Oskar Juszczyk

Roadmap for Renewable Energy Technologies Diffusion

A comparative study of Socioeconomic, Regulatory, and Technological issues in Finland and Poland

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Tiivistelmä

Energia on yhteiskuntien toiminnan ja hyvinvoinnin kannalta keskeinen perusresurssi kaikkialla maailmassa. Energian kysyntä kasvaa kuitenkin nopeasti johtuen muun muassa teollistumisesta, digitalisaatiosta ja ylikansoituksesta. Ilmaston lämpenemisen hillitsemiseksi fossiilisten polttoaineiden käyttöä energiantuotantotarkoituksiin on merkittävästi rajoitettava. Uusiutuvan energian teknologiat (RET) voivat tukea maailmanlaajuista energiasiirtymää tarjoamalla puhtaampia, kestävämpiä ja ympäristöystävällisempiä ratkaisuja. Uusiin energialähteisiin liittyvät teknologiset innovaatiot parantavat energiatehokkuutta ja -turvallisuutta, kestävää kehitystä, luonnonvarojen asiantuntevaa käyttöä, riippumattomuutta energian tuonnista sekä kansallista kustannuskilpailukykyä. Uusiutuvien energialähteiden osuus maailman energiantuotannosta on kuitenkin edelleen suhteellisen vaatimaton.

Tämän väitöskirjan tavoitteena on selvittää uusiutuvan energian teknologioiden leviämiseen vaikuttavia keskeisiä tekijöitä. Uusiutuvan energian teknologioiden leviämisen keskeisiä tekijöitä sääntelyn sekä sosioekonomisten ja teknologisten näkökohtien kannalta on tarkasteltu erityisesti kahdessa Euroopan unionin jäsenvaltiossa, Suomessa ja Puolassa. Tutkimuksessa on tunnistettu teknologioiden leviämistä vaikeuttavia tekijöitä ja niihin liittyviä parannuksia. Tutkimuksen tulokset korostavat sääntelyjärjestelmien välisten yhteistyöverkostojen merkitystä ympäristöystävällisten ratkaisujen edistämisessä, ja ehdottavat kiertotaloutta, riskipääomaa ja lohkoketjuteknologiaa mahdollisiksi ratkaisuiksi uusiutuvan energian teknologioiden leviämiselle.

Tutkimus noudattaa kriittiseen realismiin pohjautuvaa laadullista tutkimusmetodologiaa. Uusiutuvan energian teknologioiden leviämistä tutkitaan tapaustutkimuksia käyttäen. Maiden välinen vertaileva analyysi tuo esiin havaintoja merkittävistä yhtäläisyyksistä ja eroista erilaisissa uusiutuvan energian teknologioiden kehityksen haasteissa molemmissa tutkituissa maissa. Analyysien tulosten pohjalta työssä on kehitetty tiekartta, joka ehdottaa käytännön mekanismeja, toimia ja toimenpiteitä uusiutuvien energialähteiden käyttöönoton helpottamiseksi Suomessa ja Puolassa. Tämä tutkimus toimii tietolähteenä poliittisille päättäjille, toimijoille ja muille sidosryhmille uusiutuvan energian teknologisen kehityksen alueella.

Asiasanat: uusiutuva energia; teknologian levittäminen; innovaatioiden hallinta; energiapolitiikka; yhteistyöverkostot; kiertotalous; riskipääoma; lohkoketju.

Abstract

Energy is a fundamental resource required for the functioning and prosperity of societies across the globe. However, due to e.g. industrialization, digitalization, overpopulation, and growing shares of the global middle and middle-high class, the energy demand levels are expeditiously increasing. Considering climate change and global warming issues, there is a need to significantly limit the utilization of fossil fuels for energy generation purposes. Renewable energy technologies (RETs) can support the global energy transition by providing more clean, sustainable, and environmentally-friendly solutions. The expanding technological innovation advancement generates the capacity of renewables to enhance, inter alia, energy efficiency and security, sustainable development, proficient use of native resources, independence from energy imports, and escalating cost competitiveness. Regrettably, the share of renewables in global energy mixes remains relatively modest and inadequate.

This doctoral dissertation aims to explore the major factors influencing the diffusion of renewable energy technologies. Particular emphasis has been put on key regulatory, socioeconomic, and technological aspects of RETs diffusion in two European Union member states, Finland and Poland. By applying a problem-solving approach, this study initially detects the most hampering factors of RETs diffusion in order to address them and suggest effective improvement measures. The outcomes of this research highlight the importance of regulatory regimes and inter-sectoral collaborative networks to uphold the diffusion of environmentally-friendly solutions and propose circular economy, venture capital, and blockchain technology as possible incubators for RETs diffusion.

Qualitative research methodology, strengthened with the philosophical approach of critical realism has helped to thoroughly investigate the phenomenon of RETs diffusion based on selected case studies from the RETs industry. A cross-country comparative analysis reveals novel insights on major similarities and differences in various predicaments for developing RETs in both investigated countries. The collective outcomes of the analyses served to develop a "Roadmap for RETs diffusion", which suggests practical mechanisms, actions, and measures to facilitate the adoption of renewables in Finland and Poland. This study is a vital information source for the policymakers, practitioners, and other stakeholders and interest groups devoted to the widespread diffusion of RETs.

Keywords: renewable energy; technology diffusion; innovation management; energy policy; collaborative networks; circular economy; venture capital; blockchain.

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The journey called "doctoral studies" usually requires massive effort and brings many unexpected circumstances. After graduating in economics and business administration I started it with relatively limited knowledge about the energy industry *per se*. In plus, moving to Finland and adapting to its rather harsh weather conditions was a remarkable challenge. By willingly resigning from a decent job in an international corporation and leaving Friends and Family in my hometown, I initiated my Finnish endeavor with no funding or other external support. Yet, even if it all appeared as astonishingly hampering barriers, I replaced them with one word: "opportunity".

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Contents

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Abbreviations

IPCC	Intergovernmental Panel on Climate Change
UN	United Nations
RETs	Renewable Energy Technologies
RES	Renewable Energy Sources
IEA	International Energy Agency
TAM	Technology Acceptance Model
SMEs	Small and Medium Enterprises
R&D	Research and Development
WIPO	World Intellectual Property Organization
COVID-19	Coronavirus disease
VC	Venture Capital
Solar PV	Solar Photovoltaics
Energy 3Ds	Energy Decarbonization, Digitalization, and Decentralization
GHG	Greenhouse gas
EU	European Union
EC	European Commission
FiT	Feed-in Tariffs
RIS3	Research and Innovation Smart Specialization Strategy
CE	Circular Economy
ICT	Information and Communications Technology
IoT	Internet of Things
P2P	Peer-to-Peer
SWOT	Strengths, Weaknesses, Opportunities, and Threats
GDPR	General Data Protection Regulation

Publications

[1] Juszczyk, O., Shakeel, S.R. (2020) Comparative Analysis of Barriers for Renewable Energy Technologies Diffusion in Finland and Poland. *AHFE 2020: Advances in Human Factors, Business Management and Leadership*, 269-275. https://doi.org/10.1007/978-3-030-50791-6_34. This article was presented at AHFE 2020 Conference in San Diego, CA, USA, July 2020.[1]

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[5] Juszczyk. O., Shahzad, K. (2022) Blockchain for Renewable Energy – Principles, Applications & Prospects. *Energies* 15(13):4603. https://doi.org/10.3390/en15134603. An earlier version of the article was presented at IACIS Europe 2020 Conference, Warsaw, Poland, May 2020. [2]

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Additionally, throughout his doctoral studies, the Author has performed the following research:

[1] Hafeez, S., Juszczyk, O., Takala, J. (2021) A Roadmap for successful IoT implementation: empirical evidence from the energy industry. *Issues in Information Systems 22(1)*:92-113. https://doi.org/10.48009/1_iis_2021_92-113.

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[3] Juszczyk, O. (2022) Socio-economic performance of the Renewable Energy Technology companies during COVID-19 – empirical evidence. Sent for review in a peer-reviewed journal.

1 INTRODUCTION

This section provides the background of the study to support the research problem statement. Next, it introduces the concept of technology diffusion with a particular emphasis on the diffusion of renewable energy technologies. Afterward, the main research objectives and research questions are presented. The last section exhibits the context and structure of this doctoral dissertation.

1.1 Background

Energy is a fundamental resource that serves to support the economic growth of regional, national, and international communities. It is indispensable for the functioning and prosperity of perhaps every aspect of human life, such as transportation, heating, manufacturing, agriculture, etc. Starting from the industrial revolution, the global energy demand levels are constantly raising. Nowadays, the international community is challenged with overpopulation, massive migrations, a growing number of global middle-class, consumerism, military conflicts, and numerous other trends that will inevitably lead to record-breaking levels of energy supply needs (Al-Ghussain, 2019). Disastrously, the majority of global energy production is generated from fossil fuels, which have highly detrimental effects on the natural environment. A broadly understood climate change causes global warming which can be dramatically observed through e.g. increasing numbers of natural catastrophes, extinction of endangered species, deterioration of ecosystems, liquefying and greying of the polar zone, exhaustion of the ozone layer, etc. (Kaplan & New, 2006; IPCC, 2022a). According to recent reports of the Intergovernmental Panel on Climate Change (IPCC), the 1.5^{0}C global warming above pre-industrial levels will be extremely challenging to tackle even with the scenario of low-carbon and climate-resilient development. This alarming claim should motivate the international community to pursue efforts to initiate change toward a climate-neutral planet for the next generations to come (IPCC, 2022a & 2022b). Furthermore, as the UN's Secretary-General Antonio Guterres urged the General Assembly, the current world is "addicted to fossil fuels", and this situation needs hasty, immediate solutions to be able to look prosperously and favorably toward the future of our planet (UN, 2022).

A solution to this vexing problem might be to implement more sustainable and environmentally friendly energy sources into the global power generation systems (Nordhaus, 1994 & 2011). Renewable Energy Technologies (RETs) provide numerous benefits when adopted, such as e.g. energy security, resilience and efficiency, independence from energy imports, proficient use of indigenous resources, sustainable development, niche markets creation, etc., just to mention major aspects that could persuade governments or other authorities to support their utilization (Jacobsson & Johnson, 2000; Lund, 2009). Importantly, renewable energy sources (RES) are clean, sustainable, and environmentally friendly technological solutions. As the name suggests itself, renewables are unlimited and can be generated ultimately for free from natural resources such as wind, sun, water, biomass, etc. Therefore, it seems evident that strengthened efforts should be put into integrating RETs into the national, regional, and global energy mixes (Arent, Wise & Gelman, 2011; Gielen et al., 2019; Cantarero, 2020).

However, due to multifarious technological, socio-economic, or regulatory issues, the global share of renewables remains relatively negligible despite the recent enhanced growth, with only 29% of global electricity generation in 2020 (IEA, 2021). Despite the promising growth of RETs in recent years, a multi-level intersectoral contribution is still indispensable to enhance their implementation (Alagappan, Orans & Woo, 2011; Sen & Ganguly, 2017; Kim & Wilson, 2019). The next section scrutinizes the importance of technology diffusion with a particular emphasis on RETs diffusion.

1.2 Technology diffusion – introduction

As the effective diffusion of new technology can be a complex and troublesome process, it is often critical for the commercial success of a given product or service in question. However, it relies heavily on numerous aspects and factors, and therefore it became an intriguing issue for the plethora of researchers with divergent backgrounds, including, *inter alia*, rural and industrial sociology, knowledge management, marketing, economic development; medicine, communication or organizational studies (Pemberton, 1936; Rogers & Shoemaker, 1971; Valente & Rogers, 1995; Hall, 2004).

In the field of innovation, the term diffusion is described as the process by which new technology is adopted by individuals and organizations in a given society or economy, or how this new solution replaces the existing dominant technologies (Hall, 2004). However, diffusion has a vital contribution to the innovation process itself, as the technology development processes ultimately improve the initial innovation. On the macroeconomic scale, it is vital to emphasize the impact of processes of technology diffusion on socioeconomic growth and welfare which is usually substantial. Importantly, it is claimed that particularly for developing countries or technologically laggard companies, diffusion could be a critical part of the whole innovation process (Fagerberg & Godinho, 2006). As the process of acceptance and adoption of a given technology is associated with bringing this innovative solution to the market, the processes of technology diffusion and commercialization can often be inferred as corresponding notions, however, bearing in mind that commercialization is perceived as a critical part of the whole diffusion process (Bakhtiar, Aslani & Hosseini, 2020). In fact, Balachandra, Nathan, and Reddy (2010) perceive commercialization as a new market creation enhancing the competitiveness of the novel technology as well as its reliability resulting in the capability to bridge the "valley of death"[4] (Balachandra, Nathan & Reddy, 2010; Frank et al., 1996; Markham et al., 2010). Another essential aspect underlying the importance of successful commercialization is that an invention requires complete diffusion (including the introduction to the market) in order to be classified as innovation (Auerswald & Branscomb, 2003; Roberts, 2007).

Many scholars examined thoroughly various elements of the diffusion of innovative technologies. This phenomenon is commonly depicted with an S-curve, a leading technology diffusion model (Geroski, 2000; Rao & Kishore, 2010). Its sigmoid shape usually follows a logistic function, as can be seen in Figure 1. (a yellow S-curve). According to this model, there is an upper limit to the spread of the technology, which is divided into four separate stages: 1) learning, 2) growth, 3) saturation, and 4) decline, which is somehow similar to a product life cycle. When the technology in a saturation phase starts declining, then a new, more efficient technological solution enters the market. This cycle repeats with every novel technology, by gradually gaining a superior share over the previous solution (Marchetti, 1977; Rogers, 1962; Balachandra, Nathan & Reddy, 2010; Byun, Sung & Park, 2018). Notably, research particularly worth mentioning is the book by Everett Mitchell Rogers entitled "Diffusion of Innovations", firstly published in 1962, which has been one of the most recognized works in the field of social sciences and its recent 5th version considering the impact of the Internet has been published in 2003. In this seminal book, Rogers, inspired by the S-curve of diffusion, introduced newfangled categories of novel technology adopters (innovators, early adopters, early majority, late majority, and laggards), and their structure is illustrated through the Bell curve, a normal distribution chart popularly called a 'Napoleon's hat', as shown in Figure 1 (a blue Bell curve). The main criterion for the adopter classification introduced by Rogers is so-called innovativeness, which can be described as the extent to which an individual implements an original solution (Rogers, 1962). Following that principle,

[4] The valley of death is a widely-known notion in the innovation management literature, described as the gap between the initial development stages of a given technology and its market penetration, characterized by high manufacturing costs and insignificant commercial usage.

individual categories are discussed further. Innovators distinguish each other through the highest social status and financial liquidity, which enables them to invest in high-risk, early-stage technologies. Early adopters are crucial to the further spread of a novel technology as they are opinion leaders for the other adopters by making rational and thoughtful adoption decisions, and therefore can be seen as visionaries. Early majority representatives, as pragmatics, usually need significantly more time than innovators and early adopters, yet due to connections with the latter group, they often contribute to the system as opinion leaders as well. The late majority enters after the average adopter in society, as they have a strongly skeptical approach toward innovations. Lastly, laggards adopt innovative technology at the latest, as this category prefers traditional solutions and is often hermetic in its social interactions (Rogers, 1962).

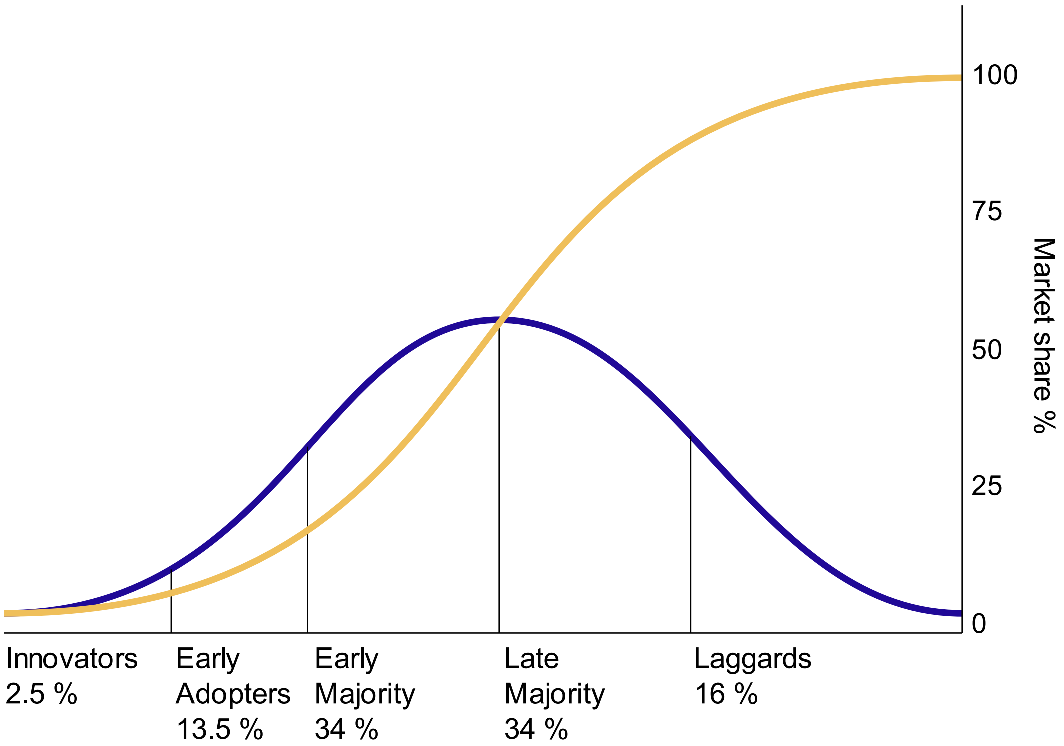

Figure 1. Rogers' diffusion of innovations (adapted from Rogers, 1962).

According to Rogers (1962; 2003), who was a prominent contributor to communication studies, the process of the adoption of a new concept relies on five key elements, which are: the innovation per se, adopters (target groups of usage), communication channels, time, and the determinants of the given social system. It is, therefore, claimed that the whole process of technology diffusion, which often enables innovation and economic growth, is heavily dependent on the conditions of the social capital of a given country or economy (Fukuyama, 2001; Landry, Amara & Lamari, 2002; Dakhli & De Clercq, 2004; Akçomak & ter Weel, 2009). Accordingly, it is reasonable to assume that the agents characterized with higher societal status and agency to initiate innovations would have more ability and motivation to support the diffusion of innovative technology (Eveland, 1986). Similarly, a user-oriented information systems theory called a Technology Acceptance Model (TAM) was created by Fred Davis in 1989 to understand what factors are crucial for potential customers to accept and adopt new technology. According to Davis (1989), *behavioral intention* is a key factor leading customers to implement the technology. It is strongly influenced by *attitude*, which can be understood as an overall perception of the technology. The TAM further indicates two major determinants of the adoption of innovative technology by new users, and they are 1) **perceived usefulness**, defined as "*the degree to which a person believes that using a particular system would enhance their job performance*"; and 2) **perceived ease-of-use**, which is *"the degree to which a person believes that using a particular system would be free from effort"* (Davis, 1989). The model was further examined and modified, namely by Viswanath Venkatesh (e.g. Venkatesh & Davis, 2000; Venkatesh et al., 2003; Venkatesh & Bala, 2008).

Another significant and thus worth mentioning contribution to the theory of technology of innovations was the book called "The Innovator's Dilemma", which is the signature work of the Harvard Business School professor Clayton M. Christensen, first published in 1997. The book introduces the concept of **disruptive innovation**[5], which differs from sustaining innovations by creating a new market and value network or transforming an existing market by providing new values that ultimately (and often unexpectedly) outperform incumbents (well-established market leaders, their products, and partnerships). Christensen further claims that technology start-ups, by introducing disruptive innovations to the market can rapidly gain superior market share by continually improving their technological solution even if they compete with presumably successful and well-managed big-sized forerunner corporations (Christensen, 1997). More recent research supports the ability of start-ups as well as small- and medium-sized enterprises (SMEs) to disrupt existing structures while leaving space for big players to further develop them (Assink, 2006; Wu, Wang & Evans, 2019). This paradoxical effect has been a source of the incumbent's dilemma either to pursue efforts to catch up with the already existing innovation or rather give up and to target the focus on some other activities that might bring a new origin of a given company's competitive advantage. This phenomenon has two major principles.

[5] Christensen (1997) distinguished two major categories of innovation. Sustaining innovations have minor impact on existing markets. They can be either evolutionary or revolutionary, depending on the customer expectations. Disruptive technology radically transforms the existing market structures, often by creating a new market.

Firstly, the value flow in innovations is the previously mentioned S-curve, which means that the process of new product development is time-consuming and requires repetitive improvements. While first improvements may not generate substantial customer value, the next iterations lead to the customer base creation which enhances the augmented increase of value making. After customer base creation, every improvement is efficaciously better than the previous one. Once all the necessary improvements are made, the value per iteration becomes gradually less significant. This shows that, according to the S-curve, the most value is being generated in the middle stages of technological development, whereas the value created at the beginning and ending stages is the slightest. *Secondly*, a smaller size can be a source of competitive advantage. While market leaders with their huge customer base depend on their shareholder's satisfaction with yearly incomes, new market entrants create business niches that attract novel customers. By being more independent, start-ups and SMEs have increased their capabilities of innovative product development (Christensen, 1997; 2008). This so-called 'incumbent innovation gap'[6], together with the introduction of the concept of disruptive innovation had a major impact on the perception of innovation by business executives across the globe.

Technology diffusion became an essential part of socioeconomic, technological, and business strategy research, which has resulted in a plethora of academic literature on this field in many industries. However, the diffusion of renewable energy technologies remains a relatively modern area of interest. The succeeding section concisely explores this phenomenon to support the research problem statement.

1.2.1 Diffusion of renewable energy technologies

As can be concluded from section 1.2., the diffusion of new technology is a complex and multifarious procedure, depending on various factors that enhance its success. Apart from strictly technological aspects, business expertise is critical to analyze and manage this process in a highly competitive and rapidly changing market environment. However, the diffusion of RETs is even more perplexing and burdensome, as numerous industry-specific barriers of divergent nature hamper their widespread adoption. It is important to note at this point that RETs are considered as disruptive technologies, which implies a laborious process of their commercialization (Green & Newman, 2017; Schilling & Esmundo, 2009; Zheng

[6] This notion is created by the Author of this dissertation and aims to describe the phenomenon of the inability of incumbent firms to catch up with the innovation already introduced to the market by new entrants (often start-up or SME).

et al., 2018; Min & Haile, 2021). Renewables have the capacity to disrupt current energy markets, which are, more often than not, strikingly centralized and managed by large, state-owned energy giants, which tend to favor conventional energy sources (Painuly, 2001). The energy transition is therefore associated with infrastructural and regulatory challenges, and there is a strong need for the contribution from different sectors of society to initiate change towards cleaner production. Moreover, green investments are prone to high-risk levels, as they require hefty investments which have rather long payback time, and market conditions are considerably dynamic (Wüstenhagen & Menichetti, 2012; Liu & Zheng, 2017; Shakeel, Takala & Zhu, 2017).

As can be derived, it is extremely challenging for the RETs to compete with the conventional energy sources, as – even if they are naturally generated and supposedly ever-lasting – there is a limited capacity for RETs deployment into the national energy mixes (Zakeri, Syri & Rinne, 2015; Hansen, Narbel & Aksnes, 2017). This is due to diverse technological, socioeconomic, and regulatory issues. Moreover, the energy transition cannot be fostered without necessary improvements in the current energy systems as well as supportive regulatory frameworks or knowledge-promotion activities within societies (Sáez-Martinez et al., 2016). Studies conducted in Finland support the claim that major factors hampering the diffusion of RETs in this country are ineffective or excessive policy schemes, uncertain market conditions, market-motivated technology development, limited financing, and infrastructural agency or internationalization difficulties (Lund, 2007 b; Aslani et al., 2013; Aslani, Naaranoja & Wong, 2013; Child & Breyer, 2016; Sokka et al., 2016; Varho et al. 2016; Shakeel et al., 2017; Panula-Ontto et al., 2018; Peura et al., 2018). It is therefore troublesome for the RETs companies to gain substantial competitive advantage without a multidimensional supportive energy ecosystem. Aside from the auxiliary regulatory frameworks, market-pull and technology-push factors are widely perceived as incubators of environmentally-friendly innovations (Horbach, Rammer & Rennings, 2012). Furthermore, a social acceptance of green innovation is a highly important – yet often underestimated – factor of successful RETs diffusion. Since any product will succeed without fulfilling the need of the end customer, companies should promote various awareness-raising actions about their technologies by underlining their beneficial contribution to the environment and society (Wüstenhagen, Wolsink & Bürer, 2007; Ruggiero, Onkila & Kuittinen, 2014; Batel, 2020).

Modern companies should therefore resign from the strictly profit-oriented business models and start to perform their daily operations according to the concept of a triple-bottom-line of economic, environmental, and societal value generation (Elkington & Rowlands, 1999; Elkington, 2013; Gimenez, Sierra & Rodon, 2012). This approach supports the claim that just by being environmentally friendly, companies would struggle to gain a long-lasting market share as there is a cost reduction requirement for the RETs to become competitive with conventionally-generated energy sources (Gross, Leach & Bauen, 2003). However, if the cost of environmental pollution would have been calculated (so-called externality costs), there is a high potential for RETs to become cost-competitive (Owen, 2006). Moreover, many RETs have experienced a significant cost decline in recent years (Timilsina, 2021), which has enhanced their widespread diffusion. However, as suggested by one of the most influential environmentalists and Nobel Peace Prize recipient Al Gore, climate change is at a 'political tipping point', and there is still plenty of effortful work to be done by governments, politicians, and businesses managers to save our planet from extinction (World Economic Forum, 2022).

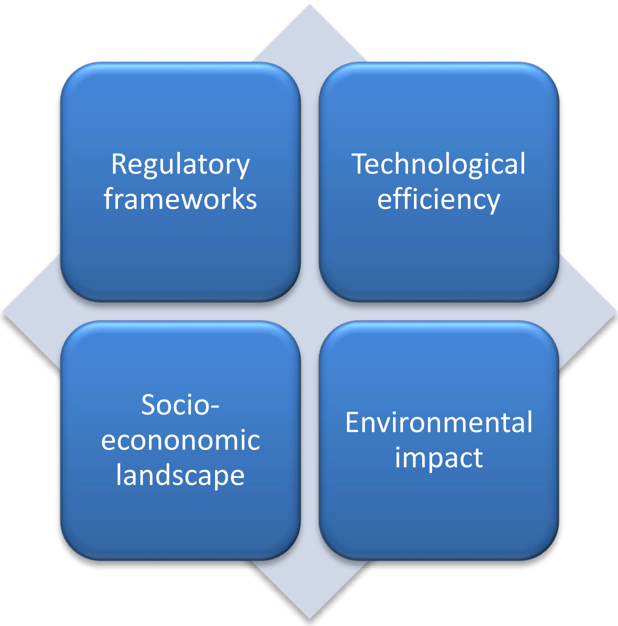

Figure 2. Key factors influencing the diffusion of renewable energy technologies (own conceptualization).

From the above deliberation, it can be concluded that effective diffusion of renewable energy technologies requires multi-factor support (*vide* Figure 2.), and if any of these elements is lacking, the process becomes tremendously problematic.

1.3 Research problems, objectives, and questions

The objective of this doctoral dissertation is to analyze the most effective ways to enhance renewable energy technologies diffusion. Experience shows that successful commercialization of RETs requires multi-level contribution from various interest groups, and therefore it is a complex and multifarious phenomenon. As discussed in Section 1.2.1, the widespread diffusion of renewables depends heavily on supportive regulatory frameworks, technological advancement, infrastructural modernization, or societal acceptance levels, which can cause multifarious challenges for the RETs companies as well as multiple stakeholders, including the policymakers. Following that reasoning, this doctoral thesis aims to explore the impact of regulatory, technological, and socio-economic factors on the successful diffusion of RETs. The empirical analysis is based on cases from Finland and Poland (the motherland of the Author). The motivation for this study is based on major differences in investigated factors in these two European Union member states.

Finland is one of the world's most innovative countries, leading in different R&D and sustainability rankings (WIPO, 2021; Kivimaa & Rogge, 2022). As a Nordic country, the paradigm of admiring and cultivating the natural environment is deeply rooted in Finnish culture. That is why Finland is considered as a European or even global role model in energy transition, as the role of renewables in electricity generation in 2020 reached nearly 40% and surpassed fossil fuels and peat combined for the first time in the country's history of records (Statistics Finland, 2021). However, there is a limited capability to commercialize innovative technological solutions in this country. Therefore, strong managerial support for the growing number of technology-oriented start-ups and SMEs is highly expected (Sokka et al., 2016; Shakeel, Takala & Zhu, 2017). The extant literature scrutinizes renewable energy technology adoption from the company's perspective, often from the regulatory or technical point of view. However, the macro-level approach highlighting the importance of multi-sectoral collaboration to support the diffusion of RETs, the role of external financing or innovative technologies in the effective adoption of RETs has not been thoroughly explored yet, and some aspects have been not considered at all. Some studies were aimed at fostering renewables' implementation in Finland, but not from the holistic managerial approach.

Poland, on the other hand, can still be classified as a developing country. Its energy sector is heavily politicized and centralized, which drastically hampers the development of the renewable energy market (Brauers & Oei, 2020). As a consequence, the Polish energy sector remains in the shadow of the coal and lignite industry (Hernik, Noszczyk & Rutkowska, 2019; Pietrzak et al., 2021; Igliński et al., 2022). Nevertheless, there is rapid growth in various RETs markets, namely solar PV and wind power. Surprisingly, due to the overall decline in energy consumption caused by the COVID-19 pandemic, Poland has managed to reach its goal of the share of renewables of 15% in the final gross energy consumption by 2020 already in 2019 (Rokicki et al., 2022; Statistics Poland, 2022). Many studies explored the Polish renewable energy sector with the aim to determine major challenges and opportunities for its further development. However, often from a regional perspective or from the specific renewable energy technology market. This dissertation provides a holistic approach towards major bottlenecks and improvement mechanisms for the Polish RETs sector by comparatively analyzing its conditions with the Finnish realities, hence it is the first comparative study about these two countries. In substance, this dissertation aims to fill the literature gap by not only considering RETs industry as a whole [as opposed to extant studies focused on specific technologies, such as solar PV (Bollinger & Gillingham, 2012; Hansen, Pedersen & Nygaard, 2015), wind power (Söderholm & Klaassen, 2007; Rao & Kishore, 2009; Bento & Fontes, 2015), or biogas (Capodaglio, Callegari & Lopez, 2016; Markard, Wirth & Truffer, 2016; Wanda & Hjelm, 2021), etc.], but also examining multidimensional aspects of the RETs diffusion [in addition to the specific aspects chiefly scrutinized before, such as e.g. market dynamics (Palmquist & Bask, 2016; Zou et al., 2017; Egli, Steffen & Schmidt, 2018), energy policies (Tsoutsos & Stamboulis, 2005; Jacobsson & Lauber, 2006; Lund, 2009; Mercure et al., 2014; Hille, Althammer & Dietrich, 2020), sustainable development (Dincer, 2000; Lund, 2007 a; Tabrizian, 2019; Bórawski et al., 2022), societal awareness/acceptance (Reddy & Painuly, 2004; Wiser, 2007; Wüstenhagen, Wolsink & Bürer, 2007; Batel, 2020), or technological requirements (Popp, Hascic & Medhi, 2011, Zakeri, Syri & Rinne, 2015; Min & Haile, 2021)]. Section 5.3 highlighting the theoretical contributions of this study provides further research gap comprehension and comparison with prior research in the field of (RETs) technology diffusion.

This study, by exploring major bottlenecks for RETs diffusion as well as suggesting practical measures to enhance this process, highlights the importance of a multi-level contribution as its indispensable element. The ultimate goal of this macro-level analysis is to provide a roadmap for a widespread diffusion of RETs in Finland and Poland. Therefore, the main research question of this study is the following:

RQ: What kind of regulatory, technological, and socio-economic factors are key to promoting the diffusion of renewable energy technologies?

In order to thoroughly address the main research question, the following sub-questions are articulated:

RQ1: What are the major barriers for RETs diffusion and how to overcome them?

RQ2: What role can circular economy and smart specialization play in adopting RETs at a regional scale?

RQ3: What role can venture capital play in the widespread diffusion of RETs?

RQ4: How significant would be the impact of blockchain technology on fostering RETs diffusion?

1.4 Context and structure of the study

As mentioned in Section 1.3., this study aims to comparatively examine socio-economic, technological, and regulatory factors in two European countries, Finland and Poland. The structure of this doctoral dissertation is divided into two major parts, as presented in Figure 3. The first part summarizing the main study objectives and outcomes is formed into five chapters. The first chapter introduces the phenomenon of renewable energy technology diffusion and highlights its importance for mitigating climate change and fostering the energy transition. This part is also indicating a research gap that the study aims to fulfill as well as study objectives and research questions. The second chapter provides a theoretical background for the study by discussing major concepts that have served as a foundation throughout this research. The third chapter presents a philosophical approach to this study as well as the key research methods implemented. The fourth chapter sheds light on the research articles supporting this study by outlining their goals, methods, and key outcomes. The final chapter concludes the Summary part with the limitations, conclusions, and contributions of the study to the theory and practice.

The second section comprises five research articles supporting the study by addressing the research questions formulated in the introductory part. By following a **problem-solving approach**, these academic papers are structured independently of their chronological order of publication. The reasoning behind a particular order is to identify the most challenging barriers for RETs diffusion at the initial stage to suggest mechanisms and measures aimed at tackling these numerous and multifaceted issues. Therefore, the first article presents a literature review of the most challenging barriers for RETs diffusion in Finland and Poland. Article 2 supports this concept by providing empirical evidence from the renewable energy industry together with practical improvement measures on a macroeconomic scale. The following articles propose potentially beneficial solutions for the RETs industry. The third article scrutinizes the concept of circular economy and its application on a regional scale to initiate green innovation. The fourth publication highlights the extra-financial value addition of venture capital (VC) to the development of RET-focused start-ups and SMEs, by presenting the VC contribution matrix. The last article presents the potential benefits of blockchain technology implementation within the RETs industry and proposes a roadmap for blockchain adoption.

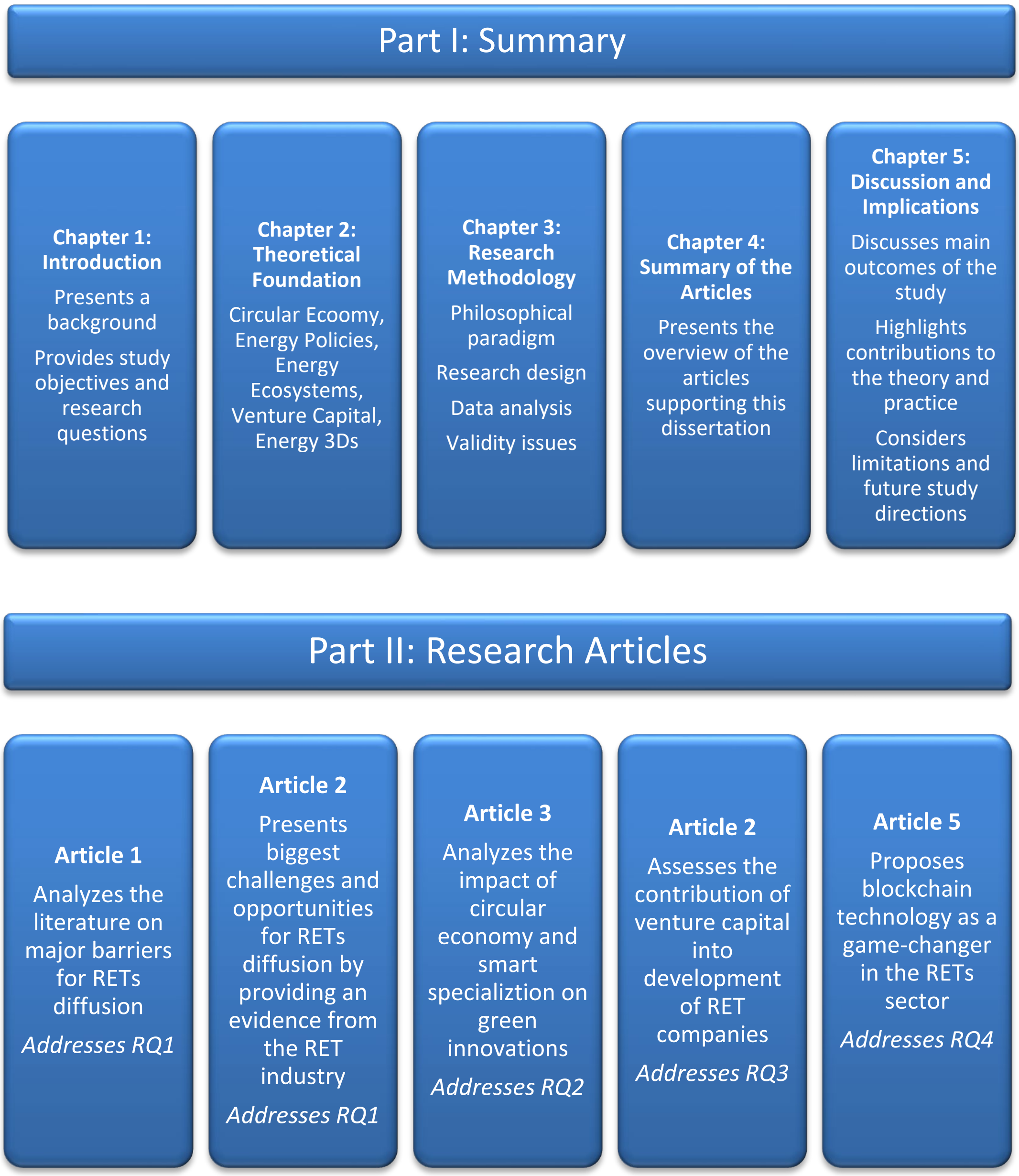

Figure 3. Structure of the dissertation (own elaboration).

All five scientific publications support this study by helping to address the main research question. The common goal of these articles was to investigate the major regulatory, technological, and socio-economic hindrances for the diffusion of RETs with the aim to find theoretical and managerial solutions to improve the current state of affairs in both compared countries. A special focus has been put into specific solutions aimed at enhancing a widespread RETs diffusion such as smart green innovation according to the concept of circular economy, venture capital's role in providing extra-financial value addition into their portfolio companies as well as digital innovation technologies such as blockchain's revolutionary impact into RETs industry. One of the articles presents a case study from Poland, two studies provide empirical evidence from Finland, whereas two papers perform a comparative cross-country analysis from both Finland and Poland.

The Polish energy sector requires effective substantial improvements in infrastructural and regulatory systems (Pietrzak et al., 2021; Igliński et al., 2022). Nevertheless, some RETs markets in Poland are developing at a fast pace, including solar PV, wind power, and bio-energy. The latter technology has been found as a source with the highest share and growth potential. As renewable energy markets are highly decentralized, local cases of performing innovations in waste-to-energy and biogas technologies have been chosen as examples of the possible direction of RETs sector development in Poland. Finland, on the other hand, is a leading country in terms of energy sophistication and innovation capabilities (Kivimaa & Rogge, 2022). Therefore, to address the challenges of a growing number of RET-focused start-ups and SMEs, venture capital has been proposed as one of the possible incubators of technology diffusion in Finland. Furthermore, the Finnish grid infrastructure is technologically advanced, which enhances the possibility of blockchain implementation in Finnish future energy systems. Finally, as there are explicit barriers for RETs diffusion in every country, two articles provide insight into the most challenging obstacles from both Finland and Poland. This comparative analysis aims to detect similarities and differences between country-specific regulatory, socio-economic and technological landscapes for renewables development in order to suggest possible improvement measures and mechanisms. All of these five articles are published after a peer-review process. Four of them are peer-reviewed journal publications whereas one study is a post-conference book chapter. The overview of the articles included in this doctoral dissertation can be seen in Table 1.

The author's contribution to each article might have been different depending on his role in a certain research project, therefore it is worth clarifying it here. In Articles 1 and 2, and 5 Author has been a project leader, the main initiator of the concept, the principal investigator, data analyst, and writer. In Article 3, the Author has assisted in data collection (including one individual study visit devoted to the official consultations with the local community) and was responsible for methodology, SWOT analysis, and final draft preparation. In Article 4, the Author was invited by his department colleague to join the research project. He assisted in data collection, and data analysis, and was particularly in charge of performing a literature review, methodology part including information about case companies as well as methods of presentation of results (i.e. developing "VC contribution matrix). Overall, the Author has been actively involved in key research activities related to each publication.

Table 1. Details about the articles included in this dissertation (own elaboration).

Article	Title	Research theme	Research design	Publication
Article 1	Comparative Analysis of Barriers for Renewable Energy Technologies Diffusion in Finland and Poland.	Identifies the most common barriers for RETs diffusion in the literature	Literature review, statistical analysis, data triangulation	Advances in Human Factors, Business Management and Leadership, Springer, Cham.
Article 2	Barriers for Renewable Energy Technologies Diffusion: Empirical Evidence from Finland and Poland	Provides insight from industry experts on how to address major barriers for RETs diffusion	Qualitative cross-case study (semi-structured interviews, data triangulation, literature review, statistical analysis)	Energies, MDPI
Article 3	Local contribution to circular economy: a case study of a Polish rural municipality	Explores local smart specialization strategies for biogas and waste-to-energy technology innovation	SWOT analysis, Constructive Research Approach, statistical analysis, data triangulation	Economia agro-alimentare / Food Economy
Article 4	The role of Venture Capital in the Commercialization of Cleantech Companies	Examines venture capital's extra-financial value addition into RETs firms	Qualitative cross-case study (semi-structured interviews, data triangulation)	Management
Article 5	Blockchain for Renewable Energy – Principles, Applications & Prospects	Explores the potential outcomes of blockchain adoption with RETs sector	Qualitative case study (literature review, semi-structured interviews, content analysis, data triangulation)	Energies, MDPI

2 THEORETICAL FOUNDATION

This chapter establishes a theoretical foundation for this doctoral dissertation. Initially, the central role of energy policies in renewable energy technologies diffusion is highlighted. Then, the requirement of strengthened multi-sectoral contribution is addressed by discussing the importance of energy ecosystems, which is further supported by the concepts of triple, quadruple, and quintuple helices. Afterward, the concept of circular economy is scrutinized with a particular emphasis on its application in smart specialization strategies of local communities. Next, venture capital and its role in providing value addition to its portfolio companies are discussed. Furthermore, the concept of Energy 3Ds of decentralization, decarbonization, and digitalization is deliberated to support innovative, future-oriented, efficiency-boosting technologies such as IoT and blockchain and their role in imminent energy systems. Lastly, the discussed concepts are synthesized to develop a conceptual framework for this thesis.

2.1 Energy Policies

The mainstream research literature firmly supports the claim that energy policies and regulatory frameworks play a pivotal role in the successful diffusion of renewable energy technologies (Jacobsson & Johnson, 2000; Lund, 2009; Monni & Raes, 2008; Klessmann et al., 2011; Kitzing, Mitchell & Morthorst, 2012; Aslani, Helo & Naaranoja, 2014; Scarlat et al., 2015; Brauers & Oei, 2020; Hille, Althammer & Dietrich, 2020). Energy policies usually comprise a set of rules, guidelines, and mechanisms that regulate the given energy sector. The goal of that regulation is to manage national natural resources, energy security, and supply, and to establish strategies for the continuous improvement of the energy system, often according to the preferred sources of energy generation (Allcott, Mullainathan & Taubinsky, 2014). Energy policies should form a comprehensive strategy to fulfill pre-established requirements for accomplishing energy independence, self-sufficiency, and security. Therefore, it is a strategic plan for the enhanced sustainable development of a given country formed mainly by its government. Energy policies can be influenced by numerous multidimensional factors, such as e.g. the availability of natural resources, visions of current authorities, energy security and efficiency aspects, environmental, economic, and sustainability factors, or legally-binding resolutions of the international regulations (Klessmann et al., 2011; Polzin et al., 2015; Lorente & Álvarez-Herranz, 2016). Reasonable and well-rounded governments should create a realistic, effective, and comprehensive plan for the sustainable development of a given country's energy system, taking into account not only the country-specific interests but also the deteriorating impact of using fossil fuels on the natural environment of our planet (Arent, Wise & Gelman, 2011; Gielen et al., 2019; Braures & Oei, 2020).

As both Finland and Poland are European Union and United Nations member states, it is important to discuss the international energy policies aimed at combatting the adverse impact of climate change. Starting from the global-range UN's resolutions, implemented namely by its agenda named Intergovernmental Panel on Climate Change (IPCC) during various COP conferences that aimed to reach a global agreement on common goals and targets for the decades to come. The conference that had a major impact in recent history was COP21 in 2015 which implemented a Paris Agreement setting the so-called "3x20%" targets for 2020. These targets corresponded to the increase in the share of renewable energy sources in final gross energy consumption and energy efficiency by 20% as well as the reduction of greenhouse gas (GHG) emissions by 20%, in relation to the state of affairs in 1990 (UN, 2016). The European Union, treating these obligations with the care of future generations, implemented various strategies to address the issues raised by the international community. Current goals for 2030 raised the levels to 32% renewables share, 32,5% energy efficiency, and GHG emissions decline of 40%, compared to 1990 (EC, 2013). Additionally, the European Commission has developed a longer-perspective policy for climate-neutral Europe by 2050, which assumes the possibility to reach a 50% share of renewables and 80-95% GHG emissions cutback, in comparison to 1990 realities (EC, 2018). Several additional EU climate change policies have been implemented, such as the "European Green Deal", or "Fit-for-55" that provide diverse multidimensional incentives for the European countries to pursue efforts to continuously become more environmentally friendly (EC, 2019 & 2021).

On the country-specific level, governments ought to implement the policies called "Renewable Energy Action Plans" that address the legally-binding obligations resulting from the resolutions mentioned above. These policies consider internal conditions of the country's socioeconomic, technological, or political implications for the energy transition in order to establish a realistic, effective, and sustainable roadmap for fulfilling international obligations (Dupont, 2015; Kettner & Kletzan-Slamanig, 2020). According to the European Union's guidelines, these strategies should principally consider the factors of 1) energy supply security, 2) internal energy market expansion, 3) energy efficiency increase, 4) decarbonization and GHG emissions reduction, and 5) enhanced support for research and innovation (EC, 2009). For the sake of fostering green and sustainable innovations, policies should include numerous subsidies and support schemes. Among the most dominant support mechanisms there are those of chiefly a financial or fiscal nature: governmental grants, feed-in tariffs (FiT), tradeable renewable energy (or green) certificates, carbon credits, and numerous tax incentives (Fouquet & Johansson, 2008; Falconett & Nagasaka, 2010; Abolhosseini & Heshmati, 2014; Mazurek-Czarnecka et al., 2022). In conclusion, energy policies play a central role in supporting the widespread diffusion of RETs, as they constitute a preliminary factor for the enhancement of renewables (Lund, 2009; Kitzing, Mitchell & Morthorst, 2012; Juszczyk & Shakeel, 2020; Juszczyk et al. 2022).

2.2 Energy Ecosystems

The diffusion of renewable energy technologies is a highly complex and multifarious phenomenon. There is a requirement of forming a supportive ecosystem to enhance this process. In addition to the necessary regulatory frameworks and governmental support schemes discussed above, other crucial factors influence the development of environmentally sound technology solutions, such e.g. as market pull and technology push effects, level of societal acceptance, cost competitiveness, etc. (Davis, 1989; Horbach, Rammer & Rennings, 2012; Batel, 2020). Therefore, a multisectoral contribution is essential to allow RETs to diffuse more effectively (Jacobsson & Johnson, 2000; Shakeel, Takala & Zhu, 2017). In order to form a comprehensive supportive environment for RETs diffusion, the involvement of numerous interest groups from various sectors of society (i.e. public, business, academia, and society) is fundamental for the creation of energy ecosystems and/or collaborative networks.

In fact, most of the economic growth theories have been founded on the assumption that innovation brings improvements in technology development, productivity, and knowledge creation; and the role of various actors contributing to innovation activities is critical. Starting from the seminal input from Schumpeter, who depicted economic growth as a procedure of qualitative, innovation-driven improvement and firmly underlined the role of entrepreneurs as agents for innovation (Schumpeter, 1911). He continued this reasoning to detect the strategic role of large enterprises in economic development, and research and development activities creating new knowledge as a vital aspect of innovation (Schumpeter, 1942). Similarly, Solow's Neoclassical Growth Theory proposes that, within the dimension of industrial contribution, long-perspective economic growth is a mix of enhanced progress in the spheres of labor, capital, and technology (Solow, 1956). Later on, Romer's Endogenous Growth Theory perceived a global transition from a resource-based into a knowledge-based economy as a central feature of socioeconomic and technological development (Romer, 1986). As can be derived from these theories, innovation plays a fundamental role in economic development and it is initiated principally based on the collaboration between academia and industry. However, to magnify the benefits for the common interest, a collaboration between all sectors of society is necessary. Especially in the energy industry, input from the public sector is required to provide regulatory support, and societal involvement is crucial for gaining more knowledge about the technologies, which will create more trust and result in a significantly higher level of societal acceptance. Therefore, the role of collaborative networks and ecosystems is critical in enhancing the widespread diffusion of RETs (Hellström et al., 2015; Cantner et al., 2016; Newell, Sandström & Söderholm, 2017; Baldwin & Tang, 2021; Oskam, Bossink & de Man, 2021).

2.2.1 Triple, Quadruple and Quintuple Helices

To support the theoretical foundation of this study, and to underline the necessity of the multidimensional contribution to the successful diffusion of RETs, concepts of triple, quadruple, and quintuple helices are scrutinized. These concepts emerged from the economic growth theories discussed above, and follow the examination of the roles of different actors representing various sectors of society in innovation, knowledge creation, and, ultimately, economic growth. The triple helix approach was developed by Etzkowitz and Leydersdorff in 1995, which, in addition to the spheres of Industry and University examined before, considers the Public sector that can govern the transfer of innovation in a systematic, top-down manner. Afterward, Yawson (2009) developed this concept by considering the significance of the input of the media-based and culture-based civil society. While industry-university collaborative networks form a principal integrated innovation ecosystem, and governments provide necessary regulatory support through innovation-driven policies and strategies, civil society can actively contribute to innovation through various bottom-up activities, e.g. demands of certain goods and services, enhancing information and knowledge circulation, activist movements, user feedback, etc. Lastly, a quintuple helix complements the quadruple helix by considering the role of the natural environment, particularly the socio-ecological interactions in the innovation, which makes this tool applicable across various approaches and disciplines for managing sustainable development (Carayannis, Barth & Campbell, 2012). The relationships in the quintuple helix are presented in Figure 4.

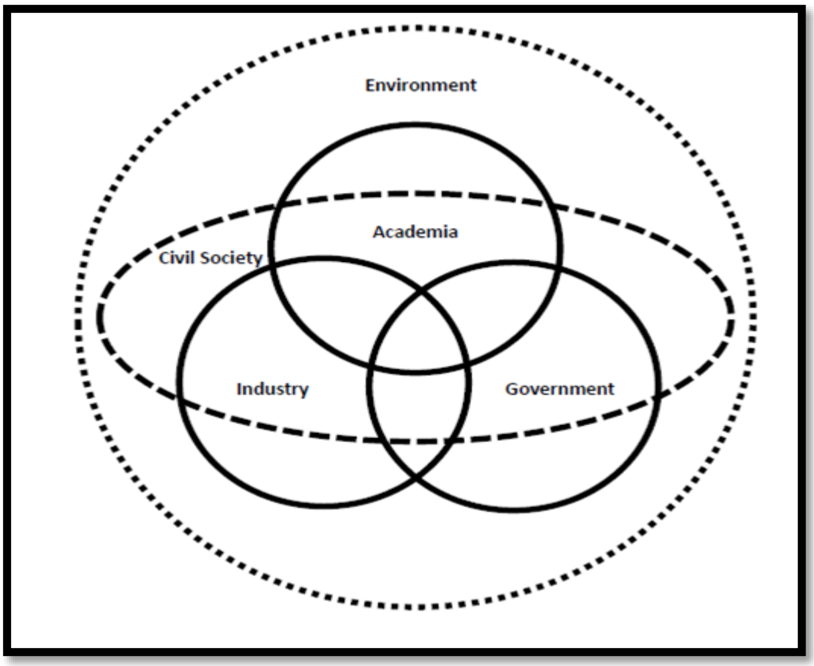

Figure 4. Dimensions in Quintuple Helix (adopted from Carayannis, Barth & Campbell, 2012).

All of these approaches of triple, quadruple, and quintuple helices provided implications beyond a mere theoretical framework, as they have been directly adopted as innovation tools for local or territorial development. For that cause, triple helix has been widely implemented in various innovation-oriented activities on a both regional and national scale, whereas quadruple and later on quintuple helices have been recognized as a tool recommended by the European Commission for the creation and application of research and innovation strategies for smart specialization (RIS3) (EC, 2012; Carayannis & Rakhmatullin, 2014; Markkula & Kune, 2015).

2.3 Circular Economy

The concept of circular economy (CE) significantly supports the diffusion of RETs by providing sustainable solutions for waste management, including waste-to-energy solutions (Olabi, 2019; Rokicki et al., 2020). Kirchherr, Reike, and Hekkert (2017), after considering 114 definitions of circular economy, describe this concept as an economic system that replaces the “end-of-life” approach with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. The concept of circular economy is widely promoted by various countries, companies, and organizations across the globe, including the European Union, which integrates circular economy into its zero-waste program that aims to improve the use of resources for economic and environmental benefits (EC, 2014). Stahel (2016) uses an aquatic comparison between linear and circular industrial economies, by referring to the linear approach as a river, where natural resources are turned into materials and products intended to be sold to the customer, to whom the responsibility of waste is transferred in the moment of the purchase. In that reasoning, the circular economy is resembling a lake, where reprocessing of goods creates multidimensional benefits, such as local jobs creation as well as reduction of resources and energy consumption and waste. Therefore, a circular economy assists in maintaining the added value of products and eradicating various kinds of waste as lengthy as possible. However, the effective transition into a circular economy entails transformation at each link of the value chain, e.g. from product design to novel business models, from new methods of converting waste into new customer behavior, etc. (Korhonen, Honkasalo & Seppälä, 2018; Lokesh, Ladu & Summerton, 2018; Järvenpää, Kunttu & Mäntyneva, 2020).

The circular economy has a huge potential to generate major changes in current production, consumption, and waste management practices (Gołębiewski et al., 2019). Starting from the initial stages of a product life cycle, the materials and design might have an impact on the product's durability and capability of reparation, modernization, or regeneration (Bocken et al., 2016). Therefore, it is expected from various stakeholders to support production practices that consider their environmental and socioeconomic impact and to foster large-scale implementation of circular economy practices (Ghisellini, Cialani & Ulgiati, 2016; Lieder & Rashid, 2016). Secondly, consumption patterns are also a crucial aspect of circular economy diffusion. Customer behavior might either foster or hamper such practices, thus it is essential to cultivate consumption activities that are aimed to reduce waste and enable the active role of the supply chain participants (Borrello et al., 2017; Camacho-Otero, Boks & Pettersen, 2018). Lastly, and perhaps most importantly, a circular economy enhances more efficient waste management and recycling practices. Principally, CE provides solutions for waste reduction through a more sustainable and environmentally friendly approach toward products. When it comes to waste management per se, CE assists in waste hierarchization, through prevention, reuse, recycling, energy recovery, to disposal, e.g. landfilling (Pires & Martinho, 2019). Such practices are prioritizing the options that have the most optimal and favorable environmental impact. Therefore, CE has a major capability to drive sustainable development, by assisting economic growth in minimizing the adverse impact or resource exhaustion and environmental deprivation (Murray, Skene & Haynes, 2017; Morseletto, 2020; Taušová, Tauš & Domaracká, 2022). Furthermore, the effectiveness of waste management ensured through CE might lead to significant improvements in RETs industry, by providing more sustainable solutions for generating energy from municipal, industrial, or agricultural waste, such as biomass, biogas, or waste-to-energy technologies (Malinauskaite et al., 2017; Olabi, 2019; Rokicki et al., 2020; Valve, Lazarevic & Humalisto, 2021; Jain et al., 2022).

2.3.1 Smart specialization

As RETs are distributed in nature, it is worth considering local and regional strategies toward more efficient and sustainable adoption of renewables that would provide multidimensional benefits for the communities at hand. Research and Innovation Strategies for Smart Specialization (RIS3) have been proposed by European Commission in 2012 as a local-based approach to using the assets and resources as well as particular socioeconomic conditions of regions with the aim of identification exceptional opportunities for their enhanced development (EC, 2012). The strategy implies the selection of the most optimal options for investment that would support technological, practice-driven, and societal innovation. The whole strategy development process, which is managed by multiple stakeholders from various sectors of society, should define precise monitoring, evaluation, and revision measures to maximize the overall sum of its benefits. Therefore, the goal of the smart specialization is not to specialize (or unify) the given region's economic system, but rather to leverage its current strengths and detect undiscovered opportunities to form strategies for the generation of competitive advantage based on high-value activities (Balland et al., 2019).

Due to some formal requirements such as ensuring ex-ante conditionality or developing action plans, smart specialization has significantly changed the current structures of innovation policy development (Capello & Kroll, 2016). This revolutionary change provides numerous opportunities for entrepreneurs not necessarily connected to the high-tech industry which drives Research and Development (R&D) and generally broadens the scope of possible contributors to regional and national innovation (Ranga, 2018). In summary, the smart specialization strategy is one of the key EU measures to enhance entrepreneurship, new jobs creation, bottom-up initiatives, and innovation for supporting regional and national sustainable development (Markkula & Kune, 2015; Polido et al., 2019; Unay-Gailhard & Bojnec, 2019).

2.4 Venture Capital

Lack of or limited financing options is considered to be one of the fundamental obstacles for technology-oriented start-ups and SMEs (Hall, 2008). Even the most revolutionary invention will not become an innovation without being successfully commercialized, which usually implies the need for strengthened financial support. Therefore, emerging, early-development-stage companies are enforced to seek external financing to support the further development of their business initiatives. The main types of such investments are banks credits and loans, crowdfunding and crowdsourcing, grants, individual investments, business angel investors, or venture capital companies (Mason & Stark, 2004; Colombo & Grilli, 2010; Bjørgum & Sørheim, 2015; Tech, 2018).

Venture capital (VC) is well-known for financially supporting companies at their seed or initial stage of development (Hsu, 2006; Bocken, 2015). As such investments are associated with relatively high-risk levels resulting due to unpredictability of success or failure of the ideas they put their resources into, venture capitalists developed their distinct investment criteria, and the VC investment process is conducted according to the “venture capital cycle” (Gompers & Lerner, 2004; Franke et al., 2006). The goal of this cycle is to estimate the opportunities and threats associated with the investment in a given company, raise necessary funds, and provide managerial resources to develop the business to the extent it will generate satisfactory profit through an exit (Tyebjee & Bruno, 1984; Kollmann & Kuckertz, 2010). From the financing perspective, VC can be seen as an ultimate tool for an organized, intensified, and professional funds acquisition. VC usually collects funds from entities that are willing to provide necessary resources that would contribute to the prosperity of the invested companies in return for a certain equity share (Hall & Hofer, 1993; Kaplan & Schoar, 2005). As can be seen, VC investment, even after careful examination of various factors, is prone to relatively high levels of uncertainty, as future market conditions are often extremely difficult to predict. Moreover, it requires a substantial input of other resources that, in case of failure, might be considered sunk costs. However, the expectations of immense returns on investment associated with the noble experience of venture capitalists persuade them to involve in numerous start-ups and SMEs, and there are more often than not successful experiences (Sandberg & Hofer, 1987; Gompers, Kovner & Lerner, 2009).

Importantly, the evidence from numerous studies suggests that VC, in addition to substantially assisting in the financial capital acquisition, provides non-financial value to its incumbent companies through various other essential skills and resources. Venture capitalists are considered active investors, which usually results in their diligent participation in the executive boards of the companies (Kaplan & Schoar, 2005; MacMillan, Kulow & Khoylian, 2022). Principally, it implies their contribution to the corporate governance, strategy-setting activities, and overall business excellence of their portfolio companies (Fried, Bruton & Hisrich, 1998; Hsu, 2006). It is particularly essential for technology-driven start-ups and SMEs, which more often than not, lack the necessary managerial skills and expertise. Additionally, VC solidly assists in enhancing cooperation through wider business networks, recruitment of the relevant personnel, gaining licensing or legitimization, improving customer outreach, or seeking internationalization directions (Megginson & Weiss, 1991; Sapienza, 1992; Mäkelä & Maula, 2005, Large & Muegge, 2008). All of these above-mentioned dimensions of VC value-added contribution to their portfolio companies, make such involvement the desired option for the enhanced development of innovative technology-focused start-ups and SMEs (Florida & Kenney, 1988; Sapienza & De Clercq, 2000; Chen, 2009; Colombo & Grilli, 2010; Bjørgum & Sørheim, 2015).

2.5 Blockchain Technology as a key to Energy Decentralization, Decarbonization, and Digitalization

It is firmly claimed in the literature that future energy systems will have to transform and innovate according to the concept of the 'Energy 3Ds', which stands for energy decarbonization, decentralization, and digitalization (Di Silvestre et al., 2018; Morell Dameto et al., 2020). Decarbonization refers to the significant limitation of energy generation from fossil fuels and the transition towards clean, sustainable, and environmentally friendly renewable energy sources. Numerous benefits of such transformation have been discussed earlier in this study, but it should be repeatedly emphasized that the implementation of RETs should be prioritized and comprehensively supported by various stakeholders across the globe in order to mitigate the adverse impact of climate change (Nordhaus, 1994 & 2011; Arent, Wise & Gelman, 2011; Al-Ghussain, 2019; Gielen et al., 2019; Cantarero, 2020). Secondly, digitalization is perceived as a source of a fourth industrial revolution (Schwab, 2017) since it provides new, digital solutions that would change current business models and other methods of value generation (Parviainen et al., 2017). The main tools for the digital revolution are cloud computing and storage, information and communications technologies (ICT), the Internet of Things (IoT), artificial intelligence, industrial and manufacturing digitalization, or blockchain technology (Nord, Koohang & Paliszkiewicz, 2019; Hafeez, Juszczyk & Takala, 2021). Thirdly, decentralization is a growing tendency of transferring authority and control over power systems functioning towards more distributed energy generation, which is usually deploying RETs (Alanne & Saari, 2006). Decentralization address the expanding needs and complexity of future energy systems that could not be effectively managed through traditional, centralized energy management techniques.

As shown, future energy systems will have to tackle numerous problems resulting mainly from growing energy demands. Therefore, new, more technologically advanced, and efficient digital solutions will be imperative for the prosperity of imminent energy markets. The key emerging technology that is corresponding to all three dimensions of "Energy 3Ds" is blockchain (or distributed ledger) technology (Juszczyk & Shahzad, 2022). Blockchain contributes to energy decarbonization by e.g. generating new energy markets, such as peer-to-peer (P2P) energy trading platforms, providing new, digital solutions such as smart grid management, demand-response mechanisms, incentives for green investments through energy tokens and cryptocurrencies, transparency and automation of carbon certificates issuance, etc. (Andoni et al., 2019; Teufel, Sentic & Barmet, 2019; Wang & Su, 2020). As a digital solution, the connection to digitalization is quite evident, which makes blockchain an exemplary future-oriented technology that will have a significant capacity to address the expanding needs of current and prospective energy systems (Borowski, 2021; Ahl et al., 2022). Lastly, as decentralization of authority through the elimination of middle men in transaction processes is a central feature of blockchains, this technology has a substantial potential to disrupt or revolutionize existing supply chains, which in addition to ensuring transparency, security, and reliability of transactions, will ultimately result in a cost-reduction of the products delivered to the end-consumers of energy (Helo & Hao, 2019; Saberi et al., 2019; Shahzad, Juszczyk & Takala, 2022).

2.6 Conceptual framework

Building upon the ideas discussed above, it is worth developing a conceptual framework to enhance the implementation fidelity of the outcomes of this doctoral dissertation (Carroll et al., 2017; Leshem & Trafford, 2007). Considering numerous and multidimensional theoretical and practical implications, improvement measures, and other significant interventions that this study proposes, the conceptual framework serves to explain the researcher's theoretical approach toward solving research problems and questions in practice, which positively affects the overall credibility and utility of research (Rocco & Plakhotnik, 2009). Therefore, the conceptual framework for this doctoral thesis is presented in Figure 5 and discussed below.

This study examines various regulatory, socioeconomic, and technological issues related to the diffusion of renewable energy technologies, with a particular emphasis on the state of affairs in Finland and Poland. As this research deploys a problem-solving approach, the major challenges for RETs diffusion were initially identified in order to suggest effective measures for improvement. Principally, the study identifies the central role of energy policies in providing a supportive regulatory and systematic framework for the diffusion of RETs. Furthermore, as the investigated phenomenon is a highly complex and problematic process, the contribution of divergent actors from all sectors of society is highlighted as a key facilitating factor for RETs diffusion. Next, more specific and practical measures are proposed, such as 1) smart specialization according to the concept of circular economy, 2) venture capital as a catalyst for the development of RETs smart-ups and SMEs, and 3) blockchain as the ultimate tool for revolutionizing energy sector and addressing future energy needs. Such a managerial approach provides insight into the Finnish and Polish energy markets and the multifaceted conditions for the RETs development, contributes to the enhanced deployment of RETs on a regional and national level, and proposes practical measures for the enhancement of sustainable entrepreneurship and lastly, recommends digital solutions for taking the renewable energy industry into the next level.

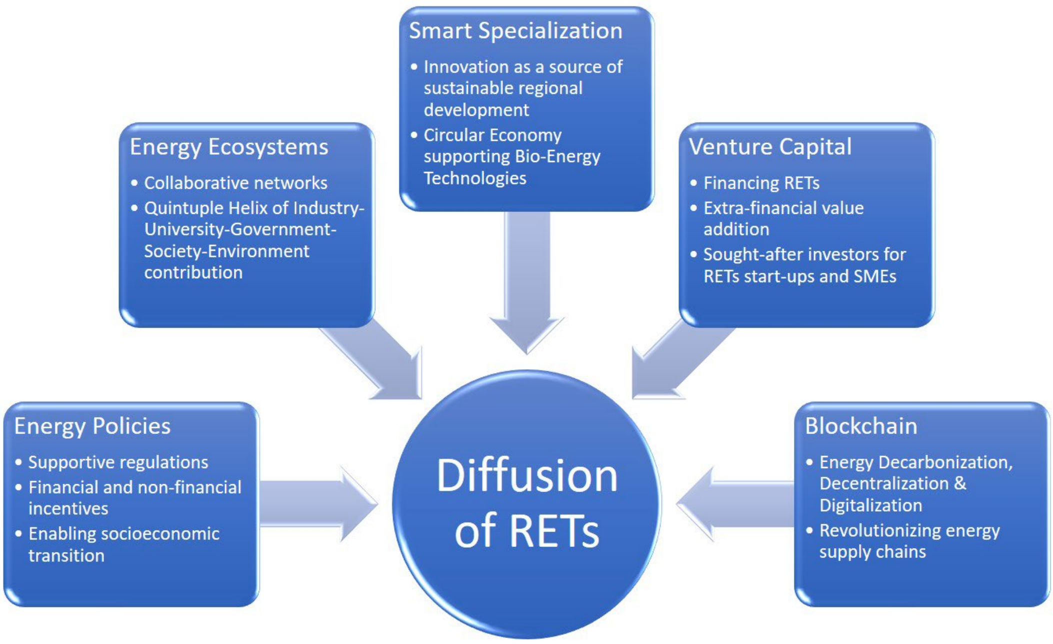

Figure 5. A conceptual framework for this doctoral dissertation (own conceptualization).

3 RESEARCH METHODOLOGY

This chapter explains the methods implemented in this study. It provides information about the philosophical paradigm, and research design, as well as methods of data collection, analysis, and presentation of results. Lastly, validity and reliability issues are discussed.

As research serves to develop knowledge in a given field of science by investigating a particular phenomenon or addressing certain research problems (Williams, 2007), it is suggested to follow the strategy of the so-called "research onion", depicted in Figure 6.

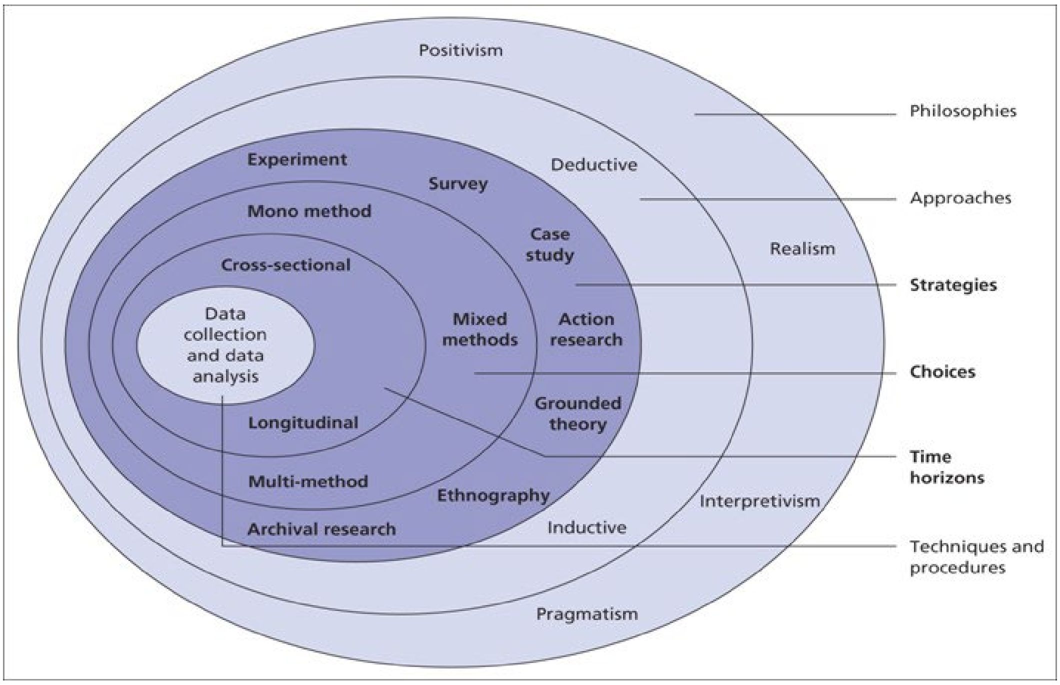

Figure 6. "Research onion" (adopted from Saunders, Lewis & Thornhill, 2016).

The research onion consists of six major layers or phases that help researchers to create a valid methodology (Saunders, Lewis & Thornhill, 2016). The process usually starts with a depiction of the key philosophy, determination of the approach to the theory development, strategic and methodological choices as well as delineation of time horizons, which leads the researcher to the main research design, which is choosing the central techniques and procedures of data collection and analysis (Melnikovas, 2018). Next, the following steps in setting a methodology according to the concept of the "research onion" are discussed in more detail.

1) *Research philosophy*: serves as a research foundation through the determination of ontology (what is real; the nature of reality), epistemology (our knowledge of reality), and axiology (research values and ethics).

2) *Approach towards theory development*: often implicit in the previous philosophical layer, and can mainly be either inductive (bottom-up, i.e. starting from observation to form a theory), or deductive (top-down, i.e. starting from theory to answer pre-determined hypothetical questions). Sometimes the third approach is applied, an abductive one, which mixes both inductive and deductive reasonings.

3) *Research strategy setting:* different tools of data collection and analysis, such as experiments, surveys, case studies, action research, grounded theory, ethnography, or archival research.

4) *Choice of methodology*: either quantitative, qualitative, or mixed methods.

5) *Time horizons:* determining the research timeframe, either cross-sectional (over a certain, usually short-term point of time) or longitudinal (observing a repetitive phenomenon over a long period of time).

6) *Techniques and procedures:* research design explaining the processes of data collection and analysis, such as e.g. semi-structured interviews, questionnaires, content analysis, statistical models, etc.

This dissertation combines the knowledge of the disciplines of Industrial Management, Innovation Management, Energy Transition, and Sustainable Development. The key methodology applied in this dissertation is qualitative analysis through within- and cross-case studies.

3.1 Philosophical paradigm

The importance of the determination of the key philosophical paradigm could be supported by the fact that it expresses the worldview of the researcher (Mackenzie & Knipe, 2006). The scientific approach toward reality and the origins of knowledge creation have been a subject of deliberation for philosophers and theoreticians across the globe for centuries (Bell, Bryman & Harley, 2022). The purposeful usage of certain methodologies implies the strategy to investigate key research problems by applying particular data collection and analysis tools. Therefore, the researcher's own set of values and beliefs can strongly determine the election of key methodology to address the problematics of a particular research phenomenon (Antwi & Kamza, 2015; Matta, 2022).

As discussed above, the basic distinction between divergent paradigms is based on differences in ontology, epistemology, and axiology. Ontology enlightens both subjective and objective beliefs and knowledge about the origins and nature of reality. Epistemology, on the other hand, by addressing the ways to understand and interpret knowledge, delineates the researcher's viewpoint towards factors establishing acceptable knowledge. At last, axiology represents the importance of specific sets of values in conducting research (Easterby-Smith et al., 2021). Based on these assumptions and applicability to particular methodological approaches, several dominant philosophical paradigms originated from positivism and social constructivism. Positivists perceived reality as an external feature that should be examined through objective measures. This doctrine was formulated by a French writer and philosopher Auguste Comte in 1848 (translated into English in 1865), who claimed that knowledge is questionable until it is supported by observable evidence (Comte, 1865). Positivism is widely adopted in natural sciences, which has its justification in the requirement of supporting knowledge with observable facts. In social sciences, positivism is usually linked with the application of quantitative methodology (Easterby-Smith et al., 2021; Bell, Bryman & Harley, 2022). Alternatively, according to social constructivism, reality is not objective or external but is constructed based on social norms and beliefs. Therefore, in addition to positivistic relying on data, social constructivists suggest examining the social perceptions, relations, and structures and linking them to the investigated phenomenon (Kukla, 2000; Adams, 2006).

These two contradictory paradigms discussed above were purist in nature and presented adverse approaches: either based on a deep understanding of an observed phenomenon or on solid, often numerical, unquestionable data (Dessler, 1999). Over the decades, many novel philosophical worldviews resulted from the "paradigm wars" of the 1980s, considering different factors, beliefs, and approaches toward reality and knowledge (Denzin & Lincoln, 2011). In the seminal studies, the most commonly implemented approaches are post-positivist, interpretivist, transformative, post-modernist, pragmatist, and realist (Creswell, 2002; Mackenzie & Knipe, 2006; Saunders, Lewis & Thornhill, 2016; Easterby-Smith et al., 2021; Bell, Bryman & Harley, 2022). The ultimate determination of the most suitable paradigm is dependent not only on previously discussed ontology, epistemology, or axiology but also on the key rhetoric and methodology applied in the study. Some approaches are predestined to have applications in quantitative (post-positivism), qualitative (constructivism, transformative, post-modernism, realism), or mixed methodology (pragmatism). As this study is purely qualitative, only preliminarily suitable worldviews will be further discussed.

Constructivism (also referred to as interpretivism) perceives reality as a constantly changing social construct, which makes knowledge and facts subjective and relative. Knowledge creation is made while investigating and solving problems through experimentation and dialog among social interaction participants (Kukla, 2000; Adams, 2006). The transformative (or participatory) approach claims that political and societal factors strongly influence the sets of fixed assumptions and expectations and aims to transform them into more inclusive, reflective, and open for change (Mezirow, 2003). Post-modernism questions the concept of a fixed and universal nature of reality by highlighting the importance of cultural differences in different communities, claiming that knowledge of truth is a social construct that cannot be measured through rational scientific measures. This approach has been widely criticized for being too tentative and inconclusive and for supporting rather unobtrusive methods (Liamputtong & Ezzy, 2005). Lastly, **critical realism** is discussed in more detail as it is a paradigm chosen for this study. It originated as an alternative to positivism and constructivism, combining ontological and epistemological elements of these both constructs (Denzin and Lincoln, 2011). However, it differs from them in terms of one's ability to capture only a minor piece of broader and deeper knowledge. The most distinguishing feature of critical realism is that "ontology is not reducible to epistemology" (Fletcher, 2017, p.182). According to critical realists, the world and reality are theory-driven, but not theory-determined, where some beliefs or knowledge might be more realistic than others, which is also applicable in terms of theories (Danermark, Ekström & Karlsson, 2019). Theories that serve to gain a deeper understanding of reality are carefully selected based on the rational acumen of the investigated phenomena. Critical realism is applicable in social sciences due to its ability to involve in interpretation based on causal analysis that can assist in developing improvement measures for social problematics (Archer et al., 1998; Fletcher, 2017; Hu, 2018). Data analysis in critical realism is performed through abduction and retroduction. Abduction (or theoretical redescription) is performed after the key empirical findings (or demi-regularities) by redefining empirical data through the lens of theoretical concepts. Retroduction is the final phase of analysis according to critical realism that concentrates on causal procedures and circumstances which makes is a fundamental mechanism of reasoning in this concept (Fletcher, 2017). While being a distinct philosophy of science, critical realism can constitute a methodological framework for analysis, although it is not firmly linked to any specific array of methods (Nielsen, 2002). Nevertheless, many studies underlined its outstanding suitability for qualitative research (Scott, 2007; Morais, 2011;

Roberts, 2014; Fletcher, 2017; Hu, 2018; Vincent and O'Mahoney, 2018; Lawani, 2020).

Table 2. Factors of different research methods (own elaboration).

Factors	Quantitative	Mixed Methods	Qualitative
Philosophical paradigm	Positivism / post-positivism	Pragmatism	Constructivism, transformative, post-modernism, critical theories
Scientific standpoint	Knowledge is objective	Knowledge can be both objective and subjective	Knowledge is subjective
Reasoning approach	Deductive (*top-down*)	Deductive, inductive, or abductive	Inductive (*bottom-up*)
Reasoning goal	Theory testing, description, and prediction	Theory testing or creating	Theory creation and exploration

Following the process described in the research onion concept depicted in Figure 3, the next step is to determine the reasoning approach. The choice is made between three key reasoning strategies: inductive, deductive, or abductive. The major differences between these approaches toward theory development have been already discussed. As stated and shown, this study employs qualitative methodology, which implies the selection of an inductive approach (Thomas, 2006).

3.2 Research design and data collection methods

As suggested above, the ultimate choice of a specific research strategy and design is strongly influenced by the researcher's philosophical standpoint (Creswell & Poth, 2016). The diffusion of renewable energy technology is a complex and multifaceted phenomenon. This dissertation aims to investigate socioeconomic, technological, and regulatory issues concerning RETs diffusion in Finland in Poland. Therefore, an appropriate research design that would highlight the complexity of the investigated issues as well as ensure the fulfillment of the research goals is necessary. Research design is a researcher's guide through data collection, analysis, and interpretation (Easterby-Smith et al., 2021; Bell, Bryman & Harley, 2022). The research strategy is influenced by the main methodology adopted: either qualitative, quantitative, or mixed methods. The choice of certain methods is in turn determined by research objectives, availability of resources, state of knowledge or philosophical approach, or preferred methods of data collection, analysis, and interpretation (Saunders, Lewis & Thornhill, 2016).

Based on chosen critical realism reasoning, this dissertation benefits from the mix of epistemological and ontological elements of constructivism and positivism, which enables to perform high-quality qualitative research. It is firmly related to social constructivist theories that, by following the inductive approach, aim to scrutinize the phenomenon in order to attain a more profound comprehension and to create knowledge that helps to solve the problematic issue and ultimately form a theory (Denzin & Lincoln, 2011; Guercini, 2014). Importantly, qualitative methods show outstanding applicability in management studies, by helping to follow the fast-paced changes in the global (often digital) environment through their ability to investigate increasingly complex phenomena (Gummesson, 2006). Furthermore, qualitative methods allow for better communication between researchers and policymakers, which generates the possibility to bridge the gap between theory and practice. In fact, by helping to investigate progressively complex and advanced interactions between observers and observed, qualitative methods offer solutions to address the so-called "Cartesian dualism"[7] that is impossible through the application of solely quantitative tools (Guercini, 2014).

This article-based dissertation comprises five scientific publications examining the regulatory, socio-economic, and technological issues in the diffusion of renewable energy technologies in Finland and Poland. Articles 1 and 2 explore the multidimensional barriers for RETs diffusion in these two European Union member states, therefore, in order to acquire an in-depth understanding of the complex issues taken into scope of the analysis, qualitative methods have been chosen as most suitable for that kind of exploratory research (Antwi & Hamza, 2015; Myers, 2019). Article 3 seeks sources of smart specialization of the local community that are in line with the concept of the circular economy. SWOT analysis serves as a key method of identifying key favorable and unfavorable internal and external factors of the prosperity of the investigated rural municipality, which is one of the main tools in strategic management research

[7] According to Oxford Languages, Cartesian dualism is a theory or system of thought that regards a domain of reality in terms of two independent principles, especially mind and matter. Descartes claims that mind can exist outside of the body, whereas the body cannot act creatively without the mind.

(Helms and Nixon, 2010). Also, a constructive research approach has been implemented as a problem-based tool to identify disadvantageous aspects and propose improvement measures through a case study (Aaltonen et al. 2006). Constructivism has been discussed above as a main philosophical approach supporting qualitative research as well as one of the foundations of critical realism, therefore the philosophical coherence of the dissertation is maintained. Paper 4 proposes Venture Capital as the catalyst for the diffusion of RETs generated by start-ups and SMEs, by highlighting VC's role in providing extra-financial value addition to the development of its portfolio companies. This analysis is also made through a qualitative within- and cross-case study. Lastly, article 5 explores the current and future applications of blockchain technology in the RETs industry, and by examining major bottlenecks and opportunities for its adoption, the study provides a "Roadmap for blockchain diffusion within RETs sector". This multidimensional and complex study adopts qualitative methods as well, by performing multiple cross-case studies. In summary, all of the articles implement qualitative methods and case studies as a key research design. As suggested by numerous seminal handbooks and articles, a case study is an ultimate, flexible tool for empirical investigation of the modern phenomenon that is fitted to its real-world context (Eisenhardt, 1989; Eisenhardt & Graebner, 2007; Yin, 2009). Case study's flexibility allows to adopt this tool in many contexts and conditions, and analyze multiple subjects and entities, based on various methods of data collection and analysis. Additionally, the utilization of the case study approach supports answering the research questions such as "why" or "how", which makes it particularly applicable to this study. Article 3 presents a single case study design in order to deeply investigate the complex factors needed to develop a smart specialization strategy for the Polish rural municipality. Articles 1 and 2 employ a cross-case comparative case study, which allows us to scrutinize major barriers for RETs diffusion in Finland and Poland and detect key similarities and differences in the investigated cases, and to ensure the validity and reliability of the results (Yin, 2009). Articles 4 and 5 explore the diffusion enhancement tools in the instances of Finnish RETs companies, by proposing VC and blockchain technology as significant boosters of the development of the current and future renewable energy companies. These articles adopt multiple case study designs to gather both individual and collective insight from the numerous companies analyzed. Such a tactic guarantees a thorough comprehension of the investigated phenomena as well as the consistency and dependability of the research outcomes (Eisenhardt & Graebner, 2007; Myers, 2019). Table 3 presents the overview of the methodology adopted in this doctoral dissertation.

Table 3. Overview of the methodological approach of this dissertation (own elaboration).

Article	Methodology	Reasoning	Research design	Data collection	Data analysis
1	Qualitative	Inductive	Multiple case study	Literature review, statistical analysis	Within- and cross-case analysis
2	Qualitative	Inductive	Multiple case study	Semi-structured interviews	Within- and cross-case analysis
3	Qualitative	Inductive	Single case study	Field study visits	SWOT analysis, within-case
4	Qualitative	Inductive	Multiple case study	Semi-structured interviews	Within- and cross-case analysis
5	Qualitative	Inductive	Multiple case study	Semi-structured interviews	Within- and cross-case analysis

3.3 Methods of data analysis and presentation of results

As shown above, this doctoral dissertation incorporates a qualitative research design, which allows investigation of the complex and multifarious phenomenon of RETs diffusion in Finland and Poland. The inductive approach serves to thoroughly investigate the problematic phenomena and to observe patterns or regularities that can lead the researcher to form a new, broader concept or a theory (Thomas, 2006). Article 1 of this dissertation incorporates secondary data gathered from the seminal literature review, statistical reports, and renewable energy action plans published by the public authorities. The statistical analysis helped to detect the renewables with the biggest share in the energy mixes, and the analysis of national and international regulations aimed at fostering renewables set the understanding of the country-specific conditions as well as criteria for the analysis – the fulfillment of the renewable energy targets. The literature review has provided background on major market, regulatory, social, and technological barriers and provided information about the RETs with the most development potential, which has assisted in suggesting practical and theoretical improvement measures. Article 2 develops this concept by providing empirical evidence from the RETs industry. Literature review and statistical analysis have helped to prepare conceptually for the data collection and analysis. 13 semi-structured interviews with the managers from 12 RETs companies from Finland and Poland were performed. The content analysis helped to categorize the most common barriers and possible improvement measures mentioned by the respondents. Qualitative e within- and comparative cross-case-studies have helped to identify major similarities and differences between the companies from the investigated countries. In article 3, three field study visits have allowed to discuss and consult with the local government authorities, entrepreneurs, farmers, and other inhabitants of the Polish rural municipality. A problem-solving constructive research approach has helped to perform a SWOT analysis that served to develop a smart specialization strategy according to the concept of a circular economy. Secondary data such as statistical reports and official materials assisted in gaining a deeper understanding of the municipality and its both favorable and unfavorable conditions. Article 4 also follows an inductive approach, which implies the adoption of qualitative methods of data collection. Primary data was collected through semi-structured interviews with the venture capital and its RETs portfolio companies. Secondary data included information gathered about the companies from their websites, reports, and press releases, as well as overall industry analyses. The data triangulation technique was adopted to obtain an in-depth understanding of the investigated phenomenon as well as to safeguard the consistency, accuracy, and dependability of gathered and analyzed data (Flick, 2004; Farquhar, Michels & Robson, 2020). By adopting within- and cross-case analysis, similarities, differences, and irregularities could be detected to provide valid and accurate results of the analysis. Lastly, the dissertation's fifth article also employed inductive reasoning which incorporated qualitative data collection methods. Secondary data consisted of a literature review as well as information and communications technologies (ICT) and energy industry analyses, that helped to better understand the problematics of the investigated issue and develop a "Blockchain Maturity Questionnaire" that served as a background for the collection of the primary data. Primary data have been collected in the form of 10 in-depth semi-structured interviews with purposefully selected 13 RETs industry experts. Data triangulation has helped to use a variety of data sources which significantly increased the legitimacy and reliability of the research outcomes. Within- and cross-case studies were chosen as key research designs which served to explore single case-specific and overall, industry-specific aspects concerning the diffusion of blockchain technology within the RETs industry. Additionally, what is important to note, the identity of the RETs companies included in the case studies in articles providing the empirical evidence (Articles 2,4, and 5) was not revealed in order to address the European Union's GDPR[8] resolutions as well as to ensure the ethical compliance and integrity of the performed research (EU, 2016; Chassang, 2017; Voigt & Von dem Bussche, 2017).

3.4 Validity and reliability of qualitative research

The validity and reliability of research findings constitute the overall quality of the research process. Creswell and Poth (2016) and Myers (2019) firmly underline the need of ensuring the research validity and reliability in order to show the dependability and applicability (replicability/transferability) of research results. In qualitative research, issues of validity and reliability usually refer to the credibility of the research process and the legitimacy of the research outcomes. According to seminal guidebooks on business research methods, issues of validity and credibility in qualitative research should be appraised through the aspects of credibility, transferability, dependability, and conformability (Lincoln & Guba, 1985; Denzin & Lincoln, 2011; Easterby-Smith et al., 2021; Bell, Bryman & Harley, 2022).

In qualitative research, the overall validity of research is examined through its credibility (internal validity) and transferability (external validity), in alternative to the analogous assessment in quantitative research (Flick, 2008). Credibility, reflecting the internal validity results from the degree of the research outcomes' capacity to exhibit real-life situations, whereas transferability, highlighting the external validity of research results, determines their applicability in other contexts and research areas (Healy & Perry, 2000). Also, reliability in qualitative research is expressed through its dependability and conformability. Dependability should be ensured by a detailed and comprehensive description of the research process, including clarity of the selection of certain research methods as well as strategies for initial identification and final determination of investigated cases, processes, and tools for data collection and fulfilling the research goals through reliable results. Conformability, on the other hand, addresses the issues of research objectivity and truthfulness. In principle, qualitative methods should serve to ensure that the obtained data were based on the actual experiences and viewpoints of the respondents and that the results are presented in an objective and unbiased way (Lincoln & Guba, 1985; Flick, 2008; Myers, 2019).

[8] The General Data Protection Regulation (GDPR) is a regulation in EU law on data protection and privacy in the European Union (EU) and the European Economic Area (EEA). The principal goal of GDPR is to reinforce individuals' command and rights over their personal data and to simplify the regulatory setting for international business.

As shown above, all of the articles were based on qualitative research. Therefore, in the correspondent sections discussing the methodology adopted, a special focus has been put into the detailed description of the research processes. Research design, approaches toward case companies' selection, and data collection aspects have been thoroughly depicted within the articles. For instance, the development of the questionnaires and surveys was performed based on numerous consultations with other researchers in the field as well as external experts. Moreover, study contexts were highlighted to show the boundaries and contexts of possible generalization of the results. Furthermore, in order to ensure the confirmability of the performed research, the concluding sections of the articles, including discussion, study limitations, and future research directions were linked to the aspects closely related to the key research findings. Lastly, as already mentioned, the data triangulation technique performed in all of the articles included in this study which, in addition to helping in gaining a deeper understanding of the scrutinized phenomena, ensured the research's reliability and veracity (Flick, 2004; Farquhar, Michels & Robson, 2020).

4 SUMMARY OF THE ARTICLES

This chapter briefly highlights the contributions of each article to this doctoral dissertation. To present this overview, every section presents the main research goals, methods adopted, and key findings of the scientific publications included in this study. As a reminder, please refer to Figure 3 to observe how each publication addresses specific research sub-questions.

4.1 Overview of most challenging barriers for RETs diffusion

The first article entitled "Comparative Analysis of Barriers for Renewable Energy Technologies Diffusion in Finland and Poland" spotlights key regulatory, socio-economic, and technological issues while adopting renewables. The analysis is based on a thorough literature review of different factors that are hampering the widespread diffusion of RETs in Finland and Poland. Statistical analysis has served to identify the most commonly used renewable energy sources to provide an overview of the conditions of the Polish and Finnish energy markets. A literature review has served to show trends in the field of identifying threats and opportunities for the diffusion of RETs. In fact, many previous studies have scrutinized this issue from the viewpoint of either a specific energy source, particular interest group, or geographical area. This analysis was based on a holistic approach towards RETs, not focusing on a given energy source, but rather identifying the imperfections in the regulatory, socioeconomic, and technological landscapes of Finnish and Polish energy markets in a comparative way. After such determination, some practical measures, based on a literature review, successful examples from other countries, and common sense were suggested for facilitating the adoption of RETs in Polish and Finnish future energy systems.

The analysis has confirmed that Finland is a leading European country in terms of implementing RETs, which was supported by the fulfillment of the augmented goal of a 38% share of renewables by 2020 in the final gross energy consumption already in 2014. However, some market-related barriers were identified as key hindrances in this country, such as relatively small energy demand on the domestic market for green energy, and cost-competitiveness issues. Specifically, barriers for start-ups and SMEs that are focused mainly on the technology development front were highlighted by the lack of or significantly limited regulatory and managerial support. In Poland, the challenges identified in this study were far more severe and structural, which has resulted in failure to meet the goals of the legally-bonding international regulations[9]. Polish coal-oriented energy mix has been determined as a core hampering factor for RETs diffusion since regulations are supporting energy generated from fossil fuels rather than from renewables. Policies aimed at facilitating RETs integration were found to be either ineffective or overly complex.

At the end of this brief publication (the limit of 7 pages including references was imposed by the publisher), some improvement suggestions were proposed. Primarily, the importance of multi-level contributions from the local and regional governments, energy industry representatives, academia, and society has been highlighted as a key factor initiating the betterment of the current state of affairs in both countries. More specifically, an introduction of a supportive regulatory framework has been recommended as a catalyst for widespread RETs diffusion. Furthermore, numerous educational and awareness-raising actions about the technological know-how and environmental impact of RETs have been recommended to address key societal issues (Juszczyk & Shakeel, 2020).

4.2 Empirical evidence aiming at facilitating RET diffusion

After the post-conference publication described above, the research on the most challenging barriers for RETs adoption in Finland and Poland has been continued, which has resulted in the article called “Barriers for Renewable Energy Technologies Diffusion: Empirical Evidence from Finland and Poland”. This article aimed to update and enrich the literature review as well as to support the findings with insight from industry experts. Similarly, the focus of this study has been put into socio-economic and regulatory issues. However, after the consideration of the most commonly identified barriers for RETs diffusion in Finland and Poland in the academic literature, the categorization of barriers was performed, which has resulted in including 1) economic and market-related, 2) political and regulatory, 3) societal, and 4) technical factors.

The methods adopted in this research were a mix of energy policy and literature analysis as well as a cross-case qualitative case study. After shortlisting the most active and influential RETs companies from Finland and Poland, as well as using personal professional networks, 13 experts from 12 business entities were asked to answer two major questions during the semi-structured interviews. Initially, the respondents were asked to detect the most troublesome barriers from the

[9] European Commission, in accordance to United Nation’s resolutions, set so-called “3 x 20%” targets for 2020, and these were: 1) 20% decrease in greenhouse gas emissions (from 1990 levels), 2) 20% of energy generation from renewables, and 3) 20% increase in energy efficiency.

perspective of their daily operations and strategic decision-making processes. Then, the executives were invited to give their proposals for various measures and mechanisms that would significantly improve the settings for running RETs businesses and also more generally, the conditioning of the Finnish and Polish (renewable) energy markets. This approach of formulating open questions in the form of problematics usually leaves space for discussion and, more often than not, for unexpected answers which can be essential for the final outcomes of the study. The interviews were recorded according to the multilateral consent, and transcriptions of these recordings served as a base for content analysis. Examples provided by Polish and Finnish RETs industry experts were comparatively analyzed which created the possibility to not only highlight country-specific bottlenecks and remedies but also to "learn from each other", and transfer technology, knowledge, or business expertise (Reddy & Zhao, 1990; Rogers, Takegami & Yin, 2001).

The collective analysis reveals that ineffective, excessive, and unstable regulations, restricted financial support, and imperfections in performing a societal change have been identified as major hindrances for RETs diffusion in both countries. Interestingly, two experts from Finland could not determine any critical barrier to the prosperity of their solar PV and wind power companies, which gives a positive example of the Finnish environment for conducting cleantech [10] businesses. However, the majority of managers from Finland were complaining about the unstable and overcomplicated regulation, which can even force them to try to develop their business as pilot projects abroad. Especially in the case of start-ups and SMEs, the challenges identified in the literature have found their confirmation in the viewpoints of the executives, namely in challenges to introducing the technology to the market due to its conservatism, financial constraints, or cost-competitiveness requirement. Polish RETs industry experts have been highly negatively influenced by the political approach firmly supporting a coal-based economy, which has multidimensional unfavorable consequences.

The study proposes various possible improvement measures for the Finnish and Polish RETs sectors. Despite relatively favorable conditions in Finland, the experts previsioned some areas for further development. As most of the renewable energy companies are smaller-sized than the country-owned energy giants, the managers expressed their desire for the government to be more entrepreneurial-driven, which would result in enhanced regulatory and financial support. Some managers

[10] "Cleantech" is a term related to the firms involved with technologies, products, or services that seek to decrease the harmful environmental impact by providing efficiencies, reducing waste, encouraging the use of sustainable sources, and environmental protection (Shakeel & Juszczyk, 2019).

also suggested improvements in customer outreach and relations to better understand and respond to their needs or finding more environmentally efficient solutions for the generation of renewables. Polish respondents rooted for a long-lasting and efficient strategy for adopting more renewables, which should be implemented by the government after the multilateral consultations. There is a strong need for a restructuring plan which would consider the needs of the representatives of different interest groups, e.g. the influential coal industry by providing alternative career opportunities, and strategy for a gradual, evolutionary transition toward renewables. Without such regulatory and socioeconomic transformation, Poland would still be struggling with the energy transition. The study concludes with collective improvement recommendations. EU countries should follow the strategies toward climate-neutral Europe (such as the European Green Deal or Fit for 55), not only incentivized by their financial benefits, but also by the opportunity to innovate grid installations, to become more secure, efficient, and independent energy-wise. To foster such change within societies, numerous education and awareness-raising actions are highly recommended. Furthermore, innovative technology solutions are proposed for the enhancement of RETs diffusion, such as blockchain technology, which answers the future energy trends by providing energy decentralization, decarbonization, and digitalization. Finally, to address the challenges of RETs start-ups and SMEs, external investors such as business angels or venture capital companies are proposed as prosperous high-added value generators (Juszczyk et al., 2022).

4.3 Smart specialization as a way to foster green innovations on a regional scale

The third article entitled "Local contribution to Circular Economy. A case study of a Polish rural municipality" applies a concept of circular economy in practice, by performing a smart specialization study on a regional scale. The aim of the study field visits was to determine existing and future circular economy solutions that are contributing to the development of the Sokoły region in Poland. Researchers were invited by the municipality officials to estimate the current socioeconomic situation, evaluate factors and provide solutions that can solve recent local prosperity issues as well as assist in local sustainable development strategy setting.

Field study visits have helped researchers to initiate a discussion with local authorities, business owners, farmers, and social organizations about the sources of strengths and weaknesses of the municipality's capabilities of performing circular economy activities. The reports from these multiple consultations and interviews served as a foundation for thorough data analysis. The insights from the local community have allowed us to perform a SWOT analysis, a well-known method in strategic management (Helms & Nixon, 2010). Following a problem-solving constructive research approach, some improvement measures could be suggested. However, many of the proposed solutions were future-oriented, and thus market-based validation in the form of e.g. weak market tests and other feasibility studies have been suggested.

The outcomes of this study positively assess the municipality's capabilities of implementing development solutions according to the concept of a circular economy. The biggest opportunity in this area lays in high motivation to adopt and develop RETs such as waste-to-energy and biogas (Scarlat, Dallemand & Fahl, 2018; Taušová et al., 2019). To foster such processes and to address key problems stated by this local community, technology and knowledge transfers have been suggested and initiated through university-industry-public collaboration networks. The study presents an example of multidimensional benefits coming from intersectoral and international collaboration, mainly by proposing outsourcing technology, marketing, education, and managerial services.

4.4 Venture Capital's extra-financial value addition into RETs companies

The article entitled "The Role of Venture Capital in the Commercialization of Cleantech Companies" aimed to explore the value-added contribution of VC to the development of RETs companies. As discussed above, technology diffusion is a complex and troublesome phenomenon. Especially, start-ups and SMEs, which have restricted financial, human, and managerial resources, often lack efficient commercialization skills. Their capabilities often are focused mainly on the technology development procedures, after which they struggle with the market and regulatory realities. Venture capital can play a key role in overcoming these numerous challenges, by providing necessary investment capital, guidance, and resources for the enhanced growth of their portfolio companies. Numerous studies exemplify successful cases of VC's involvement in technology-oriented businesses (Florida & Kenney, 1988; Sapienza & De Clercq, 2000; Chen, 2009). Moreover, several studies have suggested venture capital as a catalyst for the diffusion of clean, sustainable, and renewable energy technologies (Bürer & Wüstenhagen, 2009; Ghosh & Nanda, 2010; Bocken, 2015).

However, the levels and areas of VC's contribution may vary depending on the conditions of different industries, contexts, or geographical regions (Gu & Lu, 2011; Li & Zahra, 2012). Therefore, in this study, the extra-financial value addition of venture capital into the development of Finnish RETs companies has been examined. To perform the empirical analysis, semi-structured interviews were performed to scrutinize the VC's involvement from the perspective of both VC investors and their RETs portfolio companies. The companies for this cross-case study were selected according to the purposive sampling approach, which enabled to include the optimal selection of the investigated contribution examples (Van Ryzin, 1995; Campbell et al., 2020). In consequence, venture capital company investing exclusively in clean and renewable energy technologies was interviewed at the initial stage to explore the motivations and experiences of such activities. In the second stage, the executives from five VC portfolio companies were invited to provide insight into key areas and levels of VC contribution from their perspective. To gain a deeper understanding of the researched phenomena, and obtain reliability and accuracy of collected data, the data triangulation method was adopted (Flick, 2004; Farquhar, Michels & Robson, 2020). Within-case and comparative cross-case approaches were chosen to highlight case-specific examples as well as identify similarities and differences in areas and levels of VC involvement.

The outcomes of the analysis identify the categories of VC value-addition into RETs companies and structure them according to their significance and levels of involvement. The study reveals that VC companies are seen as active investors, which contribute substantially to the governance and strategy-setting of their portfolio firms. They provide mentoring, business excellence, and professional networks through active participation in the executive boards of the incumbents. Moreover, legitimization, licensing, or certification effects were identified as cardinally improving the market image of the companies. Simply enough, the mere fact of involvement in a particular company enhances its reliability and sends a positive message to other prospective investors. Furthermore, other effects such as assistance in the recruitment of the relevant personnel and seeking internationalization opportunities have been appreciated greatly by the VC incumbent companies. Interestingly, the study has not found any significant evidence of the VC's contribution to the technology development processes, which can be explained either by the fact of investing in already well-developed technology solutions or high levels of trust between collaborating internal engineers and external managers. These results were presented in the developed "VC contribution matrix" which can provide numerous theoretical and practical implications for the various interest groups representing different sectors and industries (Shakeel & Juszczyk, 2019).

4.5 Blockchain technology as a potential game-changer within RETs industry

The last article included in this study entitled “Blockchain for Renewable Energy: Principles, Applications and Prospects” proposes blockchain as a possible revolutionary technological solution for the multi-level improvements of future energy systems. The study provides the insight into main features of blockchain technology as well as its key applications in the RETs sector. Moreover, the article expresses the perception of blockchain technology from the RETs industry experts’ point of view with the aim to estimate the probability of its widespread diffusion within this sector and propose enhancement mechanisms based on the opinions of the respondents. Blockchain can be described as a distributed, immutable ledger or Internet of Value that serves to perform digital transactions without intermediaries in a secure and automated way (Crosby et al., 2016; Yli-Huumo et al., 2016; Tapscott & Tapscott, 2017). Due to its decentralized nature, has a significant potential to ensure e.g. transparency, traceability, security, and reliability of transactions (Helo & Shamsuzzoha, 2020; Warkentin & Orgeron, 2020). Importantly, the blockchain’s central feature, which is the exclusion of central management and other middle-men from the transaction processes has the potential to revolutionize global and local supply chains, which ultimately will result not only in increased speed and efficiency but also in cost reduction of the end product (Helo & Hao, 2019; Saberi et al., 2019; Shahzad, Juszczyk & Takala, 2022).

According to the existing studies, blockchains have numerous possible applications in the energy sector, including RETs industry. Blockchain technology can enhance energy transition and circular economy activities by providing e.g. innovative solutions for electric e-mobility, energy democratization, peer-to-peer (P2P) energy trading platforms, demand-response mechanisms, smart grid management, energy tokens, automation of green certificates and carbon trading, fostering the circular economy, etc. (Andoni et al., 2019; Teufel, Sentic & Barmet, 2019; Wang & Su, 2020; Upadhyay et al., 2021; Yildizbasi, 2021; Gawusu et al., 2022). Importantly, it is claimed that blockchain adoption will require business model innovation, due to its disruptive nature (Hwang et al., 2017; Nowiński & Kozma, 2017; Shahzad, 2020; Tiscini et al., 2020; Marikyan et al., 2022). This article aims to investigate current and future conditions for blockchain technology diffusion within the Finnish RETs industry by providing a viewpoint of the executives from this sector.

The analysis of the problematics of blockchain adoption identified in the literature served to develop a “Blockchain Maturity Questionnaire”. This survey has been used as a guide for in-depth semi-structured interviews with the Finnish RETs industry experts. After the process of purposeful selection, a positive collaboration response was obtained from 13 executives managing 10 leading Finnish RETs companies. At the initial stage, respondents were asked about their level of knowledge and trust in blockchain technology, which has led to the determination of the most significant benefits associated with integrating this innovative solution into future Finnish energy systems. Next, the experts were inquired about the business areas in which blockchain would have the biggest influence, which imposed the question about the possible impact on future business models. After this positive part, the executives were requested to identify the most challenging barriers for blockchain diffusion as well as to propose measures to tackle these numerous difficulties. These insightful perspectives from the Finnish RETs industry experts have helped to develop a "Roadmap for Blockchain Adoption", which proposes directions of focused efforts for facilitating blockchain technology diffusion within RETs industry. Lastly, the managers were invited to draw a future picture of blockchain in general and in the renewable energy sector, which resulted in a principally positive vision of disruptive innovation, provided that most critical barriers are skillfully addressed, according to the roadmap.

This curiosity study yields numerous theoretical and practical implications for the interest groups related to the RETs industry. It is important to note that mainly due to the infancy stage of technological development, the adoption of blockchains globally is meaningfully challenging. Another crucial aspect is the lack of legal and regulatory support, which is related to some extent to low levels of trust and know-how about this game-changing technology. Therefore, to overcome these challenges according to the developed roadmap, four key mechanisms are suggested as facilitators of blockchain adoption within RETs industry. *First*, big-sized companies could be used as catalysts if they would develop their technological solutions for blockchain implementation to increase the use of industrial use cases. *Second*, without necessary regulations, any revolutionary invention can be adopted. Therefore, there is a strong need to introduce supportive regulatory frameworks for blockchain diffusion at the national, international, and global levels (preferably starting rather from the international or local, such as the EU level). *Third*, to address dramatically low levels of trust and knowledge about this technology, numerous education and training activities are suggested, as know-how has the outstanding capacity to increase trust levels. *Fourth*, as can be observed even in this particular article, innovation is more often than not initiated through university-industry collaboration networks. The fusion of ideas of theoreticians and practitioners can generate seed and pilot projects which are prototypes used for feasibility studies. Therefore, strengthened intersectoral cooperation is necessary to enhance blockchain diffusion within RETs industry.

It is perceived and claimed that due to its ability to revolutionize current energy systems, the potential benefits of blockchain adoption are far more meaningful than the challenges (Di Silvestre et al., 2018 & 2020; Mengelkamp et al., 2018; Wu et al., 2022). The outcomes of this article have the capacity to provide possible measures for theoreticians and practitioners for enhancing blockchain diffusion within RETs industry. As the majority of the respondents expressed their willingness to adopt this technology in their future daily operations, it is expected that blockchains will be gradually integrated which will potentially revolutionize the existing energy systems (Juszczyk & Shahzad, 2022).

Table 4. Overview of the key outcomes of the articles included in this study (own elaboration).

Article	Title	Key Outcomes
1	Comparative Analysis of Barriers for Renewable Energy Technologies Diffusion in Finland and Poland	Energy policies play a central role in enhancing RETs diffusion. Finland is far more technologically and socially advanced; major barriers are market-related. Poland is struggling with the energy transition, mainly due to the coal-centered energy mix and politicized energy sector.
2	Barriers for Renewable Energy Technologies Diffusion: Empirical Evidence from Finland and Poland	Ineffective or excessive regulations are the key barriers for RETs diffusion. SMEs and start-ups require more support from the government, external investors, and innovative technologies. Multi-sectoral contribution is needed to enhance widespread RETs diffusion.
3	Local contribution to Circular Economy. A case study of a Polish rural municipality	Sustainable development strategy creation according to the concept of a circular economy. Waste-to-energy and biogas technology as smart specialization solutions for local communities. Numerous benefits of inter-sectoral and international collaboration.
4	The Role of Venture Capital in the Commercialization of Cleantech Companies	VC as active investors participating in corporate governance, strategy setting, collaboration, and internationalization of their portfolio companies. VC involvement provides legitimization, which attracts additional investors. VC as a catalyst for successful diffusion of RETs.
5	Blockchain for Renewable Energy: Principles, Applications and Prospects	Blockchain has the potential to revolutionize current energy systems and markets. The infancy stage of development as well as lack of regulations and trust as the biggest barriers. Increased number of use cases, supportive regulations, education, and university-industry collaboration as catalysts for blockchain diffusion in RETs sector.

5 DISCUSSION AND IMPLICATIONS

This chapter completes this doctoral dissertation. Firstly, the main study conclusions are presented in the form of a discussion. Two following sections highlight both the theoretical and practical implications of the research outcomes. Lastly, the limitations of the study are considered and future research directions are proposed.

5.1 Discussion and conclusions

This doctoral dissertation was designed to thoroughly investigate key regulatory, socio-economic, and technological issues concerning the diffusion of renewable energy technologies, based on empirical evidence from Finland and Poland. To address this main research question, this study is supported by five scientific publications which can be found in the Appendices section. As highlighted above, renewables are one of the principal measures to tackle the numerous current global challenges resulting from the adverse impact of climate change, such as global warming, extinction of endangered species and deterioration of natural ecosystems, overflooding, massive migrations, air pollution, just to mention a few drastically depicting examples of factors affecting the overall quality of life on our planet. Furthermore, renewables can significantly contribute to the country's energy security, improve energy efficiency and resilience, strengthen the independence of energy imports, optimize the utilization of indigenous resources, protect the natural environment or enhance sustainable development (Jacobsson & Johnson, 2000; Lund, 2009; Gielen, 2019). Importantly, the fact of implementing renewables itself is usually favorable for the image and perception of a given country or company, which can, for instance, attract new various investors and increase overall trust levels (Menegaki, 2008; Walker et al., 2010; Richter, 2012; Tomšič, Bojnec & Simčič, 2015; Kalkbrenner & Roosen, 2016; Bojnec & Tomšič, 2020). Based just on these few exemplifications of the beneficial impact of renewables, it can be affirmed that RETs have a lot to offer for the interest groups representing each and every sector of society. However, the diffusion of RETs is a complex and challenging process, which is observable in fairly limited shares of renewables in global energy mixes. This dissertation, by adopting a problem-solving approach, seeks to explore major regulatory, socio-economic, and technological factors influencing the diffusion of RETs in order to provide effective measures for improvement, in a practical and eye-catching form of a roadmap.

5.1.1 Addressing the first research sub-question

Initially, the major barriers for RETs diffusion in Finland and Poland are determined. Articles 1 and 2 provide a thorough literature review as well as empirical evidence from the RETs industry experts, and thus provide a comprehensive approach toward addressing the first research sub-question: *What are the major barriers for RETs diffusion and how to overcome them?* The research was performed with a particular emphasis on socio-economic, regulatory, and technological barriers, and identified the excessive, inefficient, or ineffective regulatory frameworks as the key hindrances to the enhanced development of RETs in both Finland and Poland. As one of the industry experts accurately pointed out, "When it comes to energy, there is always politics involved", which can have various consequences (Juszczyk et al., 2022). It is particularly visible in the Polish case, where the coal-based energy sector is highly politicized, which significantly hampers the avenues for widespread RETs diffusion (Brauers & Oei, 2020). Energy policies play a key role in establishing a favorable, supportive legal, political, and socioeconomic environment for the development of renewables, as regulations set structures and directions of existing rules within the energy industry.

The energy markets are particularly affected, as most of the conventionally-generated energy is produced by state-owned energy giants, and simply enough, the current regulations influence the daily operations of energy companies. Notably, more effective policies incorporating less complicated legal procedures could address plentiful market-related challenges. First of all, limited financing options for supporting RETs development could be tackled with more financial incentive mechanisms, such as feed-in tariffs, carbon credits, green certificates, or various tax reductions. Furthermore, more transparent and persistent energy policies could significantly reduce overall market uncertainty, which could also contribute to the reduction of investment risk levels. Also, as highlighted earlier in this study, RETs are innovative solutions developed mostly by high-tech start-ups and SMEs, therefore, a more entrepreneurial-driven approach from the governments is firmly expected. Renewables could disrupt the existing energy markets, as they are usually generated in a distributed manner to support the needs of local grids, which could transfer the decision-making processes from centrally- to locally-based (Abdmouleh et al., 2017). This bottom-up approach could promote more active participation of energy prosumers (which are both energy producers and consumers concurrently), and create new business models. Importantly, supportive energy regulatory frameworks are prerequisites, or in other words *sine qua non* for the development of RETs. Considering the above-mentioned numerous benefits related to increasingly adopting renewables, astute governments ought to strengthen their efforts to provide energy policies that are encouraging the widespread diffusion of RETs. This is particularly inevitable to follow the resolutions of the legally-bonding international resolutions, of which fulfillment should be prioritized as a given country's best interest.

Furthermore, the role of socioeconomic contribution to the RETs diffusion should be adamantly emphasized. Bluntly enough, technologies without sufficient societal acceptance levels could not be procured by the end-customers. As RETs are disruptive in nature, they require relatively longer periods to get commercially accepted. It often results in higher initial costs and longer payback time for green investments, therefore the so-called willingness-to-pay[11] aspects are crucial for the prosperity of renewables (Wiser, 2007; Longo, Markandya & Petrucci, 2008; Sundt & Rehdanz, 2015). Furthermore, customers most probably would not be eager to utilize technologies they know very little of, and this lack of technological know-how causes trust and overall diffusion issues. Additionally, society can influence the RETs sector through divergent activist movements, demand-pull mechanisms, and other bottom-up initiatives. However, apart from the positive mobilization factors, there are various aspects negatively affecting the development of RETs, such as overall skepticism vis-à-vis climate change, or alleged NIMBYism, which stands for "not in my backyard" customers' reserved attitude toward installing landscape-affecting and noise-making wind power parks or foul-smelling biogas plants in their adjacent community (Wolsink, 2007; Pelham, 2018). Therefore, strengthened efforts should be put into education, training, and other various awareness-raising activities to encourage the extensive implementation of renewables within society. As can be seen, the socio-economic dimension is conjointly important for the diffusion of RETs.

Moreover, there are many strictly technological barriers for the widespread diffusion of RETs. Studies in Finland and Poland detected mainly ineffective grid development as well as insufficient or obsolete energy infrastructure as key hampering factors (Aslani et al., 2013; Zakeri, Syri & Rinne, 2015; Child & Breyer, 2016; Varho, Rikkonen & Rasi, 2016; Shakeel, Takala & Zhu, 2017; Hernik, Noszczyk & Rutkowska, 2019; Pietrzak et al., 2021; Igliński et al., 2022). However, the investigated regulatory, socio-economic, and technological factors are strongly interrelated, which confirms the need for intersectoral contribution to the enhanced RETs development. For instance, if the technologies would be more customer-oriented, and fulfill the criteria of the TAM model discussed earlier in this study, i.e. highlight their usefulness in improving current structures and

[11] Willingness-to-pay can be understood as a customers' eagerness to consciously pay more for the products that are generated from green, sustainable, and renewable energy and have significantly limited environmental impact.

practices and provide the relative easiness of use, the chance of the acceptance of a given RES-based technology among the society could be significantly enhanced. Moreover, grid infrastructural innovation should be initiated by well-planned strategies formed by energy industry dignitaries and further supported by policymakers. Some innovative, future-oriented solutions that are proposed in this study could significantly contribute to the appropriately-fitted, efficiency-boosting development plans for grid modernization.

5.1.2 Addressing the second research sub-question

Secondly, this dissertation seeks to investigate the local contribution to the widespread RETs diffusion, by emphasizing the role of smart specialization according to the concept of a circular economy, in order to address its second sub-question: *What role can circular economy and smart specialization play in adopting RETs at a regional scale?* The importance of considering this small-scale, regional perspective is particularly essential forasmuch as RETs are usually generated in a decentralized, distributed manner (Mahapatra & Dasappa, 2012; Batyk et al. 2021). Therefore, it is important to improve innovation capabilities at the regional scale, since such actions would result in overall, bigger-scale betterment in supporting sustainable development. This can be achieved by developing and implementing a Research and Innovation Strategy for Smart Specialization (RIS3) by local communities. While specifically focusing on contributing to the diffusion of RETs (notably bio-energy and waste-to-energy technologies), it is worth adopting the concept of circular economy (Olabi, 2019). Such strategies would not only benefit the sustainable development and smart innovation capabilities of a given community but also could foster greener methods of energy generation which would ultimately protect the natural environment (Unay-Gailhard & Bojnec, 2019; Taušová, Tauš & Domaracká, 2022). Importantly, circular economy enhances e.g. the optimization of resources utilization, reduction of various wastes, value addition longevity, and utilization of bio-energy sources such as biogas or waste-to-energy technologies (Korhonen, Honkasalo & Seppälä, 2018). Considering all these above-mentioned favorable implications of implementing circular economy-driven smart specialization strategies, such activities, supported by intensive inter-sectoral involvement, are proposed as one of the possible measures to enhance the diffusion of RETs on a regional level.

5.1.3 Addressing the third research sub-question

Thirdly, this study explores the role of venture capital (VC) in the successful commercialization of RETs companies which serves to relate to its third sub-question: *What role can venture capital play in the widespread diffusion of RETs?* As previously discussed, new technology diffusion is a complex, burdensome, and resource-demanding process. It is particularly arduous for high-tech start-ups and SMEs, which are often focusing strongly on technology development activities, but lack or have radically limited managerial or financial resources (Hsu, 2006; Bjørgum & Sørheim, 2015; Bocken, 2015). Following the problem-solving approach, this dissertation assists in addressing numerous multifaceted challenges that clean technology-based emerging business initiatives face by recommending VC as a catalyst for RETs diffusion. First of all, by organizing external funds collection, venture capitalists provide necessary financial resources for the further development of the companies they invest it. This substantial patronage in additional financing acquiring is continued throughout the whole investment cycle of venture capital. Importantly, in addition to that, various extra-financial value-adding activities are provided by venture capital companies. In fact, venture capitalists are believed to be rather active investors, as they are laboriously participating in the corporate governance, strategy-setting, or internationalization activities of their portfolio companies (Sapienza, 1992; Samila & Sorenson, 2011). The development of the technology-based VC-backed companies is enhanced by, *inter alia*, business expertise, extensive business networks, and industry-specific knowledge provided through the participation of VC representatives in their executive boards. Interestingly though, the study did not detect any substantial contribution of VC into the technology development processes, as was the case in several studies (e.g. Gompers & Lerner, 2001; Pradhan et al., 2019). This can be explained by the fact that RETs are exceptionally innovative and complex technologies, which require input from remarkably skillful and highly specialized personnel. More often than not, VC invests in well-developed technologies or provides mentoring and support in acquiring the necessary resources needed to ensure the final stages of technology development (Sapienza & De Clercq, 2000). Furthermore, the study reveals the involvement of VC sends a positive message to additional prosperous external investors as well as improves the overall image of their incumbents, which can be depicted as a certification, or legitimization effect. Finally, through the use of its extensive collaboration networks and long-lasting experience, VC can assist in the recruitment of the appropriate personnel and outsourcing of divergent desired services. This can be facilitated by the inter-firm collaboration between different VC portfolio companies, which often share common skills, and resources as well as challenges, and so the various experiences can be beneficial to all of the interaction partners. Based upon the above discussion, this dissertation suggests VC as a sought-after contributor to the development of RETs companies.

5.1.4 Addressing the fourth research sub-question

Lastly, this doctoral thesis examines blockchain technology and its applicability in future renewable energy systems to answer the fourth research sub-question: *How significant would be the impact of blockchain technology on fostering RETs diffusion?* Mainly due to the growing global population and raising shares of the middle class in developing countries, future energy systems will have to satisfy increasing energy demand levels. In order to do so, energy operators ought to implement solutions that would increase e.g. energy efficiency, dependability, or security. Moreover, it is believed that prosperous energy structures, to foster the energy transition, should have the features called the "Energy 3Ds", which are 1) decarbonization, 2) decentralization, and 3) digitalization (Di Silvestre et al., 2018; Morell Dameto et al., 2020). Blockchain technology has considerable potential to address all these issues and, as a consequence, to innovate the RETs industry (Ahl et al. 2019, Andoni et al., 2019). Notably, blockchain's principal feature of decentralization of authority in the transactional processes has a major potential of disrupting the energy industry by providing transparency, security, dependability, or auditability of transactions. Likewise, according to the fundamental economic mechanisms and laws, the elimination of the third parties (middle-men) from the transactions on the market could have a revolutionary impact on existing supply chains, which would result in the optimization of the end-cost of energy as well as enhancing energy democratization (Helo & Hao, 2019; Saberi et al., 2019; Almutairi et al., 2022). As discussed earlier in this study, blockchain technology has a major potential of contributing to the diffusion of RETs by providing e.g. innovative solutions for electric e-mobility, energy democratization, peer-to-peer (P2P) energy trading platforms, demand-response mechanisms, smart grid management, energy tokens, automation of green certificates and carbon trading, fostering the circular economy, etc. (Teufel, Sentic & Barmet, 2019; Wang & Su, 2020; Yildizbasi, 2021; Gawusu et al., 2022). Additionally, due to its disruptive nature, the application of blockchain would require business model innovation, which would improve current value-creation activities within the RETs industry (Shahzad, 2020; Tiscini et al., 2020). However, the highly innovative characteristics of blockchains have some unfavorable implications, which are hampering their widespread diffusion around the world. This study provides numerous exemplifications of such barriers, based on insights from the Finnish RETs industry as well as suggests possible effective improvement measures that would significantly enhance the extensive adoption of blockchain not only within the RETs industry but in other sectors and geographical areas as well. The developed "Roadmap for Blockchain diffusion within the RETs industry" suggests 1) increasing industrial use cases to illustrate the theoretical benefits in practice, which would signal a positive message across the given industry, 2) introducing supportive regulatory frameworks (e.g. on a European scale) to facilitate the legal functioning of blockchain-based mechanisms, 3) development of education and professional training programs and platforms to increase the level of technological know-how and trust, and reduce the levels of overall skepticism, and 4) supporting university-industry collaboration to initiate innovations through increasing numbers of seed and pilot projects. Such activities would enhance the adoption of blockchain technology, which – due to numerous benefits outweighing challenges – is highly expected by the RETs industry experts. In sum, blockchain has a significant potential of contributing to the diffusion of RETs by providing multidimensional mechanisms for the overall improvement of the RETs market structures.

5.2 Roadmap for Renewable Energy Technologies Diffusion

The synthesized study outcomes generating voluminous theoretical and practical implications for the interest groups representing divergent sectors of society have served to design a "Roadmap for RETs diffusion" presented in Figure 7.

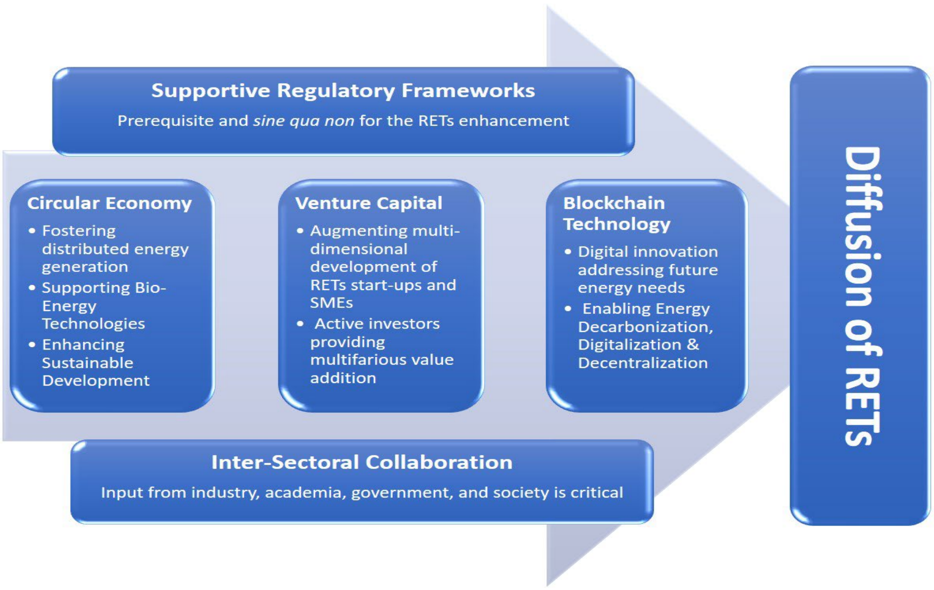

Figure 7. Roadmap for RETs diffusion (own elaboration).

As suggested in the section presenting the conceptual framework for this study, the problem-solving approach has helped to propose effective measures to overcome the major barriers for RETs diffusion in Finland and Poland by highlighting the importance of a supportive regulatory regime as well as inter-sectoral collaboration to foster the implementation of RETs on a macroeconomic level. Furthermore, three practical concepts, technologies, or mechanisms are proposed as catalysts for a widespread RETs diffusion. Firstly, the circular economy concept is proposed as an approach to foster RETs diffusion on a regional scale and to support sustainable development. Secondly, venture capital is suggested as a desired external financing option for RETs start-ups and SMEs, which are key to initiating sustainable innovations. Lastly, blockchain technology is seen as a potential game-changer within the RETs industry, which can enable digital innovation and revolutionize current energy structures. This roadmap intends to suggest possible mechanisms, managerial tools, and measures for enhancing RETs diffusion and thus can serve as a practical and theoretical guide for various interest groups representing all sectors of society. Additionally, as this study presents insights from Finland and Poland, which represent both developed and developing economies, this dissertation not only advances the discussion on the major differences between conditioning for the diffusion of RETs in such markets but also helps, *inter alia*, RETs companies considering expanding their business activities in both developed and developing countries.

5.3 Theoretical contributions

This dissertation contributes to the literature on the diffusion of RETs by emphasizing major barriers and challenges that RETs are prone to, as well as recommending a framework (in form of a roadmap) to overcome them. Prior studies have examined the phenomenon of technology diffusion from the perspective of conventional technologies (Eveland, 1986; Keller, 2004; Byun, Sung & Park, 2018), high-tech solutions (Chiesa & Frattini, 2011; Tech, 2018), or disruptive innovations (Assink, 2006; Christensen, Ragnor & McDonald, 2013; Zeng et al., 2018). Nevertheless, the literature focusing on the diffusion of RETs outlasts reasonably limited. This restricted area of academic studies has explored this issue by highlighting the various contexts of e.g. diffusion models (Schilling & Esmundo, 2009; Rao & Kishore, 2010; Kumar & Agarwala, 2016), financing and investments (Dinica, 2006; Wüstenhagen & Menichetti; Liu & Zeng, 2017; Klepacki et al., 2021), marketing and strategy (Beccali, Cellura & Mistretta, 2003; Aslani, Naaranoja & Wong, 2013; Steffen et al., 2018; Baldwin & Tang, 2021), sustainability (Dincer, 2000; Lund, 2007 a; Tabrizian, 2019; Bórawski et al., 2022), energy policy (Tsoutsos & Stamboulis, 2005; Jacobsson & Lauber, 2006;

Lund, 2009; Mercure et al., 2014; Hille, Althammer & Dietrich, 2020), technology aspects (Popp, Hascic & Medhi, 2011, Zakeri, Syri & Rinne, 2015; Min & Haile, 2021), economic development (Pfeiffer & Mulder, 2013), or social acceptance (Reddy & Painuly, 2004; Wiser, 2007; Wüstenhagen, Wolsink & Bürer, 2007; Batel, 2020). Essentially, only a few studies have scrutinized diffusion (or commercialization) conditioning in a holistic way (Jacobsson & Johnson, 2000; Painuly, 2001; Balachandra et al., 2010; Shakeel, Takala & Zhu, 2017).

This doctoral dissertation initially bridges this gap by exploring the major regulatory, socio-economic, and technological aspects of RETs diffusion in Finland and Poland, and by providing novel study contributions, it advances the discussion on RETs diffusion further. The first two articles provide both a thorough literature review as well as empirical evidence from the RETs sectors in these two European Union member states. First of all, these articles extend the literature on barriers for RETs diffusion by providing a comparative analysis of the newly investigated countries. Importantly, the findings of these studies contribute to the extant literature by highlighting the importance of inter-sectoral collaborative networks, societal awareness-raising actions, entrepreneurial-driven governmental approaches, external financing options, or enhanced technological innovations. Interestingly, the study adopts a holistic and indefinite design toward the concept of technology diffusion, and for enhanced generalization and applicability purposes, it uniquely merges this concept with other notions, such as commercialization, prosperity, adoption, implementation, development, etc. Furthermore, the study confirms and firmly supports the claims of the prior research that the political and regulatory factors are central and prerequisites for supporting the diffusion of renewables (Jacobsson & Lauber, 2006; Inês et al., 2020; Lu et al., 2020). Additionally, the improvement measures and roadmaps suggested in this study provide novel theoretical implications for the wide area of research focused on enhanced development of the renewable energy industry.

Secondly, this study contributes to the literature on various applications of the circular economy concept. Mainly due to the decentralized feature of renewables, it is worth investigating various concepts and mechanisms that aim to foster the diffusion of RETs on a regional scale. Primarily, this dissertation extends the research on smart specialization strategies for local sustainable development according to the idea of circular economy, by providing novel applications in the case of a Polish rural municipality. The majority of prior research exploring circular economy focused on cultural heritage aspects (Stanojev & Gustafsson, 2021), regional innovation (Vanhamäki, Rinkinen & Manskinen, 2021; Arsova, Genovese & Ketikidis, 2022), or optimal use of natural resources (Virtanen et al., 2019). This study not only contributes to all of these categories, but also examines the role of circular economy in fostering renewables, with a particular emphasis on bio-energy sources, such as waste-to-energy and biogas, similar to the several studies, e.g. by Pan et al. (2015), Malinauskaite et al. (2017), Diamantis et al. (2021), Valve, Lazarevic, and Humalisto (2021), or Jain et al. (2022). Importantly, the study highlights the benefits and strongly suggests the need for inter-sectoral collaboration for the effective implementation of circular economy-driven strategies for local sustainable development.

Thirdly, this study scrutinizes the role of venture capital in providing extra-financial value addition to RETs companies. Renewables-generating start-ups and SMEs significantly contribute to the diffusion of RETs by introducing innovative solutions to the existing energy markets. However, these companies more often than not have meaningfully limited financial and managerial resources, which hampers their further development. Importantly, venture capital has substantial capabilities to bridge this gap not only by providing necessary financial resources but also by improving the overall business performance of their incumbent companies through multidimensional extra-financial value addition. Literature suggests that venture capital's contributions may vary depending on different industries, contexts, or geographical regions (Gompers & Lerner, 2004; Li & Zahra, 2012). Numerous studies have explored the input of venture capitalists in specific industries, for instance in healthcare (Chakma, Sammut & Agrawal, 2013; Frimpong, Akwaa-Sekyi & Saladrigues, 2022), high-tech (Florida & Kenney, 1988; Gompers & Lerner, 2001; Colombo & Grilli, 2010; Hurry, Miller & Bowman, 2022), or ICT (Gaba & Meyer, 2008; Pradhan et al., 2019). Nevertheless, the academic literature on venture capital's involvement in the cleantech or RETs industry is fairly limited (Bürer & Wüstenhagen, 2009; Bocken, 2015; Cumming, Henriques & Sadorsky, 2016). This narrow stream of research has supported generally positive evidence of venture capital involvement; however, it usually expressed the viewpoint of either venture capitalists or their portfolio companies. This study provides a novel approach towards investigating the benefits of value-adding contributions by depicting the perspectives of both sides of this specific business partnership. Such a design helped in gaining a more in-depth understanding of the investigated phenomenon and in addressing unprecedented aspects. Furthermore, with the use of the developed "VC contribution matrix", the study supplements the literature on venture capitalism with a brand-new method of presenting the key research outcomes. In sum, this dissertation subsidizes the extant literature by providing empirical evidence on venture capital's extra-financial value addition to Finnish RETs companies and by putting a particular emphasis on contributions to RETs diffusion.

Lastly, this doctoral dissertation explores the principles, applications, and prospects of blockchain technology implementation within RETs industry. This curiosity study can help to address the future energy needs coming from increasing energy demand levels. Fortunately, due to numerous multidimensional incentives, the share of renewables in global energy systems is gradually increasing. However, renewables, due to their variability and weather-dependency, can cause serious challenges for grid managers (Eid et al., 2016). Furthermore, inconstant and decentralized features of renewables require innovative solutions to boost their utilization. Such technologies would enhance energy efficiency by providing grid stability, flexibility, demand-response mechanisms, or new means of energy storage (Lund et al., 2015; Ahl et al., 2019). Based on the increasing numbers of smart meters in current global energy systems, the potential for energy digitalization is bigger than ever (Zhou & Brown, 2017). Blockchain technology has a major potential to revolutionize current energy systems by providing secure, transparent, and reliable decentralized energy trading platforms. Previous studies have explored the potential of blockchain in the energy sector in various contexts, such as e.g. smart contracts (Cong & He, 2019), energy efficiency (Khatoon et al., 2019), peer-to-peer energy trading (Wu et al., 2022), or IoT (Li et al., 2017). This study incorporates a multidimensional and holistic approach towards exploring the benefits of blockchain application within the RETs industry. First of all, the study provides a detailed discussion of the principles of blockchain and its applications in various industries, which supplements the existing literature on blockchain in general. Moreover, a thorough literature review generates fresh insights into the benefits and barriers related to blockchain utilization in the renewable energy sector. Most importantly, the research performed for the purpose of this study reflects the viewpoints of the Finnish RETs industry experts, which has led to the development of a "Roadmap for Blockchain adoption within RETs sector". Such novel empirical evidence contributes to the literature on energy digitalization and helps to realize the potential of blockchain within RETs industry as well as address the needs of future energy systems. Finally, clearly stated study limitations and future research directions support the further development of research in the investigated area.

5.4 Practical contributions

This doctoral dissertation exhibits numerous valuable information for RETs stakeholders, as well as for experts and policymakers devoted to enhancing the expansion of the renewable energy industry. Fundamentally, as suggested in all of the articles supporting this study, it is imperative to develop a favorable socioeconomic outlook for the prosperity of the RETs sector. This inter-sectoral contribution can be enhanced through the formation of energy ecosystems, collaborative networks, or energy hubs and clusters. The multidimensional benefits generated by the strengthened inter-sectoral and inter-firm collaboration could significantly boost market development, promote sustainable entrepreneurship, and consequently, improve the overall performance of the RETs companies. The study adopts a problem-solving approach, which imposed the initial determination of the most challenging barriers for RETs diffusion. Such empirical evidence from the RETs industry experts shed insightful light on the current problems that technology-oriented companies face. Apart from strictly regulatory and policy barriers discussed below, managers mentioned issues e.g. market dynamics, internationalization challenges, insufficient levels of societal awareness and acceptance, or limited financing options. The improvement measures proposed by this study address major regulatory, socio-economic, and technological barriers for RETs diffusion in Finland and Poland, and contribute to the improvement of the conditioning for their increased adoption. Importantly, this dissertation firmly underlines the need for strengthened efforts to increase the societal acceptance of renewables, which would ultimately result in enhanced adoption of RETs. This could be achieved by organizing various education programs, conferences, workshops, and other awareness-raising actions, which would result in increased environmental consciousness and customer trust levels. In essence, the study suggests that the effective diffusion of RETs requires a whole ecosystem of interest groups that would collectively help to overcome these bottlenecks.

Furthermore, this study strongly emphasizes the central role of a supportive regulatory environment in fostering the diffusion of RETs. Essentially, excessive, overly complicated, or inefficient energy policies have been identified as the most critical factor hampering the development of RETs. It is particularly visible in the Polish case, where the highly politicized energy sector favors coal-based energy generation by state-owned energy giants. Therefore, this dissertation recommends more comprehensive, simplified, entrepreneurial-driven, and renewables-oriented regulations as a *sine qua non* for implementing increasing numbers of RETs. There is a requirement for long-perspective strategies to effectively fulfill the ambitious goals stated in the official governmental reports, and to achieve the targets of the legally-bonding international regulations. This study supports the development of these strategies by providing numerous improvement measures based on the empirical evidence from Finnish and Polish RETs industry experts. Hence, this study provides policy implications for government officials, local authorities, and other policymakers devoted to the development of the (renewable) energy industry.

Moreover, this study generates implications for local government officials aiming to develop renewables-driven innovation strategies. This dissertation proposes a specific method for enhancing RETs on a regional scale by developing Research and Innovation Strategies for Smart Specialization (RIS3) according to the concept of the circular economy. As renewables are generated primarily in a distributed manner to support the energy needs of local communities, it is particularly essential to seek and implement increasingly effective measures for their adoption and growth from a regional perspective. The study adopts a managerial and consultancy approach which has helped to perform a SWOT analysis that acts as an information provider for the other local governments and organizations forming sustainable development strategies. In synthesis, this dissertation exposes the benefits of multi-level collaboration which can enhance the flow and transfer of business expertise, technological know-how, education, and professional training through outsourcing activities.

Additionally, this doctoral dissertation provides essential insights for venture capital companies as well as for their incumbent companies on how to generate the maximized benefits from such collaboration. Particularly, the active role of venture capitalists promotes more effective information sharing and strategy setting between collaboration partners. This study highlights the numerous value-added contributions of venture capital into their RETs-focused portfolio companies, and based on that, suggests venture capital as a sought-after option for enhanced development of start-ups and SMEs developing environmentally friendly technologies.

Finally, this study provides future-oriented recommendations for the growth of the RETs industry by exploring the role of blockchain as a key technology to overcome the major technological issues as well as ensure the digitalization, decarbonization, and decentralization of the existing energy systems. The performed research provides empirical evidence from the Finnish RETs industry on possible beneficial applications of blockchain, major barriers to its extensive adoption, as well as effective measures that can foster the widespread diffusion of this revolutionary technology. The outcomes of this study provide numerous implications for the practitioners, policymakers, and multi-sector stakeholders from the renewable energy industry, which can substantially assist in bringing this sector to the next, more digitalized level.

5.5 Limitations and future research directions

This doctoral dissertation explores major determinants of technology diffusion in Finland and Poland. A particular focus has been put on key regulatory, socioeconomic, and technological issues of RETs diffusion. This study adopts a holistic approach towards RETs sector, whereas it should be noted that various renewable energy technologies have particular, distinct features, such as divergent product life cycles, potential in specific areas and conditions, degree of adoption and acceptance, thus they might require specific conditions for their enhanced development. Even though the study provides examples from companies developing all of the most commonly used RETs, they might represent a limited degree of generalization for the whole RETs industry. Thus, it is recommended that more thorough studies focused on factors specific to certain RETs are performed to unveil the particular aspects of their diffusion.

Furthermore, the research performed to support this study has been based on exemplifications from Finland and Poland. Although both Finland and Poland are EU member states, which allows a certain degree of international generalization, it should be noted that the country-specific conditions for RETs diffusion may vary in each nation around the world. Hence, further studies should explore the multifarious aspects of RETs diffusion from the perspective of particular countries or regions to wider the perspective of geographical circumstances for implementing renewables. Moreover, this study develops a framework for facilitating RETs diffusion in terms of regulations, inter-sectoral collaborative networks, sustainable development strategies, external financing for RETs development, as well as innovative digitalization solutions. A more thorough examination of both beneficial and hampering aspects is desired to increase the levels of comprehension of their applicability and importance in the context of RETs. Therefore, further studies should further explore complementary factors that are contributing to the widespread diffusion of RETs. For instance, as current international energy-related resolutions assume rather utopic targets of climate neutrality or zero emissions, future studies should monitor the factual functioning of these policies across the globe. Also, as energy is a paramount resource determining the growth and competitiveness of a given country, it seems extremely challenging to reach a political agreement towards effective universal, global measures for combatting the adverse impact of climate change. Lastly, as this dissertation incorporates a curiosity study on blockchain for renewable energy, due to its infancy stage of technological development and vastly limited number of industrial use cases, further studies should extend exploring the impact of blockchain and other digital solutions on the renewable energy industry.

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Comparative Analysis of Barriers for Renewable Energy Technologies Diffusion in Finland and Poland.

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Abstract. Renewable Energy Technologies (RETs) are critical for the energy transition towards environmentally friendly solutions. There are many international regulations enhancing climate change mitigation. However, on a national level, disruptive technologies often struggle with many various barriers. There is ample evidence supporting the claim that innovative energy technologies require the whole ecosystem to support their diffusion. In fact, it is often a case that the change starts at the regional level. Therefore, some country-specific limitations are worth investigating.

In this study, we examine various barriers of renewable energy technologies diffusion in the case of two European countries: Finland and Poland in the first phase. It served to perform a comparative analysis in a second stage, revealing the similarities and differences between them. An analysis provides insightful knowledge about the current constraints of widespread and effective renewable energy technologies diffusion. As a conclusion, the directions and possibilities for improvement are suggested.

Keywords: Renewable Energy · Barriers · Technology Diffusion · Sustainable Regional Development · Comparative Analysis

1 Introduction

Climate change is becoming an increasingly important issue for the international community. Numerous efforts to minimize its adverse impact have been made through the implementation of certain policies, namely by the United Nations and agendas of the European Union. The goals of recent regulations for 2020 were aimed at reducing greenhouse gases (GHG) emissions by 20% compared to 1990, as well as increasing the usage of renewable energy sources (RES) and energy efficiency to 20% [7]. New targets for 2030 were set and they are even more ambitious: 40% CO2 emissions cut compared to 1990 realities, 32% RES share and 32,5% energy efficiency [6]. Moreover, the European Commission has presented the strategy for climate-neutral Europe by 2050, aiming at 80-95% GHG emissions reduction compared to 1990 levels and RES usage of 50% [8]. European Union policies are in line with the UN Paris Agreement [37] objective to maintain the global temperature increase to well under 2°C and pursue efforts to cling to 1.5°C. As can be seen, international policies play a key role when it comes to leading the way towards facing the challenges connected with global warming. According to [5], renewable energy markets are likely to develop more by dint of supportive policy frameworks and less through the determinations of mere competitive and commercial interests. Furthermore, governments tend to implement the RETs into the energy sector when they can clearly observe the potential benefits, with special regard to the long-term interest, that they can provide. They can be presented in different forms, e.g. sustainable development [14], energy security [39] or proficient use of native resources [1]. However, in order to enhance an improvement in that aspect, a multi-level contribution from different interest groups coming from various sectors is necessary. It is argued that the successful diffusion of renewable energy technologies requires the whole ecosystem to support it [33]. It is also claimed that technology push, market pull, and the regulatory framework are the key drivers of green innovation and thus, of sustainable cleaner production [15]. Moreover, environmental awareness of consumers is a vital variable, since ecologically sound products may be brought in through market pull elements [31]. Therefore, environmental policies persuade businesses to develop sustainable innovations.

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Still, the challenges to business are meaningful: throughout industries, enterprises are increasingly struggling with social and environmental difficulties while stakeholders expect firms to operate according to the concept of a triple-bottom-line of economic, environmental and societal value generation [11], rather than sole short-term income orientation [14]. On the other hand, being environmentally sound and energy-efficient will not guarantee renewable energy initiatives will gain and sustain a long-period market share and there is a cost decrease requirement in order to become competitive with the conventional solutions. Nonetheless, it is argued that the cost of energy generation from renewables will become competitive if the cost of harnessing the environment and internalizing the externalities are considered [24].

There are numerous studies exploring renewable energy diffusion. As it is a complex and multi-perspective process, researchers focus on different specific renewable energy sources e.g. biogas [4], [29], [38] wind energy [22], or solar PV [28]. Moreover, authors tend to contextualize it to certain factors or viewpoints of different interest groups as well as to conduct case studies on different geographical areas. For instance, [32] or [35] examined the barriers of renewables adoption from the customer's perspective, while [5] expresses the investor's viewpoint. Studies led by [30] and [17] explored the social acceptance and so-called willingness-to-pay aspects. Authors like [36] and [27] focused on the technology diffusion process in the sustainable energy context. Nevertheless, the mainstream of research on renewable energy diffusion focuses on energy policy analysis [20], [19].

However, in this study, we decided to take a holistic approach towards RES as well as the diffusion and its barriers, following the tactic of e.g. [16], [3], or [33]. This method helps in analyzing the barriers of different kind in two European countries taken into the scope of this research: Finland and Poland, which allows us to make a cross-case comparative analysis. After making such a comparison of key barriers in each country, brief solutions for the betterment of the existing state of affairs are proposed in conclusions.

2 Major barriers of RES diffusion in Finland and Poland

The literature on barriers to the successful adoption of various RES is quite bountiful. For instance, [32] studied the non-environmental barriers in the viewpoint of Finnish electricity customers and they have identified three categories: cognitive, characterized by the lack of knowledge and trust; orientational, connected with time and effort linked to prior habits and preferences; and economic, referring to the relatively higher cost. Moreover, [24] pointed out externality costs as market-related barriers, and these are the cost of damaging the environment and GHG emissions, which are often unconsidered in business strategies. In addition, [2] studied the potential for different renewable energy sources in Finland, which concluded in collective barriers and they are the following categories: environment, cost, or policy. Furthermore, [18] presented energy efficiency barriers in Finland, and determined insufficient technical skills, non-functional regulation or imperfect information flow as key obstacles perceived by the energy companies. However, in order to express country-specific barriers, it is important to include National Renewable Energy Action Plans from both countries, which were created to efficiently, realistically and appropriately respond to the legally binding obligations resulting from the international regulations mentioned before (namely the Directive 2009/28/EC). In the case of Poland, the target for the RES share in total energy consumption in 2020 has been reduced to 15% and the goal of 10% biofuels share in the transport industry has been additionally set [21], [25]. In the case of Finland, the expected share of RES has been raised to 38%, and in terms of GHG emissions, the national target referred to the 2005 level and aimed at a 16% decrease. What makes Finland a role model for the rest of Europe, these targets have been reached already in 2014 [9].

As can be concluded from Fig. 1, solid biofuels are the main RES type in the total energy generation (for electricity, heating and transport purposes) in the whole EU. In energy statistics, they refer to the *"product aggregate equal to the sum of charcoal, fuelwood, wood residues and by-products, black liquor, bagasse, animal waste, other vegetal materials and residuals and renewable fraction* *of industrial waste", whereas liquid biofuels is "the sum of biogasoline, biodiesels, bio-jet kerosene and other liquid biofuels"* [10]. Both Finland and Poland are characterized by an abundance of forest and agricultural areas, hence wood fuels and biomass have the biggest share in these countries. However, in the case of electricity production, which has a leading position in terms of energy usage, different RES break into the mainstream. In Finland, the share of RES in electricity generation in 2018 amounted to 46%, with hydro (42%), black liquor (21%), other wood fuels (19%) and wind (16%) [23]. In Poland, the wind took the leading role with a 59% share, followed by solid biofuels (25%), hydro (9%) and biogas (over 5%) [34].

A major barrier for RES diffusion in Poland, a coal-based energy mix, is of a complex nature since it has many unfavorable implications. National energy policies are insufficient and ineffective in terms of RES adoption because the focus is still being put on the coal and lignite sector development. This is due to long-lasting experience, and thus, reluctance to change the current state of affairs, which would require the transformation of the whole infrastructure, including e.g. smart grids installment.

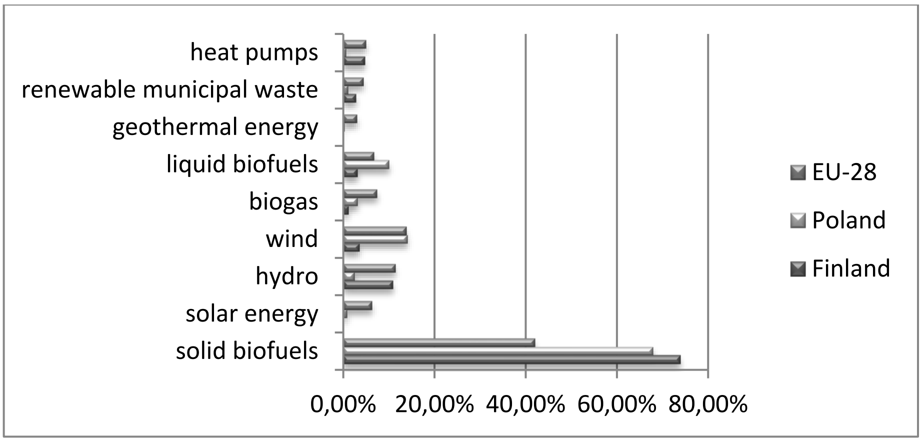

Fig. 1. Renewables by source type in 2017. Source: Own calculations based on [34]

The Polish *'coal culture'* is strongly cultivated, which has had even more socioeconomic consequences: limited financial resources and changes in the EU support (e.g. reduction of feed-in tariffs or green certificates). It results in the lack of social and political acceptance, expressed in the unwillingness to pay more for the green energy as well as fear of the consequences of such change to the mining industry.

In Finland, the major barriers to RES adoption are market-related. Finland, being a developed country, has a solid infrastructure and regulatory support needed for the RES diffusion [33]. Energy transition became the country's inter-sectoral priority. Therefore, a key barrier to the RET diffusion that Finnish companies face, is a relatively small demand for the green energy, compared to the conventional-sourced solutions.

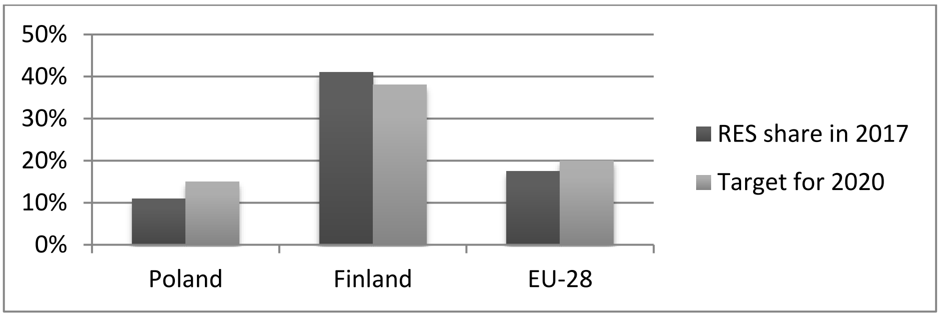

Fig. 2. Renewables share in total gross consumption. Source: own calculations based on [34]

This critical economic barrier is due to the small-sized domestic market, which in consequence, pushes business initiatives to internationalize their operations. It is even more troublesome for the start-ups and SMEs, often struggled by the lack of strategic, managerial human and financial resources, which often do not consider the commercialization aspect, but focus solely on the technology development process [33]. Moreover, according to the study by [40] with the existing energy infrastructure, Finland has a limited capacity of a maximum of 50% RES share.

Table 1. Summary of the analysis

Comparison aspect	Finland	Poland
EC & UN / national goals for 2020 – are they met?	RES share 38% - **YES** GHG emissions 16% lower than in 2005 – **YES** 10% biofuels in transport – **YES,** 18.8% in 2017 Energy efficiency of 35.9 Mtoe – **NEARLY**, 32.9 Mtoe in 2018	RES share 15% - **NO**, 11% in 2017 GHG emissions 20% lower than in 1990 - **NO** 10% biofuels in transport – **NO**, 4.2% in 2017
Major RET diffusion barrier(s): **1) Economic/market** **2) Policy/regulatory** **3) Social/behavioral**	Dynamic and small-sized domestic market, uncompetitive green energy prices, long payback time, imperfect information flow	Coal-based energy mix, ineffective policies, reduction of subsidies (e.g. feed-in tariffs), limited infrastructural and financial resources
RES with the highest share/development potential	Solid biofuels (wood fuels, black liquor), hydro, wind	Solid biofuels (biomass), wind, liquid biofuels, biogas

3 Conclusions and suggestions towards improvement

The analysis performed reveals insightful information about differences and similarities between Poland and Finland. These two European countries have agreed to implement national policies aiming at addressing obligations coming from international regulations. However, only Finland had successfully fulfilled its renewable energy goals. This is due to differences in resources, infrastructure, and behavioral patterns. Finland is one of the most innovative countries in the world

[12], having a strong cultural foundation towards climate change mitigation. The fact that it has nuclear power plants is also crucial since the usage of conventional, high-emission energy sources is reasonably limited. Conversely, in Poland, a coal-centered energy sector with nearly 90% of coal in total energy usage (coal and lignite combined), classifies this country as struggling with the energy transition strategy implementation.
In order to overcome the most significant barriers in these countries, intensive multi-level cooperation of the energy industry, government, academia, and society is highly expected. Namely, a further institutional contribution is necessary since a supportive regulatory framework is seen as a catalyst for renewable energy technologies diffusion. In Poland, the defenders of the current state of affairs could perhaps learn from the German example of a swift and effective transition from a coal-based economy towards RET (*vide* Energiewende) [13]. Moreover, societal barriers are common for both countries, and they concern e.g. noise-disturbing, animal-endangering and landscape-destroying wind power plants or foul-smelling biogas plants. This phenomenon called 'Not-In-My-Backyard' (NIMBY) [26] could be addressed by some promotion and awareness-raising actions. Lastly, efforts directed toward the further development of biomass- and waste-based CHP (combined heat and power) technologies would significantly improve the current state of affairs in both countries.

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Barriers for Renewable Energy Technologies Diffusion: Empirical Evidence from Finland and Poland

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Abstract: A harmful impact of climate change and global warming has concerned various sectors of the international community. Numerous energy policies aiming at climate change mitigation have been implemented on a national and global scale. Renewable energy technologies (RETs) play a critical role in enhancing sustainable solutions that significantly limit greenhouse gas (GHG) emissions. Such innovative technologies can facilitate energy transition through providing, e.g., energy security, sustainable development, and effective usage of indigenous resources. However, the commercialization of RETs is extremely challenging. The barriers can be of a different nature, although this study focused on socioeconomic and regulatory issues. There is ample evidence that energy policies play a central role in supporting adoption of renewables. It is also claimed that RETs require the whole ecosystem to support their successful diffusion. In this study, we explored multifarious barriers for widespread RET diffusion in two European Union countries, Finland and Poland, indicating the most common barriers existing in the literature as well as analyzing major bottlenecks from the viewpoint of renewable energy companies' executives. We also present statistics of the most commonly used RETs in these countries in order to express the diffusion issues more appropriately. The research shows that inflexible, ineffective, and excessive regulatory frameworks; limited financing options; as well as an insufficient level of societal awareness have been seen as the main bottlenecks for RET diffusion in both countries. The outcomes of this study provide useful insights for the researchers in the energy transition field as well as practical managerial and regulatory implications aimed at overcoming these challenges.

Keywords: renewable energy; technology diffusion; innovation management; energy policy; sustainable development; European Union (EU); barriers

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1. Introduction

The world's current geopolitical landscape is struggling with numerous problems. We are witnessing unprecedented issues, primarily the COVID-19 global pandemic, which has dramatically shifted the reality we exist in. Moreover, the challenges that have affected the international community the most over several decades are still present, such as overpopulation, 'consumerism', rising levels of socioeconomic inequality, military conflicts, and—especially important in this study—air pollution. The adverse impact of climate change is causing multifarious constraints. Global warming is deteriorating the natural resources of the planet, which causes massive human and animal migration as well as the extinction of different species, flooding, depletion of the ozone layer, melting and greying of the polar zone, etc. It is already common knowledge that action from different sectors of society needs to be taken immediately if we wish to protect our planet from the forecasted catastrophic consequences [1].

One of the processes that would significantly improve the quality of life on our planet is to limit greenhouse gas emission by implementing environmentally friendly technology solutions, such as a circular economy or renewable energy sources [2]. Renewables, as the name suggests, are free, constantly available, and derived from natural resources; therefore, it is in common sense to implement such technologies not only to save costs but most importantly to save our planet. However, the implementation of renewable energy technologies (RETs) into countries' energy mixes is a complex, multidimensional, and also problematic process. Such a sociotechnical transition requires, e.g., an alteration in current technological and regulatory regimes, time- and cost-consuming infrastructural investments, introduction of supportive energy policies, and awareness-raising actions within society [3].

This paper presents the most commonly used renewable energy sources in two European countries: Finland and Poland. We focus on the renewables with the highest share in order to examine the specific barriers to their implementation. We do so by presenting the most popular barriers from the literature review for categorization. We also reveal the results of our empirical analysis. It is important to note here that this study focused on the socioeconomic and regulatory barriers for successful RET diffusion. The authors' team consists of researchers from two universities in Finland and Poland. Having an extensive scientific collaboration experience, we decided to compare the multi-dimensional conditions for the development of innovative renewable energy technologies in these two countries. We believe that such a comparison will provide useful implications for the interest groups from different sectors of both Finnish and Polish society.

The differences between these two countries are meaningful and relatively easy to notice even at first glance. Finland is one of the world's most innovative countries, leading in many global R&D and sustainability rankings [4]. In the case of the economy, the share of domestic capital in total GDP generation is significantly high, making the country relatively close to the state of autarky. Moreover, as a Nordic country, the archetype of admiration and cultivation of nature is deeply rooted in Finnish culture [5]. Therefore, the circumstances for enhancing sustainable practices are strongly favorable: Where the level of societal willingness to adopt renewables is very high and the government is providing a supportive regulatory framework, businesses focused on developing RETs are emerging rapidly and have a high chance to prevail [6].

Poland, on the other hand, is still categorized as a developing country. Even though the annual GDP growth rate is steady, innovative energy investments are forced to compete with conventional solutions. There are growing numbers of solar PV and wind turbine installations; however, the country's energy mix is strongly coal-oriented. The mining industry has been important for the Polish economy for many decades and still is [7]. It is located mainly in the Silesia region; therefore, such a socio-technological transition would require systemic change that could create new opportunities for all the interest groups from this sector. The other important factors slowing the adoption of renewables in Poland is the cost of the infrastructural change required to enhance RET development and general reluctance to change the current situation within society [8]. However, there are many national and regional energy policies, activist movements, and other mechanisms that aim to support sustainable energy generation and set ambitious targets for the future.

2. Literature Review

The successful commercialization of innovative technologies is highly reliant on the technology, regulatory, and market-related aspects. This process becomes even more troublesome when the technology in question is highly innovative and requires an adjustment in current structures. Renewable energy technologies (RETs) can be classified as disruptive [9] and therefore require substantial investments usually with a relatively long payback time, have significant dependence on the available infrastructure and regulatory support, and are often challenged by unpredictable market conditions [10].

2.1. A Central Role of Energy Policies

The literature firmly supports the claim that supportive regulatory frameworks are a key factor for the renewable energy market development, suggesting that this factor is preliminary and thus even more critical than the economic, managerial, or commercial excellence of the companies [11]. Governments, often legally bound by numerous international energy policies, are nowadays more eager to enhance sustainable technologies in order to fulfill the targets of such regulations [12]. The common efforts of the international community to combat the deleterious impact of global warming have resulted in the introduction of the United Nations' Paris Agreement during the COP21 global summit in 2015. The goals for 2020 were the so-called '3 × 20%' which corresponded to increasing the share of renewables and energy efficiency by 20% as well as reducing the CO_2 emissions by 20%, compared to 1990 realities [13]. The following UN climate change conferences have updated the targets and measures for a climate-friendly world, with a most recent one, COP26, taking place in November 2021 in Glasgow, Scotland. The current targets for 2030 within the European Union aim at 40% greenhouse gas (GHG) emission reduction, compared to the 1990 situation, as well as 32% share of global renewable energy sources and 32.5% global energy efficiency [14]. Furthermore, the European Commission has implemented a strategy to make Europe climate-neutral by 2050, which imposes a 80–95% GHG emission cut in comparison to 1990 as well as increasing the level of renewables to 50% [15]. These two major policies play a leading role in keeping the global temperate increase below 2 °C with the aim to maintain it at 1.5 °C.

In addition to the strictly legal and image-creating aspects, renewables-enhancing national policies are created when the long-lasting potential benefits from RET usage are forecasted. Importantly, renewables can provide, e.g., energy security, sustainable development, and proficient use of the country's indigenous resources [16]. Moreover, RETs can help to diversify the energy supply, significantly decrease the dependency on imported fuels, and create niche markets. Governments, realizing these multifarious benefits from adoption of renewables, include such energy sources in their national energy strategies and often develop and publish suitable renewable energy action plans in order to reflect the global requirements on a country-specific level and to generate a roadmap for implementing environmentally friendly technologies in a realistic, efficient, and sustainable way.

2.2. The Importance of Socioeconomic Conditions

Studies conducted by Shakeel et al. [10] and Peura et al. [17] claim that the limited financing options, market uncertainty, infrastructural support, internationalization challenges, and market-driven technology development are some of the main hindrances causing the slow commercialization of renewable energy technologies in Finland. As can be concluded, the developing challenges for the companies are multidimensional, and RETs require the whole ecosystem to enhance their diffusion. It is argued that apart from the supportive policy framework, technology push and market pull effects are perceived as key factors for successful sustainable energy innovation adoption [18]. A relatively high level of social awareness is a crucial aspect, as various bottom-up initiatives aiming at improving the overall quality of life by introducing more and more environmentally sound solutions can be raised by, inter alia, using the market pull mechanisms to bring the sustainable products into the economy.

Similarly, ecologically conscious stakeholders often require managers to follow the triple-bottom-line approach to generate economic, environmental, and societal value for their portfolio companies [19,20]. Such business conduct styles cause an important change from the strictly short-term profit-oriented practices widely performed previously. However, it is important to note that eco-friendly practices and efficiency alone will not guarantee RETs a reasonable market share as the end-products generated from such technologies are often costlier and consequently uncompetitive with the conventional solutions. It is common economic knowledge that for the customers, the cost is often a critical variable. Nevertheless, according to Owen [21], RETs will become cost-competitive if the so-called 'externality costs' are considered, and they stand for the costs of the ecological damage inevitably related to the energy production from fossil fuels. Therefore, it can be concluded that a higher level of the environmental awareness within all the sectors of society will increase the chances of RETs being successfully commercialized.

Moreover, to emphasize the significance of the societal conditions, it is also important to mention the Technology Acceptance Model (TAM) developed by Fred Davis in 1989, which is a theory that models the acceptance and utilization processes within the end-users of new technology [22]. According to this theory, the decision of the end-user is influenced by numerous factors and mainly by (1) perceived usefulness, further defined as '*the degree to which a person believes that using a particular system would enhance their job performance*', and by (2) perceived ease of use, which can be explained as '*the degree to which a person believes that using a particular system would be free from effort*'.

2.3. Major RET Diffusion Barriers

The literature review provides plentiful examples of different barriers to successful RET adoption. Primarily, Owen mentioned externality costs as major market barriers, which are often not included in the business strategies [21]. In his analysis based on the International Energy Agency's report, he provides further commonly experienced market barriers in the energy area, as can be seen in Table 1.

Table 1. Examples of market barriers to RET diffusion. Developed based on [21].

Market Barrier	Characteristics	Solutions
Uncompetitive electricity prices and price distortion	Externality costs and economies of scale not yet included	Awareness-raising actions, Customized subsidies and taxes
Insufficient knowledge	Information about the technologies needs to be widely available	Standardization and labeling Quality certificates
Transactional costs	Administration cost, green certification, permits, and usage	Information and calculation systems for decision-makers
Financial risk	Long payback time, high entry threshold, limited financing, sunk costs	Life cycle cost analysis External funding options
Inappropriate regulations	Obsolete energy policies, often supporting traditional solutions	Future-oriented energy plans
Conservative markets	Inadequate split of benefits between different stakeholders	Market restructuring and democratization
Technology-related	Obsolete infrastructure, technological know-how required	Grid modernization, commercialization aspects, business-oriented engineering

As renewable energy sources are diversified, and the technology diffusion process is multifaceted and complex, scientists have considered diverse concrete renewable energy technologies, e.g., solar PV [23], biogas [24–26], and wind energy [27,28]. Furthermore, authors often scrutinize these approaches using particular determinants or perspectives of various interest groups and perform case studies on specific geographical areas. For example, some authors investigated the bottlenecks of RET implementation from the customers' viewpoint [29,30], whereas others reflect this issue from the investors' perspective [31]. Interestingly, a study led by Lucchi provides a conceptual framework for the integration of solar PV into heritage sites, and they determined three major criteria for governments to consider during the planning process, and these are: 'localizing', linked to location; 'qualitative', primarily suggesting the smallest possible impact on the environment; and 'quantitative', determined by technology performance and economic aspects. The study concludes with the claim that RETs require well-defined energy policies, simplified standards, skilled personnel, and a large number of existing leading examples to lead the way for the others to ensure their widespread diffusion [32].

Authors such as Ruggiero, Davis, and Jung examined the societal awareness and technology acceptance as well as 'willingness-to-pay determinants' [22,33,34]. Studies led by Popp and Tsoutsos provide insight into the technology diffusion phenomena through the lens of energy sustainability [35,36]. Nonetheless, the vast majority of research on renewable energy adoption concentrates on energy policy analysis [7,37–39]. However, in this study, the holistic approach has been chosen to present the socioeconomic and regulatory barriers of the diffusion of different RETs in general, which follows a method previously used in the literature that serves to provide the overview of the whole renewable energy industry and not to focus on the specific technology [10,16,40].

3. Methodology

In this study, we adopted a mixed methodology of policy analysis, literature review, and a cross-case qualitative case study. We conducted semi-structured interviews with a total number of 13 executives representing 12 RET companies, including 5 from Poland and 7 from Finland. Details of the investigated cases can be found in Table 2. The experts were asked two basic questions: (1) *From your perspective, what are the major RET diffusion barriers in your country?* and (2) *What are the measures to overcome these barriers?* It is important to note at this point that to assure the transparency and integrity of the study as well as to address the GDPR requirements, neither the companies' nor the interviewees' names are revealed. This anonymity has been requested and agreed upon by both researchers and the respondents.

Table 2. Details of companies in the case study.

Company	Technology Focus	Interviewee's Role	Country
A	Automation and electrification of wind power	Executive Vice President, Marketing and Sales	Finland
B	Energy technology hub; smart grids, energy efficiency, and marine solutions	Communications and Brand Manager	Finland
C	Wind and solar power	CEO	Finland
D	Solar PV in the maritime sector	CEO	Finland
E	Circular economy; waste to energy	CEO	Finland
F	Wind power	Head of Project Development	Finland
G	Wind power	Vice President, Energy Management	Finland
H	Wind energy	Managing Director	Poland
I	Solar energy	Operations Manager	Poland
J	Solar PV inverters	Head of Marketing	Poland
K	Energy from waste and biomass	CEO	Poland
L	Biogas and biomethane	(1) Managing Director (2) An external expert from academia	Poland

To perform this comparative case study, we utilized policy, statistical, and literature analysis. Energy policy review helped us in performing a thorough analysis of the regulatory environment of the two investigated countries, including the governmental strategies for the future. It also provided us the national targets for including the renewables into total energy mixes and consequently conclusions from the results of the efforts to fulfill these goals. An analysis of widely available statistics allowed us to identify the RES with the highest share in both countries to focus mainly on the most common and/or most prosperous renewables in Finland and Poland. Furthermore, the synthesis of the most popular barriers presented in the literature review was identified and structured, which enabled us to create a categorization of barriers for our analysis. We compared and combined the barriers existing in the literature with the bottlenecks most commonly identified by our interviewees.

This cross-case comparative study allowed us to extrapolate the most critical barriers for RET diffusion in both countries. This comparison generates the possibility to draw insightful conclusions as well as to suggest practical and long-lasting measures for the betterment of the current state of affairs. Moreover, practices from the countries taken into consideration may vary, which creates the capacity to transfer knowledge, technology, and managerial tools within these countries [41,42].

4. Results of the Analyses

As already mentioned, this study focused on the regulatory and socioeconomic issues of RET implementation in two European Union member states: Finland and Poland. It was thus necessary to analyze specific countrywide renewable energy action plans. These are the national policies that aim to address the legal commitments from the numerous regulations adopted by the international community. Since Finland and Poland are both EU countries, these obligations derive from the Directive 2009/28/EC [43] and are still in line with the resolutions of the UN and The Intergovernmental Panel on Climate Change (IPCC), which is the United Nations body for assessing the science related to climate change. The IPCC was created to provide policymakers with regular scientific assessments on climate change, its implications, and potential future risks, as well as to put forward adaptation and mitigation options.

In Finland, the targeted RES share for 2020 has been elevated to 38%. In the case of GHG emissions, the national target aimed at a 16% decrease, compared to 2005 levels. These targets had already been reached by 2014, making Finland a role model for the rest of Europe and the world [44]. New targets for 2030 are as follows: 51% RES share and 39% GHG emission reductions in comparison to 2005 realities. The government of Finland has also declared the ambition to become carbon-neutral by 2035 and, consequently, to become the world's first fossil-free welfare society [45].

In the Polish case, the goal for 2020 concerning the distribution of renewables in overall energy consumption has been limited to 15%, and furthermore, the target of 10% share of biofuels in transport has been established [46,47]. It is important to note that despite these reductions, Poland failed to meet the set targets [48]. New targets for 2030 aim at 21–23% RES share in gross final energy consumption, 14% of renewables in transport, as well as 32% RES share in electricity production. On the EU level, in 2018, 12 member states met and exceeded the 2020 target for the share of renewable energy in gross final energy consumption. The remaining 16 countries have yet to reach their target [49]. Figure 1 shows the effectiveness in reaching the renewable energy targets in Finland, Poland, and the whole EU-28.

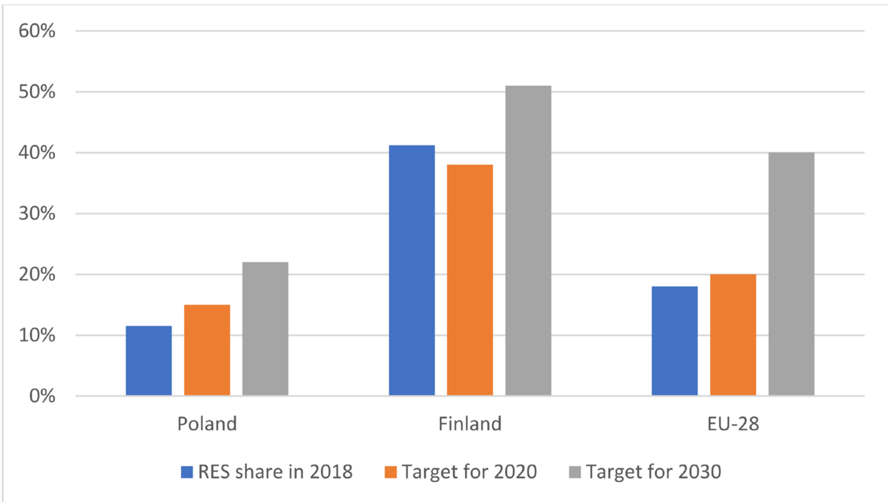

Figure 1. Share of renewables in final gross consumption. Own calculations based on [49].

As can be concluded from Figure 2, solid biofuels were the principal type of renewables in the total energy generation (for electricity, heating, and transport determination) in the whole EU-28 in 2018. In energy statistics, they are defined as the '*product aggregate equal to the sum of charcoal, fuelwood, wood residues, and by-products, black liquor, bagasse, animal waste, other vegetal materials and residuals and the renewable fraction of industrial waste*', *whereas liquid* *biofuels refer to 'the sum of bio-gasoline, biodiesels, bio-jet kerosene and other liquid biofuels'* [50]. Both Finland and Poland are characterized by richness of forestry and agricultural areas; therefore, wood fuels and biomass lead the way in these countries. However, in terms of electricity production, which has the highest share in case of the energy use, as well as commercial applications, other types of renewables take the leading role. In Finland, the share of renewables in electricity generation in 2020 amounted to 52%, with hydro (45%), black liquor (17%), wind (23%), and other wood fuels (12%) [51]. In Poland, wind energy was the main RET in terms of electricity generation in 2018 with a 58% share, followed by solid biofuels (24%), hydro (11%), and biogas (over 5%) [49].

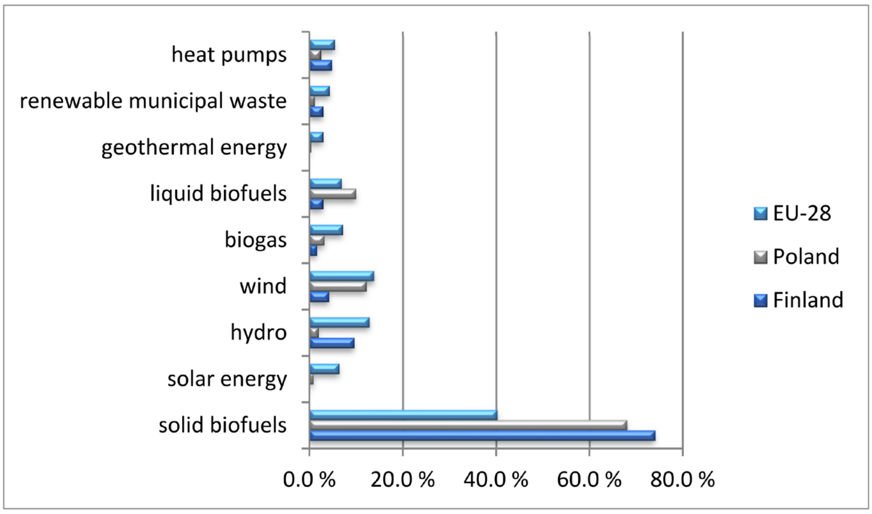

Figure 2. The structure of energy production from renewables in 2018. Own calculations based on [49].

4.1. Categories of Barriers for RET Diffusion in Finland and Poland

As already shown, the literature analysis provides different types of challenges for successful RET adoption in the investigated countries. For example, Salmela examined the non-environmental issues from the Finnish electricity customers' perspective, and they recognized three categories: cognitive, associated with the lack of trust and technological know-how; orientational, related to time and efforts put into former customer behaviors or priorities; and economic, linked with relatively higher initial costs [29]. Furthermore, Aslani considered the potential for development of various RETs in Finland and came up with joint barriers, and they fall under the three following categories: policy, environment, and cost [5]. Moreover, Kangas studied energy-efficiency-related barriers in Finland from the viewpoint of energy companies, with unsatisfactory level of technological skills, ineffective regulations, and imperfections in the information stream identified as the main difficulties [52].

In Poland, major bottlenecks identified in the literature are supporting the mainstream barrier of ineffective regulatory frameworks, mainly by underlining the excessiveness or insufficiency of the current policy support schemes. For instance, the most recent study on this topic by Brauers focuses on the political implications of the Polish coal-based energy mix and identifies major challenges linked with this issue, and these are generally economic, political, and legislative and social and environmental factors [7]. Within the first category, the most critical constraints are the regional economic dependency of the Silesia region associated with the high employment rate in the mining sector, limited financial schemes to support renewables, as well as relatively high electricity prices for households in the short-term. Under the second category, they identify energy security concern but more importantly the political influence of the coal industry and its labor unions. The last category is related to the past geopolitical experiences, which imply a threat of disruptive change within society and a lack of eagerness to deviate from coal as a source of the country's further development. Furthermore, Paska and Surma examined different national energy policies aiming at enhancing RET development as well as to fulfill the international emission targets. The study identifies the main challenges for the Polish energy sector, i.e., limited domestic fuel demand and energy generation capacity and distribution infrastructure as well as heavy dependence on an external supply of energy from natural gas and crude oil. After concluding that renewables can play a significant role in overcoming many of these obstacles, they found numerous negative implications associated with the current policy schemes, e.g., green energy certificate mechanisms generating more costs for the end-customers of electricity, lack of long-term vision from the government resulting in instability and unreliability of the regulatory environment, and ineffective grid development [47]. Similarly, Dolega determined legal/formal and technical barriers for the further RET development in Poland, including restrictive auction parameters, the complexity of processes of receiving permits for technology installations, general bureaucratization and lengthiness of administrative procedures, an unstable and unclear legal framework, lack of long-lasting financial support mechanisms, and insufficient grid infrastructure [53]. Moreover, in their case study among the renewable energy industry experts, Pietrzak et al. determined the most hampering factors for RET diffusion in Poland, starting with the strongly unfavorable influence of the coal-centered energy lobby as well as complex and unclear energy regulations as the aspects with the most impact [54]. The experts also outlined relatively high entry cost barriers of investments, unsatisfactory level of societal technology knowledge, and low and unstable green certificates prices. These numerous issues raised by the studies mentioned in this section act as a theoretical and practical foundation for this study, as the most common challenges in RET adoption in Finland and Poland can be categorized to present the results of the central analysis in a well-organized way. Table 3 presents the categories of barriers for RET diffusion in Finland and Poland identified in the literature.

Table 3. Categories of RET barriers in Finland and Poland.

Category	Examples	References
Economic and Market	Lack of financing options, high initial costs, market uncertainty, long payback time, investment risk, dependency on energy exports	[5,7,10,17,25,29,48]
Political and Regulatory	Ineffective and unstable policies, excessive and complex procedures favoring large state-owned companies or conventional energy sources	[5,7,39,47,48,52–54]
Societal	Lack of know-how, information issues, reluctance to change, NIMBYism	[7,29,47,48,52]
Technical	Ineffective grid development, insufficient or obsolete infrastructure	[10,17,25,47,53]

Additionally, the main author of this research presented the comparison of RET diffusion barriers in Poland and Finland, based mainly on the literature review and statistical analysis. This study acts as specific development of the author's research project through the support of the empirical evidence from the renewable energy industry [48].

4.2. Main RET Diffusion Barriers from the Industry Experts' Perspective

Our analysis supports and underlines the barriers already commonly identified in the literature and adds some new insight into specific bottlenecks that can be included in these broad categories. We also provide the measures that in our interviewees' opinion might improve the current state of affairs in both countries. It is also important to note that in the case of two Finnish companies, their executives could not specify any critical barriers for RET diffusion as they perceived the country's current business environment to be highly supportive. Still, they were able to suggest some steps aimed at further improvement of certain conditions.

Finnish experts agreed that '*when it comes to energy, there's always politics involved*', which can have either a beneficial or unfavorable effect. Among the latter, our respondents tended to raise the issue of unstable, disorienting, and risk-generating regulations. They have experienced some major alterations, e.g., from the changes in the government that have caused many challenges for their companies. Moreover, there are numerous environmental, economic, and technical criteria to fulfill, and '*getting these permits can last forever*', which can result in, e.g., selling pilot projects abroad, where such innovative solutions can prosper more freely. Another important issue outlined was the lack of support schemes for SMEs and start-ups focused on renewables, expressed mainly by limited financing and consequently commercialization opportunities. This may be due to the fact that '*it's a rather conservative industry, and it takes about 2–3 years to get your technology introduced in the market*'. Moreover, Finnish RET companies' executives mentioned some technological issues, such as the need for more efficient energy transfer solutions or the necessity to maintain sufficient levels of technological know-how to keep up with current changes of the customer needs as well as some socioeconomic constraints, such as the higher initial cost for the renewables compared to conventional solutions or the phenomenon called '*NIMBYism*', which stands for not in my backyard, a societal reservation and reluctance towards constructing landscape-influencing and noise-generating wind parks or foul-smelling biogas plants in their neighborhoods [55].

Similarly, Polish experts have found a coal-centered and highly politicized energy sector as a central barrier for the enhanced prosperity of renewables in that country. The main objection to the government's actions is that '*despite many promises to follow the international goals, there is still a strong coal lobby (companies and labor unions) and thus, the government is far away from giving up on coal-based energy economy*', and this lobby creates a '*fear effect of massive protests and a huge societal challenge how to perform this transition without a harm for the occupational groups from the mining sector*'. Moreover, the current national regulatory frameworks are not necessarily considered as supportive or providing stability. The authorities tend to support rather fossil fuel companies with numerous subsidies or the bailing out of bankrupt coal companies than opting for renewable energy technologies, '*which seems to be both unreasonable and irresponsible for our future*'. Furthermore, among various socioeconomic constraints, our interviewees stressed so-called 'willingness-to-pay' aspects, which they consider a hesitancy to initially pay more for the energy generated from renewables, compared to the cost of the conventionally produced energy. In its economic simplicity, '*cost is always seen as a possible barrier*' both for the companies providing green energy as well as for the end-customers. Another important issue is the societal reluctance to change the current situation, which is supported by the '*beliefs that coal is critical for Polish further economic prosperity and it should be protected by the government*'. This, in consequence, provokes a lack of interest in investing in RETs or nuclear power plants, which would significantly increase the level of Polish energy security, e.g., by decreasing the dependency on fossil fuels and energy imports (mainly in case of the Russian gas). Lastly, some public protests have been noted in response to the plans of biogas plants or wind power parks installments next to the inhabited areas, which is a clear example of the aforementioned 'NIMBYism'.

5. Conclusions and Suggestions towards Improvement

The most appealing conclusion of this study is that despite relatively huge societal, environmental, and economic differences between Poland and Finland, these countries share the major barriers perceived by their energy industry experts. In both countries, it was the political sector that appeared to have the most negative impact on the renewable energy industry. The current policy schemes were estimated to be insufficient in terms of support provided by the government or excessive when it comes to the complexity of the legal and formal procedures. In addition, systematic changes in the regulatory frameworks have been seen as a destabilizing factor generating high-risk levels. Such a comparative analysis of the conditions for RET development in these two specific European countries provides novel implications for the interest groups in the energy sector.

The analysis also shows that there are similarities between the investigated case countries in the category of socioeconomic aspects. Even though the level of societal awareness is significantly higher in Finland, there were several common barriers identified by the case companies' executives, such as high initial investment and transaction costs, doubts about RET efficiency and reliability, as well as strictly community-based issues such as NIMBYism or unwillingness to pay more for the environmentally friendly solutions. Moreover, the commercialization challenges are common within various technology-oriented SMEs and start-ups across the globe; hence, it was expected to detect such kinds of issues through this analysis.

There are, however, some differences between various case companies from both countries. Firstly, there were two managers from Finland (companies D and F) who could not determine any critical policy or socioeconomic barrier for their firms' further development. From their perspective, the conditions for developing RETs are highly favorable. It was often the case on the Finnish side of the research that experts needed more time to think about possible barriers, as they mostly underlined the benefits of being located and operating in Finland. However, the most common issue expressed by the interviewees was the insufficient support for RET start-ups and SMEs. Since such business initiatives focus primarily on the technology development aspects, they often lack financial and managerial resources that would enhance their commercialization. It has also been seen as a regulatory barrier, as '*government supports the big companies instead of small players, and it's not as much entrepreneurial-driven as it should be*'. Polish experts also repeatedly raised this bottleneck, mainly due to the fact that conventional energy companies are more often than not huge, state-owned corporations. Therefore, they receive more financial and regulatory support than smaller-sized innovative technology ventures. However, the main difference between Finland and Poland was found in the regulatory/policy support for RETs. In Poland, our interviewees firmly underlined the politically related energy sector, which is currently oriented towards fossil fuels such as coal and lignite. This significantly reduces the potential for RET diffusion, by, e.g., '*favoring the mining sector, mainly because of the social pressure*', which results in '*simply leaving less market share for such energy sources*'.

To address these numerous barriers, our respondents were also asked to provide solutions for the betterment of the current state of affairs in their countries. In Finland, where the most critical issue is the technology commercialization aspect, there have been numerous wishful recommendations for the Finnish government to become '*more entrepreneurial-driven*' and to enhance more emerging sustainable solutions. Under this rather universal suggestion, the experts expect that the procedures of acquiring necessary financial support, collecting feed-in tariffs, green certificates, or obtaining legal permits for starting the operations would be '*less challenging, much faster, and more simplified*'. This kind of more specialized support would create the '*positive push*' from the government to develop new technologies by the SMEs and start-ups, which are now dominated by large companies, which '*would have that money anyway*'. Moreover, some of our respondents expressed the will to intensify the cooperation and contact with customers, to '*listen and respond to their needs*'. This would perhaps boost the levels of customer satisfaction and willingness to adopt more sustainable solutions, which in consequence, could critically enhance RET diffusion in general. Furthermore, in the case of wind power companies, experts—perceiving the landscape-disturbing nature of the wind parks—would appreciate '*more efficient ways to use less land for wind energy generation*', taking environmental impacts of such technologies into account more appropriately.

The improvement suggestions from the Polish renewable energy sector representatives concerned primarily the most challenging issue of the coal-centered energy policy. First and foremost, there is a need to develop a long-run strategy to enhance more renewables into the system, followed by tangible outcomes and actions from the government. For instance, some immediate actions are expected, with the caveat of their political feasibility, such as dramatically reducing financial support for the mining industry, which is already in a bad economic situation, or imposing energy diversification obligations on the energy companies. Moreover, more supportive regulations could lead to improvement in terms of energy security, independence of energy imports, or competitiveness of the Polish economy, and they could be aimed at, e.g., investing more in state-owned renewable energy companies, developing more financial and socioeconomic incentives mechanisms, etc. The current Polish energy sector is '*overly influenced by the politicians and labor unions*'; therefore, a realistic restructuration plan would have to carefully take the coal industry interests into account, by providing beneficial alternatives, such as, e.g., new work opportunities, a long-term '*evolution rather than revolution*' approach, a transition period, or more efficient use of financial capital. There have been some successful examples of the swift and effective energy transition processes, e.g., in Germany, where the project called *Energiewende* relies heavily on renewables and its positive effects can be clearly noticed, which makes it a relevant case to follow [56].

This study also presents collective and universal recommendations for the RET companies and other interest groups associated within the renewable energy industry both from Finland and Poland or perhaps from the whole EU. Firstly, it is in common sense for the EU member states to follow the regulations aiming at further RET development. For instance, the 'European Green Deal' [57] and 'Fit for 55' [58] strategies can act as effective multidimensional (but mostly financial) incentives for the EU countries to strengthen their efforts to become carbon-neutral in the future. This can result in numerous benefits for both countries, e.g., using this situation to modernize obsolete grid installations which would enhance the novel, renewables-fitted infrastructural solutions as well as provide more energy security and efficiency. Another highly important hindrance to the challenge is the insufficient levels of technology know-how, information about the economic and environmental impact, and consequently support for renewables within the different sectors of society. This issue can be addressed by multidimensional awareness-raising actions, such as professional training, specialized conferences, business incubator programs, activist movements, or impactful media communications, to mention a few possibly favorable measures. Furthermore, high-tech SMEs and start-ups (including RET-focused ones), which often struggle with the lack of financial and managerial resources, should consider external funding options other than the EU subsidies, such as business angels or venture capital (VC). Numerous studies support the claim that especially VC, in addition to the strictly financial contribution, can add value to portfolio companies through providing, e.g., corporate governance excellence, business networks and internationalization options, legitimization, and managerial expertise. [59,60]. Lastly, it is critical to follow the fast-paced technological development of the energy sector, according to the so-called '*Energy 3Ds*', which stands for decarbonization, decentralization, and digitalization [61,62]. This can be achieved by, *inter alia*, smart grid investments, or deployment of the IoT and blockchain for renewable energy [63–66]. It is forecasted that such innovative technologies would revolutionize the energy supply chains by removing the intermediaries from the transaction processes, providing more transparency, integrity, and security, as well as developing energy trading platforms and automating the issuance of the green certificates, etc. [67]. However, blockchain technology is still in its infancy stage as there is no widespread supportive regulatory framework for such solutions yet.

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Abbreviations

RET	Renewable energy technology
R&D	Research and development
GDP	Gross domestic product
Solar PV	Solar photovoltaics
UN	United Nations
GHG	Greenhouse gas
TAM	Technology acceptance model
GDPR	General Data Protection Regulation
RES	Renewable energy sources
CEO	Chief Executive Officer
EU	European Union
IPCC	Intergovernmental Panel on Climate Change
SMEs	Small and medium enterprises
VC	Venture capital

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Local contribution to circular economy. A case study of a Polish rural municipality

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Summary: The concept of circular economy is becoming increasingly important not only for academics, but also for other stakeholders. Notably the local government representatives are implementing such solutions, in response for the population growth and development, connected with increased consumption. This paper aims to recognize existing local solutions of circular economy as well as to identify possible ways for its development. Mixed methodology is used, including constructive approach, SWOT analysis, descriptive statistics or weak-market test. An analysis emphasizes a positive impact of circular economy on local development of the investigated municipality. However, it is still necessary to continue and intensify information and education activities for increasing public awareness of waste prevention, their removal under communal waste collection and collection systems, and proper management of municipal waste (especially biodegradable waste).

Key words: circular economy, waste management, sustainable development, technological innovation, waste-to-energy.

JEL codes: Q53, R58, O13

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Introduction

Circular economy has been gaining more and more attention among academics and practitioners during the last decade. Increasingly, the main emphasis has been put on global problems and solutions aimed at improving the situation from a perspective of use of natural resources and recycling of materials. From this perspective a local approach, focusing on solving problems related to the re-use of raw materials and waste, can be not stressed enough or even omitted. That is why we would like to investigate opportunities for starting internal loops of the circular economy at the local level. The case study selected represents a rural municipality located in the area of intensive agricultural production, peripheral from a perspective of an administrational region but characterized by environmental features of high value. The work aims to recognize existing local solutions of circular economy as well as to identify possible ways for its development. Closing loops in local systems can contribute to solving problems at the regional level and in the global systems. In the study, we map the conditions of the municipality development as well as problems of raw materials and waste management. An analysis of statistical data and focus discussion involving representatives of local authorities, entrepreneurs, farmers as well as individuals and social organizations proves a need to look for business models that will help solve problems of municipal waste, water and sewage management.

1. Background

The increase in population and rising consumption related entails growing problems regarding waste production and scarcity of natural resources. For this reason, solutions aimed at reducing waste and recycling development as well as at re-use of materials have been becoming increasingly important. In this context, the concept of circular economy has been attracting more and more attention from politics, science, business and civil society. An analysis of 114 definitions led Kircher *et al.* (2017) to define circular economy as an economic system that replaces the "end-of-life" concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. What is important to stress from the perspective of the study, the circular system operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond). This kind of approach is related with a few principles, of which the most important ones can be defined as following (EMAF, 2012):

1. products are designed and optimized for a cycle of disassembly and reuse. These tight component and product cycles define the circular economy and set it apart from disposal and even recycling where large amounts of embedded energy and labor are lost;
2. a strict differentiation between consumable and durable components of a product. Consumables are largely made of biological ingredients or 'nutrients' that are at least non-toxic and possibly even beneficial, and can be safely returned to the biosphere - directly or in a cascade of consecutive uses. Durables, such as engines or computers are made of technical nutrients unsuitable for the biosphere (e.g. metals, plastics), which are designed from the start for reuse;
3. the energy required to fuel a cycle should be renewable by nature, again to decrease resource dependence and increase system resilience (e.g., to oil shocks).

Circular economy (CE) is a concept currently promoted by some European Union Member States and several other countries, including China, Japan, Canada, as well as several companies around the world (Korhonen *et al.*, 2018a). The concept of circular economy has been expressed in the EU policy. In the program 'Towards a circular economy. A zero waste program for Europe' adopted in 2014, the European Commission states that Europe can benefit economically and environmentally from better use of resources (EC, 2014).

Since the industrial revolution, the "take, produce, consume and discard" growth model has been consolidated in economy. It is a linear approach based on the assumption that resources come in abundant quantities, are available, easily obtainable and can be removed at a low cost. However, problems related to access to natural resources and the amount of waste generated are forcing a search for new models of economic development (Korhonen *et al.*, 2018b). Circular economy systems allow in this context to keep the added value of products and eliminate waste as long as possible. The transition to circular economy requires change at every link in the value chain, from product design to new business and market models, from new ways of transforming waste into new consumer behaviour (Lokesh *et al.*, 2018). The main areas for change within circular economy are production, consumption and waste management (EC, 2015).

Circular economy starts at the very beginning of the product life cycle. Both the design and production stages have an impact on the processes of obtaining raw materials, using resources and producing waste throughout the product's life cycle. Thanks to better design, products can be more durable or easier to repair, modernize or regenerate (Bocken *et al.*, 2016). Better design can help recycling companies to dismantle products in order to recover valuable materials and components. Even in the case of products or materials designed in a smart way, inefficient use of resources in production processes may lead to the loss of business opportunities and the production of a significant amount of waste. In this context, attention should be paid to the environmental and social impact of production, both in the EU and in third countries. Joint actions and support from all stakeholders are necessary to effectively implement the large-scale CE concept (Lieder & Rashid, 2016).

Consumption is the second area of implementation of circular economy. Choices made by millions of consumers can support or hamper the development of circular economy. This stage is also crucial for preventing and reducing household waste. Circular economy strategies are crucial for restructuring the take-make-dispose model through the active participation of all actors of supply chains (Borrello *et al.*, 2017).

Waste management is the third component of circular economy. It plays a key role through determining how the waste hierarchy is applied in practice. The waste hierarchy sets the order according to priority: from prevention, preparation for reuse, recycling and recovery of energy to disposal, such as landfilling. This principle aims to encourage the use of options that bring the best overall environmental effect (EC, 2017). The way we collect and manage waste can lead to high recycling rates and make valuable materials return to the economy, or it can result in an inefficient system where most recyclable waste goes to landfills or to incinerators, which it may have harmful effects on the environment and cause significant economic losses. This is partly because in practice the material collection system in place is waste management, rather than manufacturing-centered take-back systems (Singh & Ordoñez, 2016).

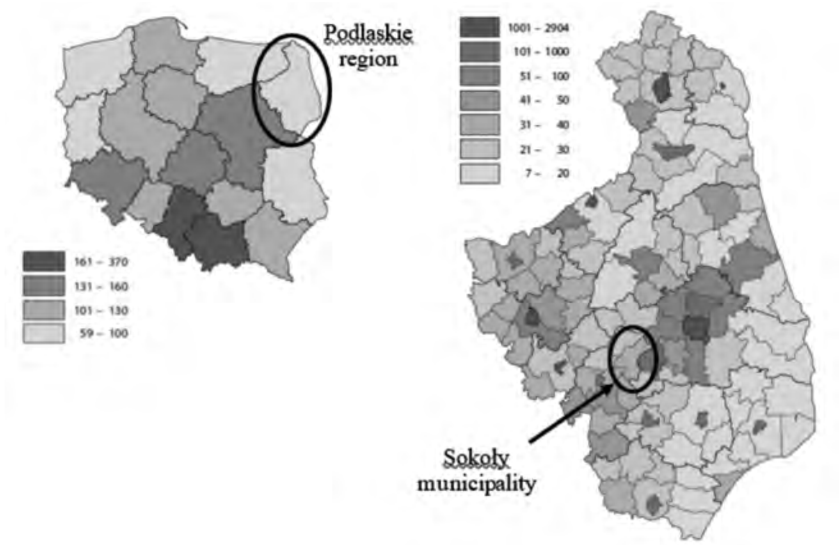
As waste management is in fact organized by municipalities, this level of investigation seems to be an appropriate one in the study of local contribution to circular economy. Municipalities represent both a public policy entity and a key managerial unit and as Agovino *et al.* (2019) indicate, a more recent strand of the literature shifts the focus of the research on the degree of efficiency of waste collection from households to administrative units.

2. Materials and methods

Sokoły rural municipality is a case study selected to recognize existing local solutions of circular economy as well as to identify possible ways for its development. It is located in the Western Functional Area of the Podlaskie Region (north-eastern part of Poland). The eastern border of the region is also the Polish border with Lithuania and Belarus. According to the data of the Central Statistical Office, at the end of 2015, this region was inhabited by 1,188,800 people, with the population density respectively 59 people /

km², making up less than half of the national average (123 people / km²) (Figure 1). The settlement network covers 40 cities, inhabited by 60.4% of the province's population, of which small units with less than 10,000 of population are dominant. The leading role is played by Białystok, numbering 295.98 thousand residents according to the state at the end of 2015, being the capital and largest city of the region.

Figure 1 - Population density in Poland, Podlaskie region and Sokołów municipality (persons / km²)



Source: own based on: Statistical Atlas of Podlaskie Voivodship 2018. Statistical Office in Białystok - Podlaski Regional Research Centre, Białystok.

In 2015, the regional structure of land use was dominated by arable lands (60.1%), followed by forested and wooded lands (31.9%) in terms of area occupied, wasteland engaged 2.7% of the area of the region, land under waters - 1,4%, while built-up and urbanized lands - 3.7%. The forest cover of the region in 2015 was 31.2% and was slightly higher than the national average (30%) (Podlaskie, 2016).

Podlaskie region is characterized by the highest share of national parks and the second in terms of NATURA 2000[1] areas in the total area (the area

1. NATURA 2000 is a network of nature protected areas program on the territory of the European Union aiming at preservation of specific types of natural habitats and species that are considered valuable and endangered across Europe. It is based on two EU directives -

of national parks represents almost 30% of all areas of national parks in Poland). Legally protected areas in 2014 occupied 32% of its territory (645,1 thousand ha). The system of protected areas of the voivodship consists of: 4 national parks (Białowieża, Biebrza, Narew and Wigry), 93 nature reserves, 3 landscape parks, 15 protected landscape areas, 2 documentation sites, 271 ecological sites, 1998 nature monuments, 5 nature-related complexes landscape, 36 Natura 2000 areas. This region is well-known in the country and Europe because of its unique natural and landscape values, making it very attractive in terms of tourism. The entire region is located in the functional area of the Green Lungs of Poland. The Sokoły municipality is situated in its central part. It consists of 48 villages and covers 156 km^2.

Table 1 - Basic characteristics Sokoły municipality

Specification		**2014**	**2015**	**2016**
Population		5826	5804	5790
Population per 1 km^2		37	37	37
Non-working age population per 100 people of working age		60.7	61.4	61.4
Forest area % of total land area		19.6	19.6	19.5
Employed people per 1000 population*		81	78	75
Population (%) using:	water supply system	93.4	93.4	93.5
	sewerage system	23.2	23.4	23.4
	gas system	0.6	0.6	0.6

* Excluding economic entities employing up to 9 persons and individual farms in agriculture.

Source: Statistical vademecum for local self-governments, https://stat.gov.pl/statystyka-regionalna/statystyczne-vademecum-samorzadowca/ (accessed 03.02.2019).

In accordance with the design science vision, constructive research (CR) was chosen as the key research methodology, mainly for practical motives. CR is usually observed as a case-study technique which targets to find solutions to prearranged problems (Aaltonen *et al.*, 2006). The important feature of CR is the generation of innovative information about the objective area. As stated by Kasanen *et al.* (1993), defining a practically appropriate research problem, attaining a broad and complete understanding of the

the Birds Directive, adopted in 1979, and then replaced by the 2009 Directive and the 1992 Habitats Directive. In 2016, the entire Natura 2000 network has over 27000 areas about 1,150,000 km2 both on land and marine areas, which is around 18% of the area of European Union countries (EC, 2018).

subject matter, as well as innovating and creating an academically grounded solution are essential phases in the constructive research approach (CRA). In the concluding steps of the CRA, the established solution ought to be evaluated and verified through an investigation of its applicability and a diagram of its theoretical influences as well as research input (Kasanen *et al.*, 1993). Figure 2 illustrates the relations between different elements of CRA. Oyegoke (2011) related this method to the modern reality and further developed this model.

Figure 2 - Elements of constructive approach

Source: Kasanen *et al.* (1993)

The constructive approach can be described by separating the research process into phases, with the note that the order of which might differ from case to case (Kasanen *et al.*, 1991):

1. Define a practically applicable problem which also has exploration potential.
2. Acquire an overall and comprehensive understanding of the subject matter.
3. Innovate, i.e., create a clarification idea.
4. Prove that the solution is applicable.
5. Demonstrate the theoretical relations and the research contribution of the concept.
6. Scrutinize the range of applicability of the solution.

Nonetheless, the definite practicality of a managerial solution is never proved before an applied examination is passed. Hence the main criterion to evaluate the outcomes of functional studies is their concrete usefulness, which increases the issues of the significance, simplicity and easiness of operation of those effects (Niiniluoto, 1984).

Kasanen (1986), in his dissertation implementing the constructive approach, uses an example for market-based validation of managerial solutions, arguing that the whole process is time-consuming and necessitates a number of attempts of application. The following market tests are established on the conception of innovation diffusion, i.e., managerial constructions are regarded as products competing in the market of solution concepts.

- **Weak market test**: Has any manager accountable for the financial outcomes of his or her business unit been eager to apply the construction in question in his or her definite decision making?
- **Semi-strong market test**: Has the construction become extensively implemented by companies?
- **Strong market test**: Have the business units applying the construction systematically created improved financial results than those which are not using it?

It should be highlighted that even the weak market test is reasonably strict – it is perhaps not often that an uncertain construction is capable to pass it. For instance, there is no lack of formal optimization models which allegedly solve managerial control problems however which no one is using in practice (Kaasanen *et al.*, 1993).

It should be emphasized that in our case we are able to perform weak market test only, since this is a preliminary phase of research and business implementation. Moreover, this research is based on few experts' opinions, which have been presented and confronted with the views of municipality's representatives. It was done during three study visits of members of the research team in the investigated municipality in autumn 2018 and winter 2019. Therefore, there is a strong necessity to get deeper into a specification of this project, by e.g. performing numerous feasibility studies. Nevertheless, a certain level of insight was possible after numerous business meetings. In result, we were able to perform a specific form of preliminary analysis of various aspects of further development of the investigated municipality.

We have also applied a SWOT analysis grid, which is commonly used by numerous experts, marketing scientists, and is a frequent and widespread instrument. Its minimalism and catchy acronym propagates its implementation in business and beyond since the tool is used to evaluate alternatives and complex decision conditions. It can benefit from various viewpoints as a brainstorming exercise. SWOT analysis helps in the identification of environmental interactions as well as the development of appropriate conduits for organizations, countries, or other entities to follow (Proctor, 1992).

The main usages of a SWOT analysis by community organizations are as follows: to organize information, provide understanding into obstacles that might be met while engaging in social transformation procedures, and recognize existing strengths that can be initiated to overcome these barriers (Chermack & Kasshanna, 2007). Bearing in mind the fact that the SWOT analysis is a snapshot of the situation at a specific moment in time, it should be perceived and taken into consideration that both the internal and external circumstances of every entity are continuously modifying (Menon *et al.*, 1999).

3. Results

3.1. *SWOT analysis*

Table 2 presents results of the SWOT analysis of the investigated Sokoły municipality. It has helped us determining the strengths, weaknesses, opportunities and threats of the region in order to emphasize its quite unique investment incentives, which can be applied for implementation of the circular economy concept.

Major strengths are thus visible satisfactory level of enthusiasm and eagerness to innovate. Therefore, the entrepreneurial culture is a strong motivator to invest in this region's further development. There are many good examples which can inspire the rest of a local community. It is especially important that the local self-government creates the environment for local activities, influencing the investments (and also investing on their own), stimulating the improvement of quality of life for their inhabitants (Drejerska & Braja, 2014).

One cannot forget about the extended scope of possibilities, which is provided by the world of academia. The support by the scientific specialists is priceless, and could serve to e.g. optimize many solutions, increase their efficiency, etc. The theoretical background, including international dimensions, is very important as well. By explaining and implementing such notions as circular economy or corporate social responsibility, scientific expertise can support local actions to reach much further. At present, we can observe cooperation of local stakeholders with for example Warsaw University of Life Sciences (Poland) or University of Vaasa (Finland).

Experience is always regarded as a potential strength. This region has already implemented many programs aiming to develop multifarious skills (entrepreneurial, technical, regulations knowledge, agriculture specialization, etc.) Once the municipality's inhabitants acquire useful skills (i.e. in marketing which at this moment was identified as not sufficient - a weakness), it will become more competitive and thus, more attractive to potential investors.

The case of Krzyżewo (a village of Sokoły municipality) is also worth presenting as a sort of a role model, since it is a one of a kind medical complex (a building used previously as a primary school). It provides

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Table 2 - SWOT analysis of Sokoły municipality

Strenghts	**Weaknesses**
High level of motivation and enthusiasm, entrepreneurial culture	Not enough skills for marketing services - previous experience with milk-based products, not familiar with innovations
Cooperation with academia	Limited capabilities, need to be sufficient
Experience in arranging various trainings and related services for agricultural specialized organizations	Small-sized, about 6000 inhabitants
Krzyżewo case - experience	Long distances
Plans to implement biogas solutions for heat and electricity	Language barriers
Potential for further development - agriculture, tourism; agritourism	Podlaskie voivodship - lowest level of investment attractiveness in Poland

Opportunities	**Threats**
Dynamics – Trans-rol case	Changes in agricultural sector - hard to follow
Growing skills coming from farming experience	Rapid structural changes
Collaboration with entrepreneurs and foundations	Coal-based Polish energy mix
Partnership with Finnish professional training organizations, e.g. Finnish entrepreneurship school - export oriented	Politically sensitive sector
Migration tendencies (urban-rural, cottages)	Competitors coming to Poland
Profitable energy prices	Inefficiency in decision making - different interest groups, financing structure

Source: own study.

healthcare services, with special units for mental treatment, nursing (for elderly people) and rehabilitation. It attracts patients from not only all over the country, but also from abroad. Such initiative could serve to promote the region, know-how exchange with other entrepreneurs operating in the municipality and hopefully, it will attract many partners by the fact of being socially responsible.

Furthermore, there is a idea to implement a biogas plant of 1.9MW capacity for both electricity and heating purposes. Such a smart, innovative and eco-friendly solution is a remarkable sign of the municipality representatives' approach towards transformation answering the trends of sustainable development and circular economy.

One biggest, overall weakness is a small size of this municipality which is rural/agriculture oriented, not so familiar with innovations (except from agriculture and food production, especially dairy production) or marketing services. Hence, its capabilities are in need for some optimization. Typical barriers coming from geographical placement are both long distances and possible languages difficulties. Nevertheless, the geographical barriers could be rather easily overcome by strengthened collaboration with foreign investors (e.g. Finnish ones, some of which were already presented to local authorities as a result of networking with academia), which are providing innovative technical and training support. In case of distances on a national level, thanks to a new highway, the placement of Sokoły municipality became very attractive.

There are various external opportunities for this territory. Dynamic development of agriculture can assure some potential demand. The case of Trans-rol can be presented here. The company is a distributor of high-quality fertilizers and other production factors for plant and animal production. Owners of the company are actively engaged in different activities for the local society.

Farms operating in the area investigated are highly specialized, mainly in milk production. Experience acquired by milk-based production enhances the use of top level of farming skills. By consequence, it can serve to promote this region abroad. In case of collaboration with Finnish side, many products or even some know-how can be launched and transferred in both directions, as milk production is also important in this Scandinavian country.

What's more, in case of financing possibilities, Finnish foundations are often eager to promote smart and courageous projects. In Finland, there are many innovation-oriented companies that seek for internationalization and thus can not only financially support such initiatives. Only in Ostrobothnia there are about 10 technology companies that could fit to this kind of solution. Examples of such are *Ecohel* or *Recomill*, which have already very strong connections with the University of Vaasa. Their operational focus is aimed to produce sustainable energy from industrial and residential waste, including typical agricultural by-products. Therefore, a regional smart specialization has a huge potential to be introduced. Finland has more to offer, as there are multiple professional training organizations, which could help e.g. by providing managerial support, marketing solutions, etc. Good example of such initiatives is Finnish Entrepreneurship School, which is known to be strongly export-oriented.

Another important aspect is a good, affordable electricity price in Poland. There are much more attractive than Finnish ones, estimated about 12 €cents/kWh for 2019. This market specification together with an impression of being strong in manufacturing (which still expresses huge potential) generates a big interest of Finnish companies to invest in these kind of activities.

Another potential opportunity is a phenomenon described as reverse migration (Day *et al.*, 1987). Nowadays, we can observe rural-urban migration tendencies. However, the society is getting older. This process creates an opportunity for the Sokoły municipality to attract mainly older part of the society to move to countryside in search for peaceful, environmentally friendly and stable life. Moreover, there is a growing number of strictly urban-connected diseases, e.g. allergies, respiratory diseases. This can convince people to move to the areas, where the air is less polluted. In other words, maintenance and improvement of quality of life opportunities can result in development opportunities as far as rural areas are able to innovate their productive offer (Schimmenti *et al.*, 2017). If the municipality would continue to develop itself, it could attract people to build e.g. cottages or summer houses there.

Moreover, there are plans to introduce a special economic zone in this municipality, which should be regarded as a huge development opportunity.

There are some threats as well. First, the most obvious but yet hard to overcome, are the rapid changes in the agricultural sector, especially the structural ones. They include decrease in farm's number with increase of their average area. More and more specialized agricultural production requires high technology solutions at the same time reducing demand for labour force. As a result lack of job opportunities determines outflow of youth from the region. Moreover, agriculture is not perceived as a very interesting option for professional career (Drejerska, 2018). Altogether it can lead to depopulation resulting then in worse economic performance of the region.

In case of green/renewable energy implementation in Poland, there is still a huge regulatory obstacle. Polish energy mix is based on coal and it will remain the leading energy source for at least a decade. Fortunately, there are many international regulations which push the signing members to follow the green rules. Thanks to UN COP21 Paris Agreement (Bulkeley, 2015) followed by the COP24 Conference in Katowice, and European Commission regulations, EU and Poland will reduce the CO_2 emissions and involve more renewable energy sources in their energy mix.

In the situation of many different interest groups being involved, there is often a possibility to have decision-making difficulties. In case of financing, every investor wants to have the highest possible return, but also the fair share. However, many suitable solutions for such cases already exist in Polish and European labor law.

Another potential threat could be a growing number of competitors coming to Poland. It is caused by constant economic growth of Poland which makes this country attractive to invest. It is a typical case of crisis of wealth.

Further actions need to be performed. First and foremost, the business model has to elaborated. As noticed before, numerous feasibility studies are necessary to push municipality development forward. There is a need to determine such data as size of a facility, the cost of raw material, including delivery and energy price, while producing heat, steam and electricity.

Moreover, flexibility level needs to be put at a highest possible at a given moment. During a consultation process, the idea of introducing the network of businesses appeared. This could show the potential to develop the whole region in a long term. In the form of orientation or simulation, it could help to adjust the necessary volumes and therefore, determine the whole business strategy.

Another important aspect inevitably necessary is the level of socioecological acceptance. The studies may be conducted to demonstrate the key issues among the local society. As a source of reference, the thinking according the TAM (Technology Acceptance Model) (Davis, 1989) could be used.

3.2. *From waste to resources: stimulating the secondary raw materials market and reusing water in the Sokoły municipality*

In a circular economy, materials that can be recycled are brought back into the economy as a new raw material, which increases the security of supply. These "recyclable materials" can be sold or sent, as well as primary raw materials from traditional natural resources. At present, secondary raw materials are still only a small part of production materials used in the economy. Waste management practices at the local level have a direct impact on the quantity and quality of these materials and, therefore, measures to improve these practices are essential.

The system of collection and collection of municipal waste in municipalities results from the amendment of the Act of 13 September 1996 on maintaining cleanliness and order in municipalities, which entered into force on 1 January 2012. In the new system introduced by the Act, municipalities were obliged to organize a system for collecting municipal waste from property owners where residents live, with the possibility of extending this system to other properties on which municipal waste is generated. The essence of the system was the taking over by the municipalities of the obligations of property owners in the field of municipal waste management in exchange for the payment made. Taking over of these duties by the municipality is obligatory in relation to the real estate on which the residents live (it takes place by virtue of the Act), optional in relation to real properties where municipal waste activities are carried out (may take place on the basis of a municipal council resolution). The fee depends on the number of inhabitants, the area of the property, the amount of water consumed, or it can be a flat rate for a household, but the rate of the fee for separately collected waste should be lower. In exchange for the payment, the municipality provides collection of municipal waste by the entity selected in the course of the tender procedure and their proper development. After the entry into force of the law on the maintenance of cleanliness and order in municipalities, there was a decrease in a production of mixed waste in entire Poland (Gołębiewska, 2017).

The municipal waste management system in the Municipality of Sokoły is based on the assumptions of the Waste Management Plan for the Podlasie Voivodship for the years 2016-2022. According to this plan, the municipality was qualified for the region in which there are two regional waste treatment installations, i.e. Waste Processing and Neutralization Plants in Czerwony Bór and in Czartoria. Mixed municipal waste from the entire Sokoły municipality is transferred to the first of these two plants. The collection of waste from the investigated municipality is carried out by a specialized enterprise selected on the basis of an unlimited tender. The company is responsible for the collection of mixed municipal waste, segregated municipal waste, large-scale waste collection, expired drugs, used batteries and accumulators.

The entity collecting municipal waste from the property owners (all mixed municipal waste and residues from sorting, mechanical and biological treatment of municipal waste), transfers it to the installation located in the waste processing and disposal plant. In 2018, a total of 973 tonnes of mixed municipal waste were collected and transferred to a waste treatment facility and processed (mechanical-biological treatment processing). It should be noted that the total amount of collected waste, including waste collected selectively, was growing in the period 2018-2014. Municipal waste was received mainly as mixed. According to the most recent data, the studied municipality reached the following levels in 2018 (Analysis…, 2019):

a) the ratio of recycling, preparation for re-use and recovery of paper, plastic metals and glass - 40.44% (a the minimum level of 30%),
b) the ratio of mass of biodegradable municipal waste transferred to storage - 42.83% (at the maximum level of 40%),
c) the level of recycling, preparation for use and recovery by other methods of construction and demolition waste - 100% (with the minimum level of 50%).

This summary shows that the current waste management system in the Sokoły municipality does not function ideally as it did not allowed to achieve all required ratios. However, it should be noticed that they were achieved for previous years. In such a situation, the priority task of the Sokoły municipality for the coming years is to increase the awareness of inhabitants in the proper management of municipal waste in order to reduce the amount of municipal waste generated and to sort them efficiently to achieve the required levels of recovery and recycling, thus reducing the costs of their management.

Investigated municipality is not only an interesting example of solid waste management but also implements good solutions devoted to liquid waste management. They are significant as in some parts of the EU, water scarcity has become a major problem in recent decades and has had a destructive effect on the environment and economy. In addition to measures for efficient water use, re-use of treated wastewater in safe and cost-effective conditions is a valuable but rarely used way to increase water resources and relieve over-exploited water resources in the EU. The reuse of water in agriculture also contributes to the recycling of nutrients that replace solid fertilizers.

The Sokoły municipality, like majority of others in the Podlaskie region, is a typically agricultural where predominantly dispersed farm buildings predominate. These municipalities are struggling to find the solution to the problem of wastewater management. Construction and operation of a sanitary sewage system is too expensive investment for communes and inhabitants of villages. The solution that has been implemented in the municipality in the field of wastewater management is the construction of home sewage treatment plants based on a plant filter and a denitrification pond. This process began already at the beginning of the 21st century. In 2004, 11 pilot sewage treatment plants were completed. Further implementation of the construction of this type of treatment plant in the municipality of Sokoły is carried out by the municipal self-government. The simplicity of construction of wastewater treatment plants makes farmers perform them on their own, in an economic manner, with the supervision of an employee of the Sokoły Municipal Office. No construction permit is required for it, in fact only a notification should be given to the district office. In the Podlaskie region, the Sokoły was the first to address this issue with wastewater management solutions. About 25 municipalities have already benefited from the Sokoły's experience by building about 640 wastewater treatment plants.

The implementation of home sewage treatment plants based on a plant filter and a denitrification pond is a cheap and effective way to treat wastewater from rural households. The advantages of this type of treatment plant are not only the simplicity and low construction costs, but also the ease and negligible operating costs and, above all, the positive impact on the natural environment. These purifiers also increase the aesthetic value of the plot on which they are built. What is worth emphasizing, the Sokoły Municipal Council supports construction of household sewage treatment plants by granting subsidies of up to 50% of documented gross costs, but not more than PLN 1,000 (which is about 230 €).

Conclusions

The study was aimed to recognize existing local solutions of circular economy as well as to identify possible ways for its development. It was completed with a special regard to the waste management issue, as this is one of the crucial areas of circular economy for which local authorities are responsible for. A mixed methodology analysis performed emphasizes a favorable environment for an enhanced development of this concept, which is also in line with a fact that innovative technology solutions need to be decentralized.

A circular economy at the local level requires appropriate technical and educational infrastructure as well as innovative communication systems with the public. It also means that a new approach to the issue of municipal waste in rural areas is critical. Waste, according to the assumptions of circular economy, ceases to be unnecessary objects and becomes potential raw materials for production of various goods of market value. Implementation of the circular economy principles requires interaction and cooperation between local self-government, the business sector and an effective education system.

As concluded during the SWOT analysis, the local authorities of the investigated area have expressed a satisfactory extent of a willingness to implement innovative waste treatment solutions. Some supportive policies have already been implemented to foster the idea of sustainable society and further projected initiatives, such as biogas plant of 1,9MW capacity, are aimed at increasing development of the circular economy concept within the community.

Entrepreneurial culture of local actors and an attractive localization of the Sokoly municipality have resulted in established cooperation with international partners, both from academia and business side. Experience from Finland, which is a leading country in the areas of innovations and sustainability, can boost the process of introducing waste-to-energy projects. In addition to the municipality waste solutions, industrial waste can be processed in a very effective way. The Podlaskie region is known to be a leading producer of animal products, such as milk or meat in Poland. The animal by-products can be recyclable into energy (vide *Recomill*) and such investments have been suggested by the Finnish side and are now considered by the local government. However, in order to develop a clear and comprehensive investment strategy, numerous more advanced feasibility studies need to be performed.

It is necessary to continue and intensify information and education activities in the area of increasing public awareness of waste prevention, their removal under communal waste collection and collection systems, and proper management of municipal waste (including food waste and other biodegradable waste). This sector is strongly influenced by the public regulations, therefore, more focused cooperation between different stakeholders is recommended.

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The Role of Venture Capital in the Commercialization of Cleantech Companies

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Venture Capital (vc) plays an important role in the success of their portfolio companies. Small- and medium-sized companies often struggle with the resources required to succeed in the market. vc not only helps companies with the required financing but also provides the knowledge, understanding and expertise required to excel in the market. The study explores vc non-financial value-added contributions in the commercialization of clean technologies. Cleantech is a term associated with the companies involved with technologies, products, processes or services that seek to lower the negative environmental impact by improving efficiencies, reducing waste, encouraging the use of sustainable sources and environmental protection. However, the success of companies operating in this sector, at times, becomes challenging since these technologies are often disruptive in nature, contest business-as-usual practices by inducing efficiencies in the current processes or radically transforming the existing infrastructures. This qualitative case study is based on five companies operating in the Finnish clean technology sector. Data is collected in the form of semi-structured interviews whereas within the case and cross-case analysis approach is adopted to gain a comprehensive understanding of the studied phenomena. This study delineated vc's contribution to technology development, corporate governance, mentoring & industry expertise, recruitment, collaboration & internationalization, acquiring additional financing and certification effect. The findings of this research provide important insights for the industry specialists, managers as well as the scientists involved in this field of research.

Key words: venture capital, non-financial value addition, clean technology, commercialization
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Introduction

Venture capital (vc) can play an important role in assisting companies in successfully commercialize their technologies (Samila and

Sorenson 2010). Klofsten (1999) states that bringing new technologies to the market is a challenging and resource-intensive process requiring a huge amount of money, knowledge, skills and understanding of the market. The evidence suggests that a number of disruptive solutions have failed to become successful in the market due to their inability to cope up with the challenges and complexities faced during the process of commercialization (Bocken 2015). Venture capital can help companies in addressing these challenges by providing necessary financing, knowledge, understanding and expertise required to excel in the market (Hellmann and Puri 2002). The contribution becomes even more important for start-ups and small- and medium-sized enterprises (SMEs) as these are often characterized by limited human and financial resources (Hsu 2006). There is plentiful evidence to support the proclamation that VC involvement was a critical factor in ensuring the effective commercialization of various business initiatives across the globe (Kerr Lerner, and Schoar 2014). However, the having VC on board is not always an assurance for success as there are many examples where collaborating with VC have led to the less desired results, often in the form of failures and bankruptcies of the incumbent companies (Busenitz, Fiet, and Moesel 2004; Gaddy et al. 2017). Research conducted by Popov and Roosenboom (2012) and Hsu (2007) found that collaborating with venture capital has helped companies in developing core technology, finding collaboration partners and improving the legitimacy of the company. On the other hand, authors such as Dimov and de Clercq (2006) and Anokhin, Wincent, and Oghazi (2016) have presented cases where collaboration with VC has adversely affected companies' performance. Ghosh and Nanda (2010), Guler (2007) and Anokhin (2006) studied the causes of the failure and identified that lack of industry-specific specialization, high technology risk, accelerated exit plans or opting for less suitable deals are some of the causes of these failures.

Kaplan and Strömberg (2000) state that the level of VC's involvement and the type of input towards its portfolio businesses may differ in distinctive perspectives and industries. The existing studies have explored VC's contribution in the conventional industries (Dushnitsky and Lavie 2010; Maula, Autio, and Murray 2010; Bertoni, Colombo, and Grilli 2011), however, the literature concentrating on the contributions of VC in the Cleantech is rather limited (Bürer and Wüstenhagen 2009; Marcus, Malen, and Shmuel 2013; Cumming, Henriques, and Sadorsky 2016) and has scarcely been studied in the context of Finland. The novelty of this research, therefore, is that it seeks to explore VC value-added contributions in Finnish-based Cleantech companies.[1] Finland offers a unique case to study venture capital's value-added contribution in the Cleantech companies for two reasons. Firstly, the country is ranked as one of the leading countries when it comes to innovating new technologies. According to the latest Bloomberg Innovation Index (Jamrisko, Miller, and Lu 2019) and The Consumer Technology Association ranking (2019), Finland is the third most innovative country in the world, while it ranked at number two when it comes to clean technologies (*The Global Cleantech Innovation Index 2017* 2017). The innovation input, public R&D and innovation culture are some of the driving factors, however, the country is found to be lagging behind when it comes to commercialization (Shakeel, Takala, and Zhu 2017). Secondly, the country is considered as a great start-up hub (Business Finland 2019) attracting substantial investments in conventional as well as environmentally friendly technologies (European Chamber 2019; Näyhä 2019). Therefore, it offers an interesting case to explore venture capital's value-added contributions in the Cleantech companies operating in Finland. The remaining parts of this article are structured as follows. The second section presents a literature review, the third section details the methods adopted whereas the fourth section presents analysis followed by the fofth section presenting discussion and conclusion.

Literature Review

VC's non-financial value-added contribution has grown as an important field of research. A number of studies have explored VC contribution to technology development (Chen 2009; Lahr and Mina 2016). The literature on VC is rather rich and comprehensively explains certain types of possible VC input. The review of the literature reveals that collaborating with venture capital can have a mixed result i.e. it can help companies in ensuring success or can also cause companies to struggle. Nevertheless, a vast stream of research concludes that the influence is positive (Samila and Sorenson 2011; Sørheim 2012). Gorman and Sahlman (1989) classify the value-added contributions of VCs and point out that VC support can be observed in finding supplementary financing, strategic development, operational planning, management recruitment presentation to potential customers and suppliers and resolving compensation concerns (Gorman and Sahlman 1989). In their analysis of 20 peer-reviewed articles on studying VCs value-adding performances Large and Muegge (2008) recognize ten different value-adding services provided by vcs. Contributions made on the external fronts are legitimation and outreach, whereas internal ones deal with recruitment, strategy, consultation, operation, mentoring and mandating.

Burt (1992), Aoki (2000), Gans, Hsu, and Stern (2002) and Lindsey (2002) state that venture capital can also serve their portfolio companies as information intermediaries, ensuring privileged business networking information access and decreasing exploration expenses during the process of pursuing proper cooperation partners. A study conducted by Sapienza, Manigart, and Vermeir (1996) found that relevant industry experience is vital to be able to add more value since their findings have shown that vc investors with experience from the venture's industry provided significantly more value-added than vcs without such specific industry know-how. vcs guru entrepreneurs, using their connections and knowledge, often contribute as referring points and participate in strategic planning (MacMillan, Kulow, and Khoylian 1989; Kaplan and Schoar 2005). Moreover, this reputational effect can be critical in encouraging potential stakeholders to participate in the venture's further development (De Clercq et al. 2006). Additionally, vc's informational advantages could improve timing in realizing the collaboration process as well as start-up patent productivity (Kortum and Lerner 2000). Fried and Hisrich (1995), in addition to the elements mentioned before, included moral support and discipline as a significant aspect of vc's contribution provided to the portfolio companies. Moreover, start-ups are often not yet satisfactorily developed to the extent that they could attract partners for collaboration on its own. Collaborating with vc can help in establishing contacts and finding partners. Major literature on the role of vcs has highlighted their capability to professionalize employment customs and human resources management (Cyr, Johnson, and Welbourne 2000; Hellmann and Puri 2002) as well as corporate governance (Lerner 1995; Baker and Gompers 2003).

Though, innovative technology solutions often struggle with a so-called 'valley of death' between research supported by the government and commercialization (Frank et al. 1996). To overcome this obstacle and to find a way to capitalize on the early stages of commercialization, characterized by a high level of risk, entrepreneurs usually seek to partner with vcs (Gompers and Lerner 2004). It is important to note that the interest of the venture company usually comes from the so-called 'exit' procedure (Megginson and Weiss 1991; Lerner 1994), which is generating a return through an initial public offering (ipo) or even a merger and acquisition by another company. Therefore, VC often enhances this procedure. Hsu (2006) argues that VC support is positively correlated with the probability of a portfolio company obtaining an IPO.

In general, VC as a financing institution improves start-up performance (Kaplan and Strömberg 2003). Kelly and Hankook (2013) in their empirical study found out that VC's financial support fosters both accelerated company's development as well as processes of innovation and commercialization of a given initiative. Moreover, it is important to note that VCs are not just passive investors (Samila and Sorenson 2010). Many studies concluded that VCs are critical contributors not only in filling the financial gap but also in providing value-adding services such as technological, managerial and financial support or industry-specific networking as well as understanding of foreign markets (Florida and Kenney 1988; von Burg and Kenney 2000; Caselli, Gatti, and Perrini 2009; Bertoni and Tykvova, 2012; Dubocage, Rivaud-Danset, and Redis 2012). As can be observed, VC's contribution is of various and wide-range forms, and in the rapidly changing environment it is difficult to determine and put them all together, which simply means that any list of such types cannot be treated as exhaustive.

Methods of the Study

The aim of the study i.e. to explore venture capital value-added contribution in the commercialization of Cleantech companies and to study the phenomenon in the natural setting makes qualitative case study a suitable research approach. The case study approach is an appropriate strategy in the studied context as it provides researchers with an opportunity to study the phenomenon in detail to address the questions at hand. The purposive sampling technique was implemented to identify cases (Ritchie et al. 2013). We have studied five firms operating in the Cleantech sector in Finland, each accounting for an individual case. The incorporation of multiple cases not only provides an opportunity to enhance the validity and reliability of this research but also allows studying the cases in detail and identifying similarities and differences between each case (Eisenhardt and Graebner 2007). The details of companies and their operations are provided in table 1.

The data collection was done in the form of semi-structured interviews. The approach provides researchers with the luxury of obtaining rich information while being focused on the studied context. The respondents were either founder/CEO/board of the directors of the companies, thus had solid knowledge about the firm's history,

TABLE 1 Case Companies Details

Company*	Core technology	Founded
A	Ceramic anode-supported solid oxide cells and stacks	2002
B	Dynamic compensation solutions for power quality, energy efficiency, and grid connections	2010
C	Solid oxide fuel cell (SOFC) systems for distributed power generation	2012
D	Wave energy converters generating direct-to-grid electricity	2008
E	Auxiliary wind propulsion for ships	2012

NOTES * The names of the companies are replaced with letters to ensure anonymity.

operations, and strategic plans. The companies were asked to provide detailed account of contributions the venture capital has made on different fronts, the concerns they had and the challenges faced. The interviews were transcribed and the summary was shared with the interviewees to avoid any misunderstanding as well as to ensure that their viewpoint is well understood and presented.

The data triangulation technique was implemented to enhance reliability and ensure the accuracy of the findings. The sources of supplementary data include case companies' websites, press releases, news articles, and industry analysis. Within case analysis and cross-case analysis methods have helped in scrutinizing each case as well as to perform a comparative analysis of case companies.

Analysis – VC Contribution Categories

The VC firm's value-added contribution can be observed in various forms. Table 2 presents the VC value-added contributions observed in the case companies. We have grouped each VC contribution category into three levels based on venture capital's contributions. To recognize the extent of contribution and the amount of engagement, we have scaled the contribution from insignificant, to moderate, and high. Insignificant refers to minimal to no contribution, while high means that the VC has contributed significantly. Moreover, we have developed a Venture Capital Contribution Matrix (figure 1), taking into account both the extent and engagement levels. Engagement refers to whether a VC has been directly involved in the process, contributed indirectly, or not played any role in the investigated aspect at all. In order facilitate the analysis and ensure the readers' understanding of our research outcomes, we have indicated a representative capital letter for each contribution category in the first place, and they are following: T – Technology Development, R – Recruitment, I – Internationalization and Cooperation, F – Financing, G – Corporate

TABLE 2 Venture Capital's Contribution Categories

High	Moderate	Insignificant
Corporate governance, monitoring & industry expetise	Certification, recruitment, cooperation & internatiolization	Techology development, additional financing

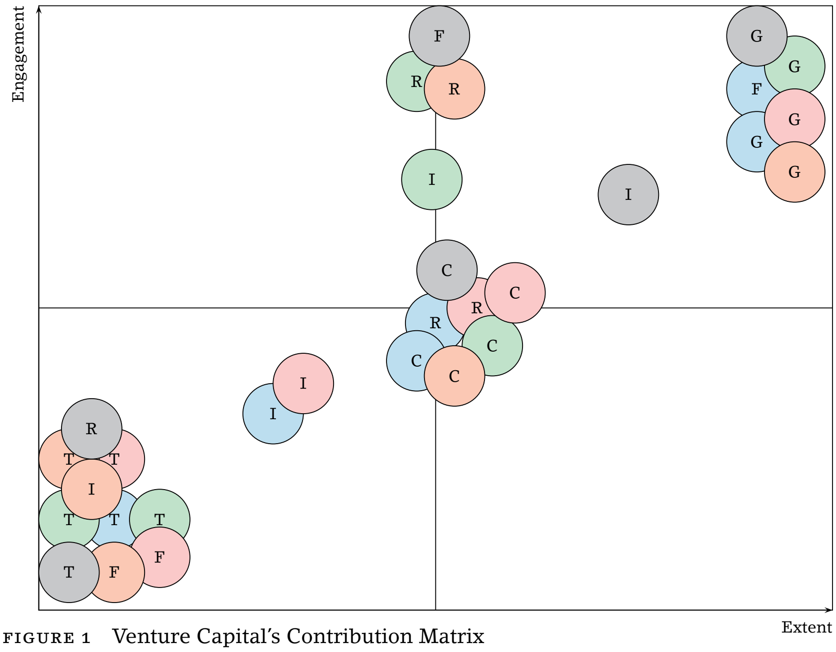

FIGURE 1 Venture Capital's Contribution Matrix

Governance, Mentoring & Industry expertise, and C – Certification effect. After that, we presented the findings in the context of each Case Company by grouping them by colors, which are the following: A – green, B – blue, C – pink, D – orange, E – gray.

TECHNOLOGY DEVELOPMENT

Technology development can be one of the value-added benefits that VC brings to the company as suggested by (Pradhan et al. 2019). However, in our study, we have hardly seen any VC activity attributing to the direct development and shaping of the technology. Due to the complex nature of the technologies, the valuable input that can help in shaping the technology can only come up from someone who is either an expert in the field, has been working with the technology or knows the technical aspects.

The characteristics of the technology and the extent of technical understanding needed to make valuable contributions in technology development is the key reason why we have seen very little to no value added contribution by the vc.

CORPORATE GOVERNANCE, MENTORING & INDUSTRY EXPERTISE

Improving the strategy and setting strategic orientation right is found to be one of the key contributions by the vc firm. The technology-based start-ups are formed by a team of technical experts, generally found to be lacking understanding of the business know-how. The portfolio companies have ranked vc contribution in this domain as of high importance. Mostly the fact of having a vc representative on the board of directors is highly appreciated by its companies. The companies which are in the early stages of development are usually running low on resources and success is often connected to supportive policies and infrastructure support. The vc companies being well connected to the industry and having knowledge of the market can provide valuable information that can help mitigate the effect of such asymmetries. The market knowledge of the vc encouraged its portfolio companies to fasten the process and develop the technology quicker and better than the competitors. Access to the resources necessary to perform various tasks is also a valuable contribution that vc brings to the table. Moreover, a fact of having past experience of working with a firm ensures that the portfolio company can immediately find the required resources without needing to go through an extensive market search process and finding a reliable partner. It reduces the time, efforts and associated transactional costs.

RECRUITMENT

Team building is one of the domains where vc tends to contribute. The contribution may come in the form of recruiting new people, making changes in the top management or restructuring of the core team. The vc is mostly active in assisting with profiling and suggesting what sort of person could be suitable, which sectors to look at, how much resources should be dedicated and how the compensation plan should be. However, in the example of one case company, vc was directly involved in the recruitment process, as there came a time when they needed to establish an office in Finland. The vc helped the company in setting up the office, building a competent team and discussing on setting compensation packages. Similarly, in the situation of another firm the suggestion was made that the company should look to hire a new ceo. At the same time, the existing

CEO, an engineer knowledgeable in technology development could have more time to spend on improving the technology, reducing the cost and making it more efficient. The new CEO was proposed by the VC.

COLLABORATION & INTERNATIONALIZATION

Working with VC can offer an excellent opportunity to collaborate with the portfolio companies who are in a relatively similar stage of development and operating in similar markets. In the case of its two companies, the VC firm provided an opportunity to collaborate with each other to develop the technology further, share their experiences and learn from each other. Nevertheless, the collaboration should be a voluntary act and firms involved in partnership should decide by themselves whether or not they wish to establish such type of cooperation.

Moreover, internationalization is an important area where VC can assist companies (Lutz and George 2012). Due to the small local market, technology companies have very little choice apart from looking for customers and projects in the international market. VC has used its connections to find partners to expand its portfolio companies' operations.

ACQUIRING ADDITIONAL FINANCING

VC supports companies in fulfilling their financial needs through an investment. However, in most of the cases, VC is not the only investor in a portfolio company. The company may need additional financing from different sources such as bank loans, business angels, crowdsourcing, and grants. VC can help companies in finding this additional financing, as witnessed in the situation of one case company, which acquired financing from two VCs. The second VC firm was involved in the process through the connection initiated by the first VC. In the instance of another company, VC assisted the company in applying for an EU grant. Similarly, in one case company, the VC used its connections and involved a multinational business entity to invest in its portfolio company.

CERTIFICATION EFFECT

Improving the company's image and the legitimization is similarly an essential aspect that VCs contribute. Having VC on board, in itself, signals the company has a potential and the technology may offer a unique value proposition. In such situations, having a VC on board is certainly helpful. However, in some cases, it may not have the expected outcome. This is no secret that vcs' investments in the portfolio company are for profit-oriented and thus they are constantly looking for the exit procedure. This situation might be concerning for prospective allies if they are seeking for a long-perspective partnership.

Discussion and Conclusion

This section concisely presents the extent to which vcs have provided a benefit to the portfolio companies. The analysis highlights that shaping the strategic orientation right is one of the contributions that has been valued highly, both by the case companies and the vcs. The understanding required keeping the business operations running optimally, taking care of business, marketing, and management related issues often seemed lacking within the core teams, comprising mostly of technical experts. The vcs' experience and expertise in working with such projects can bridge this gap. The additional challenge that companies face in Finland is a small domestic market (de Jong et al. 2015). The companies often feel a need to go international from a very early stage to thrive and gain access to a large customer base. vc can provide market knowledge, network, and contacts needed to make these big steps in the foreign markets.

The analysis reveals the importance of having open communication between the portfolio companies and the vcs regarding how the business should be taken further. A company having a vc on board may leave the business-related activities like financing, finding partners and strategy setting for the vc so that the core team could focus on the technology development aspects. Moreover, when it comes to creating trust, collaborating with vc has a dual consequence. A vc can help in establishing sureness with the prospective partners who are fearful of companies' resources; however, it can also result in uncertainties for those who wish to form long-lasting business alliances with a vc-backed firm.

Notes

1 Cleantech is a term associated with the companies involved with technologies, products or services that seeks to lower the negative environmental impact by brining efficiencies, reducing waste, encouraging the use of sustainable sources and environmental protection. Cleantech companies can be characterized by high investments ventures, usually operates in rapidly changing business environment, have relatively longer payback time and often require adaptive changes in the existing infrastructure.

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Article

Blockchain Technology for Renewable Energy: Principles, Applications and Prospects

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Abstract: Blockchain, or distributed ledger, is an innovative technology that is emerging in various sectors and industries across the globe. It has attracted the attention of different interest groups such as energy companies, SMEs and start-ups, information technology developers, financial institutions, national authorities, and the university community. Through, for example, the decentralization of authority in transactions, Internet of Things (IoT) implementation, and smart contracting, the improvement of the daily business operations is firmly forecasted. In the energy sector, digitalization is already present in solutions such as smart grids, smart meters, electric vehicles, etc. Moreover, a new concept of the Internet of Energy (IoE) has been introduced in the academic literature. In this article, the level of trust and maturity of Blockchain technology implementation is investigated through the Blockchain Maturity Questionnaire, developed by the authors. The database consists of responses from upper management professionals from the renewable energy industry. The analysis reveals the state of know-how about Blockchain, the main benefits and bottlenecks associated with its implementation as well as willingness to integrate this technology in the case companies' future operations. The insight from the industry experts helped to provide a "Roadmap for Blockchain Adoption" in future energy systems. This curiosity study yields numerous applications not only for the renewable energy industry experts but also for the interest groups coming from different industries, as well as public authorities and researchers scrutinizing the fields taken into its scope.

Keywords: blockchain; technology adoption; business models; peer-to-peer (P2P); distributed energy; smart contract; energy digitalization; renewable energy; circular economy; Finland

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1. Introduction

The current energy systems are incorporating increasing shares of renewable energy sources (RES). This transformation, driven by a sustainable triple-bottom-line concept of generating value through economic, environmental, and societal performances of the energy companies, has been further boosted by privatization, as well as financial and energy policy incentives [1,2]. In 2020, the share of renewable energy sources in Finland has raised to nearly 40%, which has exceeded the share of fossil fuels and peat combined for the first time in the country's history [3]. However, RES are inconstant, hard to forecast and weather-depending, which causes difficulties in operations management of electricity systems [4]. The emergence of distributed energy markets requires novel technology solutions to support energy and information sharing. Hence, due to distributed and irregular nature of renewable energy sources, innovative technologies are essential to bringing their expansion to the next level [5,6]. Therefore, some flexibility measures are required to enhance grid stability, such as timely supply and demand response mechanisms or energy storage solutions [7]. Based on a rapidly growing number of incorporated smart meters across the globe, it is claimed that energy systems are on the verge of performing a digital revolution [8]. It is evident that this revolution cannot be achieved with the centralized energy markets of today [9] as there is a need for better information-sharing solutions such as ICT [10]. These novel, often local energy markets, which provide improvements in, for example, energy efficiency, environmental and socioeconomic sustainability performance, etc. require decentralization and digitalization solutions to become more proactive (by including more actors) and effective in peer-to-peer energy trading management [11].

The solution to these issues can be blockchain technology, which was primarily designed to enhance decentralized transactions by removing the central authorities from transactional processes. It can be also defined as a distributed ledger technology (DLT) or Internet of Value [12] that securely stores and shares digital transactions without the centralization of management. This structure allows for the automated execution of smart contracts in peer-to-peer trading platforms [13]. Blockchains can be also perceived as a global database that allows multiple users to modify the ledger, and automatically updates those modifications by making multiple copies of the new records in the chain. Contrary to centralized, single-authority management systems, changes must be approved by the users through consensus mechanisms, which makes this network transparent, secure, and "trustless". To ensure even more resilience to human-specific misconducts and errors, the anonymity of users is covered by implementing cryptographics while connecting new transactions to the existing ones in a block. The literature suggests that such radical technological changes in the existing structures would generate a need for new business models and reconsideration of the current technology paradigms [14–17]. For instance, in supply chain management, the current schemes would be revolutionized by removing the intermediaries through decentralized, blockchain-based supply chains [18,19]. Importantly, blockchain seems to perfectly fit into the context of '*Energy 3Ds*', which stands for decarbonization, decentralization, and digitalization, by offering solutions to obtain these energy capabilities in the near future, and to foster energy transition and dynamic innovation in the field of renewable energy technologies (RET) [20,21]. However, as there is a limited number of use cases, it should be noted that blockchain adoption in the renewable energy industry is not definite and there are other digital solutions that may enhance the performance of the companies in this sector. Blockchain is still an emerging technology, and its widespread diffusion requires multi-dimensional contribution from various sectors of society, as suggested further in this study.

However, while not being universally implemented yet, blockchain usage is associated with numerous regulatory, societal, and technological barriers, such as scalability issues, lack of regulations, integration challenges, etc. Nevertheless, it is claimed that the potential benefits coming from blockchain integration far outweigh these bottlenecks [22].

Most current studies provide reviews of the literature and use cases of blockchain utilization. However, the mainstream of research refers to the overall energy sector, and thus, there are limited studies that are focused solely on renewable energy technologies. Furthermore, authors tend to specialize in specific features or applications of blockchains, such as smart contracts, peer-to-peer platforms, energy efficiency improvement, IoT enabling, etc., whereas in our article, we provide a multidimensional and holistic approach towards DLT application in the RET industry. This curiosity study can contribute to the existing literature on energy digitalization, by providing the prospective viewpoints of the executives of the Finnish renewable energy companies. Because Finland is a member state of the European Union, this research can provide implications for the European energy policy and energy transition analyses, as well as suggest new directions towards achieving the energy decarbonization, digitalization, and decarbonization within the EU. In this article, we present empirical evidence from the Finnish renewable energy industry through the 'Blockchain Maturity Questionnaire' developed by the Authors, revealing the level of knowledge and trust in DLT, followed by an indication of the major potential benefits and challenges in implementing blockchain in Finland, its impact on business models as well as the willingness of the industry experts to utilize blockchains in future. Such a novel insight will shed new light on the principles of blockchain, its applications in the renewable energy sector, and prospects for the future. The remainder of this article is structured as follows. Section 2 analyses the academic literature on blockchain and its usefulness for the renewable energy industry. The methodology implemented in this study is presented in Section 3, where case companies are introduced as well. Section 4 reveals the results of our empirical analysis and its multidimensional implications. Section 5 provides limitations of the study as well as future research directions. Lastly, the main outcomes of this article are summarized in Section 6.

2. Literature Review

In this section, we will provide theoretical background for our study. First, we will explain the basic architecture and principles of blockchain. Then, we are going to present the favorable features of this technology, which will be supported by successful examples of use cases. Finally, we will focus on our core area of renewable energy by reviewing the possible pros and cons of blockchain implementation within the RET sector.

2.1. Basic Principles of Blockchain

Blockchain (or distributed ledger technology—DLT) is a technology that ensures digital information distribution in a shared database that contains a continuously expanding log of transactions and their chronological order. In other words, it is a ledger that may contain digital transactions, data records, and executables that are shared among blockchain partaking agents [13,23]. Blockchain technology is distinct from other previously known information systems by its four main features: non-localization (decentralization), safeness, verifiability, and smart execution [24]. It is a highly innovative technology that is the outcome of a decade's efforts from "*an elite group of computer scientists, cryptographers, and mathematicians*" [25].

The basic procedure within blockchains is structured as follows. Initially, the agent creates a new transaction to be included in the blockchain. This recently created transaction is distributed with the network for authentication and audit. As soon as the transaction is authorized by most of the nodes based on pre-determined and multilaterally established rules, this activity can be transferred to the chain as a new block. A record of that transaction is stored in separate dispersed nodes to ensure the safety of the whole system. In the meantime, the smart contract, as a key component of blockchain, facilitates trustworthy transactions to be performed without third party contribution [18,26]. Figure 1 illustrates this process.

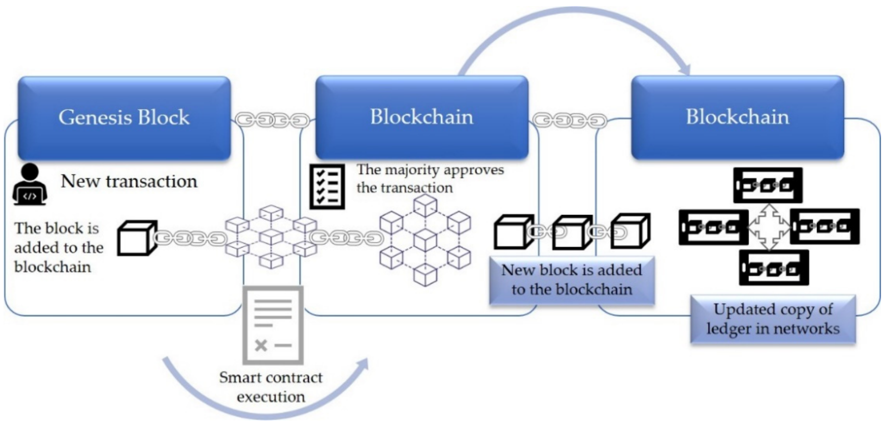

Figure 1. Basic steps in blockchains.

To illustrate the substantial change in current information systems, a comparison with the Internet could facilitate the realization of the possible effect of blockchain technology on current structures. Principally, the Internet (as opposed to blockchain), was designed to transfer information (not value) as well as to process and relocate copies of things (not original information). Therefore, in blockchains, value is generated through transactions logged in a distributed ledger, which is secured by arranging a certifiable, time-stamped record of transactions that results in protected and verifiable information [27]. These digital transactions go through auditing and verification processes that are agreed upon by the system consensus guidelines. When the new record passes this whole process, it is verified and included in the blockchain, and then multiple copies are generated in a decentralized way to establish a trustworthy chain [18].

2.2. Features and Applications of Blockchain Technology

One of the most significant features of blockchain is decentralization, which meaningfully improves information legitimacy. Accumulation, updating, or deleting information in centralized information systems is not only inefficient and expensive, but such structures are more vulnerable to hacking, fraud, or critical errors [28]. Blockchain, by arranging decentralized information sharing systems, significantly increases the trust level of the performed transactions, as per there is no longer a requirement to appraise the reliability of the middle-men (who are removed) or of any other network participants, and this data is effortlessly available and verifiable. This decentralization creates an additional substantial advantage attributed to blockchain implementation, which is the transparency of information whereas safeguarding the anonymity of participants, for example, through cryptographic systems [29]. Additionally, this design enhances minimizing any human, social or behavioral misconduct such as fraudulence or sluggishness, guaranteeing the security and integrity of the network.

Depending on a specific technology application, blockchain architecture can be divergent while establishing public ("permissionless") or private ("permissioned") data systems and ledgers. Both public and private blockchain systems are decentralized and distributed between their users to track all peer-to-peer deals without the involvement of habitually trusted middlemen to approve them [30,31]. However, in private or closed blockchains, the partners can identify each other so there is no anonymity, which creates a necessity to introduce certifiers who are accountable for verifying network members as well as maintaining these private systems. In contrast, in public or open blockchains, cryptographic solutions are utilized to guarantee trust among numerous anonymous participants to permit them to access the network and perform operations inside of it.

To linger on this comparison, let us deliberate on the main distinguishing aspects. First, private blockchains have higher transaction processing rates with fewer authorized members. Hence, a shorter time is needed to achieve the network consensus and a bigger number of transactions can be managed within a given time. By contrast, public blockchains are characterized by limited transaction processing rates. The consensus mechanisms, like Bitcoin's Proof-of-Work (PoW) inside public blockchains, require the entire network to reach an agreement on the current status of transactions. Moreover, data privacy for public blockchains is more prone to risk due to their distinctive nature. On the other hand, private blockchains have more solid data security foundations where any modification can be made only when all nodes approve that the information can be altered through a consensus mechanism [31].

Concurrently, the innovative transactional applications that augment trust, transparency, and auditability are possible through blockchain, and these applications are run by smart contracts. Smart contracts are software solutions for storing principles and regulations throughout the negotiation of terms, conditions, and activities between participants. They serve to automatically verify if pre-established rules and conditions have been fulfilled and then, (if so) to execute transactions. Smart contracts could alleviate informational asymmetry and develop welfare and customer surplus by providing enhanced access and competition, although distributing information throughout consensus creation might cause larger complicity [26].

Blockchain technology was first introduced in 2008 as a trading platform supporting the Bitcoin cryptocurrency [23], but since then, its applications are numerous across different sectors, such as fintech, healthcare, luxury goods, etc. These successful use cases are presented in Table 1 and show the universal applicability of blockchain. However, it should be noted there are only few examples of blockchain utilization at the advanced stage of development, as many applications are still at their infancy level and most of them are at the testing or pilot phases [13,15]. Even though it is no longer an unknown technology, its rapidly developing applications are innovative and thus have a disruptive nature due to its transparency, interoperability, and decentralization, which helps markets to provide more secure, resilient, and both cost- and time-efficient solutions [6].

Table 1. The application of blockchain in various industrial segments.

Industrial Segment	Application of Blockchain	Authors
Government/Public sector	• Voting • Taxes • Tender processes	[32–38]
Industrial sector	• Manufacturing processes • Internet of Things (IoT) device management • Service industry	[39–44]
Financial services	• Foreign exchange • Corporate debt/bonds • Trading platforms • Payment remittance	[45–48]
Insurance policy	• Claims processing • P2P insurance • Ownership titles • Sales and underwriting	[49–51]
Retail business	• Loyalty points • Identity management • Trust industry • Capital asset management • Letters of credit	[52,53]
Luxury business	• Luxury items	[54–56]
Sustainable and circular supply chains	• Sustainable Supply Chain Management (SSCM)	[18,57–59]
Supply chain and logistics	• Food supply chain • Drug supply chain • Textile and clothing supply chain • Agricultural supply chain • Automotive supply chain • Freight logistics • Construction supply chain	[19,60–64]

2.3. Blockchain for Renewable Energy

Blockchain technology has also gathered considerable attention in the energy market, where blockchain has already contributed to the emerging concept called the Internet of Energy (IoE) [65] which enables transparent, decentralized energy prosumer networks, including energy trading platforms [66]. There have been several successful applications of blockchain in the energy industry, where improvements provided by this technology fostered the energy transition and circular economy initiatives through for example, novel solutions for electric e-mobility, energy democratization, P2P energy trading platforms, demand-response mechanisms, smart metering, smart grid management, automation of green certificates issuance and carbon trading, etc. [13,24]. In substance, as Wang and Su highlighted, blockchain can provide three major benefits for the energy sector, which are (1) decentralized energy trading and energy supply, (2) effective, automated control of energy and storage flows through smart contracts, and (3) secure records of all the business activities in the energy industry [67].

In this part, we will discuss the applications of DLT in RET and circular economy in more detail, which will help us to categorize major possible benefits and barriers to use in the research results presentation. The list of identified categories of main advantages of blockchain in the (renewable) energy sector is presented in Figure 2.

Figure 2. Applications of blockchain technology in the renewable energy industry.

Next, we will discuss the highlighted benefits coming from possible blockchain adoption within the renewable energy industry in a detailed way, one by one.

2.3.1. Distributed Energy Trading—P2P Platforms and Energy Democratization

As previously mentioned, decentralization is one of the key features of blockchain technology. The concept of removing the intermediaries from the transactional processes emerged from the introduction of smart contracts, that serve to automatically verify and execute the contract rules. Therefore, security and trust, previously granted by third parties, now can be ensured by blockchains [24]. Blockchain, by being a distributed ledger technology (DLT) enhances the integrity and reliability of the stored data, by limiting the need to authorize new transactions and updates by certified third parties. Such processes are automated through consensus mechanisms, which improves time- and cost-efficiency as well as provides transparency and interoperability of the blockchain-based systems. Moreover, asymmetric cryptographic systems serve to ensure the trustworthiness and anonymity of the transaction parties.

This decentralization can act favorably, particularly in the Solar PV generation, trading, and storage activities, where energy prosumers (producers and consumers all at once) can have a more active role in the market, by forming local energy communities, such as so-called crowds. Crowd energy can be understood as the enhanced cooperation of energy prosumers where their resources are traded with the use of ICT solutions [68]. This concept could be further described as a “decentralized autonomous organization”, a distributed network of sovereign agents, based on flawless and reliable operation. Therefore, the crowd energy idea seems to perfectly fit as the background for blockchain, enhancing for example, direct peer-to-peer (P2P) energy transactions, traceability and provenance of energy, smart contracts, etc. Furthermore, according to the seminal study by Andoni et al., decentralized energy trading appeared to be the most common application of blockchain in the energy sector, followed by (2) cryptocurrencies and energy tokens and (3) IoT, automation, and asset management [13]. It has gained the attention of energy companies due to its capability to significantly reduce transaction costs and trading volumes, which attracts smaller-sized prosumers to actively participate in the energy markets. Moreover, prosumer-oriented energy markets can provide more flexibility to the grid, but also the transparency which could result in a significant increase in the customer awareness about the source and quality of chosen energy services. Such an improvement could lead to enhanced competition and so-called energy democratization. Lastly, local energy trading platforms, by forming microgrids, can generate novel revenue streams and potentially decrease the total cost of energy for end customers [13].

2.3.2. Cryptocurrencies and Energy Tokens

The mainstream of initial know-how about blockchain technology links DLT with cryptocurrencies, such as Bitcoin or Ethereum. Therefore, as this is one of the most acknowledged applications of blockchain in general, new cryptocurrencies and tokens are emerging in the energy industry. They can serve as an incentive for low-carbon energy generation, hence some cryptocurrencies act as a reward for most socially and/or environmentally sound practices in the system and, therefore, can enhance clean energy investments. Furthermore, cryptocurrencies can serve to tokenize resources, which creates a possibility to shape novel markets and innovative business models, based on the division of assets and ownership. Interestingly, numerous companies are applying cryptocurrencies to allure new investors and organize additional financing options, such as, for instance, Initial Coin Offering (ICO). There are already several examples of inventing new cryptocurrencies and energy tokens aimed at fostering IoT, sustainable and renewable energy investments, such as SolarCoin, EverGreenCoin, EECoin, EcoCoin, or NRGcoin [69–73], to name a few most popular ones as well as numerous Ethereum-based tokens and platforms.

2.3.3. Enabling IoT and Asset Management

The application of innovative ICT solutions such as the Internet of Things (IoT) can bring numerous benefits to energy companies [74]. The rapidly growing number of smart devices, such as smart meters and ICT tools, fostered by automation processes and big data management results in the potential to remodel the energy sector's value chain. Such innovative digital support can improve the energy system's overall performance and resources analytics which could help the companies to cut down operational costs [75]. Especially in the instance of electricity generators, smart technologies grant the capability of boosting the network efficiency through enhancing billing automation, optimization of demand control (i.e., aggregation and response) mechanisms, and revolutionizing the existing supply chains [18]. Moreover, an introduction of innovative digitalization solutions such as IoT and/or ICT- and blockchain-based technologies can inspire companies to seek innovation paths and to innovate their current business models [14,15,17]. As it is claimed in the literature, the energy sector digitalization will require the reconsideration of existing structures and business models, mainly due to the decentralization of authority, entirely virtual, and new local, self-sufficient markets where consumers are more motivated to actively participate [76,77].

Primarily, IoT solutions are associated with hardware and software smart automation technologies, such as sensors, meters, cloud connectivity and controlling tools, etc. which could, among other things, significantly limit the maintenance and management costs for smaller-sized RET companies [75,78]. Notably, the application of smart grids can improve the grid management and grid stability through smart devices, and enhance real-time coordination and adjustment of the energy demand and supply, and electricity prices accordingly to the current power consumption levels [11]. Finally, it is important to note that blockchains can strongly support further IoT-based solutions' development as blockchains can be used as a solid technological base for creating and sustaining IoT platforms, and provide the reciprocity and interoperability of IoT operations [79,80].

2.3.4. Smart Metering and Smart Grid Management

Blockchains, mainly due to the rising number of smart meters, can play a key role in fostering more efficient, automated methods for metering and billing procedures. The principal benefit coming from such automation is the potential of cutting down administrative costs within the grid and market. Moreover, it provides transparency and trackability of the energy generated and consumed, informing the customers about the source, price, and provenance of the particular energy supplied to them (renewable energy tracking), which positively affects the competition in the market and societal awareness about the environmental aspects of energy. Furthermore, through its data security feature, blockchain can ensure personal and business fragile data privacy and protection against cyber-attacks. Another aspect concerning hazardous events such as power outages and wastes can be tackled by using blockchain's smart contracts while forming a new smart grid [41,67,80].

Interestingly, one of the initial utilizations of blockchain in the energy industry was the introduction of cryptocurrencies as a payment method for electricity and energy bills [13]. Nowadays, an increasing number of companies permit payments for their services through cryptocurrencies, including those of the energy companies, where BAS Nederland is perceived as a leader in this matter, by allowing payments for the energy bills issued by them in Bitcoins, the most globally popular cryptocurrency [81], which was rapidly followed by other companies like German Enercity [82] or Japanese Marubeni [83].

Smart meters and smart contracts provide numerous benefits for the energy sector while administered through blockchain. Another important example of a possible improvement opportunity is the automated and decentralized grid management system through smart grids [10]. Such a smart grid management method, which is based on blockchain's main feature—smart contract—can ameliorate, for example, supply to demand balancing, distribution system coordination, grid assets verification and visibility, through smart contract's capability to effectively control energy network, which is based on pre-established rules and performed in an automated and reliable way [11,26,84,85].

2.3.5. Green Certificates and Carbon Trading—Automation

Importantly, blockchains can contribute to the energy transition toward renewables by facilitating and promoting carbon emissions and cleaner energy trading [86]. Notably, DLTs can foster innovative renewable energy financing by introducing green energy tokens or other tradable digital assets in the energy market or developing P2P energy trading platforms where information about the provenance of the given energy source as well as funds allocation are easily trackable and accessible due to blockchain's transparency and interoperability [87,88]. It is even more important for small-scale energy producers, which are often excluded from the carbon credits procedures due to their relatively complex nature and high claiming costs.

Blockchains, independently of the trading volumes, can automate the issuance of green energy certificates, generate international, transparent markets for green assets trading, and decrease transaction expenses also through preventing double-spending [76,89].

2.3.6. Fostering Electric Transportation

Electric e-mobility is one of the most promoted ways to mitigate the adverse impacts of climate change and to make the transport industry more environmentally friendly. Moreover, digitalization, as a central differentiating factor from conventional, fuel-based vehicles, strongly fosters and enhances electric transportation [90]. Therefore, the inevitable future fast-paced development of electric vehicles (EV) will require improvements in cost efficiency and vehicle performance, but most importantly, in charging speed, the convenience of use, availability and shared charging infrastructure, etc. The decentralized nature of modern transportation trends (on-demand car renting or automated mobility applications, such as Uber) makes blockchain a natural application in this field [13]. In fact, EV charging and shared charging infrastructure are one of the most promising scenarios for blockchain utilization in the energy sector [84]. Blockchains can enable transparency for the EV owners about the charging prices and energy source selection. Moreover, local grid operators and energy suppliers could establish charging prices by the use of blockchain microgrids [91,92]. Furthermore, blockchain wallets could be implemented to facilitate payments at charging stations [15]. Importantly, what is blockchain's unique capability, is to deliver a one-of-a-kind validation and communication platform that is universal despite of location, which would be suitable for cross-border mobility as well. Furthermore, blockchains can provide a market-oriented mechanism for management optimization and EV charging coordination. Charging station operators, with the help of blockchains, could improve the easiness of use for EV owners, but also infrastructure management, the security level of the system as well as promotion of the shared energy concept [93]. Finally, blockchain can serve to guarantee tamper-proof vehicle security and defend programmed cars from being hacked [94], which is often a major concern while employing self-driving cars. Such a guarantee of safety could boost electric and automatic car consumption, which would result in a significant reduction in fuel usage and GHG emissions in the transport industry [95].

2.3.7. Contribution to the Circular Economy

As previously mentioned, blockchains, by providing multidimensional benefits for the RET companies, can play a key role in strengthening the energy transition and promoting more sustainable practices in the energy sector. Notably, a study led by Upadhyay claims that blockchains can contribute to the circular economy concept by facilitating transaction costs reduction, performance and communication improvement within supply chains, human rights protection safeguarding, healthcare patient confidentiality, and welfare enhancement, and carbon footprint reduction [22]. Blockchains, by enabling automation of transactions in a permanent and verifiable way [96], can also serve to optimize time and resources, which could effectively eliminate operational disorganizations or production waste. According to Ghisellini et al., the goal of the Circular Economy approach is to promote greener production measures, the implementation of renewable energy technologies as well as the advancement of optimal strategies and mechanisms [97]. Blockchain can help to achieve these objectives through its ability to generate more sustainable commercial transactional procedures and assist in attaining the necessary equilibrium and harmony between the environmental, economic, and societal dimensions of sustainability.

Blockchain, by its revolutionary decentralized nature, could have a major impact on supply chain management [18,59,60]. For example, blockchain can be used to track and verify the origin of raw materials, production locations, product carriers, storage, and retailers to buy products. Moreover, blockchain enables an efficient tracking and transparency of defective and substandard goods [18]. It also helps to verify the provenance of a product and related sustainability practices, that is, if there are any fraudulent and unethical labor practices involved [98]. In manufacturing processes, blockchains can be utilized for spare parts tracking and monitoring of the current equipment, but also for shipping automation, which has the major potential to provide more time efficiency and reduce operational and repairing costs [44,61,62].

Blockchain can promote circular economy practices, which include reducing materials and waste, reusing products, and recycling. The traceability and transparency features mean that operating costs decreases and so can waste be reduced. Blockchain can be used to incentivize new behaviors by verifying social sustainability claims, tokenizing sustainable purchases, and creating new systems for pricing and trading. Furthermore, the transparency proposed by blockchain can aid in achieving more sustainable practices and controlling contractors to avoid human rights violations, child labor, inhuman working conditions, or corruption.

Within the concept of the circular economy, we may consider blockchain technology as a social tool for coordination, by its ability to join and coordinate numerous distributed databases, where they could all be updated instantaneously and available to all the network participants [22,99]. This can also transform the current concept of value creation and value appropriation by proposing a decentralized convention of value creation and circulation [100]. This fundamental aspect of DLT could substantially help in accomplishing the circular economy principles through its attributes of decentralization, distributiveness, and tamper-protection, in addition to its suitability for smart contracts and tokenization [26,96,100].

2.4. Barriers and Limitations

Even though the potential benefits provide a promising development perspective for the renewable energy sector, blockchain implementation is still associated with some technological, societal, and economic risks and bottlenecks. The major technology-oriented challenges associated with decentralized energy trading are the scalability and speed of blockchain-supported transactions, low initial digitalization levels as well as grid infrastructure innovation requirement. Social concerns are related to data protection, low level of know-how as well as lack of legal compliance or supportive regulations, which strongly hinder the development of new use cases of blockchain adoption that could lead the way and clear the pathway for the hesitant stakeholders to follow. The key economic constraint refers to the high electricity costs of required huge computational power to execute common consensus algorithms, such as the proof-of-work as well as costs of infrastructural innovation necessary for blockchain enhancement. Next, we will discuss major barriers to widespread blockchain technology diffusion within the renewable energy industry in detail.

2.4.1. Scalability and Speed of Transactions

Mainly due to the initial stage of development and applications, a fundamental technical issue is the scalability and performance of blockchain-based transactions. With the growing number of participants, the blockchain faces performance efficiency challenges. It is challenging to ensure the network's coherence via decentralization while sustaining the system's speed [24]. It is important to note that the degree of decentralization strongly influences the overall blockchain's performance. Therefore, every new additional node in the system makes it more challenging to achieve a common consensus. Currently, in a Bitcoin system, there is a limit of 1 MB for the maximum block size, which hampers the network to add just one single block per 10 min. In consequence, the network speed is negatively affected as it can process seven transactions per second at its peak [101].

Moreover, as a study by Di Silvestre et al. suggested, operations can be controlled in a decentralized manner only to some extent as several technical matters are managed centrally (i.e., balancing). According to the so-called blockchain trilemma [102,103], higher scalability is required while high intensity, which results in the necessity of limiting either decentralization or security levels. The blockchain trilemma concept claims that a blockchain-based network can offer a maximum of two of the following three features:

- Ultimate decentralization of block construction;
- System security (its resilience to cyberattacks);
- Scalability of the system (its capacity to process an ever-growing number of transactions during a certain period of time) [104].

2.4.2. Lack of Legal and Regulatory Compliance

As suggested by Teufel et al., policy and regulatory factors might have either positive [105] or negative [106] influence on the further development and diffusion of blockchain-based energy. Concerning the latter, the main challenge is the harmful side effects triggered by a political transformation [47]. However, the lack of prevailing regulatory frameworks opens the opportunity for local or regional policymakers to support the formation of early-stage proto-markets [105].

Importantly, apart from the technical problems mentioned above that need to be solved, the lack of legal compliance and supportive regulations are perceived as a major hindrance to the widespread adoption of blockchain in the energy sector. The most problematic legal and regulatory aspects are related to the smart contract's legal status, energy law, or data security and independence. Moreover, as there exists the risk of cyberthreats and system malfunction, the potential leakage of sensitive and personal data would cause serious privacy issues. This challenge must be solved especially in public blockchains, where all customer and business data are widely open, and there is a need to develop legal solutions to fit under the GDPR requirements, for instance [24,47].

2.4.3. Infancy Stage of Technological Development

Apart from the above-discussed regulatory and strictly technical issues, the disruptive technology of blockchain is hampered by the lack of growing numbers of its applications. This issue is actually resulting from the barriers presented previously, but it strongly affects the low level of technological maturity and consequently know-how or trust about the blockchain technology among the society. Pilot projects, often led by big companies and corporations, can encourage governments to provide supportive regulatory frameworks for new technologies and financing options for their development. Therefore, a low number of use cases results in significantly limited successful examples to follow by other energy companies and the lack of standards causes the interoperability of various technologies extremely challenging [15,24].

3. Materials and Methods

In this curiosity study, we adopt a mixed methodology of seminal academic literature analysis and multiple qualitative case studies. To perform our empirical analysis, we conducted semi-structured interviews with executives representing Finnish RET companies as well as associated consulting agencies focusing on fostering RET-based business clusters. At the initial stage of data collection, we contacted managers from purposefully selected 30 leading RET-focused Finnish companies, using the long-lasting fruitful university-industry collaboration with our extensive professional networks; we received a positive response on their willingness to collaborate from 10 of them, therefore, our positive response rate is 33%. According to the reports, there are approximately 47 RET companies or successful start-ups operating in Finland [107,108], therefore, we have contacted most of them. The relatively low response rate could be explained for example, by the infancy stage of the technological development of blockchain, lack of supportive regulations, and a rather low level of know-how or interest in blockchain at the moment. The interviews were starting with a multilateral consent to record the meeting as well as to ensure the anonymity of both the executives and their companies' names. Therefore, the companies' names were replaced with A, B, C, etc. This approach serves to follow the GDPR requirements as well as ensure the ethical transparency and integrity of this research. Table 2 briefly describes the companies included in our case study.

Table 2. Details of the companies in the case study.

Company	Technology Focus	Interviewee's Role	Length of the Interview
A	Wind Power	Head of Project Development	1 h 10 min
B	Wind Power	Vice President, Energy Management	1 h
C	Automation and Electrification of Wind Power	Executive Vice President, Marketing and Sales	55 min
D	Wind and Solar Power	CEO	55 min
E	Solar PV	CEO	1 h 20 min
F	Circular Economy, Waste to Energy	CEO	1 h
G	Energy hub; Smart Grids, Energy Efficiency, Marine	Communications and Brand Manager	1 h 10 min
H	Cluster management; Electricity from Wind and Hydrogen	(1) CEO/Managing Director (2) Head of Digitalization (3) Project Manager	1 h 45 min
I	Smart energy solutions	CEO	1 h
J	Electricity and district heating from renewables	Development Director	1 h 20 min

Built upon theoretical convenience sampling criteria, the selected cases become relevant to our study as they empower the availability and information richness [109] and to identify cases purposefully which supports in imitating or outspreading emergent theory from the case in which the process of interest is 'transparently observable' [110]. Moreover, the purposeful sampling technique was employed to attain maximum variation, which occurs in adapting to different conditions [110]. The selection of the respondents was based on multiple criteria, for example, characteristics of the population, objectives, and research questions [111]. This criterion guaranteed that our interviewees have rich knowledge about the topic and adequate experience. Thus, the purposeful sampling approach, as an effective technique with limited resources [112], is suitable for our research as it is supported in the selection of the information-rich cases and the identification of individuals that are particularly relevant, knowledgeable, and experienced [113] with the phenomenon of blockchain. This sampling strategy allowed for in-depth multiple case exploration of blockchain-related topics with interviewees, thereby contributing to the reliability and consistency of the findings.

The recorded interviews were transcribed, and as the length of the meetings varied from 55 min to almost two hours, the amount of gathered information was different in every case. However, the overall number of pages per case amounted to approximately 10 pages, which resulted in a total of 105 pages of materials to analyze. This has served to analyze the different factors mentioned during the interviews and seeking for some patterns or common viewpoints, which has also supported our thematic analysis, primarily based on the questionnaire form.

Methods adopted in this research serve to provide the overview of blockchain technology—its main principles and applications in the renewable energy sector, including main possible benefits as well as key barriers to its widespread diffusion. The thorough literature review has served as a theoretical and practical foundation to develop our semi-structured interview protocol named Blockchain Maturity Questionnaire which was created before the data collection stage and was shared with the interviewees in advance to familiarize themselves with the main aspects of the study. The questionnaire form can be found in Appendix A. The empirical part, which is based on this survey, allows expressing the viewpoint of the RET industry experts on the future possible impact of DLT on the daily operations of their companies. Therefore, the results of this study have the potential to provide novel theoretical and practical implications for the interest groups in the fields of blockchain and (renewable) energy.

4. Results

The literature review has served us to categorize possible benefits and barriers of blockchain implementation for our analysis. The outcomes of our interviews with Finnish RET industry experts will be presented in this section, following our developed Blockchain Maturity Questionnaire, which can be found in Appendix A.

4.1. Initial Level of Know-How about Blockchain Technology

At the starting point of our interviews, after briefly introducing themselves and their companies, our respondents were asked an introductory, basic question about their level of familiarity with blockchain technology. As it is an emerging technology with a reasonably limited number of use cases, the overall level of know-how about blockchain and its applicability in the renewable energy sector was intermediate. Some experts were interested in novel technologies in general, so they were aware of this solution, but the degree of knowledge of most of our respondents was limited to the name and its connection to cryptocurrencies like Bitcoin or Ethereum, as the latter strictly relates to energy.

Like the managers from the companies A and D mentioned: "*I am familiar with the concept in general, as we all relate blockchain with Bitcoin and cryptocurrencies*", and "*I've heard some applications in fintech, but I don't know how we could use it in our renewable energy sector*". However, as the expert running the digitalization academy in the company H claimed: "*Yes, we have projects for students' theses. We are reading about it and studying it but from the industry, it has been a little bit hard to find any use cases so far (...) big companies—they surely* *have it. But they don't tell it outside. They are testing it still. I mean, it would be unwise if they're not investigating it*".

4.2. Biggest Benefits from the Experts' Perspective

Next, we asked our interviewees about the major possible benefits associated with blockchain adoption in their companies. The process of content analysis has helped us to identify, categorize and list the most commonly mentioned benefits, which can be seen in Table 3.

Table 3. The most common benefits identified in the case study.

Benefit Category	Favorable Implications	Mentioned by Companies
Decentralization of authority	Transparency, cost- and time-efficiency, P2P energy trading platforms, novel markets creation, energy democratization	A, B, C, D, F, G, H, J (80%)
Smart contracts, smart meters, IoE	Automation, integrity, trust, security, energy digitalization	A, B, C, D, E, F, G, H, I (90%)
Traceability	Energy provenance, auditability, green certification, CSR and image improvement, circular economy practices	C, D, E, F, G, H, J (70%)

For instance, the CEO of company D said: "*I think that the most critical benefit is the cost-efficient way to sell the energy products for the customers. And of course, everybody has to trust the system. And there are two major advantages: one advantage is that everybody has to trust the way how we or everybody is working. And another reason is that what is the cost-efficiency rate? Also, for the customer*".

Moreover, as the expert from company A highlighted: "*if I take out the main words: integrity, transparency, and security—that is what also maybe adding up flexibility and speed, I would add that the Finnish market especially needs the well-developed permitting process*".

Decentralization and transparency that blockchains offer have been also appreciated, as the CEO of company F added: "*if it can support these types of transactions in a transparent way, that might be revolutionary, for the whole business, not only in ours but in general. Blockchain might be a technological solution that saves cost and time and effort from technology companies like us*". Similarly, a manager from the company H stated: "*Decentralization, smart contracts offer many benefits as middlemen could be avoided to a great degree, especially when selling your technology abroad, and the whole process is more efficient, transparent and automated*".

Energy traceability has been strongly highlighted as a key potential favorable outcome of DLT adoption, in the viewpoint of experts from companies H: "*I think it's this traceability to see where the energy is actually coming from*", and E: "*There's a huge potential in traceability so that you can trace the energy source and consumption and link them together*".

4.3. Application of Blockchain in Specific Business Areas or Departments

Blockchains can have applications in many different business areas and company departments, therefore we asked the managers to estimate in which aspects blockchains could improve their companies' performance.

As the expert from company H mentioned: "*Well, it probably starts from the accounting and agreements—legal department. So, the ways of handling customer relations, customer usage, customer invoicing, and such. And then the bigger agreements between business to business, international especially. So, they are probably the first ones to come. And the anti-counterfeiting will be the second one and probably the spear parts business will be the biggest solution for all logistics, namely international shipping and tracking of high-value parts. Also, the transparency about the ethically correct manufacturing could be significantly boosted*". Similarly, as the expert from company B confirmed: "*If I have to guess something, I'd say it might one day somehow be related to energy accounting or energy settlements. It is a huge Finnish and Nordic issue, as it's not in our* *own hands to decide how the national and Nordic energy clearing and settlement are done. Perhaps one day blockchain technology will be a way to replace this centralized clearing and settlement*".

Moreover, experts perceived the opportunity to create novel markets for renewable energy trading, as the CEO of company D said: "*If there is some solution to sell that renewable energy for the customers using the blockchain technology if we can make some kind of deals with some example special deals with the only one of a kind-customers in Finland or in Europe or even all over the world. And how we handle it, I think that there is a lot of room to develop that kind of technology or that kind of new philosophy*". And the company's J executive added: "*New P2P energy platforms, especially local ones, would transform the way electricity is sold to the customers and it will challenge companies like us to be even more customer-oriented*".

Case company's G manager highlighted the opportunity to improve transparency in spare parts tracking: "*As we're talking about future, I'm forced to speculate all of these and basically make it up as I go along. But this is the kind of application where I can see is tracking of service, verifying the parts are correct, they're authentic, and so on. Because blockchain offers a really good digital signature, basically, that this part is authentic, you cannot really fake it in such a way, you can also trace where it's been, who has been there fixing it, add stuff to it, and so on*".

4.4. Impact on Business Models

As it is claimed in the literature, the implementation of highly disruptive blockchain technology would require business model innovation [14–17,66,76]. Hence, the experts were invited to present their perspective on the blockchain's potential impact on current business models in general as well as their specific components.

Most experts perceived the blockchain's ability to revolutionize supply chains, as, for example, case company's G executive stated: "*The energy value chain at the moment, it's extremely long, there is a lot of different players. And I think that if we can use blockchain technology, that value chain can be much shorter and we could have easier access to more customers. Therefore, I think that the way how the whole market works at the moment might be changed in a radical way*".

However, there have been other interesting insights from the RET industry experts, such as from case companies A: "*If it is a new product, it is principally the sales and marketing that would affect our business model. But if it would be a more efficient way of working in our traditional business then it would require the training of personnel*".

F: "*I would still consider this as more in the kind of customer interface and then secondly, in the supply chain, so the effects probably could be the not in the value proposition as such, but probably kind of how to make more effective business if we can cut some something from the overall value chain and replace it with blockchain. So, it's more like business model fine-tuning and optimization rather than revolution, in my mind*".

Or E: "*Blockchains could help to automate and improve customer interfaces and standardized systems, which would save a lot of time and effort for us*".

4.5. Role in Fostering CSR, Sustainability, and Circular Economy

Blockchains can foster environmentally friendly practices, which can be a source of multidimensional benefits for the companies. In addition to the aspects mentioned in the literature review, the leading advantages in the experts' views about the potential of blockchain's adoption, such as were the tracking of spare parts, detecting their status for either repair or replacement, or efficiency boost in recycling. As recycling and reusing is the most common idea associated with the circular economy concept, some managers identified blockchain's potential to improve such practices, as confirmed by the expert from the case company C: "*As you may know, we are forerunners for recycling things in Finland. And if you compare kinds of wind parks, nowadays, about 70% of the materials are renewable and can be reused. Blockchains can provide this data transparency on depending what kind of technology they are using and can it be replaced or does it need to be totally renewed during the time life lifecycle, and so on. Overall, I can see that recycling part is a very big part of the whole blockchain thinking and way of working in the process*". This traceability of spare parts and manufacturing processes has been also appreciated by the company's H expert: "*Companies will need to show some certain percentage of how much they are reusing things and the origin is like, where are their materials coming from? They need to see also the life span of the products. So, if you're selling something, when is it destroyed or reused, or made with new materials? So, I think that is one of the first places where blockchains will be used*".

Moreover, blockchains can bring transparency to the ethical and sustainable production and other social actions that might positively affect the company's CSR (Corporate Societal Responsibility) level and thus, gain more recognition among the growing number of environmentally conscious customers and stakeholders. In fact, many managers perceived a possibly beneficial outcome of blockchain's transparency and integrity on their companies' future image, just like in the case of company G: "*Nowadays, every company is starting to give out their plans officially, how are we doing things for the environment—and it will be the new generations that are now in school and will be in the workplace in five or 10 years, they are more environmentally-conscious in their buying decisions, who are they are buying from, they're looking into more of these things. So then, if blockchain can certify that you have a proven track record for 10 years, that you have done these green things, you are environmentally conscious, you don't use low-cost labor and these other things, then you have a much better opportunity of being their company or provider of choice*". Company's D manager added: "*First of all, such practices can save time, improve our performance and reduce our transaction costs. But also, if we use block blockchain technologies in the right way, I hope it will be easier to say this is the real renewable energy that you buy and that is the reason why it might be a little bit extra expensive or all that kind of things. But if, we can use that technology and increase the trust among other counterparties—that is a huge advantage for everybody*".

4.6. Most Challenging Barriers

As blockchain is a disruptive and immature technology, its widespread diffusion within the renewable energy sector is reasonably limited by multifarious factors. Overall, it can be said that the biggest constraints presented in the literature review have been confirmed by the doubts and constructive criticism expressed by our interviewees. The most challenging barriers were identified in the lack of a sufficient amount of use cases within the RET industry as well as the lack of supportive regulations. For instance, in the viewpoint of the company's D representative: "*Of course, legal questions are the ones which we have to solve first. because I think that the most critical thing is that counterparties trust each other. Especially in the energy area—it takes time to implement new solutions. (. . .) I think that huge companies have to start using blockchain first. And after that, smaller companies can use the same rules and same systems*". Managers from the case company H also highlighted: "*The question is, if some countries or regions regulate in one way—will the others follow the same way. Business is global nowadays, companies sell the same stuff all around the world. And they will not want to have maybe regional-sized blockchain systems. So, the standardization, making it global—it's going to be a big problem*".

A manager from the case company G also confirmed the significance of the legal issues but mentioned some technical transition difficulties as well: "*You can't play with your own rules on this side. So, either everybody takes this technology or nobody. (. . .) I think there is a big barrier to replacing the whole infrastructure with some new technology, like blockchain technology, it's a huge effort, it won't be easy*".

Moreover, several managers referred to the low levels of trust and negative reputation of blockchains at the moment, just as case company's G executive stated: "*If we take Bitcoin that is very computationally heavy at the moment, is that you're using energy, and the only outcome is heat. Basically, when a computer is calculating the bitcoins, it will become hotter. But to make this electricity, you have also gotten a lot of other wasted heat, and emissions. So, this, this is really the problem. (. . .) Right now, blockchain carries along with a very negative reputation. And really, if you're going to have something using blockchain, you actually have to have the proof somehow that this is not an environmental disaster*". These concerns have been followed by the company's F CEO: "*I think blockchain's image is somehow still connected to crypto. And crypto is still for many* *people, a mystery or very insecure and something new and scary. So, it's also for us. So probably the main thing why we haven't investigated this more is that, you know, if the cryptocurrency can drop 50% in one day, if that is somehow linked to the blockchain, then it's not secure. Because, for example, in the energy business, everything has to be double-checked*".

4.7. Requirements for Improvement—"Roadmap for BC Adoption"

Most of the case companies suggested the need for increasing the level of technological know-how and introducing more successful use cases that could foster the development of blockchain in the renewable energy industry, as stated by an expert from the company E: "*The first obstacle I see is the lack of education or understanding of the system, and the other one is that there are not many available systems where the blockchain would be implemented at that at the moment*". Experts from the case company H added to that: "*As long as nobody knows anything about it—it's really hard to be implemented. (. . .) if we could get one project at the university, that would produce a practical thing, at least doesn't need to be a real product, but a real case about how to use it for the energy industry, a good example of how to implement blockchain in there. For example, students would be doing a thesis work about it, I think that would be really important because then we could refer to that okay, there's a successful example about it*". Furthermore, as an executive from the company C stated: "*Well, it's interesting to see that how these political and country-wise barriers are going to take down and what is going to be the speed for those legal things that are obstacles for nowadays. (. . .) But what are the drivers for the change? If there are big companies running those drivers further, it will happen quite soon. If this kind of development goes on, it will take time before the legislation will change, and enable this kind of change overall, but I think the world has changed so much already, that it will go much faster than we expect*".

Moreover, the successful examples of blockchain adoption would act as the information provider about the benefits for the companies and other sectors of society B: "*The benefits must be very clear (. . .) Anything you are doing with directly your customers, I think there is a low barrier to implement blockchain technology. If there is some benefit for the reseller around the customer. For us, it has to primarily provide more efficiency and cost reduction*". Furthermore, there is a strong need to solve the legal issues through standardization as suggested by the company's G expert: "*First, we do require some sort of standardization, which blockchain standard, which type of everything to use, and then getting everybody to use it. It should be something that the European Commission wants to implement, not just one country like Finland. This standardization, legal framework, it would need to be European or perhaps even global*". This was also firmly stressed by the CEO of the case company F: "*I think the biggest bottleneck is that we need to have this standardized regulation. (. . .) but also, people are skeptical and there's a need to educate society about the technology, that it's not just related to cryptocurrencies, and so on. So, if the blockchain's image will improve, it will have more chances. I would say it's a marketing problem. I don't think it's a technology problem. The technology looks good, efficient, and new*". The initial steps of change are often the most difficult ones to arrange, therefore, besides the overall viewpoint of starting from big companies, an expert from the company A suggested: "*Well, I see some options—academic commercial first or and some kind of seed somewhere like a seeding in the academic world and through the network building up to the commercial world*". Importantly, it mentions the requirement of involvement from different sectors of society in fostering the widespread implementation of blockchain in the renewable energy industry.

Such insights from the RET industry experts as well as a theoretical foundation based on literature review have served to develop a "Roadmap for Blockchain Adoption", which is presented in Figure 3. It proposes measures that could significantly boost the DLT adoption perhaps not only in the renewable energy sector but in other fields as well. We suggest that multi-sector involvement is needed to implement this disruptive technology. We believe that the university-industry collaboration could lead to introducing several pilot projects aiming to show the practical applications of blockchain and to reveal the most burdensome challenges during its performance. Such actions could raise the interest of the R&D or digitalization departments of the leading energy companies, including the ones focused chiefly on renewables. In fact, the so-called 'big players', which are often partly country-owned or strongly supported by the government, have a reasonably higher possible influence on the policy makers, which could result in the introduction of supporting regulations, that are inevitably a *sine qua non* for the functioning of blockchain in a given country or region. This would result in growing numbers of new use cases, to which—with the help of training and information activities—the society could swiftly adapt.

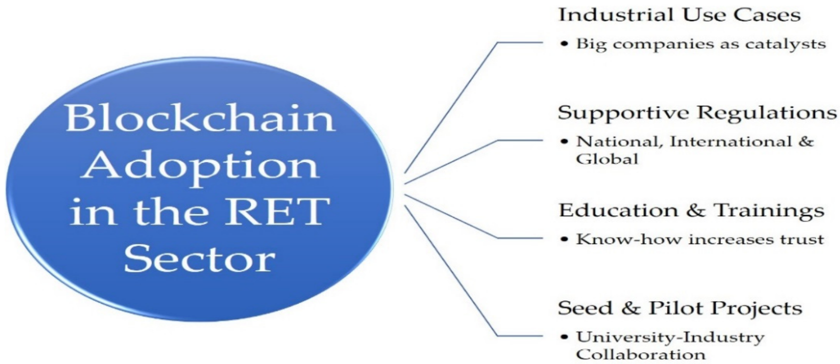

Figure 3. Roadmap for Blockchain Adoption.

4.8. Future of Blockchain within the Finnish RET Industry

Lastly, we asked the RET industry experts how they perceived the potential of blockchain utilization in future energy systems. Most of the companies expressed a positive perspective on blockchain's future, realizing its capability to transform and innovate the whole industry, even though the barriers are meaningful at the moment. As previously mentioned, there is a critical need to implement favorable legal frameworks and to let the leading energy companies initiate this change. Here are some testimonies supporting these promising scenarios for the RET sector:

Case company A: "*Well, as always, there are two scenarios that whether it is a game-changer or it is fading out technology that didn't do enough. But in mind, it can be a game-changer in energy trading markets, especially*".

Case company C: "*I believe that it's possible to make it and it ought to be used in renewable energy. I see that there is a good opportunity to run blockchain-based business in renewables, overall*".

Case company J: "*There is huge potential to innovate this industry and I believe the benefits are much bigger than the challenges. However, the prerequisite is the digitalization of the whole energy sector, which might take some time*".

Case company F: "*Well, I think renewable energy might be in the front end. You know, of this whole change. Now, governments are spending a huge amount of money on renewable energy, and then you have to find new ways to get grants, etc. So, if they would be smart, they would introduce also new ways of doing transactions and this blockchain is part of that. Definitely. (...) I think there has never been a better momentum for renewable energy than now because of the issues like COVID, and so on*".

Case company D: "*I think so that there is a huge opportunity to mainly have an effect on business models and in value propositions because at the moment there is a very long decision-making chain, so there's a lot of different profit-oriented players on market. But if blockchains can change the models, that might be more effective for the deals. For example, energy producers, the customers could make deals only with them. Nowadays we need five or 10 different players between producers and customers. So, I think that might be a huge change in the business models in the future*".

Case company B: "*There might be good possibilities on the end-user side because in the future, they are generating power themselves and they are also storing it. So, there might be different players, some player is offering storage services some player is offering solar panels, and so on. So, they need to exchange that customer data and measure data from different consumption and production streams. That data exchange might be a place for blockchain technology*".

5. Discussion

After fulfilling the requirements for facilitating blockchain adoption and following the proposed roadmap, there is an increased opportunity of introducing DLT at a large scale within the RET sector. However, these measures are proposed at a very general level and the initial stage of blockchain's technological development. It should be noted that at present, we were restricted to conduct a so-called curiosity study, exploring the future beliefs and viewpoints of the RET industry experts. Even though the results appear to be relatively concise and comprehensive, a study on a bigger sample could perhaps shed some new light on the Finnish or European state of affairs. Especially when based on real use cases or even pilot projects, which we were not able to do now.

Future research should examine further use cases of blockchain in the (renewable) energy sector in different geographical areas, and explore new applications, which will inevitably be associated with specific benefits and challenges to define. Studies around the world show that developed countries have more resources, higher R&D rates, modernized infrastructure (including microgrids or smart meters), and stronger governmental support for distributed energy technologies like blockchain. Therefore, these countries will probably be the initiators of this technological change, and Finland is among them. On the other hand, developing countries are still based on centralized energy systems, which makes the widespread adoption of DLT in the global energy systems more challenging, as the digital transformation there might take years, or even decades [67].

The potential of blockchain application in the (renewable) energy sector is reasonably high and multidimensional [10]. Future studies could further explore for example, more effective methods of blockchain application in the Internet of Energy (IoE), smart grids, microgrids, and distributed energy trading markets, or how to improve the efficiency and security of the blockchain-based transaction. In fact, the biggest potential lies in the electricity part of the energy, which is already noticeably digitalized. Moreover, a central feature of blockchains, smart contracts, but also local P2P trading platforms, will be research hotspots as well [88]. Furthermore, the role of blockchain in fostering renewable energy technologies, circular economy, as well as electric mobility, and charging will remain an important area of future research in the blockchain and energy fields [84]. Lastly, as blockchain is expected to revolutionize supply chains, future research should examine its impact on global and local energy supply chains and the concept of sustainable supply chain management [18,19,39,43,52–64].

6. Conclusions

The goal of this article was to introduce blockchain technology, present its applications in the renewable energy industry and evaluate the potential benefits and challenges associated with its utilization. Building upon a thorough literature review, we have conducted our empirical analysis based on semi-structured interviews with Finnish RET industry experts.

The analysis reveals that the level of technological know-how about DLT and its applicability in the RET sector is reasonably limited. This was further mentioned as one of the biggest barriers to be overcome through education and other awareness-raising actions. The experts, after realizing the potential impact of blockchain on their daily operations, detected numerous possible advantages of blockchain application (which were summarized in Table 3), and these are, for example, increased overall cost-efficiency and performance of the companies, higher trust among the trading partners, energy decentralization and democratization, as well as transparency and traceability of energy and automation of complex transactions and procedures. The business areas where blockchains could have the biggest impact were identified as well, such as energy accounting and legal agreements, anti-counterfeiting, logistics, spear parts tracking transparency, or creating novel energy trading markets. We also asked the experts about the impact of blockchains on their business models, and they have acknowledged, *inter alia*, improved and automated customer interface thanks to much shorter value chains or enhanced marketing and sales opportunities.

The study also examined the role of blockchains in fostering a circular economy, and such influence has been strongly detected in the areas such as spear parts management (quality reports, repair or reuse real-time status, etc.), enhanced transparency, and traceability of manufacturing processes, or integrity and verifiability of ethical working practices, which positively affects the company's CSR. Moreover, blockchains can provide unbiased and auditable information about the energy provenance, which in other words, serves to verify if the energy generated and sold to the customers comes from renewable energy sources or not.

Mainly due to its infancy stage of technological development and low level of industrial application, blockchain technology is hampered by various obstacles on its way to being widely implemented within the renewable energy sector. Our interviewees determined the following most challenging bottlenecks: lack of regulatory and legal compliance, global standardization issues, infrastructural transformation challenges, or blockchain's trust and reputation problems. In response to that, we have asked the managers to propose measures to tackle these barriers and to enable blockchain implementation, which served us to develop a "*Roadmap for Blockchain Adoption in the RET Industry*". According to this framework, multi-sectoral involvement is required to promote DLT as a source of numerous benefits for the sector. The proposed change should be initiated by big energy companies that would lead a way for the rest of the energy industry. This would encourage governments to implement supportive policies for such innovative solutions. However, without a sufficient level of know-how about blockchain technology, its potential could not be recognized in the first place. Therefore, there is a strong need to organize information and education events for all the sectors of society, including academia, where seed and pilot projects could facilitate the transition from theory into practice.

It can be concluded that the potential of blockchain to disrupt the renewable energy industry is meaningful and the benefits far outweigh the challenges [10,22]. Even though this study only estimates future possible benefits coming from blockchain's adoption in the RET sector, the vast majority of the interviewed industry experts expressed a promising will to implement this technology in their future operations.

We believe that the insight and practical contributions provided by this research will help the interest groups from the blockchain and (renewable) energy fields to realize the potential of this technology as well as major barriers to be overcome while using it, and ultimately, to adopt DLT in their daily operations.

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Appendix A. Blockchain Maturity Questionnaire

1. What kind of renewable energy technology is your company focused on?
2. Are you familiar with Blockchain technology and do you use it in your day-to-day business operations?
3. If YES, please explain the main reason why.
4. If NO, please explain the main reason why.

5. If YES—What kind of factors convinced you to implement BC in your company? If NO what kind of BC features do you perceive as potentially beneficial for your company in future?
6. If YES—In which departments of your company are you using Blockchain? If NO—in which departments of your company could you use BC in future (where exactly is the need in the company, in which department, or business area etc. and why?
7. If—How significant was the influence of BC technology on your business model? If NOT—how would it influence your BM?
8. [. . . on specific BM components, such as:
   8.1 key resources (infrastructure),
   8.2 value proposition,
   8.3 revenue streams,
   8.4 client interface,
   8.5 external value chain.
9. How do you perceive the possible impact of BC on the issues such as Sustainability or Circular Economy in your organization and in overall?
10. If YES—What kind of major barriers have you experienced so far while using BC? If NO—What are the main possible disadvantages coming from BC usage (factors that keep your company away from implementing BC)?
11. In your opinion, what kind of measures should be taken to improve the current state of affairs—how to overcome the main possible barriers?
12. How do you see the future of BC in the renewable energy sector? How do you foresee the role of blockchain in renewable energy sector and how would it impact on operational excellence, business models and value propositions?
13. If YES—On a scale 1–5, how would you estimate your experience of using BC? if NO—On a scale 1–5, how is it likely that you will use Blockchain in future, and why?

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