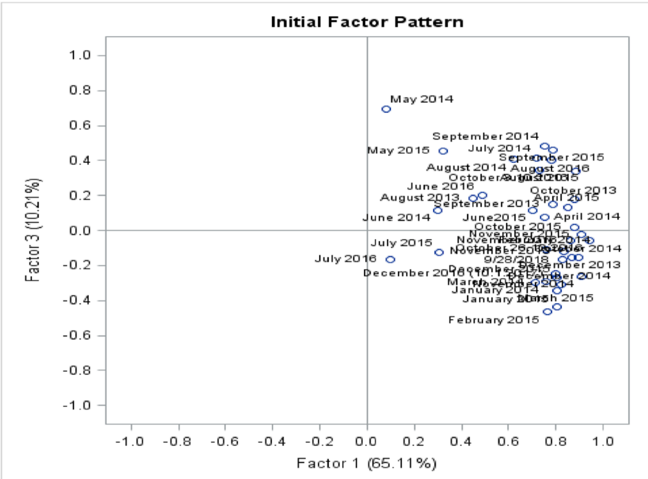
(**a**) (**b**)

Figure 16. Scree plots (**a**) Eigenvalue vs. factors and (**b**) proportion vs. factor: five factors are retained by the PROPORTION criterion.

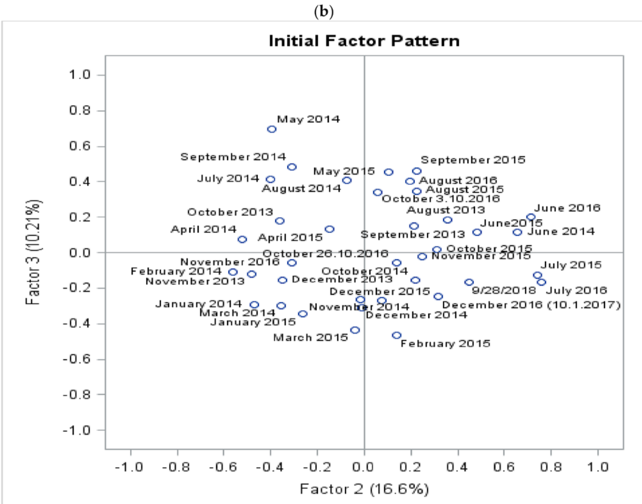
Comparing the score plots of Figures 17 and 18 with those of Figure 15, there is a clear difference. In Figure 15, the winter and summer months cluster separately, but in the next two figures, both seasons' data clusters are in one location, with the summer months' data above the main section and the winter months' data below. This can be explained by the differences in site specification between the analysis of the two sites.



(a)

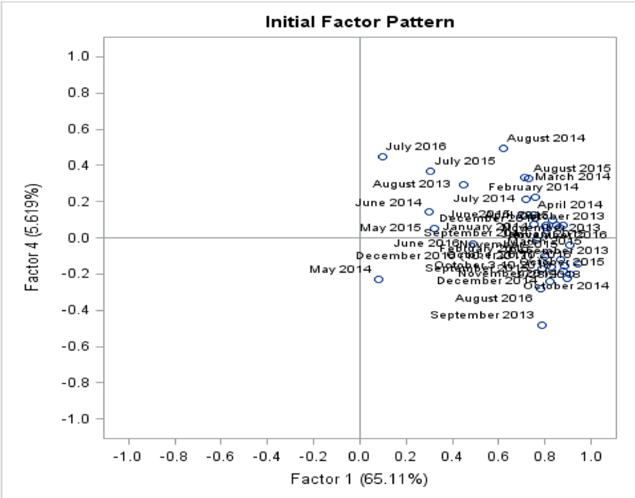


(b)



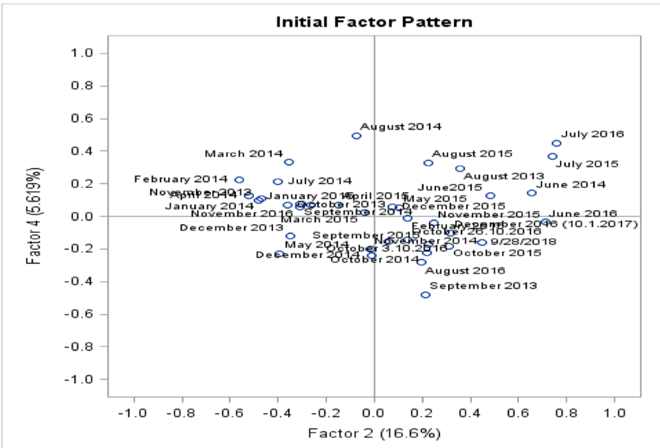
(c)

Figure 17. *Cont.*

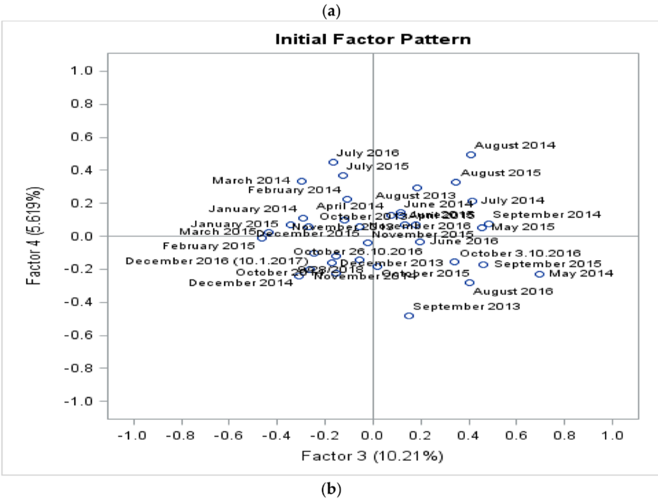


(**d**)

Figure 17. Four score plots built for five factor combinations at the Liito-oravankatu site. (**a**) Factor 2 vs. Factor 1. (**b**) Factor 3 vs. Factor 1. (**c**) Factor 3 vs. Factor 2. (**d**) Factor 4 vs. Factor 1.

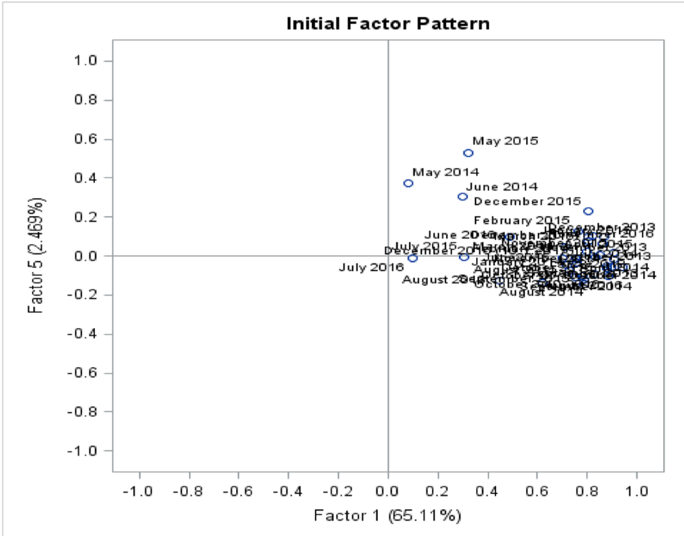


(**a**)

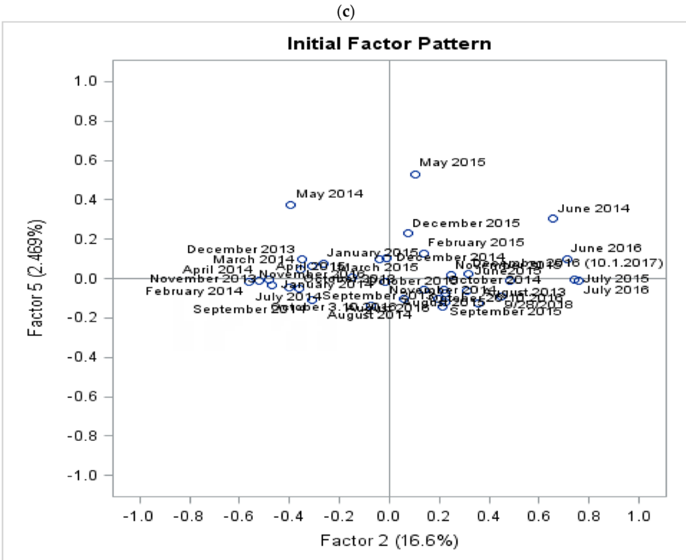


(**b**)

Figure 18. *Cont.*

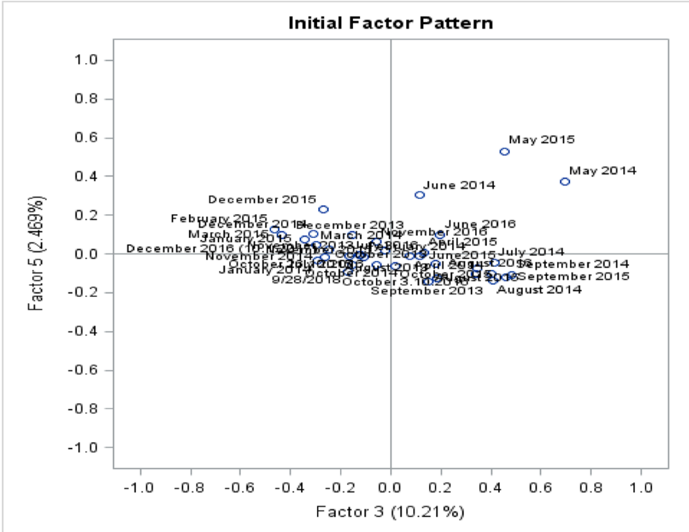


(**c**)

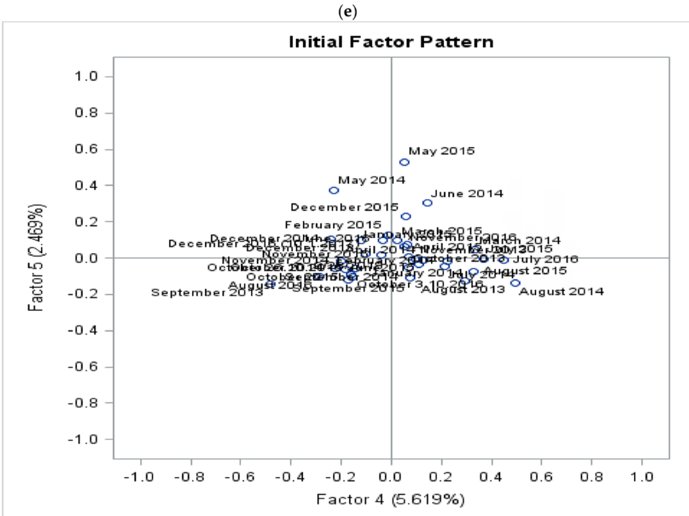


(**d**)

Figure 18. *Cont.*



(e)



(f)

Figure 18. Six score plots built for five factor combinations at the Liito-oravankatu site. (**a**) Factor 4 vs. Factor 2. (**b**) Factor 4 vs. Factor 3. (**c**) Factor 5 vs. Factor 1. (**d**) Factor 5 vs. Factor 2. (**e**) Factor 5 vs. Factor 3. (**f**) Factor 5 vs. Factor 4.4. Discussion.

The Suvilahti, Liito-oravankatu site data may explain factors based on the data for Figures 17 and 18. Separation between the data of summer and winter months seems to be created by Factor 1. Factor 2 seems to spread the data to the upper and lower sections. Factor 3 helps to bring all the data to the center of the plots, whereas factor 4 seems to cluster all the data together in separate seasons and/or without seasonal variations. The spread of the data to the left and right sections seems to be caused by Factor 5. Most of the explanations for the factors are similar to those of Figure 15.

There are no clear outliers in Figures 17 and 18. Factors 1 and 5 explain the proportion of most of the data. Some of the score plots below show that most of the data cluster is to the right and above the value of zero. The rest of the plots show a cluster near the center area. However, everything seems to be in a normal distribution pattern, depending on the month and the site specifications.

The analysis of sediment heat temperature data between 2013 and 2018 shows that most of the data were non-normal except for a few months. The result shows that this is site-specific while generalizing the results of summary statistics in terms of yearly patterns. This is probably due to the fact that the depth of installation for the two sites is different. The mean, median, and standard deviation variations seem to be yearly natural fluctuations.

A dependency analysis showed positive and negative Pearson's correlation results. One of the main findings is that all the analyzed correlations between sediment temperature by months vs. distance were found to be statistically significant. The sediment temperature was higher on shore after sunny months. The negative correlation between sediment temperature and distance from shore can be explained by the fact that seabed sediment near the shore (smaller distance) had a higher temperature after sunny months. In addition to our findings, Kim and Cho [27] researched how seawater provides heat to the seabed at the intertidal zone (tidal flat) during the morning flood tide and gains heat from the seabed during the afternoon flood tide. Seawater heated by the atmosphere and seabed at the intertidal zone supplies heat to the sublittoral zone during spring, summer, and winter, but the opposite occurs in autumn. According to our findings, after 50 m, the sediment temperature rises in both locations. This was due to the water depth level after 50 m, which was seemingly enough to help the sediment generate more heat. One of the main findings was that distances between 100 and 190 m from the shore were best for sediment heat energy production in our sites. This result confirms our previous studies' findings. Rinehimer and Thomson [28] observed that sediment–water heat fluxes are an important component of the heat budget, representing up to 20% of the incoming solar radiation and being larger than latent and sensible heat fluxes. Moreover, Guarini and Blanchard [29] modelled the spatio–temporal dynamics of mud surface temperatures. Comparisons at different periods between measured data series and simulations clearly establish the reliability of the model, thus allowing for extrapolations over time and space [29].

ARIMA modeling forecasts might not present the exact truth, due to a shortage of data in our area; hundreds of datapoints are required to forecast for about 40 years. This means that the generalizability of the forecast is limited by this requirement in modeling. However, the result of the forecast was found to be similar to IPCC (2021) [25] forecasts, which are representative enough to show that what is expected in a local area may be expected worldwide. Future air and water temperature rises are expected to benefit sediment heat energy production, at least in summertime, with a 2-month lag. In winter, with the expectations of a decline in snowfall in the future, there may be a decline the sediment heat-energy production. This is due to ice and snow cover on the water body acting as an insulation layer, assisting in sediment heat production during winter. On the other hand, when there is no more snow cover in water bodies, it is expected that winter sediment heat-energy production will decline. This suggests that the sediment heat-energy only benefits from weather change caused by climate change in summer. This helps to increase the significance of our results by building on the theoretical and practical implications that climate change can be implemented by using the temperature increase effect in air and water temperature to increase sediment heat energy production.

Validation by factor analysis shows all the data were clustered and no particular outliers were noticed. Climate change has a clear effect on air and water temperature changes at present, as reported in the IPCC 2021 report [25]. This means that finding ways to adapt, combat, and mitigate climate change is an essential way forward. The main finding of this study is that renewable sediment heat energy uses climate change to its advantage, which could be one solution to using climate change to our advantage. The simulation results of Fang et al. indicated that the influence of water temperature on sediment temperature is very strong, especially in deep lakes [30]. Thus, our result findings that climate change causes water temperature increases, which is advantageous for sediment heat energy, at least in summertime, is supported by Fang et al. Further research and data collection in sediment heat energy production sites is recommended to establish a more compressive theory, which can be generalized to all water body types.

4. Conclusions

Our conclusion, based on a summary of statistics, is that the pattern was site-specific and depended on installation depth. This was also confirmed during dependency analysis. In addition, based on mean, median, and standard deviations, it was concluded that the data show annual natural fluctuations.

ARIMA modeling shows some limitations of our study, but is representative enough to suggest that air and water temperatures are expected to rise and snow fall is expected to decline in the future. Sediment heat energy production uses the climate change effect to its advantage, especially in the summer. There are expectations or forecasts of air and water temperature increases in the future, leading to an increase in sediment temperature with a 2-month time lag. Therefore, the air temperature and solar irradiance increases caused by the climate change effect are expected to increase water temperature. An increase in water temperature causes further increases in sediment temperatures in summer. In winter, ice and snow cover used to act as an insulation for sediment heat energy production or sediment temperature. However, due to a decline in snow cover in winter, the cold temperature of the winter air might reduce the sediment heat, especially in shallow shores. Thus, this could lead to a decline in heat-energy production from sediment in winter. However, we conclude that, in summer, sediment heat energy production has, and will, continue to use the climate change effect to its own advantage.

Dependency analysis shows negative correlations between sediment temperature per month vs. distance from shore in sunny months and a positive correlation in winter months. In addition, the sediment temperature seems to build up after a 30–50 m distance from the shore, depending on the shallowness of the water body. In winter months (starting from October), the decline in 30–50 m sediment heat temperature could occur due to the heat uptake for household use. Notably, our data show that the best distance for sediment heat energy production in summer is between 100 and 190 m (sediment temperature record distance from shore), confirming the previous studies of our research group. However, this seems to depend on the month in which the data are collected. In winter months there seems to be a constant increase in sediment temperature as the distance from the shore increases. Generally, the findings presented in this paper offer new insight into the benefits of climate change effects for renewable energy production, and can, thus, be used to combat climate change more efficiently. Therefore, this provides some good news about climate change effects, even though its disadvantages are much more significant.

Validations by factor analysis show that data analysis was performed correctly. An additional point that was noticed was that, in other analyses, the turbidity of water bodies is expected to increase in the far future. This means that, as turbidity increases, this will lead to an increase in the absorbance of solar irradiance by the water body. This leads to an increase in water temperature and is further expected to increase the sediment heat temperature. There is a clear connection between limnology and sediment heat energy productions.

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Abbreviations

ARIMA	Autoregression Integrated Moving Average
DTS	Distributed Temperature Sensing
FMI	Finnish Meteorological Institute
ELY-keskus	Center for Economic Development, Transport, and the Environment
IPCC	Intergovernmental Panel on Climate Change
Pt100s	The most common Platinum resistance thermometer
SAS	Statistical Analysis Software (Enterprise Guide 7.1)

References

1. Hiltunen, E.; Martinkauppi, J.B.; Mäkiranta, A.; Rinta-Luoma, J.; Syrjälä, T. Seasonal temperature variation in heat collection liquid used in renewable, carbon-free heat production from urban and rural water areas. *Agron. Res.* **2015**, *13*, 485–493.
2. Likens, G.E.; Johnson, N.M. Measurement and analysis of the annual heat budget for the sediment in two Wisconsin lakes. *Limnol. Oceanogr.* **1969**, *14*, 115–135. [CrossRef]
3. Oceanography 101 (Miracosta). (15 February 2021). Available online: https://geo.libretexts.org/@go/page/9666 (accessed on 18 July 2021).
4. Savola, A. Fluid Flow Modeling Inside Heat Collection Pipes with Finite Element Method. Master's thesis, University of Vaasa, Vaasa, Finland, 2012.
5. Mäkiranta, A. Distributed Temperature Sensing Method–Usability in Asphalt and Sediment Heat Measurement. Master's thesis, University of Vaasa, Vaasa, Finland, 2013.
6. Ukil, A.; Braendle, H.; Krippner, P. Distributed temperature sensing: Review of technology and applications. *IEEE Sens. J.* **2012**, *12*, 885–892. [CrossRef]
7. Wilcock, W.S.D.; Kauffman, P.C. Development of a seawater battery for deep-water applications. *J. Power Sources* **1997**, *66*, 71–75. [CrossRef]
8. Wang, Y.; Liu, D.; Richard, P.; Li, X. A geochemical record of environmental changes in sediments from Sishili Bay, northern Yellow Sea, China: Anthropogenic influence on organic matter sources and composition over the last 100 years. *Mar. Pollut. Bull.* **2013**, *77*, 227–236. [CrossRef]
9. Reimers, C.R.; Tender, L.M.; Fertig, S.; Wang, W. Harvesting energy from the marine sediment-water interface. *Environ. Sci. Technol.* **2001**, *35*, 192–195. [CrossRef] [PubMed]
10. Hiltunen, E.; Martinkauppi, J.B.; Zhu, L.; Mäkiranta, A.; Lieskoski, M.; Rinta-Luoma, J. Renewable, carbon-free heat production from urban and rural water areas. *J. Clean. Prod.* **2015**, *153*, 379–404. [CrossRef]
11. Mäkiranta, A.; Martinkauppi, J.B.; Hiltunen, E. Seabed sediment—A natural seasonal heat storage feasibility study. *Agron. Res.* **2017**, *15* (Suppl. S1), 1101–1106.
12. Mäkiranta, A.; Martinkauppi, J.B.; Hiltunen, E. Correlation between temperature of air, heat carrier liquid and seabed sediment in renewable low energy network. *Agron. Res.* **2016**, *14* (Suppl. S1), 1191–1199.
13. Mäkiranta, A.; Martinkauppi, B.; Hiltunen, E.; Lieskoski, M. Seabed sediment as an annually renewable heat source. *Appl. Sci.* **2018**, *8*, 290. [CrossRef]
14. Sebok, E.; Müller, S. The effect of sediment thermal conductivity on vertical groundwater flux estimates. *Hydrol. Earth Syst. Sci.* **2019**, *23*, 3305–3317. [CrossRef]
15. Goto, S.; Yamano, M.; Morita, S.; Kanamatsu, T.; Hachikubo, A.; Kataoka, S.; Tanahashi, M.; Matsumoto, R. Physical and thermal properties of mud-dominant sediment from the Joetsu Basin in the eastern margin of the Japan Sea. *Mar. Geophys. Res.* **2017**, *38*, 393–407. [CrossRef]
16. Guo, Y.; Ma, J. Temperature Rise of Seawater Simulation under the Influence of Sediment-Water Heat Exchange. *Water* **2018**, *10*, 656. [CrossRef]
17. Golosov, S.; Kirillin, G. A parameterized model of heat storage by lake sediments. In *Environmental Modeling and Software*; Elsevier: Amsterdam, The Netherlands, 2010; Volume 25, pp. 793–801. [CrossRef]
18. Pivato, M.; Carniello, L.; Gardner, J.; Silvestri, S.; Marani, M. Water and sediment temperature dynamics in shallow tidal environments: The role of the heat flux at the sediment-water interface. *Adv. Water Resour.* **2018**, *113*, 126–140. [CrossRef]
19. Hamilton, D.P.; Magee, M.R.; Wu, C.H.; Kratz, T.K. Ice cover and thermal regime in a dimictic seepage lake under climate change. *Inland Waters* **2018**, *8*, 381–398. [CrossRef]
20. Ellis, C.R.; Stefan, H.G.; Gu, R. Water temperature dynamics and heat transfer beneath the ice cover of a lake. *Limnol. Oceanogr.* **1991**, *36*, 324–335. [CrossRef]

21. Smith, P.N. Observations and simulations of water-sediment heat exchange in a shallow coastal lagoon. *Estuaries* **2002**, *25*, 483–487. [CrossRef]
22. Tsay, T.-K.; Ruggaber, G.J.; Effler, S.W.; Driscoll, C.T. Thermal Stratification modeling of lakes with sediment heat flux. *J. Hydraul. Eng.* **1992**, *118*, 407–419. [CrossRef]
23. Meyers, L.S.; Gamst, G.; Guarino, A.J. *Data Analysis Using SAS Enterprise Guide*; Cambridge University Press: Cambridge, UK, 2009; ISBN -13.
24. Dytham, C. *Choosing and Using Statistics—A Biologist's Guide*, 3rd ed.; John Wiley & Sons: Hoboken, NJ, USA, 2011; ISBN 978-1-4443-2843-1.
25. IPCC. Climate Change 2021: The Physical Science Basis. In Proceedings of the Contribution of Working Group— I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR6 WGI), 2021. Available online: https://www.ipcc (accessed on 31 July 2021).
26. Drucker-Godard, C.; Ehlinger, S.; Grenier, C. Validity and Reliability. In *Doing Management Research*; SAGE Publication Ltd.: London, UK, 2011; pp. 196–220. [CrossRef]
27. Kim, T.W.; Cho, Y.K. Calculation of heat flux in a macrotidal flat using FVCOM. *J. Geophys. Res. Ocean.* **2011**, *116*, 869–881. [CrossRef]
28. Rinehimer, J.P.; Thomson, J.T. Observations and modeling of heat fluxes on tidal flats. *J. Geophys. Res. Ocean.* **2014**, *119*, 133–146. [CrossRef]
29. Guarini, J.M.; Blanchard, G.F.; Gros, P.; Harrison, S.J. Modelling the mud surface temperature on intertidal flats to investigate the spatio-temporal dynamics of the benthic microalgal photosynthetic capacity. *Mar. Ecol. Prog. Ser.* **1997**, *153*, 25–36. [CrossRef]
30. Fang, X.; Stefan, H.G. Temperature variability in lake sediments. *Water Resour. Res.* **1997**, *34*, 717–729. [CrossRef]