Maarit Jäntti

Decarbonisation of District Heating System

Case: District Heating System in the City of Vaasa

School of Technology and Innovations
Master of Science in Technology
Smart Energy

Vaasa 2025

UNIVERSITY OF VAASA
School of Technology and Innovations

	Maarit Jäntti		
Author:			
Title of the thesis:	Decarbonisation of District Heating System : Case: District Heating System in the City of Vaasa		
Degree:	Master of Science in Technology		
Discipline:	Smart Energy		
Supervisors:	Mika Luoto (EPV Energia Oy), Hannu Laaksonen (University of Vaasa		
Year:	2025	**Pages:**	88

ABSTRACT:

In this thesis, methods to optimize the heating system in the Vaasa region and reduce carbon dioxide emissions are studied. The work presents already existing assets in Vaasa, such as the combination of electric boilers and thermal energy storage, which has proven effective in optimizing energy systems. This combination supports carbon neutral heat production and provides balancing services to the electricity grid by participating in different energy markets. Vaasa's CHP plants are also presented, and alternative fuels are considered to make the heating sector in the Vaasa region carbon neutral.

Sector coupling mechanisms are essential for balancing consumption and production. Sector coupling refers to the integration and optimization of different energy forms to achieve a more sustainable and efficient energy system. When renewable energy production is high and demand is low, electric boilers can use the excess electricity to produce heat, which can be stored for future use. This approach helps stabilize electricity prices and supports the integration of renewable energy sources.

In Vaasa, they have made significant progress in improving heat production. Continuous development is essential, and further improvements are needed to achieve carbon neutrality. This thesis explores various options such as developing the district heating network by combining heating and cooling solutions into bidirectional district heating and demand response in heating. Technologies such as heat-to-power, small nuclear heat, waste heat, and heat pumps are also potential alternatives.

The research problem addressed in this thesis is the decarbonisation of the heating sector in the Vaasa region. The theory and key concepts include sector coupling, renewable energy integration, and carbon capture technologies. The methods used involve analysing existing assets, evaluating alternative fuels, and exploring new technologies. In conclusion, the decarbonisation of the heating sector in the Vaasa region requires a multifaceted approach and continuous development of existing assets. This thesis provides insights into the methods and technologies that can be used to achieve carbon neutrality in the heating sector in Vaasa.

KEYWORDS: sector coupling, renewable energy, electric boilers, thermal storage, decarbonisation

VAASAN YLIOPISTO
School of Technology and Innovations
Tekniikan ja innovaatiojohtamisen yksikkö

Työ tekijä:	Maarit Jäntti
Työn nimi:	Decarbonisation of District Heating System : Case: District Heating System in the City of Vaasa
Tutkinto:	Diplomi-insinööri
Koulutusohjelma:	Smart Energy
Työn ohjaajat:	Mika Luoto (EPV Energia Oy), Hannu Laaksonen (Vaasan yliopisto)
Vuosi:	2025 **Sivumäärä:** 88

TIIVISTELMÄ:

Tässä opinnäytetyössä tutkitaan keinoja Vaasan alueen lämmityssektorin hiilidioksidipäästöjen vähentämiseen ja poistamiseen. Työssä on esitelty Vaasassa jo olemassa olevia ratkaisuja kuten sähkökattiloiden ja lämpöenergiavaraston yhdistelmä, joka on osoittautunut tehokkaaksi energiajärjestelmien optimoinnissa. Tämä yhdistelmä tukee hiilineutraalia lämmöntuotantoa ja tarjoaa myös tasapainotusta sähköverkkoon osallistumalla eri energiamarkkinoille. Myös Vaasan CHP-laitokset on esitelty ja vaihtoehtoisten polttoaineita on mietitty, jotta saataisiin Vaasan alueen lämmitys sektori hiilineutraaliksi.

Sektorikytkentämekanismit ovat olennaisia kulutuksen ja tuotannon tasapainottamisessa. Sektorikytkentä tarkoittaa eri energiamuotojen yhdistämistä ja niiden käytön optimointia, jotta saavutetaan ympäristöystävällisempi ja tehokkaampi energiajärjestelmä. Kun uusiutuvan energian tuotanto on korkealla ja kysyntä matalalla, sähkökattilat voivat käyttää ylimääräisen sähkön lämmön tuottamiseen, joka voidaan varastoida tulevaa käyttöä varten. Tämä lähestymistapa auttaa vakauttamaan sähkön hintoja ja tukee uusiutuvien energialähteiden integrointia energiajärjestelmään.

Vaasassa on tehty merkittävää edistystä lämmöntuotannon parantamisessa. Jatkuva kehitystyö on tärkeää ja lisäparannuksia tarvitaan, jotta ilmastopäästöt saadaan poistettua järjestelmästä. Tässä opinnäytetyössä tutkitaan eri vaihtoehtoja kuten kaukolämpöverkon kehittämistä yhdistämällä lämmitys- ja jäähdytysratkaisut kaksisuuntaiseen kaukolämpöverkkoon sekä kysyntäjoustoon lämmityksessä. Myös teknologiat kuten heat-to-power, pienydinlämpö, hukkalämpö ja lämpöpumput ovat potentiaalisia vaihtoehtoja.

Tämän työn tutkimusongelma on Vaasan alueen lämmityssektorin hiilidioksidipäästöjen poistaminen. Teoria ja keskeiset käsitteet sisältävät sektorikytkennän, uusiutuvan energian integroinnin ja hiilidioksidin talteenotto. Työssä käytetyt menetelmät sisältävät olemassa olevien ratkaisujen analysoinnin, vaihtoehtoisten polttoaineiden arvioinnin ja uusien teknologioiden tutkimisen. Vaasan alueen lämmityssektorin hiilivapauttaminen vaatii monitasoista lähestymistapaa, joka sisältää olemassa olevien ratkaisujen jatkuvan kehittämisen. Tämä työ antaa tietoa menetelmistä ja teknologioista, joita voidaan käyttää Vaasan lämmityssektorin hiilineutraaliuden saavuttamiseksi.

AVAINSANAT: sektorikytkentä, uusiutuva energia, sähkökattilat, lämpövarasto, hiilineutraalius

Contents

1 Introduction 11

1.1 Motivation 13

1.1.1 Decarbonisation of heating sector 13

1.1.2 Global megatrends 14

1.1.3 The climate goals of EU 14

1.2 Overview of the thesis 15

2 Commissioner EPV Energia Oy and the heating sector in Vaasa and Finland 16

2.1 EPV Energia Oy 16

2.1.1 The structure and business areas of EPV Group 17

2.1.2 Energy production of EPV 18

2.1.3 The flexibility solutions of EPV 21

2.1.4 Upcoming development projects of EPV 22

2.2 Heating sector in Finland 24

2.2.1 Guarantee of Origin 25

2.2.2 District heating in Finland 26

2.2.3 District cooling 28

2.3 Heating sector in Vaasa region 28

2.3.1 District heating in Vaasa 29

2.3.2 Vaasan Voima Oy 31

2.3.3 Westenergy 35

2.3.4 Pått wastewater treatment plant -heat pump 36

3 Theory 37

3.1 Energy markets 37

3.1.1 Electricity markets 38

3.1.2 The Nordic energy system 38

3.1.3 Electricity markets in Finland 39

3.2 Sector coupling 41

3.2.1 Definition of sector coupling 43

3.2.2 The main dimensions of sector coupling 44

3.2.3 Power to X (P2X) and Power to Gas (P2G) 45
3.2.4 Power to heat 46
3.2.5 Heat-to-power 47
3.2.6 Power to cooling 47
4 Methodologies and technologies for decarbonisation of the heating sector 48
4.1 Energy efficiency 48
4.1.1 Future district heating network 49
4.1.2 Combined production of district heating and cooling 50
4.1.3 Demand response for heating 51
4.2 Improvements for CHP-plants 53
4.2.1 Alternative fuels for CHP-plants 53
4.2.2 Carbon capture utilisation and storage 55
4.3 Waste heat 56
4.3.1 Cogeneration and Flue Gas Heat Recovery 58
4.4 Heat pumps 58
4.5 Heat accumulators 60
4.5.1 Sensible heat storage (SHS) 60
4.5.2 Latent heat storage (LHS) 60
4.5.3 Thermochemical heat storage (TCS) 61
4.6 SMR and nuclear heat 61
4.7 Geothermal Heat 61
4.8 Examples of decarbonisation of the heating sector in other countries and cities 62
4.9 Evaluation of the methodologies and techniques 64
5 Towards a carbon neutral district heating system in Vaasa 67
5.1 Challenges of the existing assets 68
5.2 Proposed strategy for achieving carbon neutrality in the Vaasa region 70
6 Conclusion 72
6.1 Recommendations for further research 73

References 74

Appendices 86

Appendix 1. The promoting mechanisms for the use of renewable energy and emission reductions 86

Appendix 2. EU funding for climate actions 87

Appendix 3. Terminology of the electricity exchange 88

Figures

Figure 1. The structure and business areas of EPV. 18

Figure 2. The electricity generation of EPV in 2024. 19

Figure 3. The flexibility solutions of EPV in 2025. 22

Figure 4. The heating buildings in Finland in 2022. 25

Figure 5. Development of electric boilers in district heating. 27

Figure 6. Vaasa heating sector. 29

Figure 7. Vaasa district heating in 2024. 30

Figure 8. District heating in Finland in 2024. 30

Figure 9. Vaasan Voima fuels 2023. 32

Figure 10. Vaasan Voima Fuels 2024. 32

Figure 11. Thermal storage of Vaasan Voima Oy. 35

Figure 12. The reserve markets of Fingrid Oyj. 41

Figure 13. Benefits of sector coupling. 43

Figure 14. The main dimensions of sector coupling. 45

Figure 15. Example of waste heat sources. 57

Figure 16. The advantages of thermal storage. 68

Tables

Table 1. The five generations of district heating systems. 50

Table 2. SWOT-analysis of technologies for decarbonisation of heating sector. 65

Abbreviations

CCS	Carbon Capture Storage
CCU	Carbon Capture Utilisation
CCUS	Carbon Capture Utilisation and Storage
CH_4	Methane
CHP	Combined Heat and Power
CO_2	Carbon dioxide
DH	District heating
DHC	District heating and cooling
DHW	Domestic hot water
DSO	Distribution System Operators
EU	European Union
ETS	Emissions Trading System
GWh	Gigawatt-hours
H2P	Heat to Power
MWh	Megawatt-hours
MWp	Megawatt peak
NOx	Nitrogen oxides
P2C	Power to Cooling
P2L	Power to Liquids
P2G	Power to Gas
P2H	Power to Heating
P2X	Power to anything

RES	Renewable energy source
TES	Thermal energy storage
TSO	Transmission System Operators
TWh	Terawatt-hours
VRE	Variable renewable energy

1 Introduction

Human activities such as burning fossil fuels, deforestation, and livestock farming increase significantly greenhouse gas emissions such as CO_2, CH_4, NOx, and fluorinated gases enhancing the greenhouse effect and leading to global warming. The 2010s were the warmest on record, with global temperatures 1.1 °C above pre-industrial levels. Human-induced warming is rising at 0.2 °C per decade. To prevent severe environmental and health impacts, global warming needs to keep well below 2 °C, ideally limiting it to 1.5 °C. Reducing emissions is crucial for slowing global warming and achieving net-zero CO_2 emissions. The EU prioritizes both mitigating climate change and adapting to its effects, pointing out the urgent need for climate action. (European Commission, n.d.)

Renewable power generation has increased and is expected to continue rising. Renewable energy sources such as wind, solar, hydro, ocean, geothermal, biomass, and biofuels are replacing fossil fuels providing sustainable and low-carbon energy. These sources reduce pollution, diversify the energy mix, and decrease dependence on volatile fossil fuel prices. (European Parliament, 2024) Despite the promising outlook, challenges remain. Renewable energy can cause imbalances in energy systems due to its inflexibility, leading to mismatches between consumption and production. Therefore, increasing flexibility solutions and electricity consumption is essential to gain benefits from fluctuating renewable energy sources such as wind and solar. Additionally, some sectors, like certain industrial processes, building heating, heavy transportation, and aviation are challenging to decarbonise. Addressing imbalances and decarbonising all sectors, smart implementation and operation are crucial.

This thesis is made for EPV Energia Oy to identify strategies to decarbonising the heating sector in the Vaasa region. EPV Energia Oy primarily through its subsidiary Vaasan Voima Oy is connected to the heating of the Vaasa region by producing about half of the district heating in the area. Vaasan Voima Oy has made significant investments in developing electrification of heat and heat storage technology. To understand the study area better EPV Energia Oy and the existing assets of Vaasa heating sector are explained in this thesis.

To develop an effective system, it is essential to consider the characteristics of the Vaasa region and the existing assets.

Sector coupling is examined in this thesis because it offers technologies and mechanisms that are claimed to be effective reducing emissions and balancing energy consumption and production (Erbach, 2019; IRENA, 2022; Abdur Rehman, Palomba, Frazzica, & Cabeza, 2021; Wang et al., 2023). Sector coupling sub concept Power-to-Heating utilizes electric boilers and heat pumps in heating sector. In addition, CHP plants are coupling electricity and heating. When these assets are operated intelligently, they use affordable renewable energy to produce heat for the district heating network. Combined with heat storage, they can provide balancing services to the electricity grid. Therefore, this thesis explains the different energy markets and their interaction with electricity markets.

Additionally, this thesis assesses other technologies and mechanisms to determine their suitability and effectiveness for decarbonising Vaasa's heating sector for example carbon capture technologies and small modular reactors are presented in this thesis.

The research questions are as follows:

- What methods and technologies are utilised in other countries and cities for decarbonising the heating sector, and what related studies have been conducted?
- What methods and technologies can be used to decarbonise the heating sector of Vaasa?

This thesis provides a preliminary analysis to identify the options that require more comprehensive calculations and analyses to support the decarbonisation of the heating sector in Vaasa and EPV's goal of achieving carbon neutrality by 2030. The thesis does not extensively examine the technical attributes or the costs of different assets and technologies.

1.1 Motivation

This thesis will be focusing Vaasa heating sector which already utilises diverse heat generation methods, including CHP plants, electric boilers, heat pumps (Pått), a district heating network, and heat storage. However, the system is not entirely carbon neutral yet. Different methods and technologies need to be explored and evaluated to achieve carbon neutrality in Vaasa heating system.

Vaasa, known for its strong energy cluster and commitment to innovation, presents a unique case for exploring decarbonisation strategies. The city has already taken steps toward integrating renewable energy and improving energy efficiency, yet challenges remain in fully transitioning away from fossil-based heating systems. This thesis is motivated by the need to understand how cities like Vaasa can lead the way in implementing practical, scalable solutions for low-carbon heating. Vaasa’s proactive stance on energy innovation makes it an ideal case study for examining the real-world application of decarbonisation strategies.

1.1.1 Decarbonisation of heating sector

The decarbonisation of heating systems is timely issue and many countries, cities, organisations and institutions and individuals are actively seeking solutions to address this challenge. The heating sector plays a crucial role in the overall energy consumption and carbon emissions, particularly in regions with cold climates such as Finland. To meet climate targets, decarbonising this sector is essential.

Heating in Finland forms a major part of residential and industrial energy use, making it critical for sustainable change. Heating sector is a challenging sector to decarbonise, and heating-related CO_2 emissions are a significant part of Finland's greenhouse gas emissions. The share of heating varies annually depending on weather conditions, but it is one of the largest sources of emissions in Finland (Tilastokeskus, 2024). Heating buildings accounts for about 25 % of all energy used in Finland. Residential buildings consume 20 % of the total energy, with approximately two-thirds used for space heating. The most used energy sources are district heating, wood, and electricity. (Suomen ympäristökeskus, 2022)

1.1.2 Global megatrends

Climate change, reliable energy supply, energy sector transition, and digitalisation are identified as global megatrends impacting the energy industry (EPV Energia Oy, n.d.). In addition, the U.S. Energy Information Administration (EIA, 2023) has identified electrification as a significant trend influencing the future of energy. Electrification involves transitioning energy consumption from fossil fuels to renewable electricity generated from sources such as wind and solar. This trend is expected to drive stable growth in electric power demand and increase the share of zero-carbon electricity generation. (EIA, 2025)

1.1.3 The climate goals of EU

The European Union (EU) has established ambitious decarbonisation goals to combat climate change and transition to a sustainable low-carbon economy. These objectives are part of a comprehensive strategy aimed at ensuring sustainable economic growth, environmental protection, and improved quality of life for all EU citizens. The EU is promoting the use of renewable energy and emission reductions through multiple initiatives such as EU Climate Law, European Green Deal, Green Industrial Revolution, Renewable Energy Directive, Energy efficiency Directive, Sectoral Decarbonisation, EU ETS, Adaptation Strategy and REPowerEU plan. (European Commission 2023; European Commission 2025; European Parliament 2024; European Union 2021; Suomen ympäristökeskus 2022) The promoting mechanisms and their explanations are listed in Appendix 1.

The EU provides funding and incentives for environmentally friendly projects, such as renewable energy production and improving energy efficiency. The EU provides financial support through programs like the LIFE Programme, the Social Climate Fund, the Innovation Fund, and the Modernization Fund. (European Commission, 2025) EU funding schemes for climate actions are listed in Appendix 2.

1.2 Overview of the thesis

The thesis is organized as follows: Chapter 2 introduces the commissioner EPV Energia Oy and the heating sector in Vaasa and in Finland. Chapter 3 introduces the basics of the energy markets and the concept of sector coupling. Chapter 4 introduce different technologies and methodologies for the decarbonisation of heating sector. Chapter 5 introduces and evaluates the different methods and technologies for the decarbonisation of Vaasa heating sector. The conclusion of the thesis is presented in Chapter 6.

2 Commissioner EPV Energia Oy and the heating sector in Vaasa and Finland

The commissioner of the thesis is EPV Energia Oy, and the study takes place in Vaasa heating, therefore they are introduced in this section. The author of this thesis has worked as an Operational Energy Engineer at EPV Energia Oy since 2022.

2.1 EPV Energia Oy

EPV Energia Oy (EPV) is a Finnish energy company established in 1952 specializing in the generation and supply of electricity and heat to its shareholders. EPV is dedicated to advancing zero-emission energy production and mitigating climate change, with a goal of achieving carbon neutrality by 2030. The company's diverse energy production portfolio comprises wind, solar, nuclear, and hydropower, as well as domestic forest energy, CHP, and energy management solutions. With decades of expertise in responsible energy production, EPV has positioned itself as a pioneer in emission-free energy generation. The company continuously enhances its energy generation capabilities, resulting in significant reductions in CO_2 emissions. (EPV Energia Oy, n.d.)

EPV ensures a reliable energy supply by investing in grid infrastructure and digitalizing energy procurement and supply management. EPV places significant emphasis on a long-term energy policy and investments in new technologies aiming at modernizing the energy system and reducing emissions. Utilising advanced technology, EPV adjusts its production processes and efficiently balances supply and demand. (EPV Energia Oy, 2025 a & b)

2.1.1 The structure and business areas of EPV Group

The EPV Group consists of subsidiaries and affiliated companies, in which EPV participates in governance and supervision. Nevertheless, these subsidiaries and affiliated companies maintain their own administrative bodies. (EPV Energia Oy, n.d.)
EPV operates under the Mankala principle (TVO, 2023), which means that energy is delivered to the owners at production cost. Instead, the owners benefit by utilising the procured energy or selling it. This model effectively pools resources and shares risks among the owners, enabling the execution of extensive energy projects while maintaining low production costs. In Finland, over 40 % of electricity is procured according to the Mankala principle. (Vaasan Voima Oy, n.d.) EPV consist of four business areas: CHP production and energy storage, renewable energy production, energy management and electricity transmission. The structure and business areas of the EPV Group are illustrated in Figure 1.

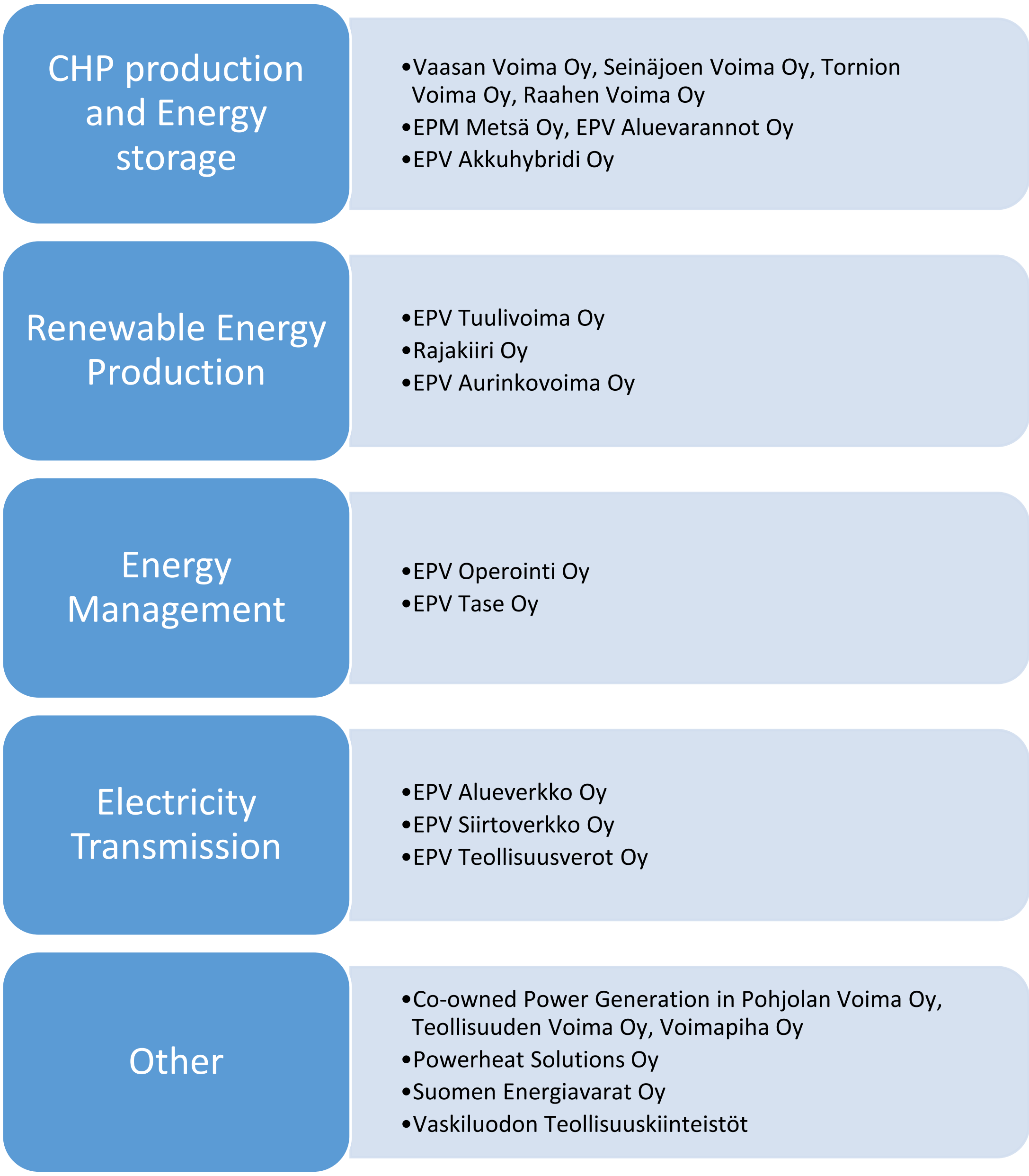

Figure 1. The structure and business areas of EPV (adapted from EPV Energia Oy, n.d.).

2.1.2 Energy production of EPV

In 2024, EPV achieved a total power procurement of 4.7 TWh, representing 5 % of Finland's total electricity consumption. Notably, 96 % of EPV's electricity production in 2024 was generated through emission-free sources such as wind, hydro and nuclear power. (EPV Energia Oy, n.d.) The electricity generation of EPV in 2024 is illustrated in Figure 2.

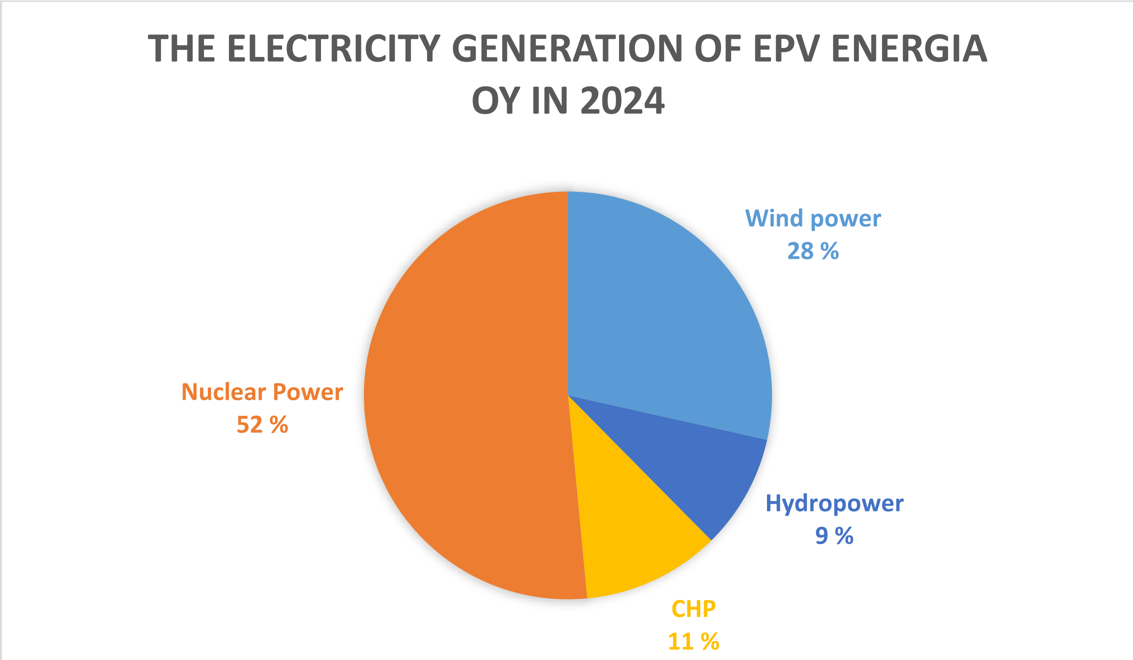

Figure 2. The electricity generation of EPV in 2024 (adapted from EPV Energia Oy, 2025b).

Wind power

EPV is one of the largest wind power producers in Finland. The company focuses on developing, building, investing in, operating, and managing wind power projects. EPV initiated its wind power program in 2006. In 2024 about 28.5 % of EPV's energy generation originated from wind power. (EPV Tuulivoima Oy, n.d.)

Hydro power

EPV contributes to hydropower electricity production through its shares in Pohjolan Voima Oy and Voimapiha Oy. Pohjolan Voima Oy generates hydropower electricity in Finland. Additionally, EPV Energy has invested in hydropower in Sweden via Voimapiha Oy. Hydropower production occurs on an industrial scale, providing balancing power for renewable energy sources. In 2024 hydroelectric power accounted for 9.1 % of EPV's energy generation. (EPV Energia Oy, n.d.)

Combined heat and power

EPV operates CHP plants in Vaasa, Seinäjoki, Tornio, and Raahe. These CHP plants produce both electricity and heat. Additionally, Tornion Voima Oy uses process heat from the Outokumpu steel factory, while Raahen Voima Oy generates electricity primarily from process gases at the SSAB steel factory. (EPV Energia Oy, n.d.) Detailed information on the operations of Vaasan Voima Oy can be found in chapter 2.3 where the heating sector of Vaasa is introduced.

EPV is also investing in Finnish biofuels to enhance energy security and employment. The company has developed a cost-effective bioenergy supply chain for CHP and aims to increase the share of domestic bioenergy in heat and electricity production. (EPV Energia Oy, n.d.)

Nuclear power

EPV produces nuclear power through its affiliated companies, Teollisuuden Voima Oy. When responsibly managed nuclear power is environmentally friendly and safe providing zero-emission electricity. For approximately 40 years, Teollisuuden Voima Oy has generated nuclear power for EPV from the Olkiluoto 1 and 2 nuclear power plants, with EPV owning over 8 % of the production. Additionally, EPV owns about 10 % of the Olkiluoto 3 production. In 2024 nuclear power accounted for 51.4 % of EPV's energy generation. (EPV Energia Oy, n.d.)

Energy management

EPV's Energy Management provides energy system optimization services to EPV shareholders and energy generation companies that are wholly or partially owned by EPV. The activities of EPV’s Energy Management focused on the Operations Centre (OC), where key functions include managing the wholesale power balance, buying and selling electricity in the Nordic power exchange, and controlling various energy production plant systems. The OC also plans and directs production for EPV companies, optimizing output in the wholesale electricity market and minimising costs in the imbalance power market (EPV Energia Oy, n.d.)

2.1.3 The flexibility solutions of EPV

To support the growing generation of renewable energy, EPV is developing a range of energy storage solutions, including electric boilers, thermal energy storage systems, engine power plants, and electrical batteries. The flexibility solutions of EPV are illustrated in Figure 3. EPV is committed to continuing its investments in clean electricity generation and flexibility solutions. These efforts are aimed at enhancing the reliability and efficiency of renewable energy integration. (EPV Energia Oy, 2025)

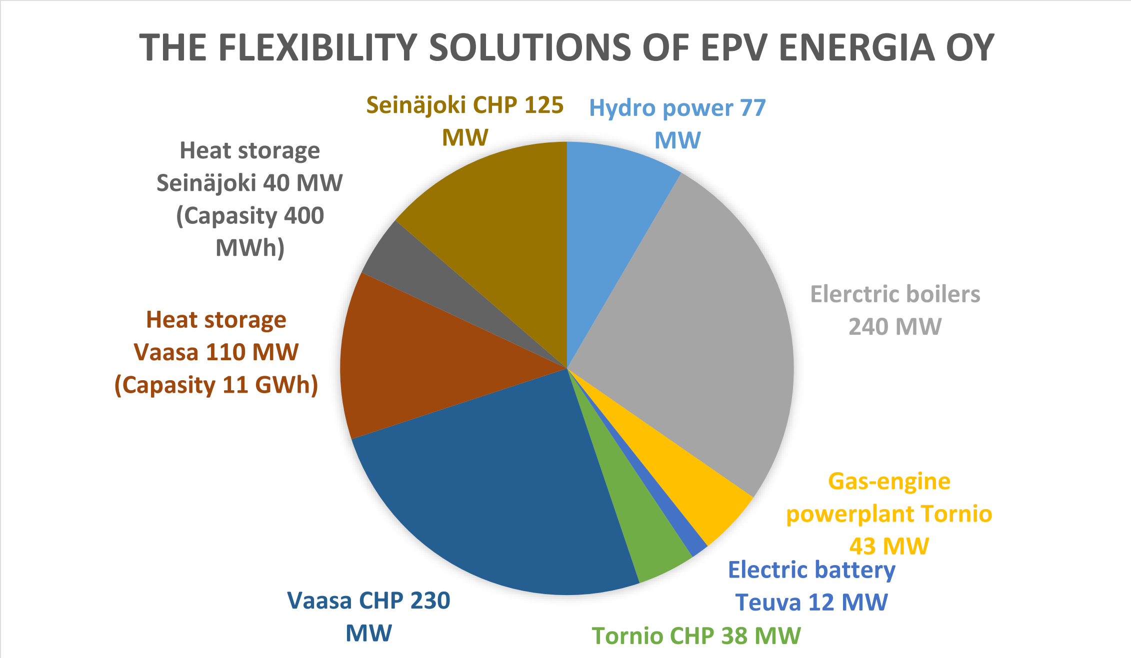

Figure 3. The flexibility solutions of EPV in 2025.

2.1.4 Upcoming development projects of EPV

EPV Energia Oy is actively advancing its strategy known as the "New Electricity Revolution," which emphasizes zero-emission energy production and sustainable innovation. The company is currently engaged in several significant development projects across Finland. (EPV Energia Oy, n.d.)

Solar power

One of the most prominent initiatives is the construction of the Heinineva solar power plant in Lapua. The first industrial-scale solar park of the EPV Group is scheduled to commence electricity production by the end of 2025. The Heinineva solar park, with a total output of approximately 86 MWp, is expected to produce over 80 GWh of electricity annually, making it one of the largest solar parks in Finland and it is expected to increase

EPV's renewable electricity production by about 6 %. The facility will feature approximately 123,000 solar panels across 120 hectares, with an expected annual output exceeding 80 GWh. (EPV Aurinkovoima Oy, 2024)

Since 2018, EPV Energy has been actively researching solar energy. The company owns land suitable for solar power generation and plans to utilise it sustainably, minimising environmental impact. (EPV Aurinkovoima Oy, n.d.) (EPV Aurinkovoima Oy, 2023)

Energy storages

In the field of energy storage, EPV is planning a 1600 MWh CO_2 battery-based storage system in Laihia. The system utilizes the phase change of carbon dioxide for energy storage. This facility will store zero-emission electricity and enhance grid stability. Helps balance the power system by acting as both a consumption and production facility. (EPV Energia Oy, n.d.)

Additionally, EPV is constructing its first electrical energy storage unit in conjunction with the Teuva wind power plant, further supporting flexible energy management. EPV is also participating in the planning of a major battery technology hub in Laajametsä, Vaasa, reinforcing its role in Finland's energy transition. (EPV Energia Oy, n.d.)

EPV has implemented Finland's largest thermal energy storage facility in Vaskiluoto. This installation serves as a strategic asset for optimizing the company's energy portfolio and ensuring a stable supply of thermal energy. Capacity of the Vaskiluoto thermal storage will be increased from 11 GWh to 17 GWh by the end of 2025. (Vaasan Voima Oy, 2024)

Hydrogen technology

Hydrogen technology is another key focus area. EPV is exploring hydrogen as a storable, emission-free energy carrier that can address the intermittency of renewable energy sources. In addition, the heat generated in hydrogen production can be utilized in the district heating network for maximising the overall efficiency. This aligns with global climate goals and supports long-term energy storage strategies. (EPV Energia Oy, n.d.)

Gas-engine technology

To maintain grid reliability with the growing integration of renewable energy sources, EPV is investing in gas-engine technology to enhance its balancing power capabilities. These investments will provide the necessary flexibility to manage the variability in energy production. (EPV Energia Oy, n.d.)

Offshore wind power

Furthermore, EPV is involved in offshore wind power development, aiming to harness large-scale renewable energy from marine environments. (EPV Energia Oy, n.d.)

2.2 Heating sector in Finland

In the Finnish heating markets customers can choose their heating and cooling methods freely. Available options include district heating, electric heating, and solutions based on heat pumps, and renewable or fossil fuels. Political decisions, such as taxes and subsidies, influence the attractiveness of these options. District heating companies procure heat at favourable prices and often buy waste heat from customers or other producers. (Energiateollisuus ry, n.d.)

In the EU, there is increasing recognition of the role of heating markets in emission reduction and energy efficiency. In Finland, district heating is the most common method for heating. The heating for residential, commercial and public buildings in Finland also comprises electricity, heat pumps, wood and fuel oil. (Energiateollisuus ry, n.d.) The shares of different heating sources in Finland in 2022 are presented in Figure 4.

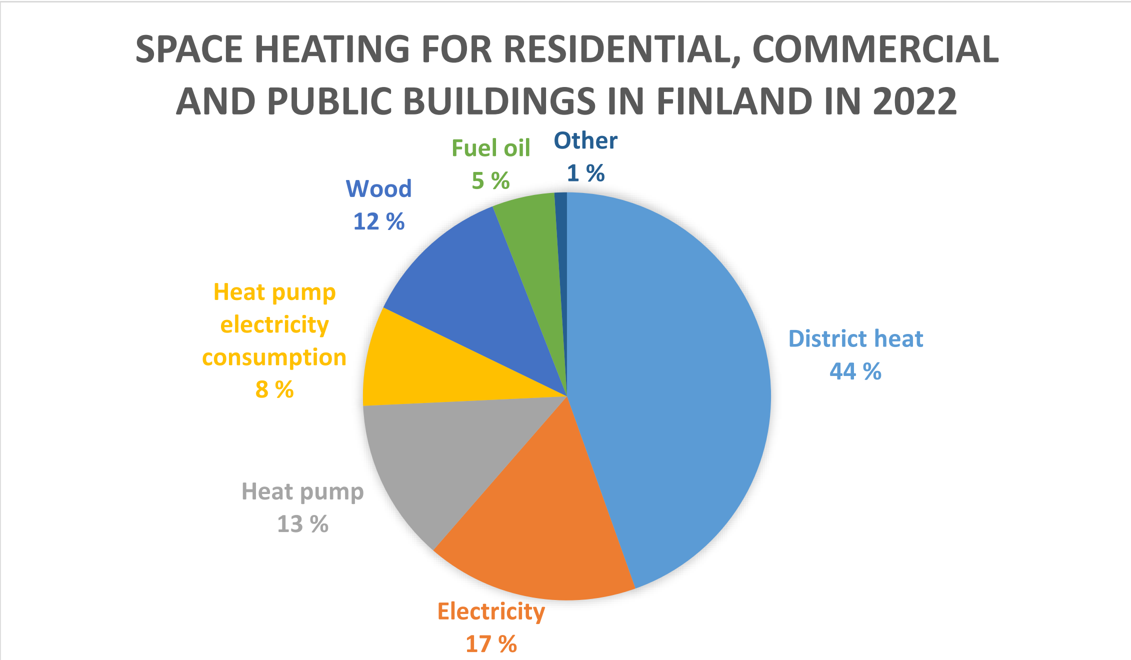

Figure 4. The heating buildings in Finland in 2022 (Adapted from Finnish Energy, 2025).

2.2.1 Guarantee of Origin

In Finland, the regulation under the Renewable Energy Directive (RED II) has revised the Guarantee of Origin Act (1050/2021). Guarantee of Origin will be issued for electricity from renewable sources, nuclear power, efficient co-production, renewable gas, hydrogen from renewable sources, heat and cooling from renewable sources, and waste heat or cold. (Energy authority, n.d.)

Producers and users claiming their heat/cooling comes from renewable sources or waste heat/cold must verify the origin. Sellers must verify the origin of renewable or waste heat/cool energy, unless transfer methods leave no doubt about the origin and no Guarantee of Origin are applied for. Fossil fuel content during maintenance and startup must not exceed 4 % of total fuels used annually. (Finlex, 2021)

2.2.2 District heating in Finland

Finland's district heating network spans about 16,000 kilometres with high reliability due to quality construction, systematic maintenance, and renovations. Heat from plants is transferred as hot water through a closed two-pipe system, where the supply pipe delivers hot water (65 to 115 °C), and the return pipe brings back cooled water (40 to 60 °C). The water is treated to prevent corrosion, and leaks are detected by coloured water. Pipes installed 0.5–1 meter underground are well-insulated, losing about 8-9 % of energy in distribution. Modern factory-made pipes with polyurethane insulation last up to 100 years and are monitored using thermal imaging. (Energiateollisuus ry, n.d.)

District heating in Finland achieves nearly 100 % reliability, with interruptions averaging less than two hours per year, mostly affecting only a small number of customers. High reliability comes from looped networks allowing bi-directional heat delivery. Faults or repairs isolate affected areas while maintaining heat delivery elsewhere. New connections and branches usually occur without service disruption. Interruptions average less than an hour per year due to faults, repairs, planned maintenance, new connections, or pipe relocation for road construction, often scheduled outside the heating season. (Energiateollisuus ry, n.d.)

Heat recovery comprises renewable heat produced by heat pumps and unused heat energy, such as that recovered from wastewater, flue gases, data centres, industrial processes, and return water from district cooling. The waste category encompasses municipal waste, recovered fuels, demolition wood, impregnated wood, plastic waste, and hazardous waste. Other biofuels include wood pellets, recovered wood, black liquor, and other types of biomasses. (Finnish Energy, 2025)

The rate of electrification in district heating has risen significantly in recent years. The development of electric boilers is shown in Figure 5. When electricity prices are low, electric boilers substitute burning fuels.

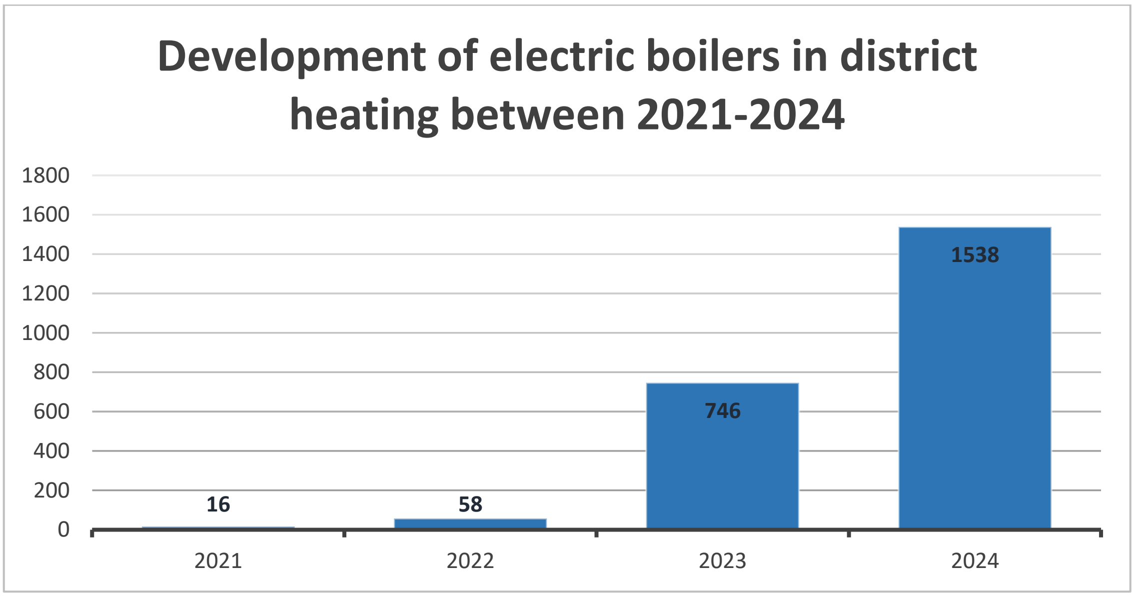

Figure 5. Development of electric boilers in district heating (adapted from Finnish Energy, 2025).

In Finland, the Energy Efficiency Act regulates district heating and cooling measurement, billing, and information provision. An amendment effective November 23, 2020, mandates that new buildings must use remotely readable meters for district heating and cooling, and existing meters must be updated or replaced by December 31, 2026. Heat energy sellers must provide detailed consumption, fuel information, and climate impact data to customers. A government decree will outline the cost distribution for heating, cooling, and water consumption. (Energy authority, 2020)

Finland's district heating supplied 35.5 TWh of heat from sources like biomass, waste heat, and electric boilers. Renewable energy, heat recovery, and electric boilers covered 73 % of production. The sources of district heating across Finland in 2024 are presented in Figure 8. District heating CO_2 emissions were 2.5 million tons in 2024, which was 19 % less than in 2023. (Finnish Energy, 2025)

2.2.3 District cooling

District cooling production in Finland in 2024 amounted to 402 GWh, marking a 20 % increase from the previous year. The district cooling is produced using heat pumps that often also produce heating energy. In 2024, 67 % of district cooling was generated by heat pumps. Additionally, district cooling utilises ambient energy from seas, lakes, rivers, and outdoor air whenever the temperature is sufficiently low. (Finnish Energy, 2025)

2.3 Heating sector in Vaasa region

The Vaasa heating sector utilises diverse heat sources. The district heating network connects consumers to Vaskiluoto power plant, electric boilers, a large heat storage facility, Westenergy waste-to-energy plant, Pått heat pump, and various heat centres. Vaasa heating sector is described in Figure 6.

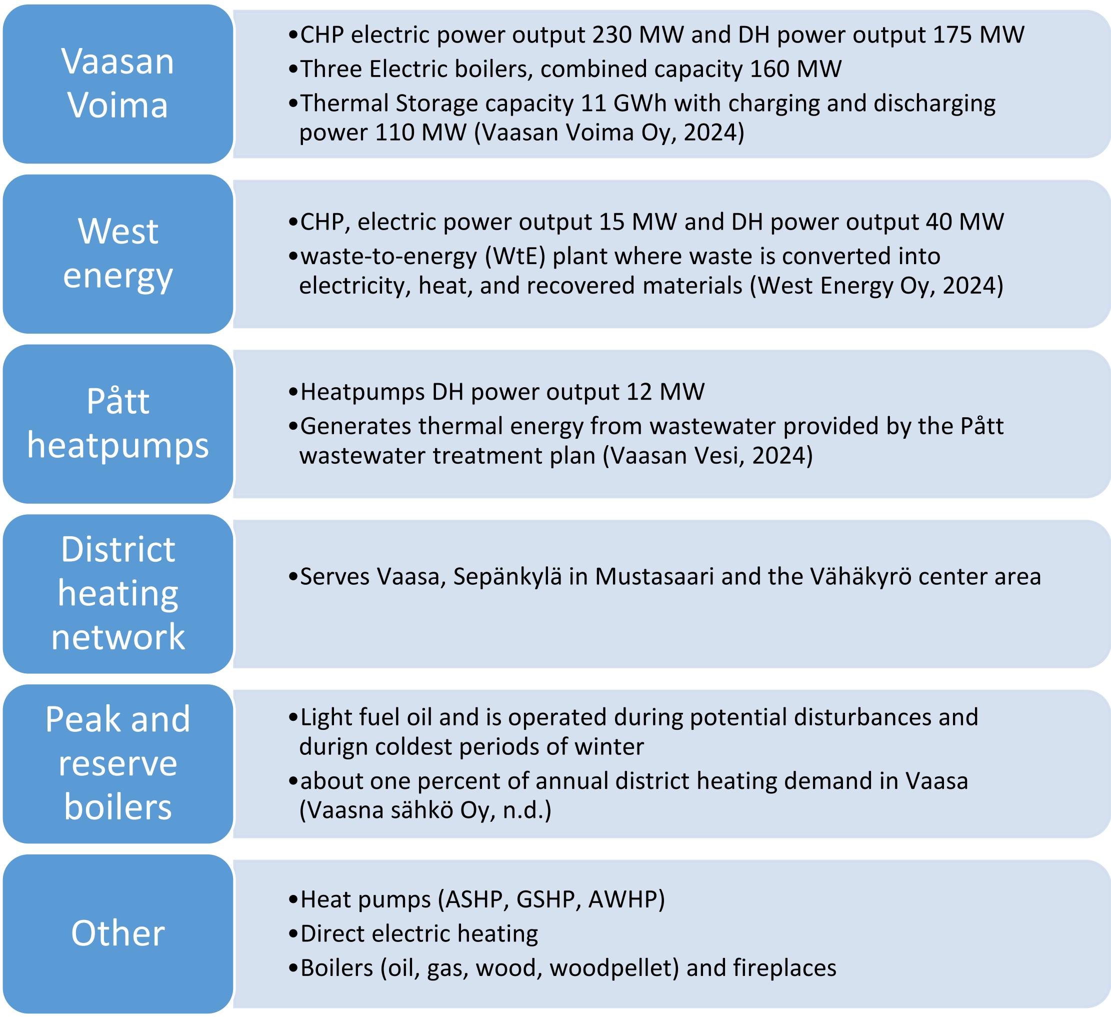

Figure 6. Vaasa heating sector.

2.3.1 District heating in Vaasa

By 2024, over 80 % of Vaasa's district heating came from renewable energy and waste energy, with specific emissions at 65.2 g/kWh. (Vaasan Sähkö Oy, n.d.) The energy sources of Vaasa district heating are presented in Figure 7.

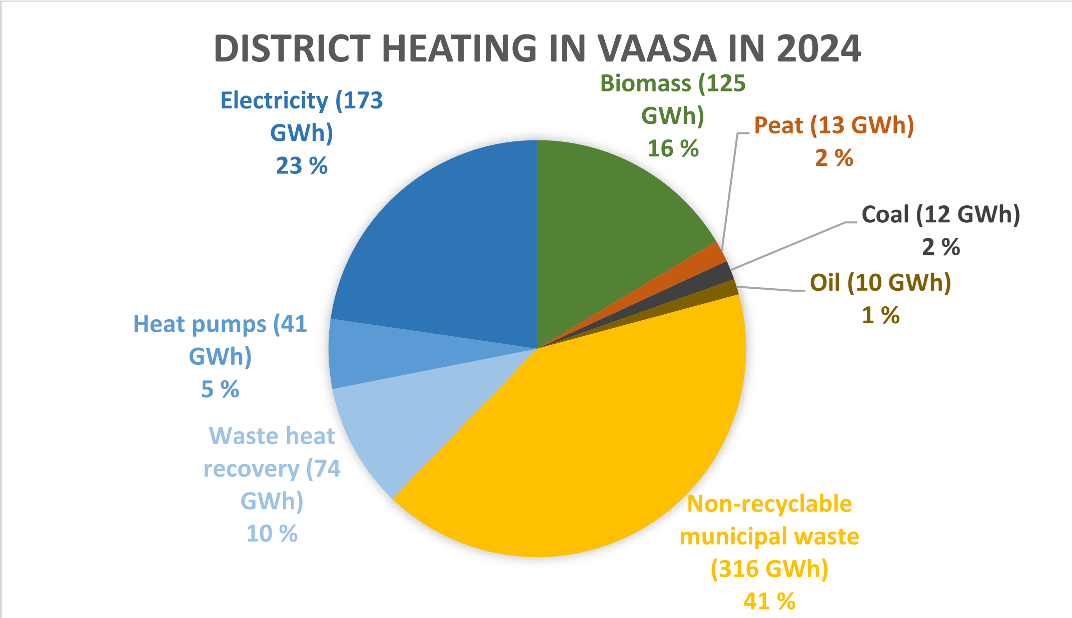

Figure 7. Vaasa district heating in 2024.

In comparison this chapter also presents the sources of district heating across Finland in 2024 (Figure 8).

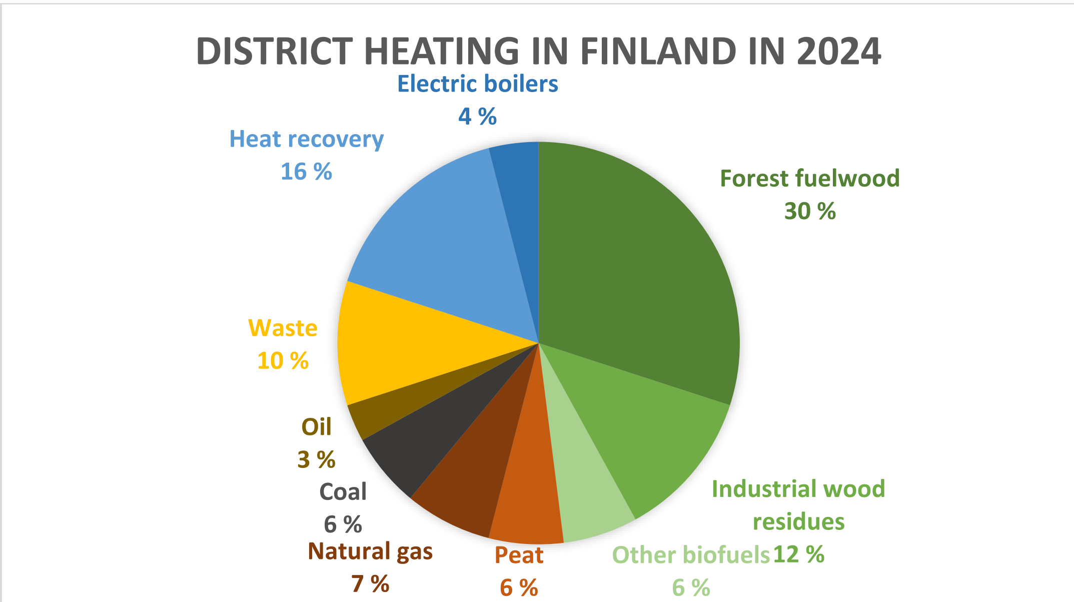

Figure 8. District heating in Finland in 2024 (adapted from Finnish Energy, 2025).

2.3.2 Vaasan Voima Oy

Vaasan Voima Oy is a subsidiary fully owned by EPV Energia Oy. Vaasan Voima produces electricity and district heating, supplying approximately half of the city's heating requirements. The company operates under the Mankala principle, providing energy to its shareholders at production cost. Vaasan Voima is committed to addressing the energy needs of various industries by developing new sources of electricity and innovative heat generation solutions. (Vaasan Voima Oy, n.d.)

Vaasan Voima leads innovation with the world's first biomass gasification plant and Finland's largest electric boiler and thermal energy storage combination. The focus is on improving energy efficiency and environmental friendliness, including increasing heat storage to 17 gigawatt-hours for better district heating in winter. Investments in Vaskiluoto include an additional 60 MW electric boiler to enhance renewable energy storage. Sector coupling will integrate various energy sectors to increase flexibility and reduce emissions. They also plan renewable hydrogen production for electricity storage, supported by significant investments. These projects aim to meet future energy market challenges and promote sustainable energy production. (Vaasan Voima Oy, n.d.)

Figure 9 and Figure 10 illustrate the changes in fuel usage between 2023 and 2024. The electrification of Vaasa's heating sector has increased due to the lower costs of electricity due to renewable energy sources like wind, solar, and hydro. The increased use of electric boilers is supported by the 11 GWh thermal storage at Vaasan Voima power plant. One factor is the increased district heating demand and higher electricity prices during cold winter days, which could make electric boilers less economical. Therefore, there is a need to find solutions to cover heating demand with renewables during times when electricity prices are high.

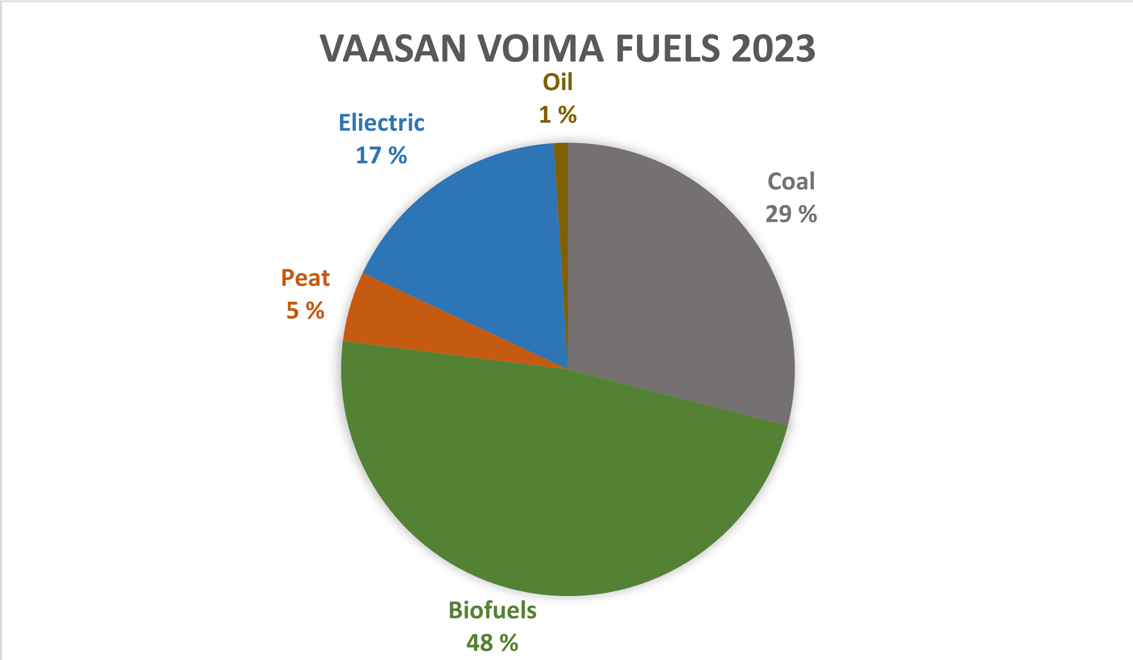

Figure 9. Vaasan Voima fuels 2023 (adapted from Vaasan Voima Oy, 2024).

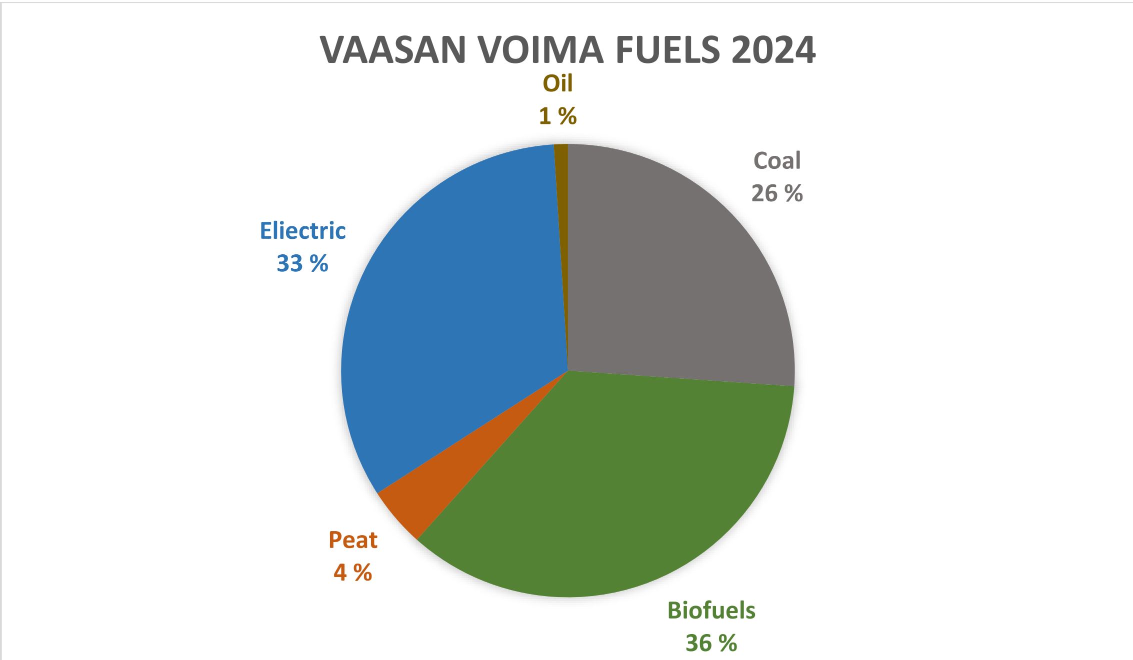

Figure 10. Vaasan Voima fuels 2024 (adapted from Vaasan Voima Oy, 2024).

Electric boilers

Electric boilers are crucial for clean heat production and provide adjustable capacity (Vaasan Voima Oy, 2024). Vaasan Voima operates three electric boilers in Vaskiluoto with a total output of 160 MW. These zero-emission boilers use electricity to heat water, supporting the district heating network. They enhance EPV's adjustable production capacity and align with climate targets of Finland and the EU. Utilising existing infrastructure makes the boilers cost-effective. Electric boilers optimize power plant operations, contributing to emission-free heat production while supporting future energy system needs. The electric boilers benefit from low electricity prices during high renewable energy availability. (Söderlund, 2021)

CHP

Vaasan Voima produces electricity and district heating through CHP which improves efficiency and lowers fuel consumption. The fuels used in the CHP include woody biomass, energy peat, and coal. The biomass gasification facility and electric boilers allow the facility to reduce the use of coal. Electrically powered on-site crushers enable forest fuels to be delivered directly from the forest to the on-site crusher. Vaasan Voima uses local biofuels like wood biomass and energy peat sourced within a 100 km radius from the power plants in Ostrobothnia and South Ostrobothnia. (Vaasan Voima Oy, 2024)

Technical Specifications of the CHP Plant in Vaskiluoto:

- Power output: Electric power 230 MW and district heating power 175 MW
- Turbine: Three-casing turbine with DH and forest chip dryer extractions
- Boiler: Benson-type once-through boiler with reheater
- Biomass gasification plant: 140 MW bio gasifier and forest chip dryer
- Fuels: woody biomass, energy peat, and coal
- Desulphurization plant: Wet scrubbing with limestone, producing gypsum

- NOx removal: Low-NOx burners and Overfire Air (OFA) system
- By-Product: Ash (100 % utilisation)

A site crusher installed in 2015 improves the management of the biofuel supply chain and reduces CO_2 emissions compared to diesel-powered crushing. In 2020, improvements to the boiler's upper air system and the installation of a urea feed system (SNCR) helped reduce NOx levels. (Vaasan Voima Oy, n.d.)

Vaasan Voima adheres to ISO 14001:2015 environmental management standards and ETJ+ energy efficiency systems. The plant also participates in a voluntary energy efficiency agreement. (Vaasan Voima Oy, n.d.)

Thermal storage

A large (currently 11 GWh) thermal energy storage (TES) in Vaasa, Vaskiluoto is connected to the district heating network with a charge and discharge capacity of 110 MW. Serving as an optimization tool for energy generation, the facility enhances thermal energy production in the region and is usable regardless of production mode. (Vaasan Voima Oy, 2024) Figure 11 illustrates the size of the thermal storage.

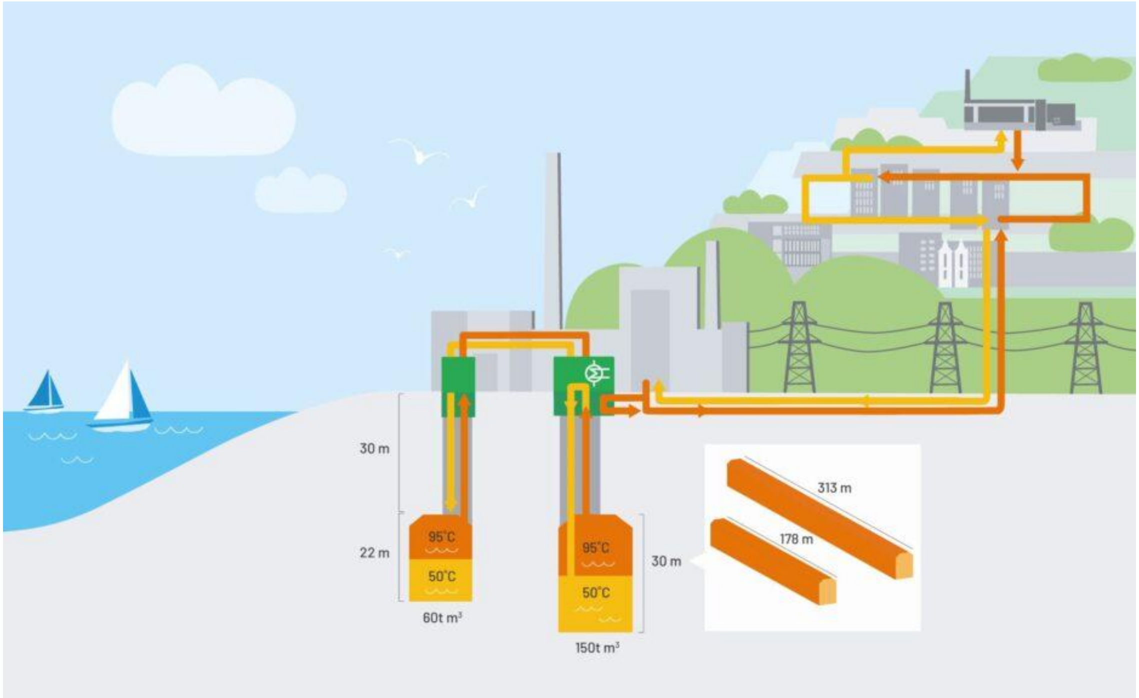

Figure 11. Thermal storage of Vaasan Voima Oy (Vaasan Voima Oy, 2024).

2.3.3 Westenergy

Westenergy is a waste-to-energy (WtE) plant where waste is converted into electricity, heat, and recovered materials. Annually, around 200,000 tons of combustible and non-recyclable waste is incinerated at the plant. (Westenergy Oy, n.d.)

During the incineration process, flue gases heat boiler water, which converts into steam to rotate the turbine and generator. Hot steam also heats water in the district heat unit. The flue gas treatment system operates in multiple stages. Acidic impurities and heavy metals are filtered out in the fabric filter. Flue gases are purified in a scrubber, and the heat is recovered in a heat exchanger. The electric power output is 15 MW, and the district heating power output is 40 MW. (Westenergy Oy, n.d.). Depending on the year and temperature levels, Westenergy produces approximately 50-60 % of Vaasa's district heating annually.

Westenergy aims for carbon-neutral energy production by 2030 and the development of a circular economy where all materials are utilised effectively. In optimal conditions, all materials, energy, water, and CO_2 are captured. The goal is to avoid waste formation, instead utilising by-products and residues of the production process as raw materials for other industries. For example, ashes from the Westenergy plant are used in earthwork materials and concrete production. Metals that end up at the plant are separated and recycled. (Westenergy Oy, n.d.)

Westenergy Oy, CPC Finland Oy, and Prime Capital AG are developing a full-scale carbon capture unit to be located in Mustasaari, Finland, with operations expected to start in 2026. The unit aims to capture all carbon dioxide from the fluid gases of the Westenergy WtE plant, reducing its carbon footprint. Most of the captured CO_2, approximately 150,000 tons annually, will be liquefied and transported to a Power-to-X site in Kristinestad for producing carbon-neutral synthetic gas. Additionally, over 30,000 tons of CO_2 will be used in the production of carbon-sequestering products, advancing the carbon recycling industry in the Vaasa region. This project promotes sustainable development and the circular economy in Finland (Westenergy Oy, n.d.)

2.3.4 Pått wastewater treatment plant -heat pump

A heat pump generates thermal energy from wastewater provided by the Pått wastewater treatment plant. The wastewater enters the facility at temperatures ranging between 8–17 °C. The heat pumps capture this waste heat and deliver it into the district heating network in Vaasa. The plant produces 50-60 GWh of heat annually, contributing approximately 10 % of Vaasa's district heating production. The heat pump plant has been operational since December 2023. (Vaasan Vesi, 2024)

3 Theory

This chapter provides an overview of the theory of energy markets and the Nordic energy system. It also details the characteristics of electricity markets in general, with a specific focus on the unique aspects of electricity markets in Finland.

This chapter introduces sector coupling, because the concept is recognised for its potential to decarbonise the heating sector (Erbach, 2019; IRENA, 2022; Abdur Rehman, Palomba, Frazzica, & Cabeza, 2021; Wang et al., 2023). Definitions and strategies vary across organizations and countries due to the lack of an official definition. This chapter aims to clarify the author's perspective on sector coupling. In addition, sub concepts like Power-to-X and Power-to-Heating are introduced in this chapter for their relevance in decarbonising the heating sector.

3.1 Energy markets

Effective energy markets support the sustainable energy transition and ensuring security of supply. Electricity markets are a key component, integrating with other energy forms and connecting low-emission energy production with industrial requirements, transportation, and heating. As society relies more on electricity, the demand for renewable energy increases, enhancing requirements for electricity transmission and grid reliability. (Energiateollisuus ry, n.d.) Electricity sales and network operations significantly influence the heating market. (Energiateollisuus ry, n.d.)

Since the 1990s, the EU has established internal markets for electricity and natural gas, facilitating the free movement of energy between member states. (Energiateollisuus ry, n.d.)

3.1.1 Electricity markets

The wholesale electricity market engages in trading for next-day or near-term needs with prices collectively set across most of Europe. It is essential that supply matches demand exactly, but limited transmission capacity can cause regional price differences. Finland benefits from having a single price area due to its strong grid, unlike Sweden and Denmark, which have multiple price areas. (Energiateollisuus ry, n.d.)

In the wholesale market, electricity prices are governed by EU-wide regulations and are determined by supply and demand principles. Increasing transmission connections is crucial for strengthening market operations and ensuring security. Maintaining a reliable and smart grid is vital to the market's functionality. (Energiateollisuus ry, n.d.) The terms of electricity markets are explained in Appendix 3.

Between 2021 and 2023, Europe experienced exceptional electricity prices, peaking in Finland in late 2022. However, prices began to decline in early 2023 in the Nordic countries while remaining high elsewhere in Europe due to reliance on fossil fuels. Finland managed the situation by utilising nuclear and wind power, thereby reducing its dependence on imports and fossil fuels. This crisis underscored the importance of relying on domestic production and advancing the green transition to replace emission-intensive production with low-emission domestic electricity. Despite this, price fluctuations remain a normal part of the market due to the ongoing need to balance production with consumption. (Energiateollisuus ry, n.d.)

3.1.2 The Nordic energy system

The functioning of cross-border electricity markets began in the Nordics, serving as an example for the rest of the EU. National energy policies continue to influence market operations. The Electricity Market Act regulates electricity production and sales as free business activities, while electricity transmission, operating as a monopoly, remains regulated and overseen by national authorities, such as the Energy Authority in Finland. (Energiateollisuus ry, n.d.)

Finnish Energy (Finland), Swedenergy (Sweden), Fornybar Norge (Norway), Green Power Denmark (Denmark) and Samorka (Iceland) have established a collaboration between Nordic associations for electricity producers, suppliers, and distributors. They represent over 2000 market actors in the electricity sector, district heating, gas, and services. Nordenergi supports the EU's goal of net-zero carbon emissions by 2050 and aims to reduce greenhouse gas emissions by at least 55 % below 1990 levels by 2030. They advocate for the EU ETS (explained in Appendix 1) as the main driver for decarbonisation and support the strengthening. Nordenergi promotes all clean investments and stresses the importance of the EU recognizing these contributions. They support a well-functioning, fully integrated power market in the Nordics and the EU to achieve climate targets. Additionally, Nordenergi works to improve finance and permitting conditions for electricity transmission and distribution infrastructure to support electrification and clean investments. They also promote a reliable and flexible power system that meets consumer needs and enables active market participation. (Nordenergy, n.d.)

In the joint Nordic system (Finland, Sweden, Norway, and East Denmark), the TSOs have agreed on maintaining reserves through the System Operation Agreement. TSOs procure their share of reserves independently, with some reserves traded between countries. A portion must be maintained nationally to ensure frequency stability during operation, with up to one-third of frequency containment reserves purchasable from other Nordic countries. (Fingrid Oyj, 2025)

3.1.3 Electricity markets in Finland

The Finnish electricity market opened to competition with the 1995 Electricity Market Act, allowing users to choose their suppliers since 1998. There are around 75 electricity retailers. Finland is part of the Nordic wholesale market, which includes other Nordic countries and the Baltic States. Market liberalization and integration have boosted productivity and environmental efficiency, enabling effective use of hydropower and green energy trading. The future goal is a European-wide market, aligned with the EU's energy supply security aims. (Ministry of Economic Affairs and Employment of Finland, n.d.) . In addition, consumers or prosumers can use their own produced electricity or sell the production to the grid.

Fingrid Oyj, Finland's TSO, manages the high-voltage grid, connecting producers, factories, and distribution networks. It operates as a state-regulated monopoly, ensuring reliable energy supply and promoting a clean, market-based power system. Fingrid maintains balance in electricity production and consumption, enhancing market functionality through connections to Central Europe and Estonia. (Fingrid Oyj, About Fingrid, n.d.)

Electricity production must match consumption to maintain grid stability at a frequency of 50.0 Hz. Market operators plan their consumption and production in advance in the Day-ahead and Intraday markets, but deviations still occur. To manage these deviations, TSOs like Fingrid in Finland procure reserves from real-time reserve markets. These reserves include power plants, consumption resources, and energy storage systems that adjust their power output as needed to balance the system. (Fingrid Oyj, 2024 and 2025)

Fingrid's reserve products include manual and automatic reserves for balancing supply and demand (Figure 12). The reserve markets use marginal pricing, where all volumes receive the same price based on the highest accepted bid, creating additional revenue for market participants. (Fingrid Oyj, 2024)

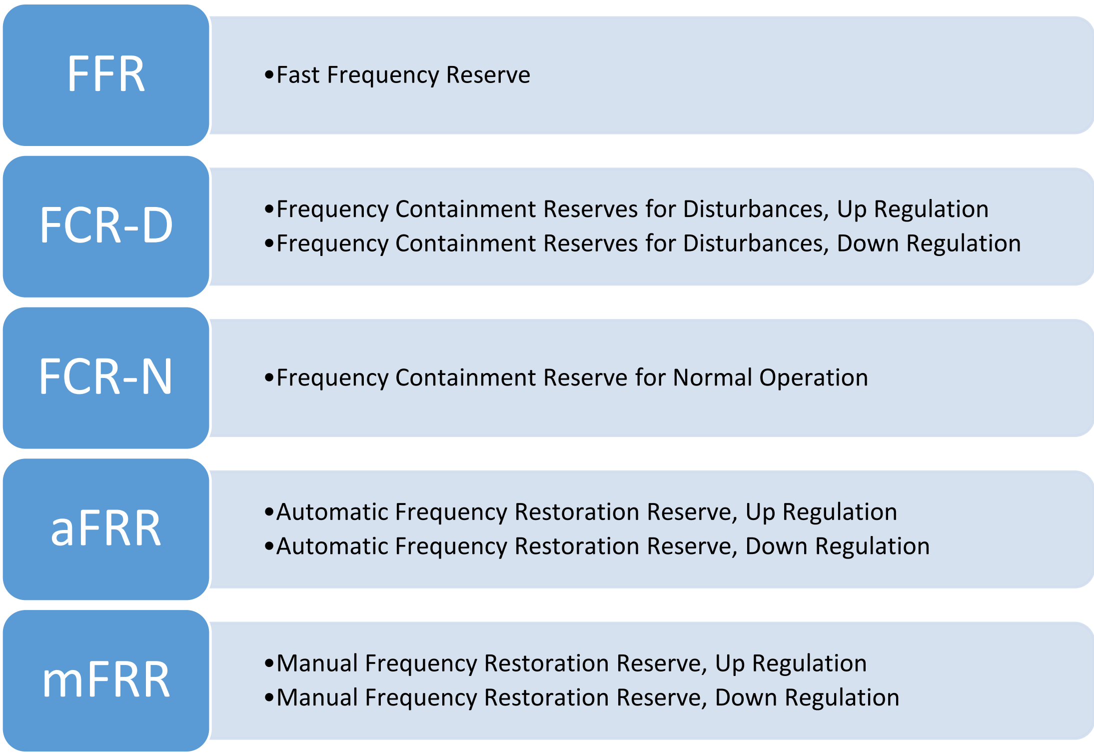

Figure 12. The reserve markets of Fingrid Oyj (adapted from Fingrid Oyj, 2024).

3.2 Sector coupling

Sector coupling enhances the flexibility and reliability of energy systems by integrating renewable electricity across various sectors, with the goal of achieving net-zero emissions. Sector coupling utilises technologies such as energy storage, electric vehicles, green hydrogen, Power-to-Gas, and Power-to-Heating to link renewable electricity with heating, cooling, transport, and industrial processes. By replacing fossil fuels with renewable sources, sector coupling supports comprehensive energy transformation and eliminate the use of fossil gas, coal, and oil. Renewable energy sources are the foundation for all energy carriers in the sector coupling value chain to be completely renewable based and environmentally friendly energy system. (IRENA, 2022)

Renewable energy in the power sector has increased significantly compared to other sectors. Connecting different sectors increases the utilization of renewable energy sources in all end-use sectors. For example, wind and solar power provide direct and indirect electrification opportunities to decarbonise these sectors. Coupling energy sources directly to service such as electric vehicles in the transport sector or heating through heat pumps or electric boilers are usually more efficient than indirect electrification. Power-to-Gas technology is an example of indirect electrification and means that synthetic fuels such as green hydrogen or methane are produced by electrolysis or methanation. Therefore, indirect electrification is reasonable only in sectors that are not able to be electrified directly or are hard to decarbonise such as transportation, aviation and some industrial processes. (IRENA, 2022)

Sector coupling requires smart operation and digitalization that improves system efficiency, flexibility, reliability and safety by enabling better observation, forecasting, monitoring, and controlling multiple energy sector integration. In addition, sector coupling supports energy storage solutions and renewable energy integration in the energy system. However, larger-scale electrification could increase peak electricity demands without price and energy signals to consumers or smart operation systems. That requires additional investments in the electricity distribution network. In addition, digitalization provides opportunities for demand-side flexibility but requires regulatory framework. Educating policymakers and integrating sector coupling into energy access projects can promote the idea. Smart sector coupling system enables cost reductions for converting energy system environmentally friendly. (IRENA, 2022) The benefits of sector coupling are concluded in Figure 13.

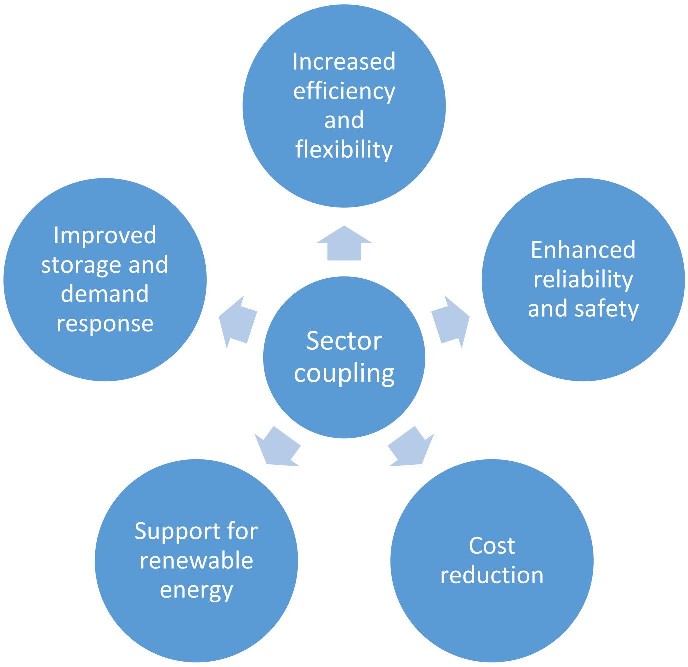

Figure 13. Benefits of sector coupling.

3.2.1 Definition of sector coupling

Sector coupling lacks an official definition, leading to multiple interpretations (IRENA, 2022). Definitions and strategies differ across organizations and countries, and various actors have refined their understanding of sector coupling over recent years.

The IRENA Coalition for Action (2021) defined sector coupling as follows:

> *"the process of interconnecting the power sector with the broader energy sector (e.g. heat, gas, mobility)."* (IRENA, 2021)

To achieve 100 % renewable energy, the concept of sector coupling must evolve to ensure a complete transformation towards reliable renewable energy across all sectors. The IRENA Coalition for Action (2022) has updated their definition of sector coupling:

> *"Sector coupling focuses on combining at least two of the different sectors of energy demand and production (i.e. electricity, heating, cooling, transport and industrial processes).*
> *Enabling technologies including smart grids, district heating and cooling, short-term and seasonal storage in pumped hydro, batteries, green hydrogen and other*

> *innovative or readily available solutions are applied to balance resource availability and energy demand. This results in significantly higher levels of direct or indirect electrification of end uses and system integration. Adapting energy market designs can effectively support the transformation towards a more electrified and renewables-based energy system*." (IRENA, 2022)

The European Commission definition for sector coupling:

> *"a strategy to provide greater flexibility to the energy system so that decarbonisation can be achieved in a more cost-effective way."* (Erbach, 2019)

A common aspect of these definitions is the integration of different energy sectors to improve decarbonisation cost-effectively.

3.2.2 The main dimensions of sector coupling

Transitioning to clean industrial processes can drive new investments, jobs, and growth. Sector coupling coordinates various technologies to optimize use of resources across end-use sectors, facing challenges in technology, finance, and regulation. (IRENA, 2022)

Technology related considerations are primarily linked to advancements and developments of technology and maturity of sector coupling solutions across multiple scales. Especially P2X-technologies should be improved so they can be implemented on a large scale. In addition, an increasing amount of renewable energy assets are needed to achieve decarbonisation goals. However, these increased assets require improvements of transmission, distribution and storage assets. (IRENA, 2022)

Financial considerations are related to the high costs of technologies such as the P2X chain and infrastructure investments. In addition, lack of financial incentive hinger the adaptation of sector coupling mechanisms. Flexibility is not always rewarded, requiring tailored market designs and viable business models for different regions. (IRENA, 2022)
Regulatory considerations require clear definitions and planning for P2X technologies and integrated system planning. The general understanding of ownership of different

assets is important and co-ordination among prosumers, DSOs, TSOs, and international arrangements to support sector coupling. (IRENA, 2022)

These three dimensions highlight the importance of technology, financial incentives, and regulatory frameworks in advancing sector coupling to achieve a fully renewable energy system. (IRENA, 2022) These main dimensions of sector coupling are summarised in Figure 14.

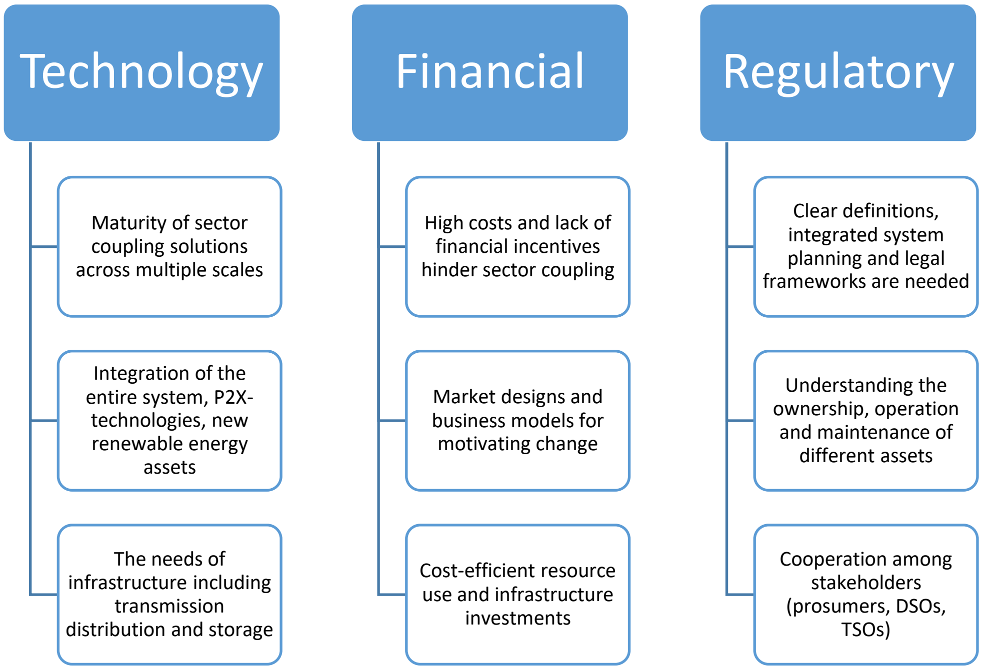

Figure 14. The main dimensions of sector coupling.

3.2.3 Power to X (P2X) and Power to Gas (P2G)

P2X is a broad concept for technologies that convert surplus renewable electricity typically from wind, solar, or hydro into other forms of energy or products. The “X” can stand for example: Gas (Power-to-Gas), Liquid fuels (Power-to-Liquid), Heat (Power-to-Heat), Chemicals or synthetic materials. P2X enables the storage, transport, and sectoral integration of renewable energy, helping to balance the grid and decarbonise sectors like heating, transport, and industry. (RWE Innovation Centre, n.d.)

P2G is a specific P2X pathway where electricity is used to produce gas, typically through electrolysis of water to generate hydrogen. This hydrogen can be used directly as a fuel or combined with CO_2 to produce synthetic methane or stored in the gas grid or used in district heating systems. Thereby enabling decarbonisation of heating and transport sectors. (RWE Innovation Centre, n.d.)

The European Green Deal promotes P2X as a key enabler of climate neutrality by 2050. P2X technologies are central to integrating renewables at scale, especially in hard-to-electrify sectors. European Energy defines P2X as the process of turning electricity into sustainable green products (the X). The input is renewable power for example from solar panels and wind turbines, and the output is a variety of clean e-fuels or chemicals. (European Energy, n.d.) In addition, according to RWE Innovation Centre (RWE Innovation Centre, n.d.) P2X is a general framework for technologies capable of utilising or storing a future oversupply of electricity from renewables such as wind and solar energy or hydropower to turn fluctuating generation from renewables into controllable energy.

According to the EU METIS Study (Bossmann, Fournié, Humberset, & Paul, 2019) P2G and P2L solutions, together referred to as P2X technologies, are promising solutions for decarbonising sectors like transport, buildings, and industry. These technologies convert electricity into synthetic gas or liquid fuels. The study emphasizes that P2G is particularly relevant for storing renewable energy, producing hydrogen or synthetic methane of feeding into existing gas infrastructure.

3.2.4 Power to heat

Power-to-Heat involves integrating electricity with heating systems. Co-generation of heat and power is a well-known sector coupling method for flexible and efficient energy systems. Large-scale biomass boilers and district heating systems can efficiently use biomass. (IRENA, 2022)

Solar thermal systems remain crucial for heating buildings, providing competitive heating and reducing pollution. Combining heat pumps and electric boilers with rooftop photovoltaic (PV) systems or battery storage can provide heating or cooling and enhance system stability by offering balancing services. (IRENA, 2022)

District heating with thermal storage, electric integration (electric boilers and heat pumps) and CHP plants with renewable fuels are examples of P2H-technologies in Vaasa heating sector.

3.2.5 Heat-to-power

Converting heat to energy is a process where thermal energy is transformed into electricity. Applications include electricity generation from industrial processes and renewable energy sources, waste heat recovery, and solar energy utilization. The advantages of this process are improved energy efficiency, clean energy production, and emission reduction. Disadvantages include high costs and technological challenges. In the future, thermoelectric materials and devices offer promising prospects for enhancing energy efficiency and promoting clean energy solutions. (Greg, 2024)

3.2.6 Power to cooling

The cooling needs of buildings are forecasted to increase due to rising global temperatures. Mini-split heat pumps provide both heating and cooling. Solar thermal cooling technologies should be considered alongside electricity-driven cooling solutions. Thermal energy from solar collectors can operate various cooling systems based on technologies such as absorption chillers, desiccant coolers, and heat ejectors. Many of these systems also have the capability to provide heating in buildings and domestic hot water. Geothermal heat, waste heat, or bioenergy can also be utilized (IRENA, 2022)

4 Methodologies and technologies for decarbonisation of the heating sector

The heating sector is moving towards electrification through Power-to-Heat technologies, such as heat pumps and electric boilers. Future energy systems that incorporate various energy carriers and fluctuating renewable energy sources regard thermal storage as an affordable, stable, and durable technology for high-efficiency energy storage. Thermal energy storage has the potential to provide the flexibility necessary to accommodate the growing share of wind and solar power. (Rämä, Pursiheimo, Sundell, & Abdurafikov, 2024)

CHP plants that utilize biomass and industrial-scale heat pumps are vital in Finland for reducing carbon dioxide emissions in district heating. Consequently, some existing district heat producers must replace fossil fuels with renewable energy sources to reduce emissions. (Haq, Valisuo, Kumpulainen, & Tuomi, 2020) In addition, carbon capture technologies are needed to reduce carbon emissions from CHP plants.

In this chapter are presented some methodologies and technologies for decarbonising heating sector. This chapter gives answers to the first research question:

- What methods and technologies are utilised in other countries and cities for decarbonising the heating sector, and what related studies have been conducted?

4.1 Energy efficiency

The EU views energy efficiency as a key pillar to meet climate objectives, reduce dependence on fossil fuels, and increase the use of renewable energy. The Energy Efficiency First Principle emphasizes the prioritization of cost-efficient energy efficiency measures in shaping energy policy and investment decisions. This principle is considered crucial in complementing the EU's objectives of sustainability, climate neutrality, and green growth. The latest recast of the Energy Efficiency Directive includes a clearer priority for this principle, with formal recommendations and detailed guidelines to ensure its implementation. (The European Council for an Energy Efficient Economy, 2023)

The goals and benefits of the Energy Efficiency First Principle are multifaceted. It aims to ensure that only necessary energy is produced, thereby avoiding investments in stranded assets. It also focuses on reducing and managing energy demand in a cost-effective manner. By treating energy efficiency as a source of energy and prioritizing demand-side solutions, the principle supports sustainability. Additionally, it increases the resilience of the EU's energy system and promotes the sustainable use of resources. (The European Council for an Energy Efficient Economy, 2023)

Energy efficiency provides cost savings and reduces system costs. Operating the system efficiently can improve overall system performance. Flexible supply from renewable sources requires adaptable demand. Shifting heat consumption from peak hours to periods when renewable electricity is more available helps avoid operating fossil fuel plants with high emissions. Energy efficiency improves buildings' thermal storage capacity, as insulated buildings retain heat longer, reducing peak hour demand. (Energy Star, n.d.)

4.1.1 Future district heating network

District heating systems have evolved over time through five main generations, each improving efficiency, sustainability, and integration with renewable energy sources. These generations of district heating are presented in Table 1. (International Energy Agency, 2023) (U.S. Department of Energy, n.d.) (International District Energy Association, n.d.)

Generation	Time Period	Heat Carrier	Temperature Range	Pipe Type	Energy Sources	Efficiency	Key Features
1st Generation	Late 19th – Mid 20th Century	Steam	High-pressure steam	Large, often above ground	Coal or oil	Low due to high heat losses	Early urban heating, especially in industrial cities
2nd Generation	1950s–1970s	Pressurized hot water	120–150 °C	Pre-insulated steel pipes, often underground	Coal, oil, and later natural gas	Improved, but still reliant on fossil fuels	Expansion to residential areas and public buildings
3rd Generation	1980s–2000s	Hot water	70–100 °C	Pre-insulated, flexible plastic or steel pipes	Mix of fossil fuels, waste heat, and some renewables	Better insulation and control systems	Modern urban developments and retrofits
4th Generation	2010s–Present	Very low-temperature water	30–70 °C	Highly insulated, optimized for minimal losses	Renewable energy (solar, geothermal, biomass), waste heat, heat pumps	High, with integration into smart grids and buildings	Sustainable cities, carbon-neutral goals, sector coupling
5th generation	Future	Ultra-low temperature water	Below 30 °C	Advanced insulated pipes	100 % renewable energy sources	Maximum efficiency with AI and IoT integration	Smart cities, complete energy sector integration

Table 1. The five generations of district heating systems.

4.1.2 Combined production of district heating and cooling

District cooling can be produced using an absorption process, which uses hot water (>80 °C) as the energy source. The process works more efficiently with higher temperature levels. The absorption heat pump operates based on the physical properties of the solvent and absorbent pair. The process includes four parts: absorber, generator, condenser, and evaporator. The intermediate cooling flow can serve as a waste heat source for a regular compressor heat pump, enhancing overall efficiency for combined heating and cooling production compared to a compressor-only solution. (VTT Oy, Miika Rämä & Krzysztof Klobut, 2020)

Combined district heating and cooling production using heat pumps, as seen in Helsinki (Helen, 2015), is a significant example of waste heat utilization. This principle also applies to integrating all refrigeration and cooling processes into district heating production. In both scenarios, the cooling requirement dictates the amount of waste heat used. (VTT Oy, Miika Rämä & Krzysztof Klobut, 2020)

D2Grids Project in Europe aims to develop 5th generation urban heating and cooling networks in several European cities. These networks are designed to optimize the use of renewable energy sources by integrating heating and cooling needs, storage capacities, and related thermal or electrical flexibility. (European Commission, 2019)

Fifth-generation district heating and cooling systems (5GDHC) use low-temperature heat pumps, enabling both heating and cooling within the same network. The advantages of 5GDHC systems include reducing heat losses and allowing the use of renewable energy sources. The disadvantages are their higher installation and pumping costs. Germany and Switzerland have the most 5GDHC systems in Europe, and their number has grown over the past decade. 5GDHC systems can significantly contribute to carbon neutrality and energy efficiency in district heating and cooling. (Buffa, Cozzini, D'Antoni, Baratieri, & Fedrizzi, 2019)

4.1.3 Demand response for heating

Demand response in heating refers to the ability of consumers to adjust their heating energy use in response to external signals such as electricity prices, grid congestion, or renewable energy availability. This is especially relevant in Northern Europe, where heating demand is high due to long, cold winters.

Northern Europe is increasingly electrifying its heating systems (e.g., heat pumps), which opens opportunities for DR. Flexible heating loads can help balance intermittent renewable energy sources like wind and solar. (Mastrucci, van Ruijven, Byers, Poblete-Cazenave, & Pachauri, 2021)

Buildings in Northern Europe often have good insulation and thermal inertia, which allows for thermal storage delaying or advancing heating without affecting comfort. Smart thermostats and building energy management systems are key enablers. These technologies allow for load shifting, where heating is pre-heated during low-price periods and reduced during peak demand, contributing to grid stability and cost savings. (Mastrucci, van Ruijven, Byers, Poblete-Cazenave, & Pachauri, 2021)

Countries like Finland, Sweden, and Denmark are exploring market mechanisms such as time-of-use tariffs and capacity markets to incentivize DR participation. Regulatory frameworks are evolving to support aggregation of residential loads into virtual power plants. Finland has been a pioneer in integrating smart electric heating systems with demand response. A key focus is on direct electric heating and heat pumps, which are common in residential buildings. (Mastrucci, van Ruijven, Byers, Poblete-Cazenave, & Pachauri, 2021)

A study using the MESSAGEix-Buildings model includes Finland in its regional analysis and shows that electrification of heating, combined with demand-side flexibility, can reduce CO_2 emissions by up to 52.5 % by 2050 under sustainable development scenarios. Finnish pilot projects have demonstrated that aggregated residential heating loads can participate in balancing markets, offering both economic and grid stability benefits. The model includes regional differentiation, including Northern Europe, and highlights the role of smart heating systems in demand-side flexibility. (Mastrucci, van Ruijven, Byers, Poblete-Cazenave, & Pachauri, 2021)

Sweden’s district heating systems and high building insulation levels make it ideal for thermal inertia-based DR. Research highlights how thermal mass in buildings can be used to shift heating loads without compromising comfort. This is especially effective when combined with time-of-use electricity pricing, which incentivizes users to heat during off-peak hours. Sweden is also exploring automated control systems that adjust heating based on real-time electricity prices and weather forecasts. (Mastrucci, van Ruijven, Byers, Poblete-Cazenave, & Pachauri, 2021)

Helen, Fortum and Tampereen sähkölaitos already offer the possibility of selling excess heat to the district heating system at pre-announced prices (VTT Oy, Miika Rämä & Krzysztof Klobut, 2020).

4.2 Improvements for CHP-plants

CHP produces electricity and heat which is more efficient than separate electricity and heat systems. CHP efficiency is typically 65-80 %. Reduces emissions during the transition to cleaner energy. Supports solar and wind power in microgrids, improving reliability and resilience. Reduces emissions in sectors that are difficult to decarbonise. CHP can serve as a cornerstone of microgrids, providing reliable electricity and heat. CHP systems can considerably lower carbon dioxide emissions compared to traditional energy systems. CHP can utilize low-carbon fuels like biogas and green hydrogen, further contribution to emission reductions. (Environmental Protection Agency, 2024)

4.2.1 Alternative fuels for CHP-plants

CHP can use renewable fuels such as biogas and green hydrogen. Hydrogen can be produced from renewable energy or natural gas with carbon capture. Hydrogen emits zero carbon emissions when burned. Using these fuels can further reduce emissions. (Environmental Protection Agency, 2024)

Power-to-X technologies

Methanol and ammonia are hydrogen derivatives that can be used in gas turbines. Hydrotreated Vegetable Oil (HVO) is a biogenic fuel that can significantly reduce carbon emissions. Other biogenic fuels include biogas, biomethane, biodiesels/FAME, and ethanol. (Siemens energy, n.d.)

Torrefied bio coal

Torrefied bio coal pellets are produced through torrefaction, a thermal process at 200-300 °C in an oxygen-free environment, which improves the energy density and storability of biomass. Different wood materials, including birch, spruce, pine, and mixed hardwood can be used for biochar production. The production cost of torrefied pellets is influenced by raw material costs, fixed and variable costs of torrefaction, and logistics, with an average production cost estimated at 39.5 €/MWh. Torrefied bio coal pellets have the potential for large-scale energy production, but further research and support mechanisms are needed to make their use economically viable. (Föhr, Seppänen, Suikki, Soininen, & Ranta, 2015)

Biochar and thermally treated wood pellets can replace peat in bioenergy production. By-products from the forest industry, such as bark, chips, and sawdust, are potential raw materials for biochar production. The production potential of biochar in Finland is significant. Biochar is produced through pyrolysis, torrefaction, or steam explosion. Biochar and thermally treated pellets are particularly suitable for pulverized fuel boilers. The production costs of biochar depend on the price of raw materials and the size of the plant. As the price of emission allowances rises, the competitiveness of biochar improves. (Korpijärvi, Björnström, Karlsson, Raitila, & Virkkunen, 2021)

4.2.2 Carbon capture utilisation and storage

CCUS (Carbon Capture, Utilisation and Storage) refers to the process of capturing carbon dioxide from large sources such as power plants and industrial facilities, transporting it, and storing it in geological formations. This technology encompasses the capture, utilization, and storage of CO_2 to mitigate its impact on the environment. CCUS plays a crucial role in reducing emissions in sectors that are difficult to decarbonize such as heating sector. It highlights the importance of integrating CCUS with heating systems to reduce emissions from fossil fuel-based heating. It also enables the production of low-carbon hydrogen, which supports the reduction of CO_2 emissions in other parts of the energy system. (IEA, n.d.)

The number of CCUS projects has increased significantly in recent years but remains below the requirements of the net zero scenario. Countries and institutions like the European Union, Germany, Japan and United States have made significant investments and legislative changes to promote CCUS. For instance, the United States has allocated $1.7 billion for carbon capture demonstration projects and $1.2 billion for direct air capture hubs. In addition, governments are focusing on public funding, strategic communication, and cross-border collaboration to advance CCUS. For example, the European Commission has allocated approximately $1.5 billion to CCUS projects in the industrial sector. (IEA, n.d.)

One example of CCS project is Northern Lights Project that captures CO_2 from industrial sources (like cement and WtE plants), liquefies it, and transports it via ship to an offshore storage site under the North Sea. Northern Lights aims to reduce and remove industrial emissions in Europe by providing CO_2 transport and storage services. Their goal is to prevent unavoidable emissions from reaching the atmosphere and to provide a safe, permanent storage option for CO_2 to be removed from the air. (Northern Lights, n.d.)

Stockholm Exergi signed a deal with Microsoft for permanent negative emissions from a planned bio-CCS facility in Stockholm. Deliveries will start in 2028 and last for ten years.

captures CO_2 from a biomass-powered CHP plant that supplies district heating to Stockholm. This is a direct application of CCS in the heating sector, and because it uses biomass, it can result in negative emissions. This is the world's largest agreement for permanent negative emissions, highlighting the project's importance, quality, and sustainability. The agreement supports ambitious climate goals, aiming to limit global warming and contribute to the Paris Agreement targets. The Bio-CCS Facility will remove up to 800,000 tons of CO_2 annually. Construction is set to begin in 2025, with sustainable biomass sourcing and permanent geological storage in the Nordic region. (Stocholm Exergi AB, 2024)

Net Zero Teesside (NZT) is part of the East Coast Cluster, aiming to be the UK’s first decarbonized industrial cluster. The cluster consists of power and industrial facilities connected to a shared CO_2 pipeline and offshore storage. This system includes facilities that produce both electricity and heat, showing how CCS can be integrated into CHP systems. The project will capture up to 2 million tonnes of CO_2 per year, which will be transported and stored offshore in the North Sea. (BP, 2024)

4.3 Waste heat

Waste heat or cold is an inevitable byproduct in district heating or cooling systems, which would otherwise be lost without utilization. Most waste or renewable heat sources are at low temperature levels and thus require heat pumps to be utilized in district heating systems. (VTT Oy, Miika Rämä & Krzysztof Klobut, 2020)

The Finnish Energy Industries and the Ministry of Economic Affairs and Employment commissioned a study conducted by VTT. The report reviews energy efficiency and renewable energy directives for utilizing waste heat, describing potential sources and special cases. The report introduces various sources of waste heat, including buildings, refrigeration systems, public facilities, industry, and energy production (figure 18). Directives aim to promote waste heat utilization but are not entirely clear. For example, residential buildings are not considered waste heat sources, and wastewater is classified as renewable sources. The aim is to encourage the use of renewable and waste heat sources to improve energy efficiency and reduce emissions. (VTT Oy, Miika Rämä & Krzysztof Klobut, 2020) Some of the waste heat sources are presented in Figure 15.

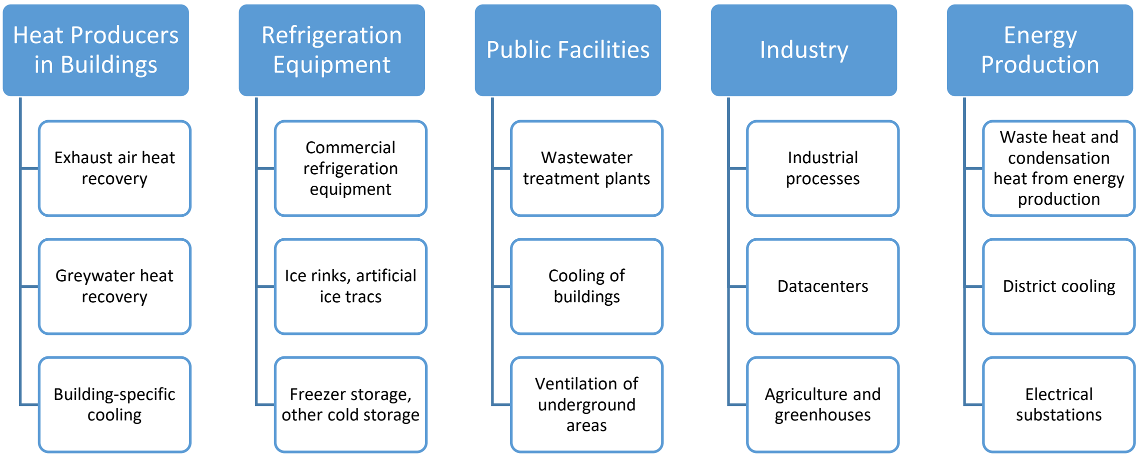

Figure 15. Example of waste heat sources (adapted from VTT Oy, Miika Rämä & Krzysztof Klobut, 2020V).

Industrial waste heat has significant potential, but its use in district heating is often limited by size and distance. As a base load source, it impacts other heat production and requires reliable industrial operations. Typically, from large sources, industrial waste heat is often far from district heating systems or nearby systems too small to use. Originating mainly from wood, paper, metal, and chemical industries, over 95 % of industrial energy consumption follows these sectors. Other local industries also contribute significantly. (Garay-Martinez & Garrido-Marijuan, 2022)

One challenge is that the amount of available waste heat can exceed the total district heating demand, and district heating companies must prepare for interruptions and long-term uncertainties in industrial operations. Additionally, district heating companies cannot control the quantity of waste heat, although it remains relatively constant throughout the year. Utilizing industrial waste heat is advantageous, but it may originate from fossil fuels. Over time, industries are expected to transition towards low-carbon energy solutions, which may affect the availability of waste heat. The potential for technical and economic utilization, implementation options, and opportunities in various industries have been extensively recognized. (VTT Oy, Miika Rämä & Krzysztof Klobut, 2020)

4.3.1 Cogeneration and Flue Gas Heat Recovery

The heat production of CHP is not classified as waste heat; however, heat recovered from flue gases using heat pumps is considered waste heat. Flue gas heat can be utilized directly or through separate recovery processes enhanced by heat pumps. These pumps use return water from district heating as a heat source, producing high-temperature district heating. In Finland, flue gas heat recovery from CHP plants using fossil fuels creates tax issues, where more efficient systems result in heavier tax consequences. Flue gas heat recovery is suitable for plants burning moist or hydrogen-rich fuels. Potential waste heat may remain unutilized due to tax reasons, as Finnish taxation makes waste heat utilization unfavourable for plants using taxable fuels. While heat pump electricity is tax-free, a heat tax applies to all produced heat. (VTT Oy, Miika Rämä & Krzysztof Klobut, 2020)

4.4 Heat pumps

Heat pumps are efficient and environmentally friendly heating methods that utilize waste heat or ambient heat from the air, water, or ground. The benefits are high efficiency because heat pumps can produce 3-4 times more heat than the electricity they consume. In addition, heat pumps use renewable energy, reducing carbon dioxide emissions. However, the efficiency of heat pumps can decrease in extremely cold conditions.

Heat pumps are anticipated to become more prevalent in both district heating production and building-specific heating production. They will be more common in Finland's heating sector. Favourable taxation requires separate measurements of electricity consumption and heat production. Decisions are needed on whether heat pumps qualify for favourable taxation when heating locally rather than producing waste heat for the district heating network. (VTT Oy, Miika Rämä & Krzysztof Klobut, 2020)

Centralized large-scale heat pumps are utilized in industrial processes, data centres, treated wastewater, and district cooling networks. Decentralized small-scale heat pumps are typically used in buildings and refrigeration equipment. Heat produced in smaller sites is often best used within the site itself, though it can occasionally supply heat to the district heating network. (VTT Oy, Miika Rämä & Krzysztof Klobut, 2020)

It is generally more economical for district heating companies or third parties to operate decentralized, smaller heat pumps. From the building owner's perspective, the impact of a single small heat pump in the district heating system or as a source of income is not significant. However, multiple heat pumps together form a larger entity from the perspective of district heating production. (VTT Oy, Miika Rämä & Krzysztof Klobut, 2020)

Interest in heat pumps utilizing waste or renewable heat sources may increase if they are classified in a lower electricity tax category in the future. This requires separate measurements of their electricity consumption and heat production. For small, decentralized heat pumps owned by individual operators, the costs of maintenance, management, and installation may outweigh the benefits. (VTT Oy, Miika Rämä & Krzysztof Klobut, 2020)

4.5 Heat accumulators

Heat accumulators, also known as TES systems, are devices or systems that store thermal energy for later use, helping to balance energy supply and demand, improve energy efficiency, and integrate renewable energy sources. TES system needs to be tailored to the specific energy system (e.g., solar thermal, CHP, district heating). TES systems can significantly reduce greenhouse gas emissions by enabling greater use of renewable energy and reducing reliance on fossil fuels. Types of heat accumulators: sensible heat storage (SHS), latent heat storage (LHS) and thermochemical heat storage (TCS). (Demchenko, Konyk, & Dekusha, 2023) (Kurpaska, et al., 2020)

4.5.1 Sensible heat storage (SHS)

SHS stores energy by increasing the temperature of a solid or liquid. Common materials include water, molten salts, and rocks. An example of this type of storage is hot water tanks. The efficiency of SHS is generally high due to its simple design. (Demchenko, Konyk, & Dekusha, 2023)

4.5.2 Latent heat storage (LHS)

LHS utilizes phase change materials (PCMs) that absorb or release heat during phase transitions such as melting or freezing. Examples of PCMs include paraffin wax and salt hydrates. One advantage of LHS is its high energy density at nearly constant temperature. However, it has limitations such as lower thermal conductivity and the cost of PCMs. (Kurpaska, et al., 2020)

4.5.3 Thermochemical heat storage (TCS)

Thermochemical Heat Storage (TCS) stores energy through reversible chemical reactions. It is characterized by high energy density and potential for long-term storage. Currently, TCS is still under development for large-scale applications. (Demchenko, Konyk, & Dekusha, 2023)

4.6 SMR and nuclear heat

VTT is developing a Small Modular Reactor (SMR) for district heating in Finnish cities. The project aims to create a new industrial sector around SMR technology, providing a cost-effective and low-emission solution for heating homes. SMRs can significantly reduce emissions from district heat production, supporting Finland's goal to phase out coal by 2029. VTT leverages its expertise in nuclear energy and advanced simulation methods. The unit size of VTT’s reactor is 50 MW. (VTT, 2020)

4.7 Geothermal Heat

Geothermal heat utilizes the Earth's internal heat for heating purposes. Geothermal energy is continuously available and not dependent on weather conditions. Geothermal energy is almost emission-free. However, installing geothermal systems can be costly and requires specific geographical conditions. Geothermal energy is only available in certain areas. (U.S. Department of Energy, n.d.)

4.8 Examples of decarbonisation of the heating sector in other countries and cities

There are multiple projects around the world that are developing heating sector and district heating systems. The cities and countries chosen to this study are chosen because they have similar weather conditions than Vaasa. This chapter reviews decarbonisation methods for the district heating systems of Helsinki, Vesterås, Cobenhagen and Sondeborg.

Helsinki, Finland

Rämä et al (2025) have introduced the concept of dynamically distributed district heating, which allows for the cost-effective transformation of an existing 3rd generation district heating system into a 4th generation system. The 4th Generation District Heating concept incorporates a more decentralized heat supply utilizing renewable energy sources and/or surplus heat, along with low-temperature distribution. This concept includes large thermal storage units charged during the summer and used in the winter. During the heating season, areas operate in island mode, disconnected from the main system. Helsinki has been used as a case study to assess the concept's impact on district heating costs and efficiency. The study concluded that the concept can be technically and economically feasible and facilitate the transition towards a district heating system based on renewable energy sources. (Rämä, Pursiheimo, Sundell, & Abdurafikov, 2024)

The Esplanade and Katri Vala heating and cooling plants in Helsinki utilize biomass and industrial heat pumps. Additionally, Helsinki is investigating utilization of bedrock and caves as thermal storage. (Haq, Valisuo, Kumpulainen, & Tuomi, 2020)

Västerås, Sweden

In Västerås, Sweden, a Cold War-era cave system carved into bedrock has been repurposed into a giant underground heat battery. Hot water is stored in massive underground caverns and is heated using a co-generation plant that burns waste and biomass to produce both electricity and heat. This stored heat is then distributed through a district heating system to warm homes during the cold winters. The system is highly efficient and significantly reduces the need for fossil fuels during periods of peak energy demand. (Rohwer-Kahlmann, 2025)

Copenhagen, Denmark

Copenhagen's district heating system connects various energy stakeholders to optimize synergies. It includes waste incineration facilities, wastewater treatment plants, CHP plants, heat pumps, electric boilers, thermal energy storage units, and peak and reserve boilers. Waste incineration and wastewater treatment provide stable heat sources for heat pumps linked to the heating network or power supply. Biogas production and solid biomass from these processes are used in CHP plants, which operate with biomass to generate heat and power. Utility-sized heat pumps co-generate heat and cooling for commercial buildings, data centres, and industrial processes, avoiding peak power periods to optimize efficiency. Sector coupling of heating, cooling, and power enhances system performance. Peak and reserve boilers fired by natural gas, biogas, or bio-oil secure the energy system and provide emergency reserves. (Danfoss, 2024)

The Greater Copenhagen Utility HOFOR has partnered with Danfoss to optimize Copenhagen's district heating network using AI-powered software. The software uses weather forecasts and real-time data to optimize supply temperature, improving efficiency and reducing fuel consumption and CO_2 emissions. (Danfoss, 2024)

Sonderborg, Denmark

Energy efficiency and diverse heating sources include various systems and technologies. The base load is managed by a waste incineration plant that produces both heat and power, and a biomass plant is used for mid-load. Peak load boilers utilize bio-oil and natural gas for peak load reserve and backup capacity, along with thermal energy storages. Additional heating sources come from geothermal heat, electrically driven heat pumps, and direct electric boilers. In the industry sector, a 6 MW substation installed by Danfoss delivers surplus heat (waste heat) from production processes to the district heating network. Sources of surplus heat in the industry sector include production processes, excess heat from air compressors, process cooling, and data centres. The district heating network functions on a two-way basis. (Danfoss, 2024)

4.9 Evaluation of the methodologies and techniques

In this chapter are evaluated the presented options along with their strengths, opportunities, weaknesses and threats for decarbonising strategy for Vaasa heating sector.

The SWOT analysis of different technologies is presented in Table 2.

Heat Pumps	
Strengths: High efficiency in converting energy to heat. Can utilize renewable energy sources. Reduces greenhouse gas emissions. Many applications in residential and industrial.	**Weaknesses:** High initial installation costs. Efficiency can decrease in extremely cold climates. Requires electricity to operate.
Opportunities: Growing market for renewable energy solutions. Government incentives and subsidies Advancements in technology improving efficiency and reducing costs.	**Threats:** Fluctuating electricity prices. Competition from other RES technologies. Regulatory changes affecting incentives.
Waste heat recovery	
Strengths: Improves overall energy efficiency. Reduces operational costs by utilizing waste heat. Can be applied in various processes.	**Weaknesses:** High initial investment costs. Utilisation of low-grade heat. Dependence on continuous industrial operations.
Opportunities: Growing emphasis on energy efficiency and sustainability. Government incentives. Advancements in heat recovery technologies.	**Threats:** Fluctuations in industrial activity affecting waste heat availability. Regulatory changes impacting project feasibility. Competition from other energy efficiency assets.
Small modular reactors	
Strengths: Low-carbon energy source. Modular design allows for scalability. Can provide reliable and consistent heat supply.	**Weaknesses:** High initial capital costs. Public perception and acceptance issues. Regulatory and licensing challenges.
Opportunities: Growing demand for low-carbon energy. Government support for nuclear energy projects. Advancements in reactor technology improving safety and efficiency.	**Threats:** Regulatory and policy uncertainties. Competition from other low-carbon technologies. Potential for nuclear accidents and associated risks. Handling and storage of nuclear waste.
Alternative fuels for CHP	
Strengths: Multiple renewable fuels available. Reduce carbon emissions.	**Weaknesses:** Some fuels might still emit pollutants and additional carbon capture techniques are needed.
Opportunities: The existing CHP plants can be utilised.	**Threats:** Political decisions.
Carbon Capture, utilisation and storage	
Strengths: Significantly reduces CO_2 emission. Can be integrated with existing infrastructure. Supports the production of low-carbon hydrogen.	**Weaknesses:** High costs (capture, transport, and storage). Energy-intensive process. Public perception and acceptance issues.
Opportunities: Increasing investments. Development of international carbon markets. Technological advancements reducing costs and improving efficiency.	**Threats:** Regulatory and policy uncertainties. Potential for leakage and environmental risks. Competition from other low-carbon technologies.

Table 2. SWOT-analysis of technologies for decarbonisation of heating sector.

Energy efficiency

Energy efficiency is crucial for cost savings and reducing system costs. It involves smart operation of the system and shifting heat consumption to times when renewable electricity is more available, thereby avoiding high-emission fossil fuel plants.

Development of district heating

Combining district heating and cooling systems, highlighting the use of waste heat, bidirectional heating, and fifth-generation networks. It emphasizes energy efficiency, renewable energy integration, and demand response methods. Bidirectional district heating allows excess heat to be sold back to the district heating system.

Dynamic control and demand response utilizes real-time data to optimize heating output, thermal storage, smart grid integration, advanced control strategies, and flexibility to accommodate renewable energy sources. Waste heat utilization focuses on capturing and using waste heat from various sources, including industrial processes and buildings. Allow excess heat to be sold back to the district heating system.

5 Towards a carbon neutral district heating system in Vaasa

The heating sector in Vaasa has made significant progress toward carbon neutrality. In 2024, over 80 % of the district heating in the region was produced using renewable energy sources and recovered waste heat. Vaasa heating sector utilizes already more environmentally friendly heat sources than in Finland in general. In addition, there are less share of fossil fuels in the heating system for example the share of coal, oil and peat was 5 % of Vaasa district heating in Finland whereas it was 15 % in whole Finland. In addition, natural gas covered 7 % of Finland's district heating whereas in Vaasa it was 0 %. The heat sources were presented in Figure 7 and Figure 8.

To develop an effective system, it is essential to consider the characteristics of the Vaasa region and the existing assets. Existing solutions include electric boilers, thermal storage facility, WtE plant, biomass gasification plant. WtE contributes a substantial share of the district heating by converting waste into electricity and heat. The heat pump at the Pått wastewater treatment plant generates thermal energy from wastewater. The region also is developing hydrogen production using renewable electricity, enabling emission-free heat production when electricity is both affordable and renewable.

Vaasan Voima Oy and EPV Energia Oy have made progress in improving heating production. Vaasan Voima Oy includes CHP plants, electric boilers, heat pumps, and thermal storage unit, focusing on efficiency and emission reductions through innovative projects. Electrification in the heating sector has grown, substituting fuels with electric boilers when there is cheap renewable electricity available. Electric boilers provide clean heat, and local biomass reduces coal usage. Electric boilers, heat pumps, CHP plants using biofuels or synthetic fuels are crucial for reducing emissions in district heating.

The combination of electric boilers and sufficient thermal energy storage has proven to be effective in enhancing the efficiency of energy systems. This setup optimizes heat production and provides balancing services to the electricity grid, increasing participation in various energy markets. Increased electrification of heating offers flexibility for renewable energy, supported by thermal energy storage, accommodating wind and solar power sector. The thermal storage allows for the separation of heat production and consumption over time, enabling heat to be produced when it is cost-efficient and stored for later use. The advantages of thermal storage are presented in Figure 16.

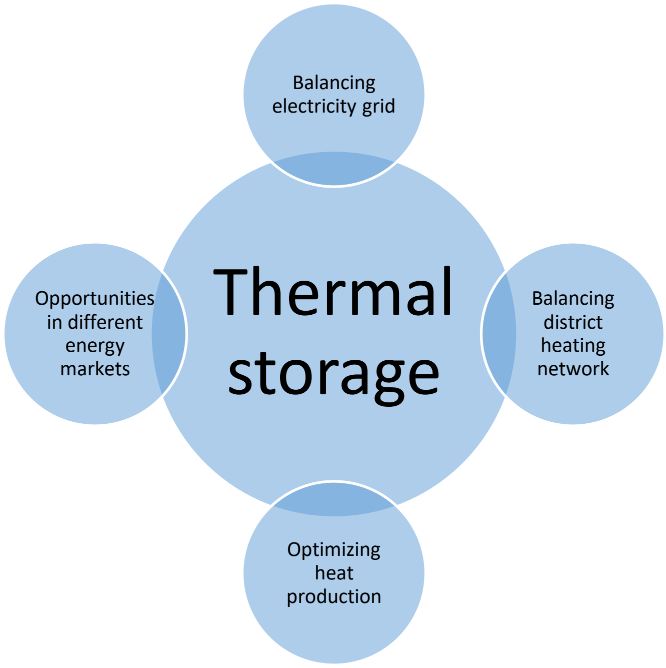

Figure 16. The advantages of thermal storage.

5.1 Challenges of the existing assets

Challenges to achieve carbon neutrality include the residual use of fossil fuels, especially during the coldest winter periods. Heating-related CO_2 emissions and the need for improved energy efficiency remain and further improvements are necessary to achieve carbon neutrality in the Vaasa heating sector.

The price of electricity creates additional challenges for heating sector because increased electrification. When electricity prices are high the heating with electricity-based heating sources such as electric boiler might become expensive. When the price of electricity is high, and heat produced by electric boilers and heat pumps becomes expensive, alternative heating technologies should be considered.

In general flexibility capabilities are primarily provided by CHP and hydropower, which constitute most of the current flexible capacity. However, CHP plants face challenges when wind power drives electricity prices down, making it challenging to cover production costs. However, CHP plants can be used when electricity prices are high. CHP plants can operate independently of electricity market fluctuations, providing heat when electricity prices are high. CHP plants utilize the energy content of fuel to produce both electricity and heat, achieving high efficiency. To significantly reduce carbon dioxide emissions and achieve 100 % carbon neutral heat production, CHP plants need to use renewable fuels. Biomass CHP plants and industrial-scale heat pumps are crucial for reducing emissions in district heating.

WtE incineration is a promising solution for reducing landfill use and generating energy from municipal solid waste, but it faces several significant challenges and problems such as air pollution, ash disposal, feedstock quality. Based on (Shareefdeen & Al-Najjar, 2022) research, environmental concerns of waste incineration are air pollution and ash disposal. Incineration can emit harmful pollutants such as dioxins, furans, heavy metals, and particulate matter if not properly controlled. These emissions pose risks to human health and the environment. The process also generates bottom ash and fly ash, which may contain toxic substances and require careful handling and disposal (Shareefdeen & Al-Najjar, 2022)

However, the carbon capture unit is expected to start operation in Westenergy in 2026. The unit aims to capture all carbon dioxide from the fluid gases of the Westenergy WtE plant, reducing its carbon footprint. Most of the captured CO_2, approximately 150,000 tons annually, will be liquefied and transported to a Power-to-X site in Kristinestad for producing carbon-neutral synthetic gas. Additionally, over 30,000 tons of CO_2 will be used in the production of carbon-sequestering products, advancing the carbon recycling industry in the Vaasa region.

Burning biomass also emits pollutants. Therefore, additional carbon capture units need to be integrated into the system. The implementation of new technologies, such as carbon capture and sector coupling, requires considerable investment and system development. However, these advancements are essential for the future combustion of waste and biomass.

5.2 Proposed strategy for achieving carbon neutrality in the Vaasa region

In this chapter are presented solutions for decarbonising strategy for Vaasa heating sector. It gives answers to the second research question:

- What methods and technologies can be used to decarbonise the heating sector of Vaasa?

To achieve complete carbon neutrality, the heating sector in Vaasa should phase out fossil fuels entirely, increase the use of heat pumps and electric boilers, and scale up carbon capture and utilization. Additionally, the development of hydrogen production and sector coupling would enhance system flexibility and support emission reductions. Energy efficiency is crucial for cost savings and reducing system costs.

To achieve carbon neutrality by 2030, Vaasa should pursue multiple solutions, sector-coupled strategy that builds on its existing strengths and addresses current challenges. Maximising the use of existing low-carbon assets such as electric boilers and thermal storage to absorb surplus renewable electricity and provide grid balancing.

In addition, CHP optimization is needed to maintain CHP operations during high electricity price periods. Transition fuels to bio coal, biogas, or green hydrogen to reduce emissions.

Expand waste heat and heat pump integration. Scale up the Pått wastewater heat pump model to other potential sources like data centres, industrial processes, and refrigeration systems. Also, mapping and integrating local industrial waste heat sources into the district heating network, using large-scale heat pumps where needed.

Implement bidirectional and low-temperature district heating. Transition toward ultra-low temperature, bidirectional networks that allow customers to both consume and supply heat. In addition, district cooling integration by combining heating and cooling production using absorption chillers and heat pumps to improve system efficiency. Enable demand response and smart control with dynamic pricing and smart thermostats. Encourage consumers to shift heating loads based on electricity prices and grid conditions.

Deploy carbon capture and Power-to-X technologies. Support the Westenergy carbon capture project and explore similar solutions for biomass-based CHP. Use captured CO_2 and renewable hydrogen to produce synthetic fuels, enabling circular carbon use and sector coupling.

In addition, diversified heat sources such as geothermal and SMRs. Investigate geothermal potential in the region as a stable, low-emission heat source. Consider SMRs as a long-term option for base-load heat, especially if other renewables are insufficient. Thermal inertia utilisation by using building mass and thermal storage to buffer demand peaks.

Policy and Market Support ensuring renewable and waste heat sources are certified and incentivized. In addition, EU Funding and EU programs like the Innovation Fund and LIFE Programme to finance infrastructure upgrades.

6 Conclusion

Vaasa heating sector utilizes already more environmentally friendly heat sources than in Finland in general. In addition, there is less share of fossil fuels in the heating system. Vaasan Voima Oy and EPV Energia Oy have continuously developed assets. However, challenges such as heating-related CO_2 emissions and the need for improved energy efficiency remain and further improvements are necessary to achieve complete carbon neutrality in the Vaasa heating sector.

To achieve carbon neutrality in the Vaasa heating sector by 2030, a multifaceted approach is essential. This involves phasing out fossil fuels, optimizing CHP plants, expanding the use of heat pumps and electric boilers, integrating waste heat and low-temperature district heating, and implementing carbon capture and Power-to-X technologies. Additionally, demand response, energy efficiency, and smart control measures should be employed, alongside exploring geothermal and small modular reactors (SMRs) for diversified heat sources. Policy and market support, including EU funding, are crucial for financing necessary infrastructure upgrades.

Sector coupling technologies and mechanisms offer significant opportunities to reduce emissions in various sectors. By integrating different energy sources and optimizing their use, it is possible to achieve a more sustainable and efficient energy system. Sector coupling mechanisms are essential for balancing consumption and production. When renewable energy production is high and demand is low, electric boilers can use the excess electricity to produce heat, which can be stored for future use. This approach helps stabilize electricity prices and supports the integration of renewable energy sources.

This thesis conducts a preliminary analysis of this extensive topic and further research is required to evaluate which methods are the most reasonable and cost-effective to implement. To develop an effective system, it is essential to consider the characteristics of the Vaasa region and the existing assets.

To scale the findings of the thesis, it is necessary to study the characteristics of different areas. For instance, if an area lacks a district heating network or suitable sites for energy storage utilization, the associated costs will increase. To apply the findings of this thesis practically, regional characteristics must be considered when evaluating the most effective methods for decarbonizing heating sectors in various regions.

6.1 Recommendations for further research

Further studies should focus on detailed modelling and simulation of technologies to evaluate their long-term impacts on the energy system in Vaasa. This includes assessing the economic viability, environmental benefits, and potential challenges of implementing these technologies on a larger scale.

Research should be conducted to optimize the design and operation of thermal energy storage systems. This includes exploring advanced materials and technologies that can enhance the storage capacity and efficiency of these systems.

Examinate the policy and regulatory frameworks needed to support the widespread adoption of different technologies. This includes identifying incentives, subsidies, and regulations that can encourage investment in these technologies and facilitate their implementation.

Conducting case studies and pilot projects to test the feasibility and effectiveness of technologies in real-world scenarios. These projects can provide valuable insights into the practical challenges and benefits of these technologies, helping to refine and improve their implementation.

By addressing these research areas, it will be possible to further advance the understanding, ultimately contributing to a more sustainable and efficient energy system. And achieve the goal to be carbon neutral.

References

Abdur Rehman, O., Palomba, V., Frazzica, A., & Cabeza, L. F. (2021). *Enabling Technologies for Sector Coupling: A Review on the Role of Heat Pumps and Thermal Energy Storage.* Energies, 14(24), 8195. doi:https://doi.org/10.3390/en14248195

Bossmann, T., Fournié, L., Humberset, L., & Paul, K. (2019). *METIS Studies: Study S8: The roule and potential of Power-to-X in 2050.* Brussels: European Union.

BP. (2024, February 19). *Net-zero-teesside-power-and-northern-endurance-partnership-awar*. Retrieved May 13, 2025, from https://www.bp.com/en_gb/united-kingdom/home/news/press-releases/net-zero-teesside-power-and-northern-endurance-partnership-award.html

Buffa, S., Cozzini, M., D'Antoni, M., Baratieri, M., & Fedrizzi, R. (2019). *5th generation district heating and cooling systems: A review of existing cases in Europe.* Bolzano: Elsevier Ltd. doi:https://doi.org/10.1016/j.rser.2018.12.059

Danfoss. (2024, December 6). *HOFOR and Danfoss future-proof heating in Copenhagen with a new data solution*. Retrieved 2025, from https://www.danfoss.com/en/about-danfoss/news/dcs/hofor-and-danfoss-future-proof-heating-in-copenhagen-with-a-new-data-solution/

Danfoss. (n.d.). How the Copenhagen District Heating System supports and benefits from sector coupling. Denmark: Danfoss Climate Solutions. Retrieved August 24, 2024, from https://youtu.be/wW3eMeSp7AM

Danfoss. (ei pvm). How the Sonderborg District Heating System supports and benefits from sector coupling. Denmark: Danfoss Climate Solutions. Haettu 24. August 2024 osoitteesta https://youtu.be/MtEom3W64UM

Demchenko, V., Konyk, A., & Dekusha, O. (2023). *Thermal Energy Storage Systems in the District Heating Systems. In: Zaporozhets, A. (eds) Systems, Decision and Control in Energy V. Studies in Systems, Decision and Control, vol 481. .* Cham: Springer Nature Switzerland. doi:https://doi.org/10.1007/978-3-031-35088-7_19

EIA. (2023, March 16). *Press releases of EIA: EIA projects that increased electrification, higher equipment efficiencies, and more zero-carbon power sources will reduce*

U.S. energy-related CO2 emissions through 2050. Retrieved from Webpage of EIA: https://www.eia.gov/pressroom/releases/press529.php

EIA. (2025, January 15). *EIA webpage*. Retrieved April 25, 2025, from Taday in Energy - In-brief analysis: https://www.eia.gov/todayinenergy/detail.php?id=64264

Energiateollisuus ry. (n.d.). *Ajankohtaista sähkömarkkinoista*. Retrieved January 5, 2025, from Energiateollisuus ry webpage: https://energia.fi/energiapolitiikka/ajankohtaista-sahkomarkkinoista/#collapse-header-36460

Energiateollisuus ry. (n.d.). *Electricity markets*. Retrieved January 5, 2025, from Energiateollisuus ry:n kotisivut: https://energia.fi/en/energy-sector-in-finland/energy-market/electricity-market/

Energiateollisuus ry. (n.d.). *Energiamarkkinat*. Retrieved January 5, 2025, from Energiateollisuus ry:n kotisivut: https://energia.fi/energiatietoa/energiamarkkinat/

Energiateollisuus ry. (n.d.). *Heating markets*. Retrieved January 5, 2025, from Energiateollisuus ry:n website: https://energia.fi/en/energy-sector-in-finland/energy-market/heating-markets/

Energiateollisuus ry. (n.d.). *Kaukolämmön luotettavuus*. Retrieved January 5, 2025, from Energiateollisuus ry:n kotisivut: https://energia.fi/energiatietoa/energiaverkot/kaukolampoverkot/kaukolammon-luotettavuus/

Energiateollisuus ry. (n.d.). *Kaukolämpöverkot*. Retrieved January 5, 2025, from Energiateollisuus ry:n kotisivut: https://energia.fi/energiatietoa/energiaverkot/kaukolampoverkot/

Energiateollisuus ry. (n.d.). *Sähkömarkkinoiden toiminta*. Retrieved January 5, 2025, from Energiateollisuus ry webpage: https://energia.fi/energiapolitiikka/ajankohtaista-sahkomarkkinoista/sahkomarkkinoiden-toiminta/

Energiateollisuus ry. (n.d.). *Sähköpörssin ammattisanasto*. Retrieved January 5, 2025, from Webpage of Energiateollisuus ry: https://energia.fi/julkaisut/sahkoporssin-ammattisanasto/

Energiateollisuus ry. (n.d.). *Tukkumarkkinat*. Retrieved January 5, 2025, from Energiateollisuus ry:n webpage: https://energia.fi/energiatietoa/energiamarkkinat/sahkomarkkinat/tukkumarkkinat/#1486-jannen-toimenkuva

Energiateollisuus, ajankohtaista sähkömarkkinoista. (2025, January 5). *Energiateollisuus ry:n kotisivut*. Retrieved January 5, 2025, from Ajankohtaista sähkömarkkinoista: https://energia.fi/energiapolitiikka/ajankohtaista-sahkomarkkinoista/#collapse-header-36460

Energy authority. (2020). *Energy authority website*. Retrieved April 6, 2025, from Lämpöenergian mittaus: https://energiavirasto.fi/lampoenergian-mittaus

Energy authority. (n.d.). *Energy authority website*. Retrieved April 6, 2025, from Guarantee of Origin: https://energiavirasto.fi/en/guarantee-of-origin

Energy Star. (n.d.). *An official website of the United States government*. Retrieved April 25, 2025, from How ENERGY STAR Protects the Environment: https://www.energystar.gov/about/how-energy-star-protects-environment/energy-efficiency

Environmental Protection Agency. (14. August 2024). *CHP's Role in Decarbonization*. Haettu 24. April 2025 osoitteesta Environmental Protection Agency (EPA) United states website: https://www.epa.gov/chp/chps-role-decarbonization

EPV Aurinkovoima Oy. (2023, December 20). *EPV Aurinkovoima website*. Retrieved April 10, 2025, from https://www.epvaurinkovoima.fi/en/epv-solar-power-ltds-first-solar-park-to-be-built-in-lapua/

EPV Aurinkovoima Oy. (2024, October 8). *EPV’s solar park is being built in Lapua*. Retrieved from EPV Aurinkovoima Oy website: https://www.epvaurinkovoima.fi/en/epvs-solar-park-is-being-built-in-lapua/

EPV Aurinkovoima Oy. (n.d.). *EPV Aurinkovoima Oy website*. Retrieved April 12, 2025, from https://www.epvaurinkovoima.fi/en/projects/

EPV Energia Oy. (2025). EPV Energy Oy Annual Report 2024. Retrieved April 10, 2025, from https://www.epv.fi/wp-content/uploads/sites/41/2025/03/EPV-Energy-Annual-Report-2024.pdf

EPV Energia Oy. (n.d.). *EPV Energia Oy website*. Retrieved April 12, 2025, from https://www.epv.fi/en/

EPV Energia Oy. (n.d.). *EPV's projects*. Retrieved May 13, 2025, from EPV Energia Oy webpage: https://www.epv.fi/en/epvs-projects/

EPV Energy Oy. (2025). *EPV Energy website*. Retrieved April 3, 2025, from EPV Energy website - the new electricity revolution: https://www.epv.fi/en/company/the-new-electricity-revolution/

EPV Tuulivoima Oy. (n.d.). *EPV Tuulivoima Oy website*. Retrieved April 10, 2025, from https://www.epvtuulivoima.fi/en/

Erbach, G. (2019). *Energy storage and sector coupling. Towards an integrated, decarbonised energy system.* EPRS European Parliamentary Research Service. Retrieved October 20, 2024, from https://www.europarl.europa.eu/RegData/etudes/BRIE/2019/637962/EPRS_BRI(2019)637962_EN.pdf

European Commission. (2019, September 3). *The European portal for energy efficiency and renewable energy in buildings-D2Grids Project*. Retrieved from An official website of the European Union: https://build-up.ec.europa.eu/en/resources-and-tools/links/d2grids-project

European Commission. (2020, March). *2050 long term strategy*. Retrieved April 21, 2025, from An official website of the European Union: https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en

European Commission. (2022, May 18). COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. REPower EU Plan. Brussels: European Union. Retrieved April 21, 2025, from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653033742483

European Commission. (2023). *2030 climate targets*. Retrieved April 21, 2025, from An official website of the European Union: https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2030-climate-targets_en

European Commission. (2023, October). *The European Green Deal*. Retrieved April 21, 2025, from An official website of the European Union: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

European Commission. (2025). *A new plan for Europe's sustainable prosperity and competitiveness*. Retrieved April 21, 2025, from An official website of the European Union: https://commission.europa.eu/priorities-2024-2029/competitiveness_en

European Commission. (2025, February). *EU action to address the energy crisis*. Retrieved April 21, 2025, from An official website of European Union: https://commission.europa.eu/topics/energy/eu-action-address-energy-crisis_en

European Commission. (n.d.). *Climate change*. Retrieved April 21, 2025, from An official website of the European Union: https://climate.ec.europa.eu/climate-change/causes-climate-change_en

European Commission. (n.d.). *Delivering the European Green Deal*. Retrieved April 21, 2025, from An official website of the European Union: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en

European Commission. (n.d.). *EU funding for climate action*. Retrieved April 21, 2025, from An official EU website: https://climate.ec.europa.eu/eu-action/eu-funding-climate-action_en

European Energy. (n.d.). *Power-to-X substitutes fossil-fuels and decarbonises industries*. Retrieved May 13, 2025, from European Energy website: https://europeanenergy.com/green-solutions/ptx/

European Parliament. (2024, April). *European Parliament website*. Retrieved April 21, 2025, from Combating climate change: https://www.europarl.europa.eu/factsheets/en/sheet/72/ilmastonmuutoksen-torjuminen

European Parliament. (2024, March). *European Parliament website.* Retrieved April 5, 2025, from Fact Sheets on the European Union- Renewable energy: https://www.europarl.europa.eu/factsheets/en/sheet/70/uusiutuvat-energialahteet

European Union. (30. June 2021). *Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law')*. Noudettu osoitteesta EUR-Lex: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R1119

Fingrid Oyj. (2024). *Reserves and reserve markets.* Retrieved January 6, 2025, from Fingrid Oyj website: https://www.fingrid.fi/globalassets/dokumentit/en/electricity-market/reserves/reservien-perusteet-eng.pdf

Fingrid Oyj. (2025, January 6). *Reserves and balancing power*. Retrieved January 6, 2025, from Fingrid Oyj website: https://www.fingrid.fi/en/electricity-market/reserves_and_balancing/#reserve-obligations-and-procurement-sources

Fingrid Oyj, About Fingrid. (n.d.). *Fingrid Oyj website*. Retrieved January 6, 2025, from About Fingrid: https://www.fingrid.fi/en/pages/company/in-brief/#36777b90

Finlex. (2021, December 3). Laki energian alkuperätakuista. Helsinki, Suomi. Retrieved April 6, 2025, from https://finlex.fi/fi/lainsaadanto/saadoskokoelma/2021/1050

Finnish Energy. (2025, January 28). *Energy Year 2024 District Heating.* Retrieved March 28, 2025, from Finnish Energy website: https://energia.fi/en/statistics/statistics-on-district-heating/

Föhr, J., Seppänen, T., Suikki, J., Soininen, H., & Ranta, T. (2015). *Torrefioidun biohiilipelletin kirjallisuustutkimus ja koeajot pilottilaitoksissa.* Lappeenranta.

Retrieved April 25, 2025, from https://lutpub.lut.fi/bitstream/handle/10024/117387/LUT%20D4%20Tutkimusraportti%20TORRE_A4.pdf?sequence=2

Garay-Martinez, R., & Garrido-Marijuan, A. (2022). *Handbook of Low Temperature District Heating.* Springer Cham. doi:https://doi.org/10.1007/978-3-031-10410-7

Greg, M. (22. November 2024). *Heat to Energy Conversion: Turning Heat Into Usable Power*. Haettu 23. April 2025 osoitteesta https://www.consumerenergycenter.org/heat-to-energy-conversion/

Haq, H., Valisuo, P., Kumpulainen, L., & Tuomi, V. (2020). *An economic study of combined heat and power palnts in district heat production.* Vaasa: Elsevier. doi:https://doi.org/10.1016/j.clet.2020.100018

Harrison, J. (20. February 2025). *The Future of Energy: Scientists Unlock the Power of Heat to Generate Electricity*. Haettu 23. April 2025 osoitteesta Engineerine: https://engineerine.com/energy-scientists-heat-electricity/

IEA. (n.d.). *Carbon capture utilisation and storage*. Retrieved May 13, 2025, from Website of IEA: https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage

International District Energy Association. (n.d.). *District Heating.* Retrieved May 13, 2025, from https://www.districtenergy.org/topics/district-heating

International Energy Agency. (2023, July 11). *District Heating – Energy System.* Retrieved from IEA: https://www.iea.org/energy-system/buildings/district-heating

IRENA. (2021). *Sector coupling in facilitating integration of variable renewable energy in cities.* Abu Dhabi: International Renewable Energy Agency. Retrieved October 20, 2024, from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Oct/IRENA_Sector_Coupling_in_Cities_2021.pdf

IRENA. (2022). *Sector coupling: A key concept for accelerating the energy transformation.* Abu Dhabi: International Renewable Energy Agency. Retrieved August 20, 2024, from https://www.irena.org/Publications/2022/Dec/Sector-coupling-A-key-concept-for-accelerating-the-energy-transformation

June, C. (2025, February 6). *Heat2Power: a hot new startup that converts stored heat into electricity*. Retrieved April 23, 2025, from Michigan chemical engineering: https://che.engin.umich.edu/2025/02/06/heat2power-a-hot-new-startup-that-converts-stored-heat-into-electricity/

Korpijärvi, K., Björnström, M., Karlsson, M., Raitila, J., & Virkkunen, M. (2021). *Biohiilen valmistus ja käyttö turvetta korvaavana tukipolttoaineena bioenergian tuotannossa. VTT Technical Reseach Centre of Finland. VTT tutkimusraportti Nro VTT-R-717-21.* Jyväskylä: VTT Technical Research Centre of Finland. Retrieved April 25, 2025, from https://cris.vtt.fi/ws/portalfiles/portal/52613617/VTT_Tutkimusraportti_BioTur21_VTT_R_717_21_Final.pdf

Kurpaska, S., Knaga, J., Latała, H., Cupiał, M., Konopacki, P., & Hołownicki, R. (2020). *he Comparison of Different Types of Heat Accumulators and Benefits of Their Use in Horticulture. Sensors, 20(5), 1417.* doi:https://doi.org/10.3390/s20051417

Mastrucci, A., van Ruijven, B., Byers, E., Poblete-Cazenave, M., & Pachauri, S. (2021). *Global scenarios of residential heating and cooling energy demand and CO2 emissions. Climatic Change 168, 14.* Climatic Change. doi:https://doi.org/10.1007/s10584-021-03229-3

Ministry of Economic Affairs and Employment of Finland. (n.d.). *Website of Ministry of Economic Affairs and Employment of Finland*. Retrieved January 5, 2025, from Electricity market: https://tem.fi/en/electricity-market

Mäki, E., Kannari, L., Hannula, I., & Shemeikka, J. (2021). *Decarbonization of a district heating system with a combination of solar heat and bioenergy: A techno-economic case study in the Northern European context.* Elsevier. doi:https://doi.org/10.1016/j.renene.2021.04.116

Nguyen, T., Kawai, K., & Nakakubo, T. (2021). *Drivers and constraints of waste-to-energy incineration for sustainable municipal solid waste management in developing* *countries.* Journal of Material Cycles and Waste Management. doi:https://doi.org/10.1007/s10163-021-01227-2

Nordenergy. (n.d.). *Nordenergy website*. Retrieved March 29, 2025, from Nordenergy website: https://www.nordenergi.eu/our-story/

Northern Lights. (n.d.). *Webpage of Northern Lights*. Retrieved May 13, 2025, from https://norlights.com/

Rohwer-Kahlmann, M. (2025, February 27). *Sweden's homes heated by a giant underground thermos*. Retrieved from DW: https://www.dw.com/en/swedens-homes-heated-by-a-giant-underground-thermos/a-71756844

RWE Innovation Centre. (n.d.). *Power-to-x*. Retrieved May 13, 2025, from RWE Innovation Centre website: https://www.rwe.com/en/research-and-development/rwe-innovation-centre/power-to-x/

Rämä, M., Pursiheimo, E., Sundell, D., & Abdurafikov, R. (2024). *Dynamically distributed district heating for an existing system. Renewable and Sustainable Energy Reviews, 189(Part A), Article 113947.* doi:https://doi.org/10.1016/j.rser.2023.113947

Shareefdeen, Z., & Al-Najjar, H. (2022). *Waste-to-Energy Technologies. In Hazardous Waste Management.* Springer. doi:https://doi.org/10.1007/978-3-030-95262-4_8

Siemens energy. (n.d.). *Sustainable gas turbine fuels*. Retrieved April 25, 2025, from Siemens energy website: https://www.siemens-energy.com/global/en/home/products-services/solutions-usecase/sustainable-fuels.html

Stocholm Exergi AB. (2024, May 6). *Stockholm Exergi och Microsoft tecknar världens hittills största avtal för permanenta minusutsläpp*. Retrieved from https://www.stockholmexergi.se/nyheter/stockholm-exergi-tecknar-varldens-hittills-storsta-avtal-med-microsoft-for-permanenta-minusutslapp/

Suomen ympäristökeskus. (2022, June 1). *Ilmasto-opas*. Retrieved April 21, 2025, from https://www.ilmasto-opas.fi/artikkelit/euroopan-unionin-ilmastopolitiikka-ohjaa-jasenmaita

Suomen ympäristökeskus. (2022, October 7). *Rakennusten lämmitys kuluttaa runsaasti energiaa*. Retrieved from Ilmasto-opas.fi: https://www.ilmasto-opas.fi/artikkelit/rakennusten-lammitys-kuluttaa-runsaasti-energiaa

Söderlund, M. (8. December 2021). *Website of Vaasan Voima*. Haettu 15. November 2024 osoitteesta https://www.epv.fi/en/2021/12/08/a-new-electric-boiler-has-been-commissioned-in-vaskiluoto-vaasa/

The European Council for an Energy Efficient Economy. (2023, February 21). *Energy efficiency first priciple*. Retrieved from The website of the European Council for an Energy Efficient Economy (ECEE): https://www.eceee.org/policy-areas/energy-efficiency-first/

Tilastokeskus. (2024, September 27). *Webpage of Tilastokeskus*. Retrieved April 25, 2025, from Suomalaisten kasvihuonekaasu- ja epäpuhtauspäästöt vähenivät vuonna 2022: https://stat.fi/julkaisu/cln1kl77mxelm0cutl6igp6hr

Tritonia LibGuides. (7. February 2020). *Vaasan yliopiston kirjoitusohjeet: Lähteet ja viitteidenhallinta*. Haettu 7. February 2020 osoitteesta https://uva.libguides.com/kirjoitusohjeet/lahteet-viitteidenhallinta

TVO. (2023, February 1). *The Mankala model is a cornerstone of Finnish energy production*. Retrieved April 24, 2025, from TVO website: https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2023/themankalamodelisacornerstoneoffinnishenergyproduction.html

U.S. Department of Energy. (n.d.). *Geothermal basics.* Retrieved May 15, 2025, from Office of Energy Efficiency & Renewable Energy.: https://www.energy.gov/eere/geothermal/geothermal-basics

U.S. Department of Energy. (n.d.). *Geothermal District Heating & Cooling.* Retrieved May 13, 2025, from Office of Energy Efficiency & Renewable Energy.: https://www.energy.gov/eere/geothermal/geothermal-district-heating-cooling

Vaasan Sähkö Oy. (n.d.). *Vaasan sähkö Oy website*. Retrieved May 13, 2025, from Kaukolämpötuotanto: https://www.vaasansahko.fi/kaukolampo/reaaliaikainen-kaukolampotuotanto/

Vaasan Vesi. (24. January 2024). *Website of Vaasan Vesi*. Haettu 8. November 2024 osoitteesta https://www.vaasanvesi.fi/-/pattin-jatevedenpuhdistamon-yhteyteen-on-suunnitteilla-uusi-laitos-joka-keraa-lampoenergian-talteen-jateveden-puhdistuksen-jalkeen?inheritRedirect=true

Vaasan Voima Ltd. (2019, September 20). *Vaasan Voima Ltd Website*. Retrieved April 20, 2025, from News-articles: https://www.vaasanvoima.fi/massiivinen-maanalainen-energiavarasto-vaasan-vaskiluotoon/

Vaasan Voima Oy. (2024). *Power plants*. Haettu 18. November 2024 osoitteesta Vaasan Voima Oy website: https://www.vaasanvoima.fi/en/power-plants/

Vaasan Voima Oy. (2024). *Storing heat*. Retrieved November 18, 2024, from Website of Vaasan Voima: https://www.vaasanvoima.fi/en/storing-heat/

Vaasan Voima Oy. (2024, October 21). *Vaasan Voima to grow the capacity of its thermal energy storage facility*. Retrieved from Vaasan Voima Oy website: https://www.vaasanvoima.fi/en/vaasan-voima-to-grow-the-capacity-of-its-thermal-energy-storage-facility/

Vaasan Voima Oy. (2024). *Website of Vaasan Voima*. Haettu 15. November 2024 osoitteesta Electrification of heat: https://www.vaasanvoima.fi/en/electrification-of-heat/

Vaasan Voima Oy. (n.d.). *Production and environment*. Retrieved April 20, 2025, from Website of Vaasan Voima Oy: https://www.vaasanvoima.fi/en/production-and-environment/

Vaasan Voima Oy. (n.d.). *Website of Vaasan Voima Oy*. Retrieved November 15, 2024, from About us: https://www.vaasanvoima.fi/en/about-us/

Van Nuffel, L., Gorenstein Dedecca, J., Smit, T., & Rademaekers, K. (2018). *Sector coupling: how can it be enhanced in the EU to foster grid stability and decarbonise?* Brussels: European Parliament. Retrieved October 20, 2024, from https://www.europarl.europa.eu/RegData/etudes/STUD/2018/626091/IPOL_STU(2018)626091_EN.pdf

VTT. (24. February 2020). *Good riddance to fossil fuels! VTT develops a Small Modular Reactor for district heating*. Haettu 25. April 2025 osoitteesta https://www.vttresearch.com/en/news-and-ideas/good-riddance-fossil-fuels-vtt-develops-small-modular-reactor-district-heating

VTT Oy, Miika Rämä & Krzysztof Klobut. (2020). *Hukkalämpö kaukolämpöjärjestelmissä.* Helsinki. Retrieved January 5, 2025, from https://energia.fi/wp-content/uploads/2023/08/Hukkalampo_kaukolampojarjestelmissa_-_maarittely_ja_luokittelu_VTT_2020.pdf

Wang, Q., Hou, Z., Guo, Y., Huang, L., Fang, Y., Sun, W., & Ge, Y. (2023). *Enhancing Energy Transition through Sector Coupling: A Review of Technologies and Models.* Energies, 16(13), 5226. doi:https://doi.org/10.3390/en16135226

Westenergy Ltd. (n.d.). *Westenergy website*. Retrieved November 8, 2024, from Westenergy-about us: https://westenergy.fi/en/westenergy/about-us/

Westenergy Oy. (n.d.). *Westenergy is an important link in circular economy*. Retrieved November 6, 2024, from Westenergy Oy website: https://westenergy.fi/en/energy-recovery/circular-economy/

Westenergy Oy. (n.d.). *Westenergy Oy website*. Retrieved November 6, 2024, from Westenergy, CPC Finland and Prime Capital plan a large-scale carbon capture plant: https://westenergy.fi/en/westenergy-cpc-finland-and-prime-capital-plan-a-large-scale-carbon-capture-plant/

Westenergy Oy. (n.d.). *Westenergy's Waste-to-Energy plant explained*. Retrieved November 6, 2024, from Westenergy Oy website: https://westenergy.fi/en/energy-recovery/wte-plant/

Appendices

Appendix 1. The promoting mechanisms for the use of renewable energy and emission reductions

Mechanisms	**Description**
EU Climate Law	Achieving climate neutrality by 2050, with a 55 % reduction in net greenhouse gas emissions by 2030 compared to 1990 levels. (European Union, 2021)
European Green Deal	A wide range of policy initiatives to achieve carbon neutrality by 2050, with an intermediate target of reducing net greenhouse gas emissions by 55 % by 2030. (European Commission, 2023) (European Parliament, 2024)
Green Industrial Revolution	Enhancing the competitiveness of Europe's net-zero industry and supporting clean technologies and green jobs. (European Commission, n.d.)
Renewable Energy Directive	Binding targets to ensure that at least 32 % of the EU's energy comes from renewable sources by 2030. (Suomen ympäristökeskus, 2022)
Energy Efficiency Directive	Reducing energy consumption by 32.5 % by 2030 compared to projected levels. (European Commission, 2023)
Sectoral Decarbonisation	Promoting innovative technologies and smart integration across various sectors. (European Commission, 2023)
Emissions Trading System (EU ETS)	A key tool for reducing greenhouse gas emissions through a cap-and-trade system. (Suomen ympäristökeskus, 2022)
Adaptation Strategy	Supporting member states in adapting to climate change impacts. (Suomen ympäristökeskus, 2022)
REPowerEU Plan	Reducing dependency on Russian fossil fuels, accelerating the transition to clean energy, and enhancing energy efficiency. The plan requires approximately €210 billion in additional investments by 2027, aiming for a renewable energy share of 42.5 % by 2030 and an 11.7 % improvement in energy efficiency. (European Commission, n.d.)

Appendix 2. EU funding for climate actions

Funds	Description
Innovation fund	Provides funding for innovative low-carbon technologies to help achieve climate neutrality in Europe.
Modernization fund	Supports the modernization of energy systems and enhances energy efficiency in 10 EU countries.
Finance Alignment	Ensures financial flows are aligned with the goals of the Paris Agreement.
LIFE Programme	Allocates EUR 905 million for developing and implementing innovative climate change responses.
EU Budget Support	Integrates climate action across the entire EU budget to meet climate objectives.
NER 300 Programme	Funds innovative low-carbon technologies, with a focus on Carbon Capture and Storage.
International Climate Finance	Provides support for climate action in developing countries worldwide.

Adapted from (European Commission, n.d.)

Appendix 3. Terminology of the electricity exchange

Term	Description
Area Price	The price of a price or bid area that differs from the system price if there is insufficient transmission capacity.
EPAD	Electricity Price Area Difference. EPAD is a derivative whose reference price is the difference between the system price and a specific area price.
Financial Markets	The most significant trading venues for derivatives markets in the Nordic countries are Nasdaq Commodities and the European Energy Exchange (EEX). The exchanges offer derivative contracts such as futures, forwards, EPADs, and options. Derivative contracts do not lead to the physical delivery of electricity.
Forward	A product in the electricity derivatives market. A forward is a contract for a future trade. Forwards are quoted according to the trading venue as monthly, quarterly, and yearly contracts.
Future	A product in the electricity derivatives market. A future is a contract for a future trade.
Price or Bid Area	In the electricity market, bids are submitted by price area. The Nordic price areas are: Finland, Sweden (4 areas), Norway (5 areas), East Denmark, and West Denmark.
Market Maker	An entity committed to maintaining the liquidity of continuous markets by submitting buy and sell bids for agreed products under agreed conditions with the exchange.
Over the Counter (OTC) Markets	In OTC markets electricity and derivatives are traded bilaterally directly or through brokers in addition to organized trading venues (e.g., Nord Pool and Nasdaq).
Intraday Trading	Trading for each for each quarter-hour is continuous and always open.
Day-Ahead Market	Markets leading to the physical delivery of electricity. The day-ahead market is a closed auction held once a day, the day before electricity delivery. Participants submit bids to the electricity exchange, where the system price and area prices are determined.
Electricity Derivative	A contract that sets a price for a specific amount of electricity (product) for a specific time in the future. The contract price is compared to an agreed reference price, which in the Nordic electricity market is usually the Nord Pool day-ahead market system price or area price. A derivative contract does not necessarily involve the physical delivery of electricity.
Electricity Derivatives Market	Trading in derivative products is conducted bilaterally (based on direct contacts between companies or through OTC markets) or through NASDAQ Commodities or EEX. Bilateral derivative contracts can also lead to the physical delivery of electricity.
System Price	The intersection of the bid curves formed by all buy and sell bids submitted in the Nordic market area, without considering possible transmission constraints.

Adapted from: (Energiateollisuus ry, n.d.)