Shah Rukh Shakeel

Commercialization of Renewable Energy Technologies

A study of Socio-economic, Technical and Regulatory factors in Finland and Pakistan

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Julkaisun nimike
Uusiutuvien energiateknologioiden kaupallistaminen: Tutkimus sosioekonomisista, teknisistä ja sääntelytekijöistä Suomessa ja Pakistanissa

Tiivistelmä
Kaupallistamisella on tärkeä rooli uuden tekniikan liiketoiminnan käynnistymisessä. Idean onnistunut kehittäminen tuotteeksi tai palveluksi voi olla vaativa ja monitahoinen prosessi. Kaupallistaminen liittyy tiede- ja teknologiaosaamisen tuomiseen laboratoriosta aina markkinoille hyväksymiseen ja käyttöön saakka. Se varmistaa, että tekniikat eivät vain täytä suorituskyky- ja luotettavuusvaatimuksia, vaan myös vastaavat markkinoiden tarpeisiin. Uusiutuvien energialähteiden tekniikoiden (RET) kaupallistaminen tulee tärkeäksi, koska RET:ien on ylitettävä lukuisia esteitä, jotta niitä voitaisiin soveltaa laajasti. Menestys riippuu usein useista eri tasojen toimijoista, mukaan lukien valtiovalta, paikalliset toimijat, sijoittajat, yrittäjät, yhteiskunta ja muut prosessissa mukana olevat sidosryhmät. Kirjallisuus on täynnä todisteita, jotka osoittavat uusiutuvien energialähteiden energiantuotannon valtavan potentiaalin. Niiden tosiasiallinen vaikutus maailman primaarienergian hankintoihin on kuitenkin edelleen rajallinen. On laajaa yksimielisyyttä siitä, että joidenkin uusiutuvien energialähteiden tekniikoiden alhainen levinneisyys ei johdu enää niiden teknisistä mahdollisuuksista, vaan niiden kaupallisuudesta.

Tämän työn tavoitteena on tutkia, miten uusiutuvan energian tekniikoita voidaan tehokkaasti kaupallistaa. Tässä väitöskirjassa tutkitaan Suomen ja Pakistanin tapaustutkimusten avulla tekijöitä, jotka vaikuttavat kaupallistamiseen ja ovat esteitä laajaan leviämiseen. Tässä työssä tutkitaan erityisesti sosioekonomisten asioiden, energiapolitiikan, yliopistojen ja teollisuuden yhteistyön ja riskipääoman merkitystä RET-markkinoiden perustamiseen.

Sovellettaessa kvalitatiivisen ja kvantitatiivisen menettelemän yhdistelmää, tämän tutkielman tulokset korostavat tukevan energiapolitiikan merkitystä, johdonmukaisen lähestymistavan kehittämisen tarvetta, sidosryhmien välisen yhteistyön vahvistamista ja ympäristötietoisuuden lisäämistä. Tulosten perusteella tämä väitöskirja tarjoaa kehykset ja mekanismit, joita tarvitaan esteiden poistamiseen kaupallistamisprosessin tieltä.

Asiasanat
Kaupallistaminen; uusiutuvan energiateknologiat; energiapolitiikka; tiekartta; yliopistojen ja teollisuuden yhteistyö; riskipääoma; käyttäytymisen teoria

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Commercialization of Renewable Energy Technologies: A study of Socio-economic, Technical and Regulatory factors in Finland and Pakistan

Abstract

Commercialization plays an important role in technologies' success and failure. The successful transformation of an idea into a product or service is a complex and multifarious process. Commercialization deals with bringing science and technology competencies from the laboratory to market acceptance and use. It ensures that technologies not only meet performance and reliability requirements, but also addresses market needs. Commercialization of renewable energy technologies (RETs) becomes important as there are a number of additional barriers that RETs must surpass to become widely adopted. Success often depends on a number of actors operating at various levels, including government, local bodies, investors, entrepreneurs, society and other stakeholders involved in the process. The literature is replete with evidence indicating the enormous potential of energy generation from renewables. However, their actual contribution to the world's primary energy supplies remains limited. There is widespread consensus that the low penetration of some renewable energy technologies is no longer because of their technical potential but their commercialization.

The objective of this study is to explore how renewable energy technologies can be effectively commercialized. This doctoral dissertation examines cases from Finland and Pakistan to study factors influencing commercialization and causing hindrances to widespread diffusion. This study particularly explores the effect of socio-economic landscape, effect of energy policies, university–industry collaboration, the role of venture capital and factors influencing adoption and establishment of RETs' market.

By employing a mixed methods approach, the findings of this dissertation highlight the role of supportive energy policies, the need to develop a coherent approach, strengthening collaboration between stakeholders, and increase the level of environmental awareness. Based on the findings, this dissertation presents frameworks and mechanisms necessary to address some of these barriers to foster the process of commercialization.

Keywords

Commercialization; renewable energy technologies; energy policy; roadmap; university–industry collaboration; venture capital; theory of planned behaviour

To my late grandfather Muhammad Hayat Taveer Sipra — a literatus person and a great poet. He passed away when I was very young, and my wish to spend time with him remained unfulfilled. His desire that I should study to the highest level still resonates in my mind. Completing this doctoral degree gives me enormous pleasure as I have fulfilled his wish. To him, I dedicate this work and pray that his soul rests in eternal peace.

PREFACE

"*If you know the enemy and know yourself, you need not fear the result of a hundred battles. If you know yourself but not the enemy, for every victory gained you will also suffer a defeat. If you know neither the enemy nor yourself, you will succumb in every battle*".

The Art of War by Sun Tzu

While reading *The Art of War* by Sun Tzu, the above-mentioned quote struck me. The book is based on an ancient Chinese military treatise, written roughly twenty-five hundred years ago, with an aim to help militaries with developing strategies to win combats. Yet, its relevance for businesses operating in today's world is astounding. It is crucial for businesses to understand their own strengths and weaknesses, as well as the ones they are competing against, to survive in a competitive environment. Businesses face a war-like situation and those who do not develop a fair understanding of themselves and their competitors are bound to suffer. This dissertation is an attempt to understand how renewable energy technologies can survive competition and gain their fair share of the market by competing with conventional energy technologies.

ACKNOWLEDGEMENTS

This long and winding journey is finally coming to an end! It gives me great pleasure to think that this will be the last text I need to write to get my dissertation published. The process of completing this doctoral degree has been a roller coaster ride. There have been surreal moments of joy, a sense of achievement, and days filled with enthusiasm, motivation and optimism. At the same time, I must concede that I have had my fair share of gloom, moments of despair, and uncertain times when I had to gather all my energy, maintain composure, and strive to complete the job at hand.

Getting to this final stage required a significant amount of motivation, hard work, persistence, and dedication. It has been a wonderful learning experience, which has had a positive influence on my personality. I am able to get this far only because I "stood on the shoulders of giants". An enormous support from a number of people has been instrumental in the successful completion of this degree. My heartfelt appreciation goes to everyone who has supported me during this process.

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Vaasa, 26.08.2019

Shah Rukh Shakeel

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1 BACKGROUND AND INTRODUCTION

1.1 Background

Energy plays an important role in the development of modern economies. It is central to all facets of human life, including infrastructure development, power generation, industrial growth, transportation, agriculture and sustainability. The last century has been a period of significant economic growth and expansion, which would not have been realised without an ample and sustainable supply of energy. However, development and modernization have not come without a cost. Excessive use of hydrocarbons, today and in the past, has caused detrimental effects to the environment and its ecosystems. According to reports published by the Intergovernmental Panel on Climate Change (IPCC) and the Environmental Protection Agency (EPA), emissions generated by conventional energy sources will lead to a rise in the average global temperature, extreme weather events, rising sea levels, increased coastal flooding, droughts and related environmental hazards (EPA, 2019; EU, 2018; IPCC, 2013).

Statistics provided by the Energy Information Administration (EIA) highlight how global energy consumption has grown over time and how the trend is likely to continue in the foreseeable future (EIA, 2018). During the 1970s, total energy consumption remained around 6,106 Mtoe (million tonnes of oil equivalent), but by 2000, it had grown to 10,119 Mtoe, and by the end of 2016, it had reached 13,759 Mtoe (IEA, 2018). This growing need for energy can be attributed to changes in demographic trends, the growth of developing economies, changes in consumption patterns and improved standards of living (IEA, 2017; OECD, 2011). By 2050, the world will need 22,000 Mtoe of energy to meet demand (EU, 2007), and this is where the concern lies. The consumption of conventional sources of energy is not only harmful to the environment, these sources of energy are also finite, meaning that continued consumption will lead to their depletion. Moreover, these resources are primarily concentrated in areas that are far from major consumer countries, and access to these often pose threats to energy security (Yergin, 2006).

Increased environmental awareness and issues related to conventional resources have triggered an inevitable focus on effective management of energy systems. It is widely believed that finding a solution may not be simple and straightforward, as the energy is deeply integrated in our contemporary lifestyle. In recent decades, momentum has shifted towards developing technologies and means through which energy needs can be fulfilled without compromising the environment. Renewable energy technologies (RETs) are believed to have the potential to meet future energy needs in a sustainable and environmentally friendly manner (Amigun, Sigamoney, & von Blottnitz, 2008; Lovins, 2011; Resch et al., 2008; Twideel & Weir, 2015). However, despite the huge potential and the technological advancements of the recent past, RETs' contribution to the global energy mix remains insignificant. To this end, renewable energy accounts for approximately 14% of the world's primary energy supply, out of which approximately 9% comes from conventional biomass and 2.6% comes from traditional hydro, leaving the share of modern RETs at less than 3% (BP, 2018; Enerdata, 2018). This low level of utilization for energy generation purposes can be attributed to a number of technical and non-technical barriers. Technological factors include high cost of the technology, connectivity to the grid, storage capacities and infrastructural issues, while non-technical factors concerns with adoption, policy and regulatory issues, societal constraints and market-related barriers (Amigun et al., 2008; Edsand, 2017; Eleftheriadis & Anagnostopoulou, 2015; Reddy & Painuly, 2004). Widespread diffusion and deployment of RETs are very much dependent on successful commercialization of these technologies. The following section sheds light on commercialization and its importance in the context of RETs.

1.2 Commercialization – An introduction

Commercialization is considered to be the most important (Eldred & McGrath, 1997a; Jolly, 1997; Touhill, Touhill, & O'Riordan, 2008) and, at the same time, least developed part of the innovation value chain (Chiesa & Frattini, 2011; Frattini, De Massis, Chiesa, Cassia, & Campopiano, 2012). A growing body of literature has highlighted commercialization as a key factor in a technology's success or failure (Cooper & Edgett, 2008; Gans & Stern, 2003). The literature suggests that the successful transformation of an idea into a product or service is a complex and multifarious process, and a significant number of new products fail to mark their presence in the market (Cooper, 1988; Kassicieh & Radosevich, 1994). Research conducted by Cierpicki, Wright, and Sharp (2000) found that one out of three products generally fails to become successful in Western economies. Boulding, Morgan, and Staelin (2006) affirm that the new product failure rate is as high as 35%. Crawford and Di Benedetto (2003) state that approximately 40% of all products launched in the market fail to gain customer trust. Such a high level of failure is a cause for concern among companies, since research and new product development are resource-intensive processes, requiring significant amounts of time, finances and human resources. The decision to launch a new technology becomes even more challenging if it is disruptive in nature and the company introducing it has limited resources. Christensen (2013) suggests that it is this resource commitment and the stakes involved that make it vital that companies commercialize successfully, as it is the stage at which the product is presented to the market, revealed to the customers, and is expected to generate revenue for the firm. Nevens, Summe, and Uttal (1990) argue that a product's penetration in the market and its imminent success or failure depends upon how proficiently the commercialization process has been carried out. Chen, Chang, and Hung (2011) affirm that successful commercialization can be vital for firms to maximize returns, gain competitive advantage and explore opportunities for trade and expansion. Eldred and McGrath (1997b) further assert that a significant number of failures can be attributed to the absence of a strategically devised commercialization process. This leads us to question whether companies and executives undermine the significance of commercialization during the technology development process. McKinsey (2010) asked this question to over two hundred practitioners operating in different industries across the globe and reported that an efficient commercialization process is indeed considered important for a new product's success. Yet, a high number of failures attributed to the lack of an explicit commercialization strategy prompts the need to investigate why such frequent failures happen. To answer this, we first need to explore what commercialization is and what makes is so important.

Commercialization, its effectiveness and the elements necessary to make the process successful have been given a variety of definitions within the literature. Siegel, Hansen, and Pellas (1995) see commercialization as converting new products, processes or know-how into a profit-making proposition. Rogers (2003) defines commercialization as the transformation of an idea into a product or a service for profit-making purposes. Adams, Bessant, and Phelps (2006) affirm that commercialization deals with converting innovative products or processes into a commercial success. Gans and Stern (2003) see commercialization as a process that enables a firm to transform a newly developed technology or product into a stream of economic returns. According to Lockett and Wright (2005), commercialization is a process of bringing science and technology competences into the market place. According to Balachandra, Nathan, and Reddy (2010), commercialization deals with bringing technology from the laboratory to market acceptance and use. Moreover, they see commercialization as a process of creating a market where a newly introduced technology can compete with the existing technologies on their own, without any kind of support, on a level playing field, without being trapped in the 'valley of death' (Markham, Ward, Aiman-Smith, & Kingon, 2010). Alam, Rahman, and Eusuf (2003) argue that commercialization ensures that technologies not only meet performance and reliability requirements, but also meet customers' needs and are available at affordable prices.

From the above-mentioned definitions, there seems to be a consensus that commercialization deals with transforming valuable offerings into profit-making propositions. However, the literature is divided regarding what the actual 'process of commercialization' is and 'what elements it entails'. For instance, Mitchell and Singh (1996) explain commercialization as the process of conceiving an idea, developing the necessary knowledge and skills, transforming it into a product that has potential, and offering it to the market for sale. According to Jolly (1997), the process of commercialization moves through imagining, incubating, demonstrating, promoting, and finally sustaining. Ambos, Mäkelä, Birkinshaw, and D'Este (2008) see commercialization as designing, manufacturing and marketing a product. Contrary to this assertion that the process of commercialization stretches from the idea development to the product launch, and subsequently sustaining the market, scholars such as Koen et al. (2001), O'Connor, Ravichandran, and Robeson (2008), and Booz, Allen, and Hamilton (1982) see commercialization as the last phase of new product development, primarily concerned with issues concerning the marketing and product launch. In light of the above-mentioned delineations, regardless of the perspectives, it is evident that an invention does not become an innovation until it is successfully commercialized (Chen et al., 2011). It is therefore important to consider that a scientific discovery alone means little unless it is transformed into a product or service that has commercial value.

According to Brockhoff and Chakrabarti (1988), a product's performance and technical functionality can be ensured in a laboratory, but its commercial success is far from being guaranteed. Enos (1962) argues that securing commercial status can be a tiresome and lengthy process, as can be observed in the case of jet engines, televisions and fluorescent lamps. Despite their diffusion potential, it took 79 years, 22 years and 14 years, respectively, for these technologies to be successfully commercialized. These examples reveal an interesting insight – i.e., it is not the technology alone, or the value it offers, that facilitates rapid adoption and ensures overnight commercial success (Rosenberg, 1972). A number of other factors play an important role in determining the future of the technology (Aarikka-Stenroos, Sandberg, & Lehtimäki, 2014). Cooper (2011) and Nevens, Summe, and Uttal (1990) report a number of cases where technologically superior products were undermined by the competing technologies that had fewer capabilities but had profited from a superior commercialization process (Griffin & Page, 1996).

This leads us to our next question: What is an effective commercialization strategy for ensuring success in the market? Is there a universal strategy – i.e., a set of standard procedures that can be followed – or does it have to be modified in different contexts? Walsh (2012) suggest that a primary choice of commercialization strategy is influenced by the type of innovation (disruptive, discontinuous, sequential)[2] and the level of risk related with presenting this to the market, which may be concerned with cost, the product itself or the market. In turn, the level of risk determines whether a strategic choice involves some dependence on third parties or whether the innovator can take the process further independently. Gans and Stern (2003) further this argument by stating that a firm operating in a business environment where intellectual property protection laws and related regulations are strictly observed, and that has the required financial resources at its disposal, may prefer going into the market independently, compared to a scenario where the regulatory environment is less stringent and the risk of replication is high. In the latter case, a company's preferred strategy could be to look for a partnership or enter into a joint venture with established firms. Scholars such as Zoltan and David (1990) and Libaers, Hicks, and Portery (2016) suggest that the size and strategic orientation of a firm may also be a determining factor in devising a commercialization strategy. Big firms generally have strict hierarchical structures, which may compromise their position in a market that is rapidly evolving and requires quick decision-making. In such cases, companies often choose to enter the market by establishing a subsidiary company or a spin-off to achieve the required level of flexibility.

This brings us to the next question: How can success be ensured? Ettlie (1997) emphasised that organizations should focus on developing technological and organizational capabilities. Menon, Chowdhury, and Lukas (2002) highlight that promoting a culture of innovation and engaging creative individuals with diversified knowledge and skills can enhance the overall efficiency of the process (Siegel et al., 1995). Manoukian, HassabElnaby, and Odabashian (2015) affirm that in addition to developing skills and capabilities within an organization, it may also be beneficial to collaborate with external partners. Ettlie and Pavlou (2006) state that the involvement of external partners can help further develop and improve the process. Bound (2011), the European Commission (2002), Mian (1994), and Wonglimpiyart (2015) stress that being part of an ecosystem and obtaining the services of incubation facilities, business accelerators and facility parks can help companies to successfully commercialize technologies. Studies conducted by Samila and Sorenson (2010) and Wonglimpiyarat (2010) highlight how partnering with business angels and venture capitals can help companies gain required finances as well as an understanding that may ensures success. Universities, educational establishments and research centres are home to

[2] Disruptive innovation is referred to as an innovation that creates a new market by radically disrupting the existing market. The discontinuous innovation deals with introducing previously unknown products or services to the market, whereas sequential innovation deals with products or services that undergoes continual improvement while maintaining its unique selling proposition.

innovative ideas and creative individuals. Collaboration with such institutes can be useful in ensuring commercial success (Perkmann et al., 2013). Robert and Kleinschmidt (2007) and Rogers, Lambert, and Knemeyer (2004) affirm that in addition to developing a technology that has a unique value offering, it is equally important to have equitable dissemination schemes in place. This part of commercialization is more related to how a technology is presented to the market for sale. Lynn and Akgün (2003) suggest that the time to market can be an important element for ensuring commercial success. A study conducted by Kirchberger and Pohl (2016) highlights how companies able to launch products on the market faster than their competitors achieve higher levels of success. Bhargava, Kim, and Sun (2013) attribute success to the timing of the product launch on the market. Qian and Li (2003) suggest that companies introducing a breakthrough technology might benefit from the first-mover advantage. However, Shankar, Carpenter, and Krishnamurthi (1998) argue that simply being the first to market may not be a recipe for success. Competitors may imitate or improve the original technology by complementing it with value-added features that can better serve customer needs (Lilien & Yoon, 1990; Suarez & Lanzolla, 2005). Asika (2006) states that a company's ability to target the international market can play an important role in a technology's success. Being a global player provides companies with an opportunity to present a product to a wider market, and efficiently addressing customer needs can ensure a product's success. Based on the above discussion, we can delineate the process of commercialization into three parts: (i) developing a new technology that has the potential to serve market needs, (ii) using a dissemination strategy that is suitable for the company as well as the technology, and (iii) introducing the product in a manner that it is accepted by the customers and can be sustained in the market on its own.

Commercialization has emerged as an important field of research in the last couple of decades, and the literature in this field has surged. However, commercialization of renewable energy technologies is a recent phenomenon. The following section briefly discusses commercialization in the context of RETs.

1.2.1 Commercialization of renewable energy technologies

As discussed in section 1.2, commercialization is a complex and multifaceted phenomenon, requiring extensive research and understanding of the business environment before it can yield the desired results. Commercialization of RETs becomes even more tactical and troublesome, as there are a number of additional barriers that these RETs have to surpass to become successful. RETs are believed to have characteristics of disruptive technologies (Wilson, 2018). Renewable energy technologies are largely different from the existing technologies serving similar markets. The existing energy system is highly centralised, owned by either a state or large-scale utility companies, and is inherently supportive of conventional means of energy generation. RETs cannot be adopted and fully integrated into the system unless there is a supporting infrastructure in place, which requires a great deal of effort, motivation and investment. Therefore, successful commercialization of such technologies is highly dependent on support from various actors operating at multiple levels, including governments, local bodies, investors, entrepreneurs, customers and other stakeholders.

According to Alam et al. (2003), successful application of RETs can be influenced by a number of factors, including resource potential, connectivity to the transmission network, the socio-economic landscape, the price of the technology and the level of awareness. Amigun et al. (2008) linked the lower level of deployment to technological and non-technological barriers associated with renewable energy technologies. Awerbuch (2000) affirms that it is pivotal that RETs become competitive with conventional technologies on price; being environmentally friendly alone will make it difficult for such technologies to sustain in the market in the long run. Verbruggen et al. (2010) argue that economic and market-related factors would play an important role in large-scale deployment of RETs. A lot of emphasis has been placed on the renewable energy resource potential and the contribution it could have towards the world's primary energy supplies, but these assessments do not seem to gauge the effect of economic and market-related factors in the actual deployment (see, e.g., Demirbas, Balat, & Balat, 2009; Sheikh, 2009). Considering the current level of technological development and assuming that normal economic and investment criteria apply, the contribution from most RETs to the world energy mix will be limited (Mignon & Bergek, 2016). To this end, most RETs are not able to compete with conventional technologies on price, making it essential to provide necessary support to ensure successful diffusion of these technologies. Painuly (2001) argues that the existing regime unfairly favours conventional technologies and makes their use cheaper compared to RETs by not imposing environment-related taxes and levies. Owen (2006) suggests that if utilities were being charged for their emissions, and were required to internalise their externalities, many RETs would become competitive. Until the cost of RETs is lowered to the point where they can compete with existing technologies on price, the role of subsidies and support schemes remains pivotal for the survival of RETs. Considering the long-term benefits of RETs in terms of the environment, utilisation of domestic renewable sources and energy security, governments are constantly seeking to promote renewables by introducing supportive mechanisms and schemes that benefit RETs. A study conducted by Lehtovaara (2013) highlights the role of subsidies and support schemes in successful diffusion of RETs. Malek, Maine, and McCarthy (2014) suggest that it is important for companies to make required changes in business models, as conventional business models may not be successful in the case of RETs. Strupeit and Palm (2016) further argue that RET companies need to look beyond conventional business models for measuring financial success.

From the above discussion, it is evident that successful commercialization depends on the right mix of technical, market and regulatory factors, and if any element is missing, success and widespread diffusion become extremely challenging.

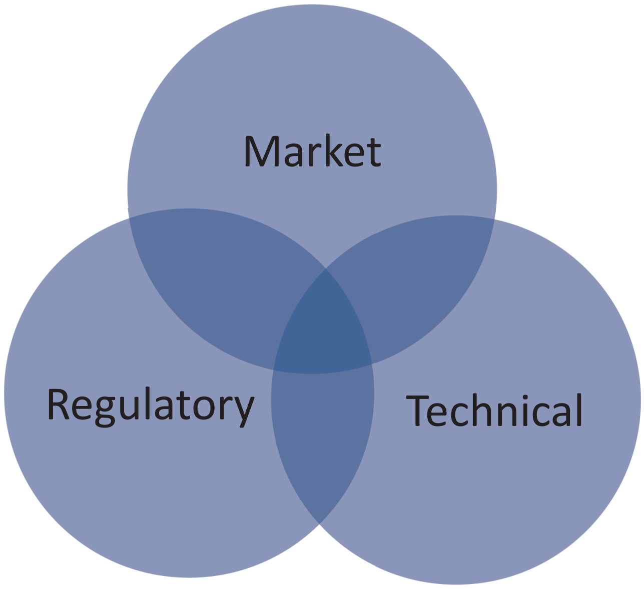

Figure 1. Commercialization of renewable energy technologies

1.3 Objectives of the study and research questions

The objective of this doctoral dissertation is to explore how renewable energy technologies can be effectively commercialized. RETs are different to conventional technologies due to a number of factors: the nature of technologies, development of industry, adoption issues and dependence on regulatory and infrastructure support (Tsoutsos & Stamboulis, 2005). Success often depends on a number of actors operating at various levels, including, but not limited to, governments, local bodies, investors, entrepreneurs, society and other stakeholders. Looking at cases from Finland and Pakistan, this dissertation seeks to explore the effect of socio-economic, regulatory and technical factors on the commercialization of RETs. The rationale for studying commercialization in Finland and Pakistan is based on the countries' socio-economic, technical and regulatory landscapes.

Finland has performed reasonably well when it comes to innovating new technologies, emerging as a front runner (Jamrisko, Miller, & Lu, 2019). According to the Cleantech Group, Finland ranks among the leading countries when it comes to innovation input, public R&D and innovation culture; however, the country is found to be lagging behind when it comes to commercializing technology – behind many of the other EU member states (Cleantech Group, 2014) – and reaping its benefits to the full, both in domestic and international markets. Earlier studies conducted in this domain have focused on commercialization from companies' perspective, and many of the issues at the macro level, such as cooperation among different stakeholders (universities, industry and government), the significance of a support infrastructure, planning and cooperation for internationalization and the role of private financing in successful commercialization, have remained under-researched, and in some cases, not studied at all.

Pakistan is endowed with enormous renewable energy resource potential, but it is not active on the technology development front, and it relies primarily on imported technologies. The existing market conditions and prevailing energy crises offer an excellent opportunity for renewable energy technologies to thrive. However, to this end, RETs have attained rather limited success. Previous research has looked at Pakistan's potential for energy generation, the state of its power sector, the effect of energy crises on society and the economy, and issues concerning emissions and energy security (Ghafoor, Rehman, Munir, Ahmad, & Iqbal, 2016; Sahir & Qureshi, 2007; Shahbaz & Ali, 2016; Shaikh, Ji, & Fan, 2015; Yousuf, Ghumman, Hashmi, & Kamal, 2014). However, studies focusing on the effect of regulatory frameworks, infrastructure, and challenges concerning the creation of renewable energy technologies' markets and their adoption remain neglected.

This study seeks to address some of the challenges faced in the commercialization of RETs by presenting the frameworks and mechanisms necessary to enhance the efficiency of the process. The study explores macro-level factors influencing commercialization and causing hindrances in the widespread diffusion of RETs in Finland and Pakistan. The main research question of the study is:

RQ: What kind of socio-economic, regulatory and technical prerequisites are necessary for firms to successfully commercialize renewable energy technologies?

In order to address this main research question, the following sub-questions are formulated:

RQ1: How do regulatory, economic and technical factors affect the socio-economic landscape and commercialization of RETs?

RQ2: How can collaboration between universities and industry be enhanced to facilitate the transfer of knowledge and the commercialization of academic research?

RQ3: What role can venture capital play in improving the process of technology development and the successful commercialization of RETs?

RQ4: What factors influence renewable energy technologies' adoption and play a role in the establishment of RETs' market?

1.4 Context and the structure of the study

This dissertation is divided into two parts (Figure 2). The first part comprises five chapters. The first chapter deals with the background and the introduction of the study. This chapter highlights the objective of the study, presents research questions and considers the context and structure of this dissertation. The second chapter presents important theoretical concepts used in this dissertation, while the third chapter deals with issues concerning the philosophical worldviews, research design and approaches used for conducting this research. The fourth chapter presents an overview of the scientific articles included in this dissertation, while the final chapter integrates the research results, discusses theoretical and managerial implications, and underlines future areas for research and the limitations of the study.

The second part of this dissertation contains five scientific articles, each addressing the research questions presented in the first part. Article 1 seeks to investigate socio-economic, regulatory and technical factors, and it aims to study the commercialization environment as a whole. This study highlights the barriers and facilitators influencing the commercialization of RETs and presents a framework to address these challenges. Article 2 seeks to gauge the effect of energy policies, explores the state of the energy sector and presents a roadmap for long-term development of the energy sector and integration of RETs. Article 3 investigates the role of personal and institutional factors in influencing academics' tendency to engage in collaboration and commercialization of academic research. Article 4 focuses on understanding the role of venture capital in fostering the development process and commercialization of RETs. Article 5 looks into how renewable energy technologies' markets can be established. This article investigates the issue by examining the factors influencing adoption behaviours and playing a role in the establishment of RETs' market.

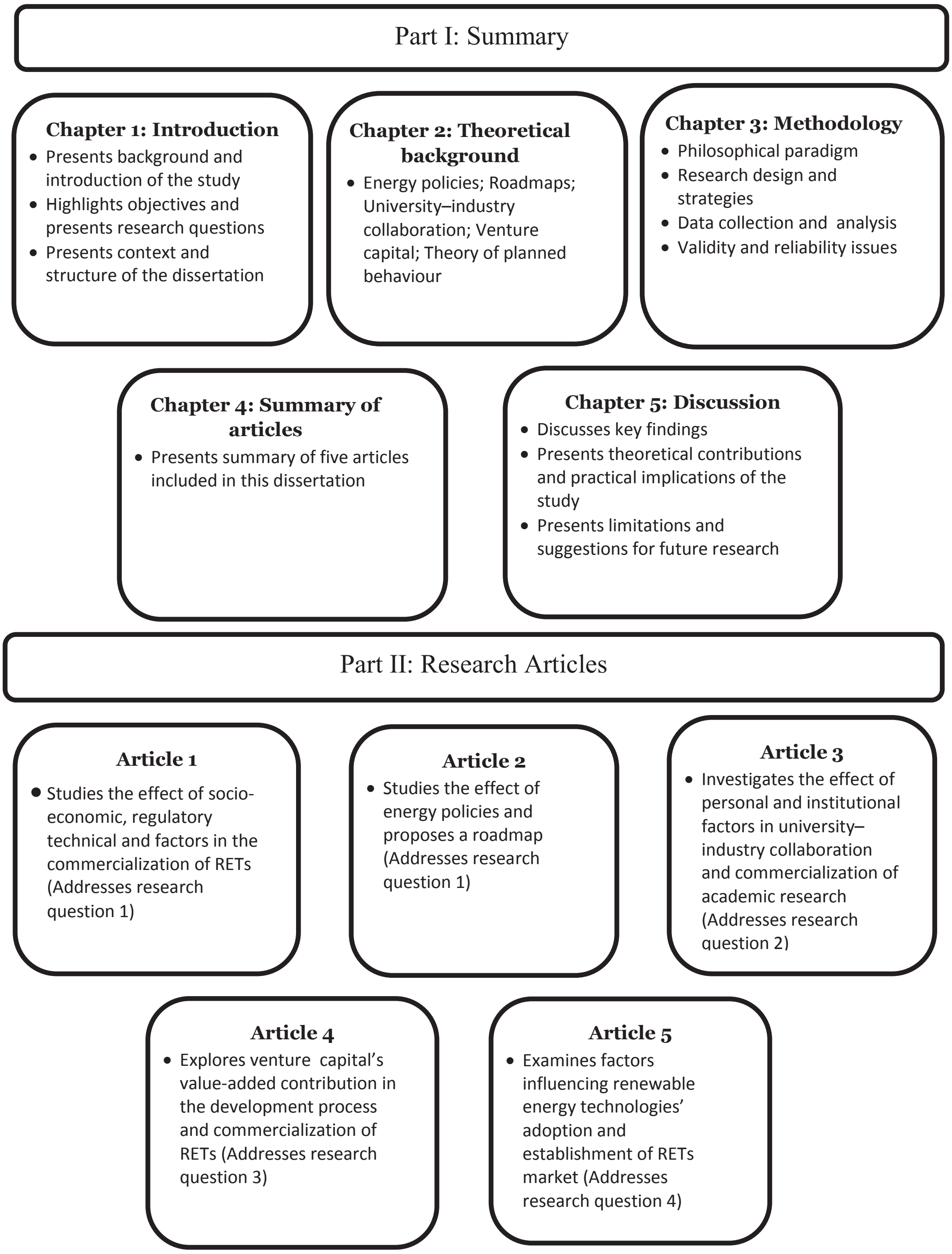

Figure 2. Outline of the dissertation

These five scientific articles study commercialization and seek to investigate the factors influencing the process at the macro level. Particular emphasis has been placed on studying the socio-economic landscape, effect of energy policies, university–industry collaboration, factors influencing adoption behaviour and the role of venture capital in assisting companies to successfully commercialize technologies. Three of the scientific articles present evidence from Finland, while the other two are based on data collected from Pakistan.

Finland is a technologically advanced country leading the clean-tech sector. Therefore, aspects that could have an impact on technology development are studied in the Finnish context. In contrast, Pakistan is endowed with enormous renewable energy resource potential but is not active on the technology development front, relying primarily on imported technologies. The market offers huge potential for RETs. Therefore, aspects concerning adoption, its impact on the establishment of the RET market and the effect of energy policies in shaping the energy sector are studied in Pakistan's context. The inclusion of evidence from Finland and Pakistan provides interesting insights and useful lessons that could be applicable to other countries and can assist in learning the prerequisites for successful technology development and deployment. Articles 1, 2 and 3 are published in peer-reviewed journals, whereas articles 4 and 5 were presented at scientific conferences and are currently under review in peer-reviewed journals. An overview of the articles is presented in Table 1.

Table 1. An overview of the articles included in this study

Article	Title	Research theme	Research design	Publication
Article 1	Commercialization of renewable energy technologies (RETs): A ladder building approach	Studies the effect of socio-economic, technical and regulatory factors on the commercialization of RETs in Finland	Qualitative case study (semi-structured interviews, literature review, data triangulation)	Renewable and Sustainable Energy Reviews
Article 2	Renewable energy sources in power generation in Pakistan	Studies the effect of energy policies, explores the state of the energy sector and presents a roadmap for long-term development of the energy sector and incorporation of renewable energy sources	Qualitative case study (semi-structured interviews, literature review)	Renewable and Sustainable Energy Reviews
Article 3	The role of personal and institutional factors in influencing academics' tendency to engage in commercialization of academic research	Examining the role of personal and institutional factors in university–industry collaboration and commercialization of academic research	Quantitative (web survey) Binomial logistic regression using SPSS	T2S 2018 – Technology Transfer Society Conference, October 17–19, Valencia, Spain (Under review in a peer-reviewed journal)
Article 4	Venture capital's value-added contributions in the development process and commercialization of renewable energy technologies	Studies venture capital's contribution in the development process and its role in the commercialization of renewable energy technologies	Qualitative case study (semi-structured interviews, data triangulation)	Management International Conference, Opatija, Croatia, May 2019 (Under review in a peer-reviewed journal)
Article 5	Towards the establishment of a renewable energy technologies market: An assessment of public acceptance and use in Pakistan	Examining the factors influencing adoption behaviour and playing a role in the establishment of RETs' market	Quantitative (survey questionnaire) structural equation modelling (SEM) using SmartPLS	Journal of Renewable and Sustainable Energy

2 THEORETICAL BACKGROUND

This chapter presents important theoretical concepts used in this dissertation.

2.1 Energy Policies

Energy policy is defined as a set of ideas, guidelines or interventions proposed for the regulation of the energy sector (Mcgowan, 1996). The objective of an energy policy may be to regulate the energy sector, undertake measures to ensure undisrupted energy supplies, govern the current and future energy balance and suggest preferred sources for power generation in a country's primary energy supplies. Energy policies typically reflect visions, goals and strategies needed in order to achieve stated objectives (Trutnevyte, Stauffacher, & Scholz, 2011). A number of factors may influence the direction of a country's energy policy, including availability of resources, visions of the future, concerns over energy security, environmental considerations, sustainability issues and international treaties that a country has ratified (OLADE, 2016; Prontera, 2009; Rehman et al., 2012). If a country has an abundance of hydro resources, the focal point of the country's energy policy could be to generate energy from cheap hydro sources. If a country's energy mix is heavily influenced by conventional hydrocarbons, the objective may be to reduce dependence on imported hydrocarbons and develop local renewables, nuclear power or other suitable alternatives. A country with a population that is sensitive to nuclear power and its potential negative effects may decide to phase it out and replace it with alternatives.

Being part of international treaties such as the United Nations Framework Convention on Climate Change (UNFCC) or being a member state of the European Union (EU) obliges countries to formulate energy policies that are in line with these organisations and their initiatives. For instance, the European Union's Climate Strategies and Targets have aimed to progressively reduce greenhouse gas emissions up to 2050 (European Commision, 2018). This objective is to be achieved by generating energy from renewables and improving energy efficiency. The 2020 Climate and Energy Framework states the need to reduce greenhouse gas emissions by 20% from their 1990 level, as well as increasing the share of renewables by 20% and improving energy efficiency by 20% (European Commision, 2010). The latest framework– the 2030 Climate and Energy Framework – has revised these targets and aims to cut emissions by at least 40% from their 1990 level, while increasing the share of renewables by 32% and achieving a 32.5% improvement in energy efficiency (European Commission, 2014).

The EU has provided a guiding framework, and the member states are obliged to formulate their national energy policies based on the guidelines, which focus on: (i) securing energy supplies, (ii) expanding the internal energy market, (iii) increasing energy efficiency, (iv) reducing emissions and decarbonizing the economy, and (v) supporting research and innovation. In order to facilitate the growth of technologies that can reduce emissions, enhance energy efficiencies and generate energy using renewables, countries have introduced subsidies and support schemes to facilitate the development and growth of RETs. The widely adopted support schemes are feed-in tariff (FIT), premiums, tax reductions, direct financial/price support, and financing accessibility (Butler & Neuhoff, 2008; Kitzing, Mitchell, & Morthorst, 2012; Ragwitz & Steinhilber, 2014; Ringel, 2006). A number of studies have highlighted the effect of supportive energy policies in the development and growth of environmentally friendly technologies. Lehmann and Gawel (2013) argue that a mix of policy and market failures has made it difficult for RETs to compete with conventional technologies on their own. Proponents of supportive energy schemes argue that such schemes will only be required until the technologies improves in terms of performance, reliability, cost and level of environmental awareness (Gross, Leach, & Bauen, 2003). However, to this end, the role of energy policies are pivotal in the commercialization of RETs.

2.2 Roadmaps

The International Energy Administration (IEA) defines a roadmap as a strategic plan devised to highlight needs, prescribe measures and suggest necessary actions to address challenges in a suggested time period (IEA, 2014). According to Garcia and Bray (1997), technology roadmaps can be useful in planning activities and coordinating necessary measures to develop technologies within a company. Amer and Daim (2010) suggest that roadmaps are useful in making forecasts about the market direction and technological developments based on which strategic decisions can be made. Galvin (1998) states that a roadmap provides an opportunity to have an extended look into the future, based on the existing knowledge, understanding and imagination of the brightest drivers of change in a field. A roadmap is helpful in communicating vision, helping to attract resources from business and government, encouraging exploration and monitoring progress. Phaal (2015) states that roadmaps are fairly flexible and can be employed to serve a variety of purposes. In his study, Phaal (2011) analysed over 2,000 roadmaps and concluded that technology roadmaps have been widely adopted in different industries and sectors, including healthcare, construction, defence, information technology, energy, transportation and communal planning.

Amer and Daim (2010) affirm that roadmaps have gained significant importance in the recent past. Phaal (2015) claims that their initial application can be traced back to the 1970s, when Motorola developed the first roadmap for its organisation. Since then, they have been widely used in different settings and served multiple needs. Phaal, Farrukh, and Probert (2005) explain that the scope of technology roadmaps has broadened with time, and regardless of their initial application, at the organisational level, roadmaps are now being developed at the industrial and national levels. According to the IEA (2013), roadmaps developed at the organisational level are devised in accordance with a company's vision, goals, approach and strategic orientation, whereas roadmaps developed at the industry level are formed based on a collective vision. Industry-level roadmaps are cooperatively developed by the actors operating in a particular industry, often including associations, industrial organisations, research centres and relevant governmental departments. Industry roadmaps encourage mutual collaboration and cooperation among the key actors in an industry to achieve specific objectives. McDowall (2012) states that such roadmaps are a good way to develop unanimity about the future direction, as they are collaborative, consultative and consist of the views and input of various stakeholders.

National-level roadmaps are similar to industry- or sector-specific roadmaps. They are developed to set a vision for a country in a particular domain and determine the measures required to achieve these objectives. Amer and Daim (2010) describe country-level roadmaps as constituting a national vision, goals and targets, proposing guidelines to the people involved at different levels, such as policymakers, industrial organisations, research institutes, and other stakeholders. Kostoff, Boylan, and Simons (2004) state that roadmaps provide an overall assessment of the technological landscape to help decision makers in making strategic choices. The defined path allows stakeholders to understand and analyse the direction a government has set and its probable impacts on the associated sectors.

Phaal, Farrukh, and Probert (2004) and Phaal and Muller (2009) state that despite the differences in their scope, level, dimensions and agenda, roadmaps are typically devised to help on three basic fronts. First and foremost, it identifies the vision, mission and objective: Where are we going? What do we want to achieve? Second, it helps in assessing and realising the existing situation: Where exactly do we stand at the moment? Third, it assesses how to reach the desired state. A realistic assessment and identification of gaps between the existing and desired states helps to narrow down the actions required, both in the short and long terms, to achieve the set goals and targets.

McDowall (2012) suggests that in addition to addressing core functions, a roadmap should encompass four traits: credibility, desirability, utility and adaptability. Credibility means that the information on which roadmaps are designed should be credible and inclusive, incorporating social, political, market and cultural aspects of the envisioned transitions. A roadmap designed considering merely one facet and failing to incorporate other elements is bound to fail or produce less of the desired result. The element of desirability considers that the proposed initiatives should be in line with the larger vision. The aspect of utility considers how the process should positively influence further development in the long run, while adaptability refers to a roadmap's ability to remain valid despite changes in time and dynamics.

2.3 University–industry collaboration and commercialization of academic research

Universities and educational establishments play an important role in accelerating a country's economic growth and competitiveness (Yusuf & Nabeshima, 2006). Traditionally, universities have primarily been considered responsible for education and training of the workforce that serves industrial needs. However, with the passage of time, universities have emerged as dynamic institutes, taking part in direct economic activities and contributing to a country's economic growth. Some see the university's new role, often referred to its third mission, as a natural extension (Geuna, 1998), pointing out that universities receive significant amounts of public and private funding and enjoy the luxury of hosting some of the brightest and skilled minds in their respective fields. It is therefore pivotal to ensure their participation and valuable input on all fronts. In an era of increasingly knowledge-based economies, future industrial growth is likely to be more dependent on the knowledge and skills of individuals and less reliant on heavy infrastructure and conventional industrial systems, as it once was (Schwab, 2016). The rise of the fourth industrial revolution and the integration of information technologies in contemporary sciences require interaction and knowledge input from different stakeholders. Therefore, the role of university researchers in advancing tacit knowledge through which technologies enter a commercial domain becomes central (Yusuf, 2008). Bekkers and Freitas (2008) affirm that approximately 10% of new products or processes receive direct or indirect contributions from academic research. A study conducted by Rasiah and Chandran (2009) acknowledges the role of university–industry collaboration in advancing the automotive and electronic sectors. Pellerito and Donohue (2018) affirm the valuable contribution that university–industry collaboration is making in progressing the biotech sector. RETs can also benefit from stronger collaboration, and the transfer of knowledge between academia and industry can help companies in developing their technologies.

The issue of university–industry collaboration and the commercialization of academic research came to prominence during the 1980s when a number of initiatives were launched in the United States to facilitate the transfer and commercial exploitation of knowledge produced in universities. Research conducted by Cohen, Nelson, and Walsh (2002) and Lee (2000) indicates that the interaction between universities and industry generate positive outcomes for both parties. For universities, collaboration can provide direct opportunities to contribute towards society, gain access to the latest equipment and laboratory facilities, generate additional finances, open up the possibility of sharing ideas with industrial colleagues, and create better placement opportunities for students and research in the industrial setup (Cyert & Goodman, 1997; Larsen, 2011). For companies, the interaction can enhance their public image, give them access to the latest research, reduce the cost of research and development activities, and provide access to talent pools at universities (Bell, 1993; Grant, 1996). Considering the success in terms of enhanced collaboration and commercial gains, a number of universities across Europe and elsewhere have started to introduce similar policy frameworks to support and encourage collaboration and commercial exploitation of academic research.

University–industry collaboration and commercialization have since become interesting topics for researchers, and the literature in this domain has surged. The emphasis has been on identifying the factors that distinguish between universities that are more active in commercialization compared to those that have achieved rather limited success. Bercovitz and Feldmann (2006) point out that universities are complex organisations, and successful commercialization is very much dependent upon the academics working in the universities as well as the supportive organisational structure. Considering the multidisciplinary nature researchers from the field of psychology, strategic management, biology, sociology and organisational studies have sought to explore the factors influencing the collaboration and commercialization of academic research. Researchers focusing on institutional factors have particularly examined the effectiveness of technology transfer offices, the influence of demographic factors, the quality of universities, the extent of faculty involvement, and a university's orientation towards collaboration and commercial exploitation of research. Researchers focusing on individuals as a unit of analysis have examined the role of personal characteristics, age, experience, gender, status, motivation, discipline, effect of training and orientation towards the commercial exploitation of research.

2.4 Venture capital

Ensuring access to adequate financing to meet technology development needs is considered one of the key challenges faced by new technology-based firms (Shankar et al., 1998). Without sufficient finances, no matter how novel an idea is, or how skilful its team is, the development process is expected to get affected. Start-ups and small to medium-sized companies often seek external financing to fulfil their financial needs. Berger and Udell (1998), Mason (2006), and Mason and Stark (2004) suggest that financing typically comes from personal investments, social networks, external grants, bank loans, business angle networks, venture capital or similar sources.

Venture capital (VC) is typically invested in the seed or early stages of a venture (Elango, Fried, Hisrich, & Polonchek, 1995). Investing at an early stage is risky, as the trajectory of a firm's development is not always obvious. Venture capitalists seek to minimise the risk by doing background research and identifying ventures with a likelihood of being successful and offering an opportunity for high returns on their investments (Amit, Brander, & Zott, 1998). Megginson (2004) defines VC as a professionally managed pool of finances collected for making equity investments in growth-seeking private ventures with a well-defined exit strategy. Zider (1998) explains that VC funds are managed by professional investors providing capital to companies with the potential for expansion and growth in return for a share in company equity. VC generally acquire financing from pension funds, large corporations, university endowment funds or similar sources with the purpose of investing it in suitable ventures where they can make profit.

Sapienza, Manigart, and Vermeir (1996) suggest that although VCs help ventures to meet their financial needs, this is not the only thing they do. In contrast to traditional moneylenders, VCs actively get involved in companies' operations and decision-making processes. Start-ups or new technology-based companies often lack resources (Weiblen & Chesbrough, 2015), and venture capitals can play an important role in bridging this gap by providing the business development skills, knowledge and understanding necessary to ensure the growth of the companies. Readily available capital for investment, prior experience of working with companies, and networks of partners and collaborators make VC a sought after choice for partnership. A number of studies have highlighted the value-added contribution of VC and the role it has played in companies' successes. Research conducted by Large and Muegge (2008) reported that VC has assisted companies in recruitment, strategy formulation, consultation, improving operations, providing mentoring, increasing legitimation and facilitating outreach. Similarly, research conducted by Lahr and Mina (2016) highlighted VC's contributions in the patenting process. Kaplan and Schoar (2005) and Macmillan, Kulow, and Khoylian (1989) affirm that VC mentor entrepreneurs, participate in the strategy planning process and use their experience and knowledge in ensuring a company's growth.

2.5 Theory of planned behaviour

The theory of planned behaviour (TPB) postulates that an individual's behaviour is driven by behavioural intentions. If intentions are non-existent, a behaviour will not be formed. The TPB presented by Ajzen (1985) is an extension of the theory of reasoned action (TRA) developed by Fishbein and Ajzen (1975). Ajzen's TPB suggests that behaviour is determined by individuals' behavioural intentions, whereby behavioural intentions are a function of an individual's attitude towards a behaviour, a subjective norm and perceived behavioural control. Here, attitude is referred to as an individual's positive or negative feeling towards performing a behaviour. A subjective norm is how individuals perceive that people around them will see them performing that behaviour. Perceived behavioural control refers to an individual's perception of how easy or difficult it would be to perform the behaviour of interest (Ajzen, 1991). For instance, in the case of RETs, an individual's decision to use an RET would be influenced by his/her intentions, with intentions formed as the result of a number of factors. Firstly, decisions are influenced by an individual's positive of negative feelings towards RETs. If individuals value the environmentally friendly offering of an RET and favour renewable sources over conventional sources, this could be an indication that they hold a positive attitude towards RETs. Secondly, decisions are influenced by individuals perception of how their decision to use RET would be perceived by peers and others around them. If taken positively, it should have a positive influence on an individual's intentions. Thirdly, decisions are swayed by how easy or difficult it is for an individual to be in control – i.e., to understand the complexities involved in the application and use of an RET.

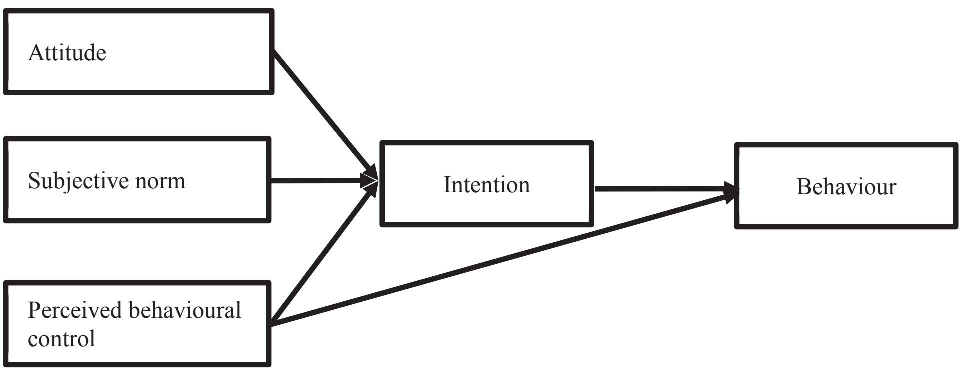

Figure 3. The theory of planned behaviour

The theory of planned behaviour has been successfully applied in a wide range of disciplines, such as healthcare, e-commerce, consumer studies and organisational studies. A number of scholars, such as Baker and White (2010), Chen and Tung (2014), Donald, Cooper, and Conchie (2014), Han and Kim (2010), and Pavlou and Chai (2002) have extended the actual TPB framework by integrating additional factors that could have an effect on framing an individual's intention to perform a behaviour. Adoption of an RET becomes complicated due to the high cost of the technology, the relatively longer payback time, and the technical and societal challenges associated with these technologies. Considering these challenges, this study has integrated three additional factors into the framework: environmental concern, cost and awareness. Environmental concern deals with the extent to which an individual is aware of environmental-related issues, cost is the total price for an individual to purchase an RET, and awareness refers to the degree to which an individual is aware of the renewable energy technology and the benefits that its use entails. Inclusion of these additional factors takes into consideration the complexity and challenges associated with RETs.

3 METHODOLOGY

The chapter presents a detailed account of the philosophical paradigm, research design and strategies, data collection and analysis, and validity and reliability issues.

3.1 Philosophical paradigm

The relationship between data and theory has been the subject of debate among philosophers for centuries (Easterby-Smith, Thorpe, & Jackson, 2008). The core of this debates lies in researchers' view of what is reality and how the truth can be discovered – referred to as the researchers' worldview or philosophical paradigm (Guba & Lincoln, 1994; Tashakkori & Charles, 1998). According to Easterby-Smith et al. (2008), understanding the philosophical issues helps researchers decide which research design should be incorporated to address the problem at hand. The chosen research design influences how evidence shall be gathered, interpreted and used to answer research questions (Marczyk, DeMatteo, & Festinger, 2005). Cohen, Manion, and Morrison (2011) explain the research paradigm as a set of common beliefs and frameworks that guide the researcher throughout the process of scientific inquiry. Saunders, Lewis, and Thornhill (2009) argue that the choice of research design is not framed in isolation but emanates from researchers' views, beliefs and assumptions, based on which their philosophical worldview is built on. Easterby-Smith, Thorpe, and Lowe (1991) maintain that researchers' views and philosophical orientation help them to choose which design is most suited and to decide whether it should it be adopted as it is or be altered to suit research objectives. Guba and Lincoln (1994) state that the philosophical worldview frames researchers' orientation, which is then reflected in their choice of methods, tools and techniques.

The existing literature has discussed different research paradigms (Creswell, 2014; Johnson & Onwuegbuzie, 2007; Rossman & Rallis, 2011). Easterby-Smith et al. (2008) argue that distinct philosophical paradigms emanates from the interplay between, or an extension of, two main contrasting worldviews that philosophers have adhered to for decades: positivism and social constructionism. Positivism stands on the belief that reality exists externally and its properties should be measured through objective methods. The origin of positivism is often linked to the French philosopher Auguste Comte, who argued that a subject cannot meet the qualification of real knowledge unless the evidence is based on observable facts (Comte, 1853). Positivism is often linked to the natural sciences, whereby the emphasis is on investigating the truth based on the observable facts. The application of a positivistic worldview in the social sciences is often associated with the application of quantitative methods. The underlying assumption in such cases is based on the following factors: (a) the researcher is independent from the research process, (b) knowledge is based on determinism or cause-and-effect thinking, (c) principles of reductionism are observed, and (d) variables are measured and theories are tested (Carson, Gilmore, Perry, & Gronhaug, 2001; Creswell, 2003; Easterby-Smith et al., 2008)

At the other end of the spectrum, in contrast to the philosophical worldviews of positivism, lies social constructionism (Kukla, 2000). Easterby-Smith et al. (2008) state that social constructionism is a relatively new paradigm, derived in reaction to the application of positivism in the social sciences. The assumptions of social constructionism are grounded in the view that reality is not objective and exterior, but is socially constructed and given meaning by people. Therefore, the role of the researcher is not just to gather facts and report, as proposed by the positivists, but to get involved in the process, focus on what and how people are thinking and behaving, and try to make sense of these interactions.

The above-presented paradigms are rather pure, presenting worldviews of those who sees the world through either the lens of positivism or constructionism. Considering the strengths and weaknesses of each paradigm and the possibility of complementing research designs – originating under one paradigm but being employed under the other – has inspired debate regarding the possibility of incorporating both views to address a problem. Building on this, Dewey (1916) emphasised the need to balance between the abstract and the concrete (positivistic) and reflections and observations (constructionist), supporting the incorporation of a pragmatic approach in the research. Pragmatism can be ascribed to pluralistic views, grounded in the notion of adopting what works in the specific situation (Creswell & Plano Clark, 2007). In the social sciences, pragmatism is often linked to the use of a mixed methods approach (Biesta, 2010). Ivankova (2014) states that, based on its flexibility, availability of diverse research designs, and the opportunity to incorporate multiple methods of inquiry, pragmatism has been widely adopted in modern research. Morgan (2007) describes how pragmatic researchers take advantage of the flexibility to choose from different methods, techniques and approaches for the collection and interpretation of evidence with an aim to attain better understanding of the studied domain.

In addition to the above-mentioned paradigms, scholars have discussed different philosophical worldviews, each having its own characteristics. For instance, Creswell (2003) outlined four philosophical worldviews: post-positivism, constructivism, advocacy and participatory, and pragmatism. Guba and Lincoln (1994) framed the philosophical views as positivism, post-positivism, critical theory and pragmatism, later delineating them into five paradigms: positivism, post-positivism, critical theories, constructivism, and participatory (Guba & Lincoln, 2005).

Denscombe (2008) and Scotland (2012) state that adherence to a philosophical paradigm influences researchers' ontological and epistemological assumptions. Ontology deals with the ideas and understanding of the social world, leading to the relationship between people and society (Eriksson & Kovalainen, 2008), while epistemology considers what knowledge is, how it can be advanced, and what the sources and limits of knowledge are (Creswell & Plano Clark, 2011). Easterby-Smith et al. (2008) explain ontology as a researcher's philosophical assumptions about the nature of reality, while epistemology is concerned with a general set of assumptions about the best way of inquiring into the nature of the world. This dissertation follows the pragmatism paradigm, based on the researcher's worldview supporting the assertions that obtaining a balance between subjectivity and objectivity can help us better understand a phenomenon and investigate the research problem.

3.2 Research design and strategies

Researchers' philosophical worldviews influence the research design and strategies used to conduct scientific inquiries (Proctor, 2013). Commercialization of renewable energy technologies is a complex and multifarious phenomenon. This dissertation seeks to investigate the role of socio-economic, technical and regulatory factors influencing the commercialization of RETs. In order to encapsulate the complexity, it is of immense importance to adopt a research design that supports investigation of the phenomenon and ensures that the stated objectives are met. Bordens and Abbott (2002) define research design as a plan that guides researchers in data collection, analysis and interpretations. Creswell and Plano Clark (2007) emphasise the importance of incorporating rigorous research designs, as this assists scientists in setting the premises on which the methods, analysis and interpretation will be based. Frankfort-Nachmias and Nachmias (1992) explain that research design establishes generalisability and guides investigators regarding the extent to which the results can be generalised to different populations and contexts.

Based on the researcher's pragmatic worldview, this dissertation has benefited from research designs adopted by positivists and social constructionists, qualifying this as a mixed methods research. Qualitative designs (associated with social constructionism) primarily emphasise exploring a phenomenon to gain a deeper understanding and produce new knowledge that helps address the problem and leads to the development of new theories (Kothari, 2004). Mason (1996) argues that qualitative designs help in understanding the complexity of a phenomenon in detail and drawing a holistic picture of how the social world is formed, understood or interpreted. In contrast, quantitative designs (associated with positivism) attempt to establish a relationship between constructs, focusing on testing established theories and frameworks (Denzin & Lincoln, 2005). Babbie (2010) states that a quantitative design enables researchers to integrate statistical data and analytical tools. Incorporation of quantitative and qualitative approaches strengthens this dissertation by complementing subjectivity and objectivity, and facts and values, and providing an opportunity to gain concise and in-depth revelations to ascertain a rich understanding of the subject matter. Moreover, following the affirmations by Ochieng (2009) and Bryman (2008) that both qualitative and quantitative approaches have limitations, a mixed methods approach has been employed to allow the quantitative and qualitative designs to complement each other, enabling the researcher to incorporate novel tools and techniques to investigate the phenomenon (Bryman, 2006; Jick, 1979). Guba and Lincoln (2005) argue that combining the quantitative and qualitative approaches helps ensure that research questions are answered.

This article-based dissertation contains five scientific articles studying commercialization of RETs in Finland and Pakistan. Articles 1 and 2 focus on exploring the commercialization environment by investigating socio-economic, regulatory and technical landscape. The objective of these papers (to gain an in-depth understanding of the factors influencing the commercialization of RETs in the studied contexts), the exploratory nature of the research and the objective of studying the phenomenon in a natural setting suit qualitative research approaches, as suggested by Miles and Huberman (1994). Article 4 of this study seeks to explore the role of venture capital's value-added contributions in a portfolio companies development processes and the commercialization of RETs. This article has also incorporated a qualitative research design. Following inductive reasoning, often referred to as a bottom-up approach, this study seeks to gain new insights by exploring VC's contribution to a portfolio company's development and the commercialization of RET. The qualitative studies – articles 1, 2 and 4 – have adopted a case study approach. According to Eisenhardt and Graebner (2007) and Yin (2014), a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-world context. Hancock and Algozzine (2016) argue that a case study is a fairly flexible design and can be incorporated in different settings whenever there is a rationale. George and Bennett (2005) and Yin (2014) explain that a case study may be the preferred choice if: (i) the studied phenomenon offers insights from a critical case, which might lead to new revelations of theory development, (ii) it offers a unique or extreme case, often in studies of medicine where the effect of a particular drug on patients is checked, or (iii) it is a revelatory case offering novel insights that have remained hidden in the past. Eisenhardt (1989) suggests that a case study methodology can be applied in various contexts, having multiple units of analysis, and can rely on diverse means for data collection and analysis. Following the definitions provided by Yin (1984, 2014), articles 1 and 2 have employed a single case study design. The objective of these articles – to explore the market, regulatory and technical factors influencing the commercialization process – requires the unit of analysis to comprise different actors and stakeholders involved in the process. In contrast, article 4 has employed a multiple case study design. The objective of this paper – to explore venture capital's value-added contribution in the development process and commercialization of RETs – requires study of VC's input in multiple firms to understand the similarities and differences between the cases (Baxter & Jack, 2008; Stake, 1995) and to ensure the gained insights are valid and reliable (Eisenhardt & Graebner, 2007).

Article 3 of this dissertation seeks to examine the role of personal and institutional factors in influencing academics' tendency to engage in commercialization of academic research. The literature has highlighted a number of personal and institutional factors affecting academics' propensity to engage in university–industry collaboration and commercialization activities. Using the deductive approach, associated with quantitative designs (Hyde, 2000), this study develops hypotheses to test relationships between variables. Article 5 appended in this dissertation examines the factors influencing adoption behaviours. Following the deductive inference, often referred to as a top-down approach, this study applies an extended model of the theory of planned behaviour to examine the effects of studied factors on the adoption of RETs (see Figure 4).

Philosophical worldview	Pragmatism (reality can be better understood by adopting a pluralistic approach; having a right balance between the abstract & concrete, and reflections & observations)				
Ontology (assumptions about the nature of reality)	Singular and multiple realities (e.g., testing hypotheses and providing multiple perspectives)				
Epistemology (assumptions about the best ways to inquire into the nature of the world)	Knowledge can be derived by integrating objective and subjective point of views– i.e., anything leading to a pragmatic solution is useful. Practical and problem focused (adopting what works in the actual situation)				
Methodological choice	Mixed methods				
Notation	Qualitative + Quantitative				
Articles	1	2	3	4	5
Reasoning	Inductive	Inductive	Deductive	Inductive	Deductive
Approach	Qualitative	Qualitative	Quantitative	Qualitative	Quantitative
Research Design	Case study (single)	Case study (single)	Survey	Case study (Multiple)	Survey
Data collection	Semi-structured interviews	Semi-structured interviews	Web survey	Semi-structured interviews	Survey questionnaire
Data analysis	Within-case analysis	Within-case analysis	Binomial logistic regression	Within- and cross-case analysis	Structural equation modelling

Figure 4. Overview of the philosophical worldview, methods, research design and strategies incorporated in the dissertation

3.3 Data collection and analysis

The use of a mixed methods design, incorporating induction and deduction, has provided an opportunity to use qualitative and quantitative data to gain a deeper understanding of the commercialization of RETs in the studied contexts. Article 1 of this dissertation has utilised both primary and secondary data sources. The primary data was collected in the form of semi-structured interviews with the participants. In total, sixteen interviews were conducted with participants from companies operating in RETs, private financiers, regulatory bodies, government agencies, utility companies, customers, experts from academia, research institutes and regional development bodies. Published literature, policy frameworks, official reports and industry analysis were used as the secondary data. Data triangulation technique was employed to ensure accuracy and obtain a balanced view, as suggested by Altricher, Feldman, Posch, and Somekh (2008). Based on the collected data, a number of factors affecting the commercialization of RETs were identified. Following the assertions of Anderson (2010) and Merriam and Grenier (2019), relevant excerpts were included to provide a deeper understanding, demonstrate the assessment and quality, and to establish links between the data, analysis and devised performance indexes. Article 2 has also benefited from primary and secondary data collection. Exploring the effect of energy policies in the development of the energy sector, this study collected primary data in the form of semi-structured interviews. In total, eight interviews were conducted with participants from relevant government bodies, RET importers, experts from the industry and NGOs working on energy and sustainability issues. The secondary data was collected from published literature, official reports and policy frameworks introduced over the years. National and international databases were used to collect statistical data to analyse the development and industry forecasts.

Article 3 of this dissertation is based on quantitative data collected from researchers working in Finnish universities, polytechnics, research institutes and industry. The data collection was done by ETLA – the Research Institute of the Finnish Economy – for the project Smart Work in Platform Economy (SWiPE). The data collection was conducted during April 2017 through a web-based survey. In total, 13,746 questionnaires were distributed. The questionnaire requested information about researcher's background, education, expertise, field of study, funding sources, motivation and challenges faced in collaboration and commercialization activities, and the role of technology transfer offices. A total of 4,735 completed questionnaires were received, corresponding to a response rate of 34.4%. Considering the objective of this paper – to study the effect of personal and institutional factors in the commercialization of academic research – the data set has been limited to researchers affiliated with universities, leaving a final sub-sample of 891 respondents. Binomial logistic regression was performed using the Statistical Package for Social Sciences (SPSS) to examine the relationship between the studied variables.

Article 4 of this dissertation is based on the inductive approach (Easterby-Smith et al., 2008) and follows qualitative data collection methods. The qualitative data was collected in the form of semi-structured interviews with participants from portfolio companies and venture capitals. In total, six interviews were conducted – four with participants from the case companies and two with the participants from the VCs– to gain a broader perspective. The secondary data included companies' websites, press releases, industry analysis, reports and information published on VCs' websites. Data triangulation was adopted to ensure accuracy and reliability and to obtain a detailed understanding of the situation. A within-case and cross-case analysis approach was adopted to analyse the cases. This approach has helped us in gaining a comprehensive understanding of each case and provided an opportunity to identify similarities and differences by comparing cases. Relevant excerpts are also added in the analysis to establish links and present a deeper understanding of the context (Labuschagne, 2003; Patton, 2005). Article 5 of this dissertation has employed the deductive approach. Using a survey questionnaire, the quantitative data was collected during the summer of 2017 from the twin cities of Rawalpindi and Islamabad. A total of 244 questionnaires were completed by the respondents. SPSS was used to analyse the demographic data, while structural equation modelling (SEM) was performed using SmartPLS 3.0.

3.4 Validity and reliability issues

Validity and reliability issues should be addressed to ensure the quality of the process through which research has been conducted and findings are obtained. Creswell and Plano Clark (2007) and Johnson and Onwuegbuzie (2007) suggest that addressing validity and reliability issues is essential in determining the extent to which research findings are reliable and replicable. The literature suggests different standards for assessing validity and reliability for qualitative and quantitative research. Since this dissertation is an article-based study, employing both qualitative and quantitative methods, each article was assessed to ensure that it satisfied suggested quality criteria.

3.4.1 Quantitative Research

Singleton and Straits (2009) defines validity as the ability to accurately measure concepts employed in research. According to Nunnally (1978), validity refers to the extent to which adopted measurements measure what they are intended to measure. Balnaves and Caputi (2001) argue that valid research should be able to establish that measures incorporated to examine the studied phenomenon are capable of gauging its effects. Validity of a study can be tested by assessing construct validity, internal validity and external validity (Heale & Twycross, 2015; Leviton, 2015; Reichardt, 2015). Construct validity concerns the operationalization of selected measures in understanding the theoretical concept under examination (Bagozzi, Yi, & Phillips, 1991; Nunnally, 1978). Construct validity can be ensured by measuring convergent and discriminant validity (Huck, 2007). Convergent validity measures if the constructs that are expected to be related are in fact related (Straub, 2006), while discriminant validity tests whether constructs that are intended to be not associated are, in fact, not associated (Messick, 1995). External validity concerns whether the findings of the study are generalizable (Dellinger & Leech, 2007; Modell, 2005), whereas internal validity measures the extent to which the findings support a claim about a cause-and-effect relationship (Reichardt, 2015). Reliability is concerned with consistency, stability and repeatability of the measures and obtained results (Selltiz, Wrightsman, & Cook, 1976). Roberts, Priest, and Traynor (2006) explain that reliability is concerned with the extent to which an instrument measures in the same way under similar conditions.

Articles 3 and 5 appended in this dissertation ensure that it meet validity and reliability requirements. Article 3 performed an independent sample t-test to measure the issue of non-response bias by comparing the results of early respondents with those of late respondents. The lack of a significant difference between the groups signifies that non-response bias was not an issue. Harman's single-factor test was applied to assess the extent to which the data is influenced by the issue of common-method bias. The constructs adopted to measure variables are based on established indices, as suggested by Adcock and Collier (2001). Moreover, the higher value of Cronbach's alpha ensured the reliability of the obtained results (Bland & Altman, 1997). Similarly, in article 5, the measures used to study the variables were adopted from previous studies. The item loadings and average variance extracted (AVE) were checked to assess convergent validity and composite reliability (Fornell & Larcker, 1981). Moreover, R^2 was used to assess the shared variance (Cohen, 1988), while the lower values of VIF ensured that multicollinearity was not an issue (Field, 2009). Following Roldan and Sanchez-Franco (2012), bootstrapping was performed to measure the accuracy of the employed model.

3.4.2 Qualitative research

In qualitative research, reliability and validity issues often deal with assessing the trustworthiness of the process and the validity of the outcomes. Golafshani (2003) emphasises the need to employ different techniques to address the validity and reliability issues in qualitative research. Mays and Pope (1995) highlight the need to ensure that the research findings are reliable. Patton (2001) argues that a qualitative researcher should be concerned with how the study is designed and the research process is conducted. Lincoln and Guba (1985) argue that validity and reliability issues in qualitative research should be assessed through credibility, transferability, dependability and confirmability. Credibility and transferability in qualitative studies are an alternative to internal validity and external validity issues in quantitative research. Credibility or internal validity in a qualitative study are concerned with the extent to which research findings truly reflect reality (Denzin, 1970; Shenton, 2004), whereas transferability or external validity assess the degree to which the findings are applicable across groups (Brink, 1993). Similarly, reliability issues in quantitative research are replaced by dependability and conformity in qualitative studies (Long & Johnson, 2000). Cohen et al. (2011) affirm that dependability can be enhanced by presenting a detailed account of the process. Shenton (2004) maintains that researchers should report the methods clearly and provide details of strategies adopted in the study for case selection, data collection and attaining results. Whereas, conformability deals with objectivity and accuracy. Qualitative research should be able to demonstrate that the obtained findings are based on the experiences and inputs of the respondents and have been reported in a desired manner – free from personal preferences or biases (Patnaik, 2014).

Articles 1, 2 and 4 of this dissertation are based on a qualitative design. A detailed description is provided, within the articles, elaborating the research design and data collection approaches. Detailed contextual information is presented to understand the context and to assess the degree to which the findings of the study are generalizable and in which contexts. Moreover, analysis and discussion sections were supplemented with the excerpts from the collected data to establish links, provide deeper understanding and enhance confirmability of the research.

Table 2. An overview of the research design, data collection and analysis techniques employed in the articles

Article	Research design	Data collection and analysis
Article 1	Qualitative (Case study)	Primary data: sixteen semi-structured interviews from technology companies, financing organisations, governmental bodies, utility companies, and experts from academia and industry Secondary data: published literature, industry reviews, and official reports Data triangulation Within-case analysis
Article 2	Qualitative (Case study)	Primary data: eight semi-structured interviews from government officials, regulatory bodies, experts from the industry Secondary data: published literature, official reports, policy frameworks, and statistics provided by various national and international agencies Within-case analysis
Article 3	Quantitative (Web Survey)	Primary data: web-based survey; 4,735 complete questionnaires; sub-sample of 891 respondents Binomial logistic regression using SPSS
Article 4	Qualitative (multiple case study)	Primary data: six semi-structured interviews from RET companies and venture capital firms Secondary data: companies' and VC firms' websites, press releases, industry analysis and reports, statistics arranged by Statistics Finland and FVCA Data triangulation Within–case and cross-case analysis
Article 5	Quantitative (survey questionnaire)	Primary data: Survey questionnaire from 244 respondents Structural equation modelling (SEM) using SmartPLS

4 SUMMARY OF THE ARTICLES

This dissertation contains five scientific articles studying commercialization of renewable energy technologies. This chapter presents a brief overview of the papers and highlights key findings.

4.1 The effect of socio-economic, technical and regulatory factors on the commercialization of RETs

The first article, "Commercialization of renewable energy technologies: A ladder building approach", investigates how renewable energy technologies can be effectively commercialized in Finland. The study seeks to address this question by exploring socio-economic, technical and regulatory factors influencing the commercialization of RETs. A number of studies have sought to address commercialization by exploring different aspects such as the effect of public policies and the impact of financing, technology development, business models and support schemes. However, very few studies have focused on the commercialization environment as a whole, and very rarely from Finland's perspective. This study aims to bridge this gap by identifying the drivers and barriers influencing the commercialization of RETs, and it presents a framework to address these issues.

The objective of this study, the exploratory nature of this research and the aim to study the phenomenon in a natural setting requires that the research employs an in-depth qualitative case study as an approach (Eisenhardt & Graebner, 2007; Yin, 1984). Since this study attempts to encapsulate the effect of regulatory, market and technology related factors, it was necessary to incorporate the input of multiple actors and stakeholders involved in the process. This study incorporates both primary and secondary sources of data. The primary data was collected in the form of semi-structured interviews from: energy technologies companies operating in Finland, firms involved in financing, regulatory bodies, governmental agencies, associations, utility companies, consumers, and experts from academia and research institutes. The secondary data included published literature and industry analysis and reports. This research has incorporated data triangulation, as suggested by Denzin (1970), to ensure accuracy as well as to obtain an in-depth and comprehensive understanding of the phenomenon.

This study has highlighted a number of factors influencing the commercialization of RETs in Finland. The identified factors are categorised into firm-specific, market-centric and policy-related factors. The study underlines that the research and development facilities, technological knowhow and availability of basic infrastructure are the driving factors; however, the country needs to focus on improving coherence and collaboration between different stakeholders, availability of financing, support available for internationalisation, business-related training and supportive policies favouring renewable energy technologies.

The study suggests that the firm-specific issues can be addressed by encouraging collaboration between companies, providing necessary financing, and ensuring strong infrastructural support and assistance in internationalisation and exports. The market-centric issues can be addressed by developing clusters, establishing facility parks and incubation facilities, and increasing environmental awareness. The policy-related issues can be addressed by having a favourable policy regime in place that encourages the use of renewables. The long-term policy initiatives should be launched to reduce the legal bottlenecks and to encourage municipalities and governmental institutes to use renewable-based solutions.

4.2 The effect of energy policies

The second article, "Renewable energy sources in power generation in Pakistan", examines the state of energy affairs in Pakistan and investigates the effect of the energy policies that the country has adopted over the years on shaping the energy sector and integration of renewable energy in the country's energy mix. The study critically examines the country's resource potential and presents a roadmap for addressing issues in both the short and long term. This study is based on both primary and secondary data sources. The primary data is collected in the form of semi-structured interviews from government officials, regulatory bodies, and respondents working in energy sector in Pakistan, whereas the secondary data included published material, official reports, policy frameworks and statistics provided by various national and international agencies.

This article highlights that Pakistan, despite having huge resources and thus having excellent potential for energy generation, is experiencing an acute energy crisis. The stretching gap between the demand and supply requires that the country should undertake measures to address this issue. The abysmal energy crisis that has affected the country's economic growth and general quality of life can be attributed to a number of factors. The country's existing energy mix is heavily reliant on conventional fuels. Excessive utilization of imported hydrocarbons for energy generation causes concerns to the energy security and the threat of increased prices and emissions. The country's abundant renewable energy sources offer an excellent opportunity to move away from imported conventional sources, but the country has not been successful in ensuring this transition.

This article suggests that the country's current state has a lot to do with the energy policies it has adopted over the years. The earlier policies have unfairly favoured conventional sources of energy over sustainable and cheap sources. The prime purpose of most of the policy frameworks appears to address energy issues in the short run by establishing power generation facilities that could be brought on stream quickly, without considering the long-term effects on the country's energy mix, generation costs and emissions. The power policy of 2002 was the first policy framework to discuss the need to develop renewable energy sources, setting a target of generating 1500 MW by 2020. However, it failed to provide a plan to translate this vision into reality. In 2006, the country introduced its first ever renewable energy policy, focusing on the development of indigenous renewable energy sources such as solar, wind and small-scale hydro. Subsequent policies introduced in 2011 and 2013 reiterated the vision of increasing the contribution from renewables, eliminating inefficiencies and reducing prices. Several initiatives were launched to foster the application of RETs at the household and commercial levels, such as waiving import taxes on solar panels, as well as introducing subsidies, support schemes and purchase guarantees to accelerate the development of power generation facilities utilizing renewable energy sources. The article underlines that having resource potential alone does not guarantee its utilisation. Despite the massive resource potential, the need for uninterruptable, cheap and clean energy, generation from renewable sources would not pick up unless supportive policies, backed by actionable strategies, are set in place.

4.3 University–industry collaboration and commercialization of academic research

The third article, "The role of personal and institutional factors in influencing academics' tendency to engage in commercialization of academic research", studies the effect of personal and institutional factors in influencing academics' engagement in commercialization of academic research. University–industry collaboration and the application of academic research can play an important role in new technology development. Development of RETs, being disruptive and high-tech in nature, requires high levels of technical skill and state-of-the-art research and development capabilities to allow them to compete with existing solutions. Universities, being knowledge hubs and having the luxury of hosting some of the brightest and skilled minds, can play an important role in improving the competiveness of technologies by adding technological aspects, reducing costs and contributing to applicability. Cohen et al (2002) affirms that technologies those are in the early phases of development require innovative research and development capabilities and can benefit from collaboration and input. A study conducted by Powell, Koput, and Smith-Doerr (2006) and Rasiah and Chandran (2009) affirms the role of academic collaboration in advancing the biotechnology and automotive sectors. This study examines the extent of collaboration in the energy sector and proposes measurements for enhancing collaboration and commercialization.

Commercialization of academic research has become an important area of research. A number of scholars have studied the influence of personal and institutional factors on academics' engagement in commercialization activities. By integrating new constructs that have largely remained unaddressed in the past, this study adds to the existing body of knowledge by investigating the moderating effect of organizational support on an individual's propensity to engage in the commercialization of academic research. The personal factors considered in this study include individuals' intentions to commercialize, their experience, their excellence in research, and their entrepreneurial intentions. The institutional factors include time allocated to research, the effect of working in multidisciplinary teams and familiarity with technology transfer offices (TTOs). The study has tested the moderating effect of TTOs' support capacity on intentions to commercialize, entrepreneurial orientations and familiarity with TTOs. The effect of discipline is gauged using discipline dummies on biotechnology, nanotechnology, energy and environmental technologies, smart and digital technologies, and social innovations.

This article is based on the data collected from researchers working in Finnish universities, polytechnics, research institutes and industry. A web survey was conducted during April 2017. In total, 13,746 questionnaires were distributed. The survey yielded 4,735 complete questionnaires, corresponding to a response rate of 34.4%. Considering the objectives of this paper – to study the effect of personal and institutional factors on commercialization of academic research – a sub-sample of 891 respondents were selected based on their affiliations with universities. A number of tests were then performed to ensure the reliability of the collected data.

Findings of this study reveal that intentions to commercialize and entrepreneurial orientations are two of the strongest individual-level factors. Excellence in research does not have an effect, whereas prior experience does have a positive impact. Working in multidisciplinary teams and familiarity with TTOs have a positive impact, whereas time allocated to research does not influence commercialization of academic research. The result of testing the moderating effect of TTOs demonstrates that TTO services are yet to reach a level where interaction could enhance the positive impact and improve the likelihood of commercialization. This finding is striking in that, rather than facilitating the commercialization process, the interaction with TTOs actually neutralises its original impact, highlighting the need to improve TTOs' functionality. The result of the discipline dummy on energy and environmental technologies reveals that academics working in this sector are not active on the commercialization front.

4.4 Venture capital's value-added contribution towards RET companies

The fourth article, "Venture capital's value-added contributions in the development process and commercialization of renewable energy technologies", investigates how venture capital firms add value to RET companies and provide assistance in successfully commercializing their technologies. Ginn and Rubenstein (1986) highlight how new technology development involves complexities. The process becomes even more cumbersome for start-ups and small to medium-sized companies restrained by their limited financial and human resources. Venture capital can play an important role in bridging this gap by providing required financing as well as making valuable contributions in the development process. Research conducted by Sapienza et al. (1996), Hsu, Shen, Yuan, and Chou (2015) and Lahr and Mina (2016) highlighted a number of contributions made by VCs that has enabled companies to successfully commercialize their technologies.

Wustenhagen and Teppo (2006) state that the extent of venture capital's involvement and the value-added contribution towards its portfolio companies varies in different contexts and industries. The objective of this study is to explore venture capital's non-financial value-added contribution to renewable energy technology companies in Finland. The objectives and the aim to study the phenomenon in a natural setting and gain a deeper understanding make it ideal for employing a case study design. A purposive sampling technique was adopted to identify cases for the study. The technique is useful when a researcher is particularly interested in identifying and selecting information-rich cases related to the particular phenomenon of interest (Polkinghorne, 2005; Ritchie, Lewis, McNaughton, & Nicholls, 2013). Four case companies were selected for this study. Baxter and Jack (2008), Eisenhardt and Graebner (2007), and Stake (1995) affirm that the integration of multiple firms to understand the similarities and differences between the cases, qualifies this as a multiple case study. Primary data was collected in the form of semi-structured interviews from case companies and venture capital firms. In total, six interviews were conducted – four with respondents from case companies, and two with those from venture capital firms. Data triangulation was adopted to ensure accuracy, reliability and obtaining a detailed understanding (Denzin, 1970; Wilson, 2016). The sources utilised to supplement the primary data includes companies' websites, press releases, industry analysis and reports, statistics arranged by Statistics Finland, the Finnish Venture Capital Association, and information published on venture capitals' websites. This approach has enabled us to gain an in-depth understanding of the process. A within-case and cross-case analysis approach was adopted to analyse the cases.

The results suggest that VC assisted companies primarily in setting strategic orientation and gaining access to external resources, but only moderate contributions were observed in providing companies an opportunity to collaborate with portfolio companies, access to market knowledge, team building and improving company's image. Weak support was found in internationalization and finding additional finances, while VC did not contribute on the technology development front. The study also highlights the importance of having clear and open communication between the venture capital and portfolio companies. By partnering with a VC, portfolio companies may very easily come under the impression that additional financing, internationalisation and collaboration-related aspects will be taken care of. However, the results reveal that it is important to explicitly discuss roles, responsibilities and duties of each party.

4.5 Factors influencing the adoption and establishment of RETs' market

The article titled "Towards the establishment of a renewable energy technologies market: An assessment of public acceptance and use in Pakistan" examines the factors influencing consumers' intentions to use renewable energy technologies in Pakistan. This article builds on the assertion that successful commercialization of renewable energy technologies is influenced by a number of factors such as a company's strategy, regulatory support and availability of infrastructure. A single company is rarely capable of being proficient on all fronts (Story, O'Malley, & Hart, 2011). Therefore, success often depends on coherence and cooperation among different actors and stakeholders. Actors surrounding the companies can impart knowledge and provide support necessary in the process of commercialization. Consumers, being the end users and the ones paying for the technologies, are an important part of the puzzle. Therefore, it becomes pivotal to understand the factors influencing their adoption behaviours, which can consequently contribute to a technology's success in the market.

This research is based on quantitative data collected from 244 households in the twin cities of Islamabad and Rawalpindi in Pakistan using survey questionnaires. Based on an extensive literature review, this paper has extended the actual framework of the theory of planned behaviour by integrating contextual factors. The theory of planned behaviour (TPB) emphasises that an individual's behaviour is driven by behavioural intentions, which is a function of an individual's attitude towards a behaviour, subjective norm and perceived behavioural control (Ajzen, 1985, 1991; Ajzen & Driver, 1992). TPB has been widely used in different streams and realms of research. To encapsulate the complexity involved with renewable energy technologies, we have extended the TPB framework by adding environmental concerns, cost, and awareness. The analysis was done using structural equation modelling. The results of the analysis reveal that perceived behavioural control, subjective norm and attitude positively influence consumers' intentions to use RETs, whereas environmental concern and awareness have no impact. Whereas, the high cost of technology is found to have a negative effect.

The study highlights important aspects that could have implications for RETs adoption and establishment of RETs' market in Pakistan. The study suggests that there is a need to adopt an integrated approach, and a coherent effort should be made by stakeholders at various levels of society to raise the level of environmental awareness. The focal point of policies and initiatives should be on increasing awareness about the environment, reducing emissions and highlighting sustainability-related issues. Companies need to look beyond the traditional models of sale-purchase to minimise the effect of the high cost of technology. Furthermore, there is a need to adopt new business models focused on offering technology at low upfront costs.

Table 3. Summary and key findings of the articles

Article	Title	Key Findings
Article 1	Commercialization of renewable energy technologies (RETs): A ladder building approach	Research and development facilities, technological knowhow and availability of basic infrastructure are driving factors; Improving coherence and collaboration between companies and stakeholders, increasing availability of financing, and ensuring strong infrastructural support, assistance in internationalization and exports, and supportive policies favouring environmentally friendly technologies can help in commercialization; Developing clusters, increasing showcasing opportunities, establishing facility parks and incubation facilities, and increasing environmental awareness can further foster development
Article 2	Renewable energy sources in power generation in Pakistan	Previous policies unfairly favoured conventional sources over renewables; Most of the measures taken were aimed at addressing the issues in the short run, without considering long-term effects; Inefficient utilisation of domestic resources is a cause for concern; Policy initiatives must be backed up by actionable strategies to help achieve the envisaged
Article 3	The role of personal and institutional factors in influencing academics' tendency to engage in commercialization of academic research	Academics' intentions and entrepreneurial orientations are the strongest individual-level factors; Prior experience has a positive effect, whereas excellence in research has no effect; Working in multidisciplinary teams has a positive effect, while no relationship was found between the time allocated to research and commercialization activities; Having TTOs in universities has a positive effect. However, the services offered by TTOs in Finnish universities are yet to reach a point where they can amplify the effect; Academics working in energy and environmental technologies are not active in commercialization
Article 4	Venture capital's value-added contribution in the development process and commercialization of renewable energy technologies	The strongest contribution was found in setting a company's strategic orientation and gaining access to external resources; Moderate contributions were observed in providing opportunities to collaborate with portfolio companies, providing market knowledge and building teams; Weak support was found in internationalisation and finding additional finances, while VC did not contribute on the technology development front; The study highlights the importance of having clear and open communication between VCs and portfolio companies
Article 5	Towards the establishment of a renewable energy technologies market: An assessment of public acceptance and use in Pakistan	Perceived behavioural control, subjective norms and attitudes positively influence consumers' intentions, whereas environmental concern and awareness have no impact. The high cost of technology is found to have a negative effect; There is a need to increase the level of environmental awareness to enhance adoption, and companies need to adopt business models that go beyond traditional sales–purchases frameworks

5 DISCUSSION AND IMPLICATIONS

This chapter briefly presents a discussion on results, theoretical contributions, practical implications, limitations of the study and avenues for future research.

5.1 Discussion

The aim of this doctoral dissertation is to investigate factors influencing the commercialization of renewable energy technologies. The main research question – 'What kind of socio-economic, regulatory and technical prerequisites are necessary for firms to successfully commercialize renewable energy technologies?' – is addressed in five scientific articles appended in this dissertation. RETs are believed to have the potential to address global energy needs in a sustainable and environmentally friendly manner. However, its contribution in the global energy supplies remains insignificant. This current low level of contribution is attributed to the challenges it faces in the commercialization process. This doctoral dissertation studies commercialization of RETs and seeks to investigate the factors influencing the process at the macro level.

Firstly, this dissertation seeks to explore the role of socio-economic, technical and regulatory factors in the development and deployment of RETs. The findings of this study suggest that the commercialization of RETs can be enhanced by providing assistance in addressing challenges concerning technology development, considering local market dynamics and introducing a policy regime that favours RETs. It is argued that the success of a technology depends upon the valuable offerings that distinguish it from its competitors (Maine & Garnsey, 2006). An RET can distinguish itself through price, efficiency or environmental offerings. Awerbuch (2000) argues that the success of an RET is linked to its ability to compete with the existing technologies on cost and functionality, as being environmental friendly alone may not suffice in the long run. Therefore, it is crucial for an RET company to ensure that it has the strong knowledge base, expertise and resources required to develop a new technology that can meet customers' needs. Development can be facilitated by providing the right level of infrastructural support for RET companies. Support in the form of facility parks, incubation facilities and professional organizations, whereby expert opinion is readily available, can help address the challenges related to technology and market development.

RETs differ from conventional competing technologies on many accounts. The disruptive nature of the industry and a long developmental cycle make RETs a less desired avenue for investment. Uncertainty and a longer period of time to realise returns on investments make private investors reluctant to invest in such technologies. Therefore, it is important to ensure that there is ample financing available from the state – in the form of grants, awards and related financial instruments – to address the financial needs of companies involved in research and development.

Market dynamics play an important role in the development of RETs' market. Finland is a technologically advanced country with a small local market. In order to be successful, RET companies have to look for international markets. A particular challenge associated with the renewable energy industry is that not all markets and regions are suitable for RETs. For instance, a company working on solar photovoltaics would need to explore places that receive higher levels of solar radiation; for wind turbine manufacturing companies, generation can be optimum and economically viable only if these are installed in corridors suitable for wind technologies; a technology generating energy from waves and tides may only be suitable in certain parts of the world where currents and tides are strong enough to generate power. Such markets may be located far from where an RET company is based. Therefore, companies often face a challenge of going international from a very early stage. Small to medium-sized companies, which are often the source of radical innovations, often struggle to explore markets on their own, as they lack necessary resources, knowledge and connections to explore an appropriate segment of the international market. Therefore, it is important to ensure that the appropriate forums are developed to facilitate the companies in exploring suitable markets. Moreover, it is equally important to develop clusters where innovative technologies can demonstrate their workability by running pilot projects. This will not only provide companies with an opportunity to test and improve their technologies, but also serves as a real-time showcase to demonstrate a technology's performance to international clients and market them. The findings of this dissertation also highlight the role of a regulatory regime in setting the overall trajectory of the industry. Many RETs cannot compete with conventional technologies based on economics alone. Existing regimes favour conventional technologies and make their use cheaper compared to renewables, leaving RETs in need of policy support until they can compete with hydrocarbons on price. Henceforth, the role of subsidies and support schemes becomes imperative in ensuring RETs' competitiveness. Effective implementation of support schemes helps countries in fostering the development of RETs (Chowdhury, Sumita, Islam, & Bedja, 2014; Nicolini & Tavoni, 2017).

The findings of this dissertation affirm the effect of policies in shaping an energy sector. Irrespective of the need, such as integrating renewables into the energy mix to address energy requirements or to address environmental issues, development tends to be hindered unless a supportive policy regime is set in place. In-depth study of Pakistan's case highlights that despite the immediate need to boost energy generation, and the abundant availability of indigenous sources, energy supplies have failed to keep up with demand due to the poor focus of energy policies introduced over the years. Making changes in the policy regime and introducing measures favouring renewable energy by providing subsidies and purchase guarantees, as well as adjusting taxation and duties, can foster the development of the RET sector in a country.

Secondly, this dissertation seeks to investigate how collaboration between universities and industry can be enhanced to facilitate the transfer of knowledge and the commercialization of academic research. The rise of industry 4.0, increased reliance on automation and digitalization, and integration of information technologies in the energy sector provide an opportunity for industry and education establishments to reconsider their interaction and facilitate the transfer of knowledge. Recent advancements in technologies suggest that technological progress is associated with scientific developments (Gambardella & McGahan, 2010). Therefore, the role of research conducted in educational establishments in advancing tacit knowledge through which technologies enter a commercial domain becomes central (Yusuf, 2008). Research conducted in universities can help companies in reducing cost, improving functionality and increasing competitiveness (Cohen et al., 2002; Lee, 2000). Evidence suggests that collaboration between universities and industry has helped companies to ensure technologies become commercially successful (Boccanfuso, 2016). Scholar such as Powell et al. (2006) and Sen, Hall, and Petryshyn (2011) have emphasised the effect of collaboration between academia and industry in the advancement of biotechnologies and improving commercial aspects. RETs can also benefit from collaboration between industry and academia. However, findings of this dissertation suggest that existing collaboration between industry and academics working in universities needs to be strengthened to have desired results. Interaction between university researchers and industry can be influenced by personal and institutional factors. It is therefore important to understand the role of these factors in influencing academics' tendency to engage in collaboration and commercialization. The results of this study indicate that individuals' intentions, entrepreneurial orientation and prior experience are important personal-level factors influencing their tendency to engage in commercialization activities. Likewise, working in multidisciplinary teams and having a technology transfer office available in a university are found to have a positive effect. The findings of this study highlight an immediate need to revamp the functionality of the technology transfer offices in Finnish universities. The results suggest that the services offered by technology transfer offices must be developed further in order to foster commercialization activities. The results also highlight that academics working in energy and environmental technologies are not active on the commercialization front.

Thirdly, this dissertation explores venture capital's value-added contribution in assisting RET companies' development processes and ensuring successful commercialization. New technology development is known to be a resource-intensive process (Robert & Kleinschmidt, 2007). It becomes even more challenging for companies that are small in size and lack resources (Nicholas, Ledwith, & Perks, 2011). Venture capital is known to help companies in meeting their financial needs as well as improving overall business performance (Samila & Sorenson, 2010). VC's potential contribution towards portfolio companies includes technology development, team-building, facilitating collaboration, assistance in internationalisation, helping in acquiring additional financing, sharing resources, providing market knowledge, assistance in setting company's strategic orientation and improving the legitimacy of a company. The results suggest that VCs did not contribute to technology development front. This could be attributed to the fact that RETs are very specialised, and only people having specialised skills or working with the technology are able to contribute on the technology development front. VCs' strongest contribution was reported in setting portfolio companies' strategic orientation. The core teams of the studied portfolio companies comprised of technical experts. Therefore, the understanding required to keep business operations running in an optimum manner – taking care of operations, marketing and management-related issues – often seemed lacking. VCs can help companies in addressing this gap by providing expert opinion and forming a strategic focus. Likewise, VCs make a valuable contribution to portfolio companies by providing access to necessary resources and services. VCs work with a portfolio of companies that are at a more or less similar level of development and have similar needs. Therefore, the resources acquired by one can also serve other companies' needs. For instance, hiring the services of a lawyer, consultant or similar services can be a time-consuming process, but VCs, having worked with a number of service-providing firms in the past, ensure that their portfolio companies can immediately find required resources without needing to go through extensive market research to find a suitable and reliable partner to work with.

VCs can offer an excellent opportunity to collaborate with other portfolio companies. This can help companies developing technology further, sharing experiences and learning from each other. The findings suggest that associating with a VC can also help in finding additional financing, building company image, finding partners and exploring international markets by using VCs' connections and experience.

Fourthly, this dissertation investigate the factors influencing RETs' adoption and playing a role in the establishment of RET markets. Energy, as a commodity, is very different to any other product or service. Conventional products such as mobile phones, televisions, computers, cars and many other products, contend with competitors by highlighting their value offerings. However, in the case of energy, the end product remains the same, irrespective of whether it was produced using finite emission-generating hydrocarbons or clean and sustainable renewable energy sources. Therefore, the success of RETs depends on how consumers perceive renewable energy, since they are the ones who have to make a final choice between conventional or environmentally friendly solutions. Therefore, the issues related to consumers' RET adoption becomes key in ensuring successful commercialization and attainment of a sustainable future. This dissertation suggests that consumers' attitudes towards renewable energy technologies, their ability to understand and deal with the technicalities, and their understanding of how their decisions will be perceived by their peers positively influence their intentions to adopt RETs. However, the high cost of technology is a barrier. Therefore, it is important for RET companies to adopt innovative approaches and look beyond the traditional model of sales–purchases. Providing a technology at lower upfront costs and setting up a power purchase agreement whereby customers are charged for the power generated by an RET can help address this issue. It is also important to raise awareness about RET-based solutions and highlight environmental issues. Currently, information on value offerings and the potential of these technologies do not seem to be sufficiently emphasised. If consumers are well advised and are made aware of the long-term social, economic and environmental benefits that RETs can offer, their adoption can be enhanced.

5.2 Theoretical contributions

This study contributes to the literature on commercialization of RETs by highlighting some of the challenges that RETs are facing, as well as presenting a framework to address these. The extant literature has focused on the commercialization of conventional technologies (Kang, Gwon, Kim, & Cho, 2013; Kim, Lee, Park, & Oh, 2011; Wonglimpiyarat, 2010), high-tech industry (Beard & Easingwood, 1996; Chiesa & Frattini, 2011; Easingwood & Koustelos, 2000) and disruptive innovations (Christensen, 2013; Day & Schoemaker, 2000; Wood & Brown, 1998). However, literature focusing on the commercialization of RETs has remained rather limited. This limited stream of literature has studied the phenomenon from the perspective of resources (Amigun et al., 2008), technology type (Staffan Jacobsson & Lauber, 2006), financing (Walters & Walsh, 2011), marketing (Costa, Fontes, & Heitor, 2004), demonstration (Harborne & Hendry, 2012), collaboration (Matti, Kirsi, Petri, & Tuomo, 2011) and business models (Richter, 2013). Very few studies have examined the commercialization environment as a whole (Balachandra et al., 2010; Harborne & Hendry, 2012).

This dissertation firstly seeks to address this gap by presenting empirical evidence from Finland and highlighting the role of socio-economic, technical and regulatory factors in commercialization of RETs. The findings of this study bring new insights and emphasise the need for market-orientated technology development, increased availability of infrastructure and the development of clusters for demonstration purposes. The study also supports previous research findings, stressing the need for supportive legal frameworks and collaboration in fostering development (Abdmouleh, Alammari, & Gastli, 2015; Eleftheriadis & Anagnostopoulou, 2015; S. Jacobsson & Johnson, 2000; Staffan Jacobsson & Lauber, 2006; Suzuki, 2015). This research adds to the extant literature by supporting the assertion that measures taken at the earlier stages of development do have an effect on commercialization. To this end, the literature on commercialization is divided regarding what entails the process of commercialization. Scholars such as Booz, Allen and Hamilton (1982), Koen et al. (2001) and O'Connor et al. (2008) consider commercialization to be the final phase of technology development, whereas researchers such as Jolly (1997) and Mitchell and Singh (1996) see commercialization as a process that goes from idea development all the way through to the product's launch, and subsequently sustaining it in the market. The findings of this dissertation support the latter. Secondly, this dissertation also highlights the importance of a regulatory framework and energy policies in the development of the energy sector. This dissertation extends the application of roadmaps by presenting a roadmap for the development of the energy sector.

Thirdly, this dissertation adds to the literature on university–industry collaboration and commercialization by examining the moderating effect of organizational support on an individual's propensity to engage in commercial exploitation by integrating new constructs – e.g., the impact of team structure, time allocation and the TTOs support capacity – that have largely remained unaddressed in the past. Moreover, this study contributes to the existing body of knowledge by investigating the effects of age, gender, excellence, impact of industrial financing, and experience. Existing studies conducted by Ambos et al. (2008), Audretsch (2000), Azagra-Caro (2007), D'Este and Patel (2007), Gulbrandsen and Smeby (2005), Powers and McDougall (2005) and van Rijnsoever et al. (2008) tested the effect of these factors and found mixed results. Additional testing of these important factors has offered an opportunity to explore the mechanisms and boundary conditions of these relationships to better understand the phenomenon. Moreover, the findings of this study support the previous research conducted by Ambos et al. (2008), Siegel, Waldman, and Link (2003), affirming that having a TTO in a university positively influences university–industry collaboration and commercialization.

Fourthly, this dissertation explores venture capital's value-added contributions in the commercialization of RETs. Small to medium-sized companies often struggle to meet their financial needs. Venture capital not only provide companies with the additional financing but also contributes to its overall performance by adding value on multiple fronts. A review of the literature reveals that the extent of VCs' involvement and the value-added contributions to its portfolio companies varies across contexts and industries (Wustenhagen & Teppo, 2006). The extant research has studied contributions in different industries such as high-tech (Bertoni, Colombo, & Grilli, 2011; Florida & Kenney, 1988; Maula, Autio, & Murray, 2005), information technology (Dushnitsky & Lavie, 2010; Hogan & Hutson, 2005), and healthcare (Rosiello & Parris, 2009; Silverstein & Osborne, 2017); however, the literature focusing on the role of VCs in the context of renewable energy technologies (RETs) is rather limited (Bjørgum and Sørheim, 2015). This limited research has explored contributions from either the perspective of portfolio companies or the VCs, but few have considered the viewpoint of both actors. This approach has helped us in developing our understanding of the contributions made by VCs. However, there has been an inherited limitation with such an approach: most of the findings reported are based on the perceived value addition from either the companies' or VCs' side. This study distinguishes itself by considering the perspectives of both VCs and the RET companies. The approach can help us explore the phenomenon in detail and enable us to highlight important factors that may have remained unaddressed. Building on this, this research contributes to the existing literature by studying the role of VC's value-added contributions in the case of RET companies in Finland and examines its effect on commercialization.

Finally, this dissertation highlights the role of consumers' technology adoption in the establishment of RET markets. Successful diffusion of a technology is heavily dependent on how it is perceived by customers. The literature suggests that consumers' decision-making processes can be influenced by a number of economic, social and psychological factors (Olshavsky & Granbois, 1979). This dissertation applies the theory of planned behaviour to examine the factors influencing the adoption of RETs. TPB has been widely used in different realms of research (Alam et al., 2014; George, 2004; Korcaj, Hahnel, & Spada, 2015; Kumar & Chandra, 2018; Lin & Syrgabayeva, 2016). Considering the complexities involved with RETs, we have extended the actual model by supplementing it with additional factors: environmental concern, cost, and awareness. This study contributes to the existing literature by applying the extended model and studying the factors influencing the adoption of renewable energy technologies and the establishment of RETs market.

5.3 Practical implications

This dissertation offers interesting insights for professionals in the renewable energy industry, as well as practitioners and policymakers working on facilitating the development of RETs. Firstly, this study affirms that the commercialization of RETs can be enhanced by having a supportive socio-economic landscape in place. There is a need to develop coherence among stakeholders to facilitate the development and growth of RETs. RET companies often needs to look beyond their borders in order to find customers and markets for their technologies. Internationalization becomes challenging for resource-starved companies to present their technologies to prospective customers and potential markets. It is therefore necessary to devise instruments that can effectively help companies to explore international markets. Similarly, there is a need to develop clusters. Considering the market dynamics – a bottleneck of the local Finnish market – it becomes important to support technology companies by providing them with a stage on which to demonstrate the functionality of the technologies. Clusters can increase collaboration among participating companies as well as serving as a real-time showcase for demonstrating to international clients.

The dissertation also highlights the need to have a supportive policy regime to encourage the development of RETs. The findings of this dissertation suggest that the desired level of renewable energy's integration in a country's primary energy mix can be ensured if policies are backed by measures that support renewable energy sources. This dissertation stresses the need to develop long-term plans and strategies to develop the energy sector. A number of policy reports have proclaimed ambitious scenarios whereby a country's energy mix can be fully based on renewables. However, more often than not, a clear strategy and a set of actions are lacking. This study shows that framing roadmaps can help in assessing a country's needs, setting milestones and suggesting how these objectives can be achieved.

This dissertation also presents guidelines on how collaboration between universities and industry can be enhanced to ensure that research conducted by academic institutions can help technology companies. Finland is among the highest-ranking countries on different innovation indexes. However, it lags behind when it comes to knowledge diffusion (Global Innovation Index, 2017). Despite having good research facilities in universities and contacts with industry, the country has struggled to ensure that commercial gains are generated from these interactions (Shakeel, Takala, & Zhu, 2017). The rise of the fourth industrial revolution, the integration of IT with contemporary technologies and the increased reliance on automation and digitalization require Finland to reconsider interaction between institutions and to facilitate the flow of information. Moreover, the education system in Finland is under constant pressure to change. Historically, being public-sector institutions, universities have been financed through public funding. However, the dynamics are changing and universities are required to generate additional revenue to ease the burden on public financing. Closer collaboration between academia and industry can help companies in developing technologies further while also generating revenue for universities. This study also suggests that Finnish universities should place emphasis on improving TTOs services. It is further advised that TTOs should not limit themselves to facilitating the transfer of knowledge, but also focus on creating awareness among young researchers and promoting an environment that is conducive to collaboration and commercialization.

Furthermore, forecasts suggest that an increasing number of future Ph.D. graduates in Finland will have to seek employment outside academia, highlighting the dire need to train young researchers to undertake this challenge by becoming ambidextrous and proficient in both academic research and its commercial application. The study also provides useful insights for companies interested in collaborating with academics by highlighting the personal and institutional factors that influence the propensity for collaboration. The study also suggests that the existing collaboration is less extensive than desired, and there is a need to develop closer cooperation between companies working with RETs and researchers in universities.

This study also provides guidelines for venture capitals and their portfolio companies regarding how they can maintain a better relationship and benefit from the interaction. The study sheds light on the valuable contributions that venture capitals can make by collaborating with companies operating in the renewable energy industry. The study proposes that the relationship can be beneficial if the VCs and portfolio companies maintain clear and open communication from the very beginning regarding what roles and responsibilities each of them has and how the business should be moved forward.

Moreover, this dissertation provides guidelines on how RETs' adoption can be enhanced. The study suggests that a coherent and integrated effort should be made by all stakeholders in society, including local government, entrepreneurs, civil society and NGOs, to raise awareness concerning environmental issues. Seminars, workshops and information-sharing sessions should be organised to disseminate information to the general public. Sustainability-related studies should be integrated into school and college curricula to encourage sustainable ways of living. RET companies need to think outside the box and adopt innovative business models that can lower upfront costs, with the remaining amount covered by offering power purchase agreements or similar initiatives. Companies are also advised to improve their customer service. Emphasis should be placed on offering post-purchase services in the form of warranties, repair and maintenance services at reduced prices, as well as periodic visits to installation sites to ensure the technology is functioning as desired. This step will enhance consumer trust and confidence in the technology. Similarly, companies need to highlight the long-term economic benefits, such as reductions in utility bills and additional savings gained by using RETs. Finally, by presenting evidence of socio-economic, technical and regulatory challenges of a developing country and a developed country, this dissertation presents guidelines to RET companies looking to explore markets in both developed and developing countries.

5.4 Limitations and suggestions for future research

This dissertation aims to explore factors influencing the commercialization of renewable energy technologies in Finland and Pakistan. The study brings important insights on the influence of socio-economic, regulatory and technical factors on the process of commercialization. The analysis presented in the dissertation is based on different RETs, but each renewable energy technology is different from the others in terms of potential, development cycle, level of adoption and the support it may need from the external environment. Therefore, it is probable that the findings and framework presented may not be applicable to all RETs. It is therefore advised that an in-depth study be conducted for different RETs in order to explore the factors that play a key role in their commercialization and diffusion.

Moreover, as the findings of this dissertation are based on cases from Finland and Pakistan, it is important to note that the resource potential, regulatory framework, business environment and market dynamics of these countries are different to others around the world. Therefore, it is advised that these results be generalised with caution. Further study should be conducted in each country’s context to understand how these forces influence and interplay in local contexts. Furthermore, this dissertation incorporated the effects of regulatory frameworks, collaboration between industry and educational establishments, the role of venture capital and the factors playing a role in the establishment of RETs' markets. Future research could study the effect of start-up programmes, incubation facilities, and facility parks in assisting technology development and commercialization of RETs.

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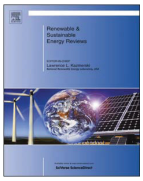

Commercialization of renewable energy technologies: A ladder building approach

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A B S T R A C T

The objective of this study is to investigate how different renewable energy technologies (RETs) can be effectively commercialized in Finland. The country, not being endowed with natural reserves of hydrocarbons, is striving to increase the share of renewable energy generation in its primary energy supplies. Finland has long been involved in the development and innovation of technologically advanced products and services. The recent economic meltdown and decline in the information and communication technology (ICT) sector have triggered the inevitability of developing a sector that can serve as the backbone of the economy in the years to come. Clean technologies offer an excellent opportunity for a technologically advanced country like Finland to become a key player in the emerging market. The country has excellent standing when it comes to innovation input, innovation culture and public R & D in clean technologies; however, it lags behind when it comes to the commercialization of these novel technologies.

This study aims to address the problem by investigating questions such as: What are the key factors that influence the commercialization of RETs in Finland? How do technological, regulatory and market-related factors affect the widespread adoption of RETs in Finland? The study also highlights the significance of support mechanisms and suggests the improvements required, at the micro-level (firms) and macro-level (policies, regulation and infrastructure), to develop a successful RET market in Finland. The findings of the study are presented against the backdrop of existing literature, energy policies, and the data collected from the energy experts in academia, technology firms, utility companies, investment firms, and regulatory bodies. The study has thus identified the factors that are central to the acceleration of RETs commercialization in Finland. Based on the findings, the study presents a comprehensive framework for the commercialization of RETs in Finland.

1. Introduction

Commercialization is considered to be the most important [1–3], and at the same time, least developed part of innovation management [4,5]. The literature is full of evidence indicating the significance of commercialization in the technology's success or failure [6–9]. The successful conversion of an idea into a product or technology is extremely challenging [10]. A staggering number of inventions have failed to become successful products due to a weak commercialization strategy [11,12]. A study conducted by Cierpicki et al. estimated the failure rate of commercialized products to be over one-third of all those introduced in the western economies [13]. Similarly, Stevens and Burley have demonstrated that out of a hundred small R & D projects, only one or two reach the market-launch stage and become successful [14].

Research, development and the introduction of new technology in the market are a costly business, consuming a significant proportion of a firm's resources. The process becomes even riskier if the technology in question is high-tech and the company has invested a significant amount of time and resources in the development process. Chakravorti [15], Chesbrough and Rosenbloom [16] have explained that the resources commitment and the stakes involved make the process pivotal for companies, as it is the stage where the product is launched into the market, exposed to the customers, and is expected to generate revenues. A product's penetration into the market and its success or failure is heavily dependent upon how efficiently the whole process has been carried out. Perez-Bustamante affirms that mastering commercialization is of utmost importance, as it is the last stage of the product innovation chain, through which an innovation is transformed into the final product and becomes a part of mainstream economic activity [17]. According to Aalam et al. commercialization guarantees that the product not only fulfils performance and reliability requirements, but also meets consumer demand and is available at reasonable prices [18]. It is further argued that the successful commercialization process can be a key

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for companies to maximize return on inventions, gain competitive advantage and explore opportunities for trade and market expansion [19].

A significant number of market failures are attributed to the lack of a strategically devised commercialization process, and its significance highlighted by the practitioners are no secret [20]. However, a number of companies, one way or another, tend to find themselves trapped in this phase. This leads us to ask if companies and executives underestimate the importance of commercialization during the technology development phase. The answer to this question in most cases will probably be in the negative. An online survey of over 2000 executives from around the world, working in a wide range of industries, regions, areas of expertise, tasks and responsibilities, found that a significant portion of the professionals considered the step crucial for a company's success and growth [21]. However, more often than not, companies leave a loophole in the process, which can then lead to the failure of the technology in the market. Acknowledging the importance of the process yet failing to deliver has raised researchers' interest in the topic and has prompted them to investigate the reasons behind such failures.

Commercialization, by its very nature, is a complex and multifaceted phenomenon, requiring extensive research and understanding of the business environment before it can yield the required results. Due to its overlapping nature and the interaction of various actors, players and stakeholders in the process, the phenomenon has been studied through the lens of economics, entrepreneurship, innovation, marketing, transition management, strategic management and international business. This multidisciplinary nature has encouraged researchers of diverse backgrounds to study the process from different perspectives, such as technology development, sociological aspects, socio-technical systems, marketing, consumer behaviour and finance.

Rogers [22] defines commercialization as the conversion of an idea to the product or services for sale in the marketplace. Siegel et al. [23] describe commercialization as the process of converting a new product, processes, and related know-how into a profit-generating venture. According to Aarikka-Stenroos and Lehtimaki [24], commercialization can be seen as the marketing of the innovation with the objective of converting it into a profit-making proposition. Balachandra et al. explain commercialization as a process of bringing technology from the laboratory to market acceptance and use. Furthermore, the notion is unfolded as the formation of a market that can sustain and thrive on its own, without backing and support, on a level playing field with competing technologies, thus helping technologies to avoid being trapped in the 'valley of death'[1] [25]. Cooper has introduced a seven-stage model, asserting that the process starts with the generation of the idea followed by preliminary assessment, concept and product development, trial production and lastly the commercialization phase where the product is launched in the market [1]. Vijay elaborates that commercialization is an arrangement between the key process (imaging, incubating, demonstrating, promoting and sustaining) necessary to develop and sustain the product in the market, combined with sub-processes, facilitating the transition by mobilizing essentials to ensure success at each phase [2].

Contrary to the belief that commercialization is an integrated aspect in each stage of new product development – from idea generation to the product launch and the subsequent sustaining of the market, scholars such as Koen et al. [26], O'Conner et al. [27], and Booz, Alan and Hamilton [28] have considered commercialization as the final stage of product development, predominantly dealing with measures such as marketing strategies and their implementation, introduction of the product to market and the launch of the technology. However, findings of recent research have highlighted that many decisions and activities seemingly performed in the earlier phases of the development process do have an impact on the overall commercialization and success of a technology [29], strengthening the argument that the process evolves simultaneously and commercialization and product development are interlinked [3,24]. In the light of the above-mentioned definitions, irrespective of the orientation towards the phenomenon-stage based approach or the process-driven approach, it is obvious that a scientific discovery or an invention does not become an innovation until it has been successfully commercialized [19,30], diffused [22,31] and sustained in the market [2].

The process of commercialization can be tiresome and lengthy, as can be observed in the cases of the jet engine, television and fluorescent lamps, where it took a number of years[2] before these technologies were actually commercialized [32]. These cases reveal that it is not just the scientific discovery or the benefit a technology offers that will ensure its success or rapid adoption [33]. There are a number of forces at play that determine the future of a technology [34]. There have been cases where technologically advanced products were overshadowed by inventions that were considered inferior in terms of technological capabilities and benefits, but had benefited from a better commercialization process [9,35]. This leads us to the discussion of what companies should do to avoid failures and achieve success. According to Zahra and Nielsen [36], the commercialization of a technology can be improved by developing efficiencies in the technology development process. Overall success lies is the sum total of successes achieved at each stage of the new product's development [2].

Ettlie [37] emphasized that an organization should be strong when it comes to core knowledge and organizational capabilities [38]. Many authors have embraced the issue and have studied the ways through which competencies can be developed at the firm level [39,40]. According to Teece et al. [39], capabilities can be enhanced by developing the skills and knowledge of the personnel involved, bringing improvements in the overall processes, systems and equipment. Smith et al. [41] have emphasized that the knowledge and expertise of the individuals can lead firms to gain competitive advantage. Menon et al. elaborate that developing the culture of innovation [42] and engaging creative individuals who have diversified knowledge and skills can enhance overall efficiency [23]. In addition to developing internal capabilities, it may also be a good idea to involve external partners in order to augment the skills-base, bridge any gaps, and gain complementarities. A study conducted by Manoukian et al. [43] highlights that the engagement of an external partner can help in developing the process and improving the overall performance of the organization. Chen [44] and Snow et al. [45] have shown in their studies that the organization attained success by integrating an external partner in the development process. Being part of ecosystems [46] and obtaining the services of business incubators [47], an accelerator programme [48] and facility parks [49] can also help companies develop the product further and ensure the efficient use of the resources. Universities and research centres are home of innovative ideas and creative minds. Collaboration with academic institutions and research centres can be very useful in the development and successful commercialization of technology [50]. Similarly, the involvement of venture capital organizations can also be useful in improving the overall process of commercialization [46]. Small- and medium-sized companies often find themselves in a situation where they are lacking the financial resources to perform necessary product development features and launch the technology in the marketplace [51]. Cooperation with such organizations will not only help address the financial issues, but can also complement the firm with the skills and knowledge necessary to commercialize the technology successfully.

It is equally important to have the right dissemination scheme in place. This aspect of a commercialization strategy is more concerned with how the technology should be launched in the marketplace. The literature

[1] In transition from the demonstration to the commercialization phase where the cost of production is higher and the market penetration is low.

[2] 79 years for the fluorescent lamp, 22 years for the television and 14 years for the jet engine

suggests that the primary choice of commercialization strategy is influenced by the type of innovation and related commercial risk associated with introducing that innovation to the marketplace, which may be concerned with costs, the product itself and the market [6]. In turn, the level of risk determines whether the strategic choice involves some dependence on third parties or whether the technology entrepreneur can pursue their strategy independently of other players in the marketplace [52]. The strategy may also be influenced by the overall environment in which a firm operates. Gans and Stern articulates that firms operating in strict regime, having strong intellectual property protection, and owning the required resources may prefer going into the market on their own, compared with the scenario in which the protection environment is relatively less stringent and the dangers of replication are high. In the latter case, companies tend to look for partnership and joint ventures with established firms [10]. Likewise, the nature and size of the firm can also be a driving factor behind these choices. Zoltan and David [53] and Libaers et al. [54] suggest that big firms usually face problems with a rigid hierarchal structure, which may compromise their position in a marketplace that is rapidly evolving and requires quick decision-making. The preferred choice may be to enter the market by means of spin-offs and subsidiaries in order to achieve the flexibility required to compete with innovative small-sized organizations that enjoy flexible working structures [16,55].

Many scholars have also attributed the time to market [42], the portfolio of the products [9] and launching products at the right time [56] as key to commercialization success. Li et al. found that the companies that have introduced more products in the market compared with their competitors had achieved higher success [57]. Similarly, companies entering the market early with breakthrough technologies might enjoy the 'first mover' advantage [9]. However, a number of scholars have stressed that getting first to market may not guarantee success alone, especially if the nature of the technology is disruptive, as followers may imitate or complement the original technology by improving it to the level where it can better serve the customer's needs [58,59]. Moreover, in today's competitive world, internationalization can play an important role in a firm's ability to commercialize a technology successfully. Companies that can overcome the obstacles and enter the international market will have a larger market to serve, and addressing its needs in the right manner can enhance the chances of successful technology commercialization. From the discussion, we can infer that a successful commercialization process can be divided into three basic aspects: i) development of a technology that has a potential of serving market needs; ii) using a channel that suits the technology and the company best; iii) in a manner that the technology is accepted by the customers. Based on this, we can define commercialization as a process of developing a functional technology, complemented with the features required by its target market, which is supported by an effective dissemination strategy that have a probability of thriving in the marketplace.

Notable work has been done in the past couple of decades on technology commercialization and exploring the factors that hinder its success [2,22,33,60,61]. However, the commercialization of renewable energy technologies is a thing of the recent past, and scholars have started to focus more on how RETs can be made part of the energy system. There is a wealth of literature highlighting the massive energy generation potential of renewable energy sources [62–65]. However, to this end, the share of RETs in the world energy mix is insignificant [66,67]. It has been debated that the low proportion of renewable energy in the global energy supply is no longer because of their technical potential alone [68–71], but rather a consequence of how these technologies are commercialized [71]. Commercialization becomes important in the case of RETs, as without commercial status these technologies will neither gain consumers' confidence nor benefit from the dynamism of the private economy [25].

1.1. Commercialization of renewable energy technologies

The commercialization of renewable energy technologies is even more tactical and troublesome as there are some additional barriers that these technologies have to surpass before they can achieve success. According to Aalam et al. the successful diffusion of RETs depends on a variety of factors, including, but not limited to, availability of renewable energy resources, remoteness and isolation, socio-economic conditions, affordability of technology, willingness to pay and the level of awareness [18]. Amigun et al. studied the potential of biomass in Africa and identified the factors that have caused hindrances in its widespread diffusion and adoption. The barriers identified are categorized as technical and non-technical. The high cost of raw materials and other economic constraints are considered as the technical barriers, whereas non-technical barriers include policy, legal, financial, institutional, cultural and societal constraints [72]. Sustainable energy technologies are primarily different from the standard technologies due to the nature of the industry, the type of technologies, the level of awareness, and the need to have the right public policies and infrastructure in place.

Renewable energy technologies are known to have the characteristics of disruptive technologies. These technologies are fundamentally different from preceding technologies serving similar markets. Their success in the commercialization process becomes dependent on a number of actors operating at various levels, including, but not limited to, the government, local bodies, investors, entrepreneurs, society, stakeholders and the customers. It is evident from the literature that, more often than not, the originators of disruptive technologies are small-sized organizations. These companies are usually strong in technology development but often struggle to commercialize on their own [73]. At present, in the majority of the countries, energy infrastructure is centralized and operated by the large utilities companies, owned by either the state or very large corporations. Renewable energy technologies cannot be adopted on a large scale unless the supporting infrastructure is in place, which often requires great motivation and investment from several parties. Moreover, some of the renewable energy technologies have not yet fully matured or gone through the cycle of development. These technologies face natural reluctance from customers, as the likelihood of adoption increases once the technology meets performance and reliability requirements [74]. Olleros argues that commercialization becomes extremely vital for the technologies that are emerging and are in a relatively early phase of development [75].

Verbruggen et al. assert that economics and market-related factors are extremely important and require fair consideration, while formulating strategies for the commercialization of RETs [76]. It is argued that in a period when technological progress is closely tied to commerce and finance, many renewable energy technologies trail behind conventional technologies in terms of adoption, despite the long-standing efforts to promote them [25]. Golder et al. [77] believe that the majority of people in academia overlook the economic, environmental and market-related factors when discussing the true potential of RETs. The effectiveness of RETs and the role they can play cannot be determined solely by the world's resources. In the light of the current development of various technologies, assuming normal economics and investment criteria apply, the contribution from most of the renewable energy technologies is likely to be only a small proportion of its potential. [25] states that the technologies that are superior in terms of performance, initial cost, quality, reliability and user friendliness have achieved a fair level of market penetration. However, many of the RETs have failed to gain sizeable market share, as being environmentally friendly and energy efficient alone will not help them to sustain the market for a long period and there is a need to bring the cost down to a level where it becomes competitive with the existing solutions. To this end, the majority of RETs cannot compete with conventional technologies based on economics alone, making their commercialization imperative as they may struggle to survive otherwise. Nonetheless, it is widely believed that the existing regime favours conventional technologies and makes their use cheaper compared with ambient energy technologies [78]. It is argued that if the cost of polluting the environment is imposed and the utilities are required to internalize the externalities, the cost of energy generation from renewables will become competitive [79]. Therefore, in the existing scenario, the role of subsidies and support schemes becomes very important. The long-term benefits that the RETs can offer in the form of energy security [80], sustainable development [81] and efficient use of indigenous resources [82] put pressure on governments to ensure their integration into the energy system. Governments are constantly looking to devise the support mechanism and strategies to ensure the adoption of environmentally friendly technologies. Walters and Walsh [6] and Wiser [83] suggest that renewable energy markets tend to develop more because of supportive public policies and less through the efforts of competitive and commercial interests alone. The study conducted by Lehtovaara et al. on the role of governmental support schemes and market penetration found that well-structured support schemes and subsidies are essential to ensure the successful commercialization of renewable energy technologies [84].

Furthermore, companies should develop innovative business models that can not only make the business proposition profitable for the incumbent firm but also make it viable for the customer to purchase the technology. A traditional model of sale purchase may not be very effective for ensuring the enhanced diffusion of these technologies [85]. Companies need to look beyond the conventional measures of probing investments in renewables like payback time and net present value. The initial cost of these technologies has been seen as one of the main hurdles in their adoption, so companies that can devise plans where the initial cost is dispersed during the period of use are more likely to gain customers' trust in the technology. From the above discussion, it is evident that successful commercialization is the right mix of technical, market and regulatory factors, and if any of the elements is missing, the success and widespread adoption of the technology becomes extremely challenging (Fig. 1).

1.2. Objective and structure of the study

The objective of this study is to investigate how different renewable energy technologies can be effectively commercialized in Finland. A number of studies have focused on the commercialization of technologies [86–89], while some have focused on high-tech industry [4,90,91] and disruptive innovations [92–94]. However, the literature focusing on the commercialization of renewable energy technologies is rather limited. This limited stream of research has attempted to investigate the phenomenon from the perspective of the resources [72], the role of public policies [95], technology type [71], financing [6], marketing [96], demonstration [97], business models [98] and collaboration [99]. However, there have been very few studies focusing on the commercialization environment of renewable energy technologies as a whole [25,97], and seldom from Finland's perspective. This study contributes to extant literature by presenting a comprehensive review of the commercialization of renewable energy technologies in Finland and attempts to investigate how the technical, economic and environmental factors are actually playing a role from the country's perspective. The main research question of the study is thus: What are the key factors that influence the commercialization of RETs in Finland? This research seeks to address this question by identifying the drivers and barriers affecting the process, and presenting a framework for addressing these barriers in order to foster the process of commercialization. The study conclude that the country has fairly strong standing when it comes to research, developments, technological know-how and basic infrastructure; however, there is a need to improve coherence between stakeholders, financing facilities, internationalization, and collaboration between industry and academia. The study also highlights the significance of support mechanisms and suggests the improvements required, at the micro-level (firms) and macro-level (policies, regulation and infrastructure), to develop a successful RETs market in Finland.

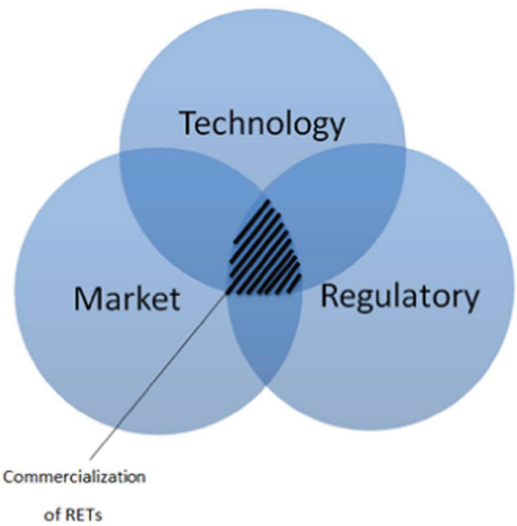

Fig. 1. Commercialization of renewable energy technologies.

The remaining parts of the study are structured as follows. Section 2 sheds light on how the review was conducted. Section 3 discusses the Finland's energy outlook and is followed by Section 4 on RETs and their significance for the country. Section 5 identifies the factors influencing the commercialization of RETs in Finland. Section 6 presents a discussion and proposes a framework for the enhanced commercialization of RETs. Lastly, in Section 7 the limitations of the studies are discussed and in Section 8 the conclusion of the study is presented.

2. Methods and research setting

The basic research questions of the study (factors influencing the commercialization of RETs), the exploratory nature of this research, and the aim of studying the phenomenon in its natural setting make the in-depth qualitative case study a suitable approach for this type of research. A case-study methodology can be applied in various contexts, having multiple units of analysis, and can rely on different means for data collection and investigations, such as ethnography, longitudinal studies, interviews, observations and secondary sources of data [100]. Since the study seeks to explore the commercialization process as a whole, the research could not have been confined to a single organization, but required input from the multiple actors and stakeholders involved in the process. In our case, confining the study to a single unit increased the probability of leading to biased and less accurate results. Therefore, the study has incorporated input from different actors and players, such as energy technology companies, financing companies, regulatory bodies, government agencies, utility companies, and experts from academia, research institutes, customers and other stakeholders involved in the process. This approach has helped us in gaining an in-depth understanding and in constructing a comprehensive picture of the overall process by listening to the diverse voices and exploring the phenomenon through a diverse range of lenses. The primary data collection was conducted through semi-structured interviews with the participants. The data triangulation technique was adopted to ensure accuracy, obtaining a detailed and balanced picture of the situation

[101]. Published literature, policies, reports and industry analysis were used as the secondary sources of data. A comprehensive review was conducted based on the collected data and key factors were identified that are central to the acceleration of RETs' commercialization in Finland. The relevant excerpts were selected to establish the links with devised performance indexes, as suggested by [102]. This approach not only creates the links between the data and analysis, and demonstrates the assessment of the quality of cases, but also allows the reader a deeper understanding and overall picture of the context.

3. Energy consumption in Finland

Finland is a Nordic country, located in the northern part of Europe, sharing its border with Norway to the north, Russia to the east, Sweden to the west and to its south Estonia, which lies across the Gulf of Finland. The country is fairly big, the eighth largest in Europe, with a land area of approximately 338,145 km^2 and 5.5 million inhabitants. The majority of its territory, over one-third, lies above the Arctic Circle, which makes its weather relatively colder than that of its neighbouring countries. It is sparsely populated, with the majority of its population residing in the southern part of the country. Finland's cold climate, scattered population, highly industrialized economy, urban structure and high standard of living make it one the highest per-capita energy consuming country on the planet [103].

Finland's existing energy mix is quite diversified and its generation comes from both conventional sources and renewables (Fig. 2); however, the higher level of fossil fuel consumption is still a great concern [104]. Finland, not being endowed with natural reserves of hydrocarbons, imports the majority of the fuel it consumes. The frequent fluctuation in prices and its dependence on external countries not only hinders economic development plans [46,105], but also presents a great concern for the energy security of the country.

The government is developing policies and strategies to drive the country towards a decarbonized economy [106]. Finland has an ambitious plan to increase the share of renewable energy in its final consumption to 38% by the year 2020 [103]. The long-term objective of reducing emissions, increasing the share of indigenous sources and enhancing energy security may not be achieved without developing cleaner sources of energy generation and consumption. The Ministry of Employment and the Economy (MEE) suggests that the adoption of cleaner technologies can save the country around \$3–5 billion in the future [107]. Furthermore, being a part of the EU, Finland needs to develop policies and strategies that comply with the EU's environmental regulations. In this regard, Finland is among the successful European states that are on their way to achieving the EU's 2020 objectives. Finland's energy and environmental policy stresses the need for substituting fossil fuels and electricity imports with indigenous renewable energy sources [108]. The Finnish Energy Industries stated that the country's heavy reliance on energy presents an opportunity and the steps taken in the right direction are bound to generate favourable outcomes [109].

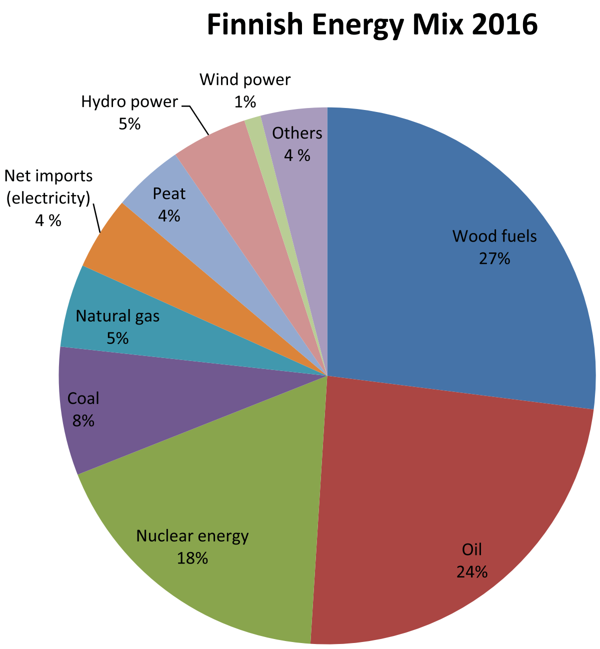

Fig. 2. Finnish energy mix.
Source: Statistics Finland, Energy.

4. Renewable energy technologies in Finland

The concerns surrounding sustained development without compromising the environment have led to the development of cleantech industry. The shift in focus of international policies towards the successful establishment of sustainable energy technologies has made cleantech one of the fastest growing sectors globally. In the year 2013, the size of the market reached over \$1600 billion, roughly 6% of the world's GDP [108]. The year 2014 witnessed growth in the investments made in renewable power and fuels, reaching over \$270 billion, a rise of 17% since the previous year. Europe is a forerunner in the development of renewable energy technologies and has invested over 57 billion dollars during the year. The sector has witnessed exponential growth and almost half of all the new power generation capacity added worldwide has come from renewables, making the cumulative capacity over 100 GW for the first time in history [110].

Finland, having a strong industrial base, is in an excellent position to become a key player in the emerging renewable energy technology market. The country's vision of improved environmental conditions, compliance with international environmental regulations and strict emission reduction targets is a strong force behind the growth of Finnish cleantech industry. Investments in RETs and expansion in the local industry are important needs of an energy-intensive country like Finland, as reasonable energy prices are important for the stability and growth of the economy [108]. Besides, the demand of sustainable energy technologies is increasing globally, especially in the developing world. According to the United Nations Environmental Programme (UNEP), the developing countries' investment in cleaner technologies increased by 36% in 2014, compared with the previous year, reaching \$131 billion [110]. The combination of soaring energy needs, less developed energy infrastructure and a weak industrial base in the emerging economies offers an excellent opportunity for a country like Finland to target the market and become a leader in the industry.

Technology is imperative in attaining sustainability, as the transition towards a low-carbon society will remain only a dream if we fail to develop technologies and the means for economic growth to be uncompromised by the pursuit of environmental objectives. The development of clean technology has become a prime focus of Finland and the country is trying to become a key player in the industry. Finland is one of the world's leading countries when it comes to R & D in the area of energy and environment. Despite being a small country, its share in the global cleantech market is over 1%, more than twice of its contribution to the global GDP [111]. According to Cleantech Finland, the combined turnover of the industry was over \$25 billion in 2012, an increase of 15% on the preceding year [112]. The sector has roughly 50,000 employees and is expected to create 40,000 new jobs by the year 2020.

Cleantech is a relatively broad field, including companies of diverse nature that in one way or another are associated with environmentally friendly technologies [113,114]. Among these, renewable energy companies accounts for the highest percentage [115]. Table 1 and

Table 1
Top ten Finnish Cleantech Companies.

Top Ten Finnish Cleantech Companies
Wartsila
Mesto
Neste Oil
Outotec
Kemira
YIT
ABB
Kuusakoski
Outokumpu
Cargotec

Table 2
Top ten Finnish Cleantech Markets.

Top Ten Markets for Finnish Cleantech Companies
China
Russia
Germany
Sweden
Brazil
India
USA
UK
France
EU

Table 2 present the list of leading Finnish companies engaged in cleantech business, along with the top ten markets [111].

Though the country has achieved reasonable success, Finland's existing share in the international market is considered insignificant compared to its potential. The Cleantech group has evaluated countries based on different innovation drivers and has ranked Finland among the leading countries. The study reveals that the country scores extraordinarily highly when it comes to the innovation input, public R & D and innovation culture, while its score is low in commercialization, lagging behind many of the member European countries [116]. The following section briefly highlights the factors influencing the commercialization of RETs in Finland.

5. Commercialization of renewable energy technologies in Finland

5.1. Market dynamics

Market dynamics play an important role in the development of the RETs market in Finland. Finland has long held the image of an environmentally friendly country. The concerns of climate change and the need to develop cleaner sources of energy generation worldwide have provided an opportunity for a country like Finland, which has a history in the development and innovation of technologically advanced products and services, strong technological know-how and an established infrastructure suitable for becoming a key player in the industry. In addition, the recent economic meltdown and the decline of the information and communication technology (ICT) sector have triggered the inevitability of the development of a sector that can serve as the backbone of the economy in the years to come. Considering the growth potential and the urgent need, the government has started taking the initiative in order to develop the sector as a priority [117]. However, one of the key challenges the sector is facing is the bottleneck in the domestic market.

Finland is a developed country, with a small domestic market where energy is affluently available to the public. In developing countries, renewables are perceived as a vital source of energy generation for meeting basic requirements, as a sizeable portion of the population lives in villages and rural areas, far from the population centres and with very limited access to the electricity grid [118]. On the other hand, in a country with a developed energy infrastructure, the incorporation of sustainable energy technologies has emerged more due to the concerns of energy security, gaining economic benefits, improving the environment and the effective utilization of indigenous resources. The fundamental principle of economics applies here: the product will only make ground if the demand exists. In the first scenario, the demand is obvious and clear. However, when it comes to the countries that have an established energy network, RETs, in most cases, are regarded as an alternative to the conventional means of generation, more often than not an expensive one, requiring changes in the established infrastructure and consumption behaviours, and in such cases, commercialization becomes somewhat tactical as the demand for the technology needs to be developed.

This issue can be dealt with on two fronts. Firstly, the use of sustainable energy technologies can be supported and encouraged at the domestic level by developing the necessary measures and policies to encourage their adoption. Secondly, the right level of support can be provided to the companies in the internationalization process. The analysis of Finnish cleantech industries shows that the sector is dominated by small- and medium-sized enterprises. As shown in Fig. 3, approximately 68% of Finnish cleantech companies are either micro-organizations or SMEs, having fewer than 250 employees [115]. The SMEs are characterized by good market understanding, technological know-how and a forward-looking mind-set; however, they usually lack resources and an understanding of internationalization [119,120], which makes their survival difficult in a country where the domestic market is small and competitive. The government has established a number of programmes and initiatives that are aimed at developing companies' abilities to internationalize their operations [121,122]. The ultimate growth and success of the sector lie in the ability to cater global markets. Support and assistance shall continue and an attempt should be made to assist a larger number of companies in their international endeavours. The managing director of the technology centre stated:

> *"The long-term survival and potential to grow lies in the markets that are far from here and are very different fundamentally. Therefore, the support is pivotal to encourage companies to go international and avoid failures."*

5.2. Availability of financing

As discussed in the previous section, the cleantech industry in Finland is dominated by the small- and medium-sized enterprises. Due to the resource constraints, the firms often require additional funding to transform their inventions into great innovations. According to Greene et al. financing works as oxygen for the companies, as it is essential to keep them operational [123]. Finland's research and

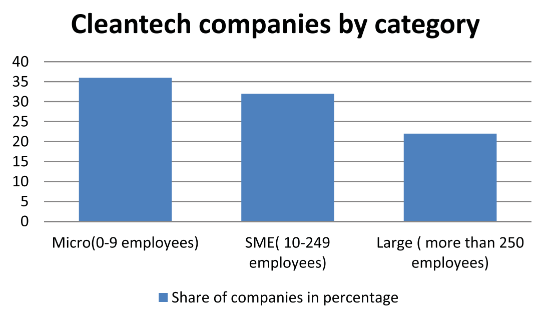

Fig. 3. Cleantech companies by category.

development budget is among the highest compared with similar economies [116]. The monetary support from the state-based institutions has helped a number of companies in meeting their financial needs. However, the access to capital, in general, is seen as a great concern, especially for the companies looking to acquire financing during the later stages of product development. A significant amount of money is required at the early stage (research and development) and the middle phase, when the product is set to be launched in the market (commercial stage). The majority of funding from state-based financial institutions is directed towards the companies undertaking R & D tasks and the companies seeking resources for the market launch often struggle to obtain financing [112], as stated by the chief financial officer of a company:

> *"If one has a prototype ready and [the] company is planning to get the product to the market, seeking financing at this stage is almost impossible. If you will ask them [state governed financing institutions] for funding, you can only expect a rejection."*

There is a need to develop special financial mechanisms to meet the financial needs of the companies that have gone through the research and development phase and are planning to get their technologies to market. A business advisor of a regional development organization echoed the concerns:

> *"The financing is offered to the companies that are involved in the research and development. We should have more financing instruments at our disposal, for the commercialization phase, as most of the companies struggle to obtain [the] funding required to efficiently launch their product in the market."*

Furthermore, the existing structure and system of support is also believed to be somewhat complex as identifying the right agency and suitable instruments sometimes becomes challenging [124,125]. According to Cleantech Finland, 58% of the firms have encountered problems with public financing. A number of different public institutes are engaged in providing financing to the firms and the process can be tiresome, as there are a number of administrative and lengthy procedures involved in the process [125]. It may be more efficient if the support for the start-up is centralized in one place and the financing is provided at once.

To this end, the opportunities for getting investments from the private sector and venture capitalists are also very stringent. The ventures specifically investing in the cleantech sector are limited in number, which puts further pressure on the public sector to provide the financial support. The future growth of the sector will be very much reliant on the firms' ability to obtain financing from the private sector. According to the assessment of Ministry of Economic Affairs and Employment, it is anticipated that 54% of all the growth-oriented SMEs will require funding during the year 2017, which further puts pressure on the government to find means and financial instruments to bridge the gap [126].

5.3. Skilled personnel

The success of a business venture is dependent upon both technological competence and managerial expertise. The studies have shown that despite having superior technology, a product may underperform in comparison with those that are technologically less distinctive but have been managed and presented to the market in a proficient manner [9,11]. The tradition of technological expertise and developing innovative products runs deep in the Finnish customs [127]. The majority of start-ups and SMEs we studied were incorporated by individuals who had a strong technical background and experience of working in the Finnish tech industry. The opportunity to provide solutions to the industry's existing problems has encouraged them to develop the technology. However, the expertise of professionals in management and marketing is rarely sought. The core team typically comprises technical experts, whose focus is almost entirely on the technology development aspect and less on how efficiently it can be presented to the target market. A number of studies have shown that Finnish tech companies lag behind in non-technical skills, especially the sales and marketing of technical products, which makes their commercialization difficult [128,129]. The managing partner of a venture capital firm said:

> *"These entrepreneurs often imagine that the product will sell itself, if it has a value, which is often not the case in real competitive world. We have seen companies fail just because they were not able to reach to their customer[s] and present their products in the manner they should have, mostly because they did not have anyone who was specialized in doing so."*

Involvement of expert personnel from different backgrounds will help companies to understand the complexities and devise strategies that are more practical and address real issues.

5.4. The role of energy policies

As discussed in Section 1.1, the RETs are competing with mature technologies that have gone through the development cycle and offer relatively better value when it comes to the price and ease of use. A number of studies have shown that the adoption of clean technologies is subject to the right set of policies and governmental support schemes [130,131]. It is often claimed that subsidies and support schemes will only be required until the industry develops the technology and means that can sustain the market on its own. A comparison of the energy generation costs of the RETs with the conventional sources in Finland leads us to the fact that there may still be some time before the renewable energy market can be driven by the market fundamentals of demand and supply. In the existing scenario, if only the market forces are to be relied on, the diffusion of RETs may remain hindered. The supportive role of the forward-looking energy policies in the development of the Finnish clean technology market cannot be overlooked. The country has achieved reasonable success in realizing its vision of becoming market leader by devising the right policies and measures to support the development. However, at times, the lack of a long-term approach and consistency in the policies has raised concerns of the players involved in the sector. The chief executive officer of a company operating in the wind sector said:

> *"…..having feed-in tariff[s] in place has encouraged the companies to get into this business of wind energy. Now that they [the government] have started considering revision of the limits [referring to the government's plan of reducing the predetermined quota of 2500 MVA to 2000 MVA], what impacts do they [the government] think it will have, except discouraging investors. These sorts of things should be settled before the policies are formulated."*

The perception that policies may change in a relatively short span of time can raise concerns in the minds of entrepreneurs and technology developers about the future of the industry. In order to encourage development, the industry should be given continuous support and confidence. The growth potential of technologies such as solar or wind is tied to the government's ability to maintain favourable conditions by having the right policies in place. According to Finish Energy Industries, the long-term success and growth of the industry lies in consistent energy policies, as the energy sector requires a lot of capital, and investments cannot be encouraged without having a stable and predictable environment [109].

5.5. Nature of risk within a firm

In addition to the financing (Section 5.2), market dynamics (Section 5.1) and consistent policies (Section 5.4), the culture and psychology of the individuals in the society as a whole and within a company play a pivotal role in entrepreneurial success and the expansion of the business ventures [132]. The firms' appetite to take risks and explore new avenues increases the chances of getting more out of the existing market or out of a new market that it is about to explore. According to Lee and Peterson, the firm's ability to undertake risk comes from a number of factors, such as experience, behaviour, the individual's psyche, society and the environment [133]. It has been observed that the culture of Finnish companies is somewhat conservative. The companies feel satisfied if they achieve moderate growth and do not bother much about expansion. SITRA has emphasized that Finnish business culture should develop and learn from the bold and risk-taking initiatives often pursued by firms operating in the United States or Israel [134]. An international business advisor working in a technology centre also affirmed the statement:

"We have found many of the entrepreneurs to be risk averse and avoiding making bold decisions. The companies often find themselves trapped in their conservative mind-set, depriving them from the real growth."

5.6. Level of public awareness

As discussed earlier, the need for RETs in Finland has arisen more because of the environmental and energy security concerns than because of the value alone that such technology brings. To this end, the additional cost of using these technologies is one of the biggest obstacles to their adoption. According to Dodds et al. the price of a product is determined by the value and perceived benefits it has in the mind of a customer [135]. In order to make people pay relatively higher prices for a technology, there is a need to increase the level of awareness among people. The awareness can be increased by addressing the benefits of the clean technologies, both for the economy and environment, to the extent where the benefits justify the additional cost to the consumer of the product. Generally, the awareness of the need for improved environmental conditions exists in Finnish society. A study conducted by Moula et al. on the social acceptability of renewable energy technologies in Finland reflects that people, in general, have positive tendencies towards the environment and the adoption of renewable energy technologies [136]. This is iterated by a household customer:

"…of course, it is everyone's responsibility to use the cleaner sources of energy generation. Solar, wind or any other forms of green energy [ies] are definitely better than coal as they do not pollute the air we breathe in."

However, a small percentage of the population is willing to pay extra for clean products that offer similar value to conventional technology but have positive environmental impacts [136]. There is a need to raise the level of awareness to a point where the willingness to pay for the environmentally friendly products equals the cost of energy generation using renewable energy technologies, thus making it competitive with the conventional means of energy generation (Fig. 4).

5.7. Infrastructure support

Infrastructure support is vital for smaller companies attempting to establish themselves as a successful business venture. The establishment of incubation facilities for start-ups, accelerator programmes, private and public research institutes, and facility parks can assist companies on multiple fronts. A country like Finland, which has good technical expertise, a culture of innovation and a network of universities offering sound technical education, can further foster the sector's performance by improving facilities that can help the firms to reduce operating expenses, gain expert opinions, managerial expertise and assistance in exploring new avenues. The chief executive officer of a company engaged in biomass energy generation technologies stated that:

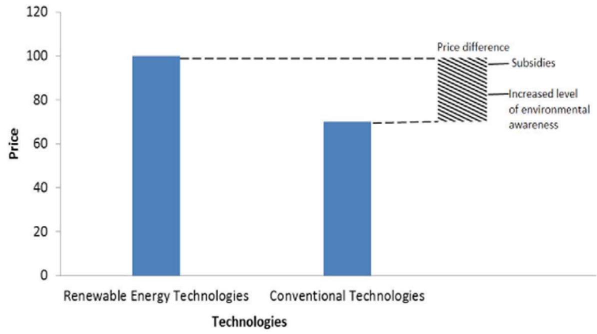

Fig. 4. Environmental awareness and willingness to pay.

"The expert advice we got [from Science Park] not only improved the technology a great deal, but also helped us in developing [the] company's business model and marketing plan. The combination of [these] things helped us in obtaining funding, as our proposal was practical, comprehensive and market-oriented."

The rising number of cleantech companies and dominance of small- and medium-sized companies in the sector [122] will certainly require support from the network. The existing structure may not be enough and there is a need to develop more of such facilities to increase the level of success.

5.8. Market-oriented technology development

For a technology to become successful, it is important to have a value proposition that makes it unique and valuable in the eyes of the customer. The offering could possibly be in the form of a product's ability to deliver a value-added feature in terms of efficiency, productivity or performance. A technology may offer an excellent solution to an existing problem or have a positive environmental impact, but if it is not commercially viable, i.e., it does not match the customer's willingness to pay for it, the probability of failure increases. Such technologies also remain unable to gain the investors' confidence, as people only tend to invest in the projects that are likely to yield a reasonable return on the investments. In Finland, a number of products could not gain a market share, as the entrepreneurs failed to consider the commerciality aspects. The problem could be observed particularly in the cases where companies do not value the customers' feedback during the product development phase. The managing partner of a venture capital firm, who has assisted a number of ventures in their efforts of becoming successful, stated:

"If you ask me about one major reason of why companies fail to develop [a] market for their products is that they do not take [the] right measures during the development stage. How can a product or technology get acclaim, if the development of the product is undertaken in isolation, without discussion, having a feedback from the potential customers, and integrating aspects, they [customers] needed the most? This is something we discourage the most. We want products to be sold as soon as they get to the market. Only then we can ensure return on the risky investments we make. The first thing we probe while discussing the investment is why they [companies] think that customers will pay for their technology. We get so many enthusiastic entrepreneurs often emphasizing the great deal of environmental benefits their technology can offer. It really surprises us when we have to dig deep to get an idea if the commercial aspects are considered."

5.9. Cleantech clusters

To accelerate the commercialization of clean technologies in

Finland, it is of immense importance to have a higher level of coherence between the industry, government, research institutions and other stakeholders [111]. Considering the domestic market bottleneck (Section 5.1), the state and municipalities should play a proactive role by adopting innovative technologies. This step will encourage entrepreneurs as well as providing a stage on which to demonstrate local inventions [117]. Furthermore, the measure will not only test and transform the product, but will also work as a real-time showcase for the companies to demonstrate their products to international clients and interested parties and market them [119]. Likewise, it may help companies to increase collaboration within the industry as well as finding international partners. The Finnish cluster programme has attained worldwide acclaim and ranks among the best in the world [137]. The government has supported development activities in the regions of Kupio, Oulu, Lahoti and Uusimma. The collaboration between the cluster participants has earned reasonable success by developing a number of innovative solutions [138]. The programme has assisted companies in exploring new business opportunities and promoting business in domestic markets as well as providing support for internationalization. Special measures are taken to assist companies in being successful in the growing markets such as the US, India, Russia and China [117,139], as affirmed by the director of a solar company which has recently expanded its operations in the international market:

> *"The cluster programme has helped us to expand our operations in [the] international markets in a proficient manner. We were given practical advice, training and [the] opportunity to get in touch with [the] right connections. The results are encouraging: we have generated more jobs, higher revenues and strong international references."*

5.10. Legal structure

The overall legal structure in Finland is supportive for the industry. According to Global Entrepreneurship Monitor, Finland has performed better than its peers when it comes to governmental support for entrepreneurship activities, start-ups and expansion of businesses. The regulatory environment is perceived to be stable and suitable for the business [140], as discussed by the assistant professor in the industrial engineering department of a Finnish university:

> *"The supportive legislation and policy frameworks have paved the way for development. Our [Finland's] image of being a stable democracy [with a] rule of law and conducive business environment has presented us [Finland] as a country to invest in and deal with."*

The overall structure is found to be supportive. However, when it comes to licensing a technology, the process is quite lengthy, involving a number of steps and procedures that can possibly be eliminated [112]. Improving the legal structure will further assist companies to accelerate the commercialization of green technologies.

5.11. Collaboration between academia and industry

In an industry that is abrupt, evolving and resource-intensive, in which innovations may be short-lived, it is imperative for the companies to have the right mix of resources and competencies to survive [141]. Through collaboration, a firm can share its resources and expertise, can achieve economies of scale, enhance product value and gain access to new markets and technologies [120]. The small- and medium-sized companies should constantly explore the opportunities to collaborate, not only in their own industry but also with the firms operating in the adjacent market in order to avoid direct competition and to gain benefits from the cooperation. Finnish companies generally have a good level of trust among themselves and collaboration can achieve reasonably decent outcomes [51,142,143]. The desire to have a successful footing in the global market and to negotiate the barriers to internationalization can be addressed through collaboration. According to an international business professor:

> *"The need to collaborate is greater now than it probably ever was. The success in international markets is dependent on the establishment of [the] right links and connection[s] with partners. The companies that have achieved success in their international endeavours can support others [Finnish firms] to collaborate [with international partners] and use the already established links, as the trust is already established and connections are strong."*

Such collaboration can speed up the process, reduce costs, resolve trust issues and compensate for the lack of internationalization experience by providing the necessary information and support for companies to globalize their operations. Similarly, collaboration between universities and industry can play a vital role in the development of energy technologies. Interaction between education establishments and industries can not only provide vital resources to the companies, in the form of human capital and knowledge that can be useful in improving the technical aspects of a technology, but also can offer infrastructural support and make the overall process more efficient. Our analysis shows that the collaboration between universities and industry should be developed further to gain benefits from educational establishments.

6. Discussion

The previous section has briefly discussed the factors influencing the commercialization of renewable energy technologies in Finland. Despite the fact that factors are quite diverse, an attempt has been made to categorize them according to the following headings: firm specific, market centric and policy related. Core competencies, size of the company, resources, expertise and the risk nature of the company are included in the firm specific factors. The issues can be resolved by encouraging collaboration among the companies, developing strong financial institutions, providing infrastructural support, developing clusters, assistance in exploring markets and internationalization. The market centric factors include the disruptive nature of industry, size of the domestic market, infrastructural support, skilled personnel and public awareness and consciousness about the environment. These issues can be resolved by establishing specialized institutes for start-ups and small-sized organizations, working closely with the companies to provide the expertise and resources they require, and by providing assistance and guidance about the internationalization. The policy related factors encompass subsidies and support schemes, a supportive legal framework and measures that encourage companies to invest in the clean technologies. The problems can be addressed by devising policies and support programmes to increase the renewable energy technologies' competitiveness with the traditional technologies. In addition, the legal structure should be supportive and ought not to discourage companies. The government can play a proactive role by encouraging municipalities and government institutions to prefer RETs solutions and encourage their adoption (Fig. 5).

6.1. Proposition

As discussed earlier, commercialization is a complex and multifarious phenomenon and firms should be tactical when devising their commercialization strategies. Findings from the study suggest that successful commercialization is dependent on a number of factors and it would be unwise to expect that focusing on either one can lead to the successful achievement of objectives. Therefore, it is recommended that a firm should gain proficiency at the first step before leaping on to the next. A proficient initial stride would enable a firm to reach the next phase by capitalizing on the proficiencies gained in the preceding level.

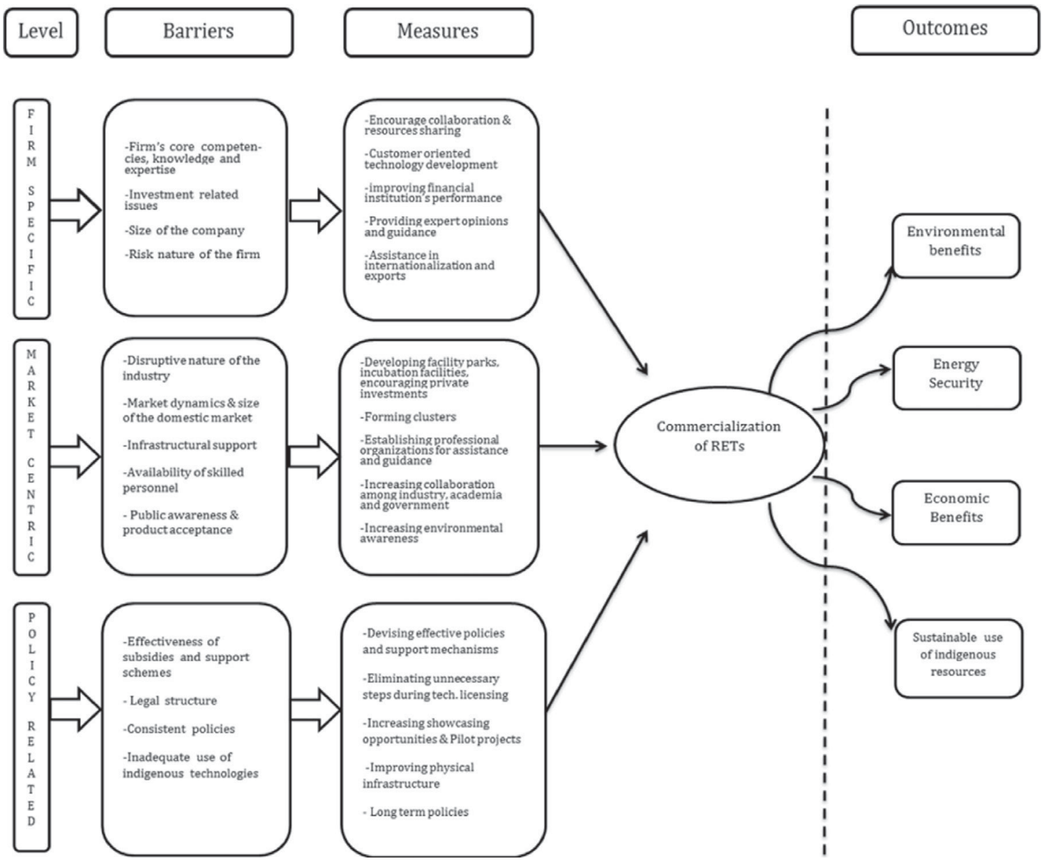

Fig. 5. Framework for the Commercialization of RETs in Finland.

The concept is very similar to a ladder, in that the process of reaching the top begins with the first footstep, striding on to the next and continuing until the destination is reached. A step-by-step approach ensures a smooth progression from the ground to the highest level, reducing the probability of stumbling.

Based on the findings, the study suggests that the fundamental step for a company is to ensure they have a strong knowledge base, the expertise and the resources required to develop a technology. The subsequent stage is to have the right level of infrastructural support available, especially for the start-ups, spin offs and small- to medium-sized enterprises operating in the industry. The support in the form of facility parks, incubation facilities and professional organizations where expert opinion is readily available can compensate for their limited resources. The third most important phase in the process is acquiring financing. The RETs industry is resource-intensive and requires substantial amounts of money in the earlier stages of development. The financing can either be obtained from public bodies or from private investors. The probability of gaining investors' interest increases once the firm has successfully acquired technical expertise and has a clear plan for development. Likewise, a key step is to have the right level of customer involvement throughout the technology development process. A number of technologies have either failed to gain customers' attention or have underperformed because the company did not seek customers' feedback during the development phase. The technology that is developed based on the team's own assumptions lacks the features that customers may value. This step will help companies to develop a technology that can better serve the needs of their target market. The last stage in the process is to have the right level of public awareness and acceptance in the market. This step is essential because, as of now, most RETs lag behind when it comes to the price comparison with the conventional technologies. The stakeholders involved in the process should play their part in spreading awareness and encouraging society to value the technology's environmental offering. The external elements, such as policies and governmental support in the form of subsidies and different support mechanisms, also play a critical role in the commercialization of RETs, as without these most of the RETs may not able to hold the ground (Fig. 6).

It is important to mention here that a number of steps could be added or removed from the list. The structure and significance of the steps varies, depending upon: the firm's size, resources, level of expertise, image of the company, understanding of the market, and connections, both at the national and international levels. The steps are not universal, and are devised considering the needs of small- and medium-sized companies; therefore, some of the phases, for instance the infrastructural support and financing, may not be effective in the case of large-sized enterprises.

7. Limitations of the study

The article presents an overall picture of the industry by exploring the factors influencing the commercialization of RETs, as a whole, in Finland. However, the technologies actually differ greatly in nature, use and development phases, and thus have distinct challenges. In this study, an attempt is made to identify the key factors affecting different technologies and to present a holistic view of the sector. Henceforth, the findings may not be applicable to one specific technology. An in-depth study shall be conducted for each of the technologies in order to explore the factors

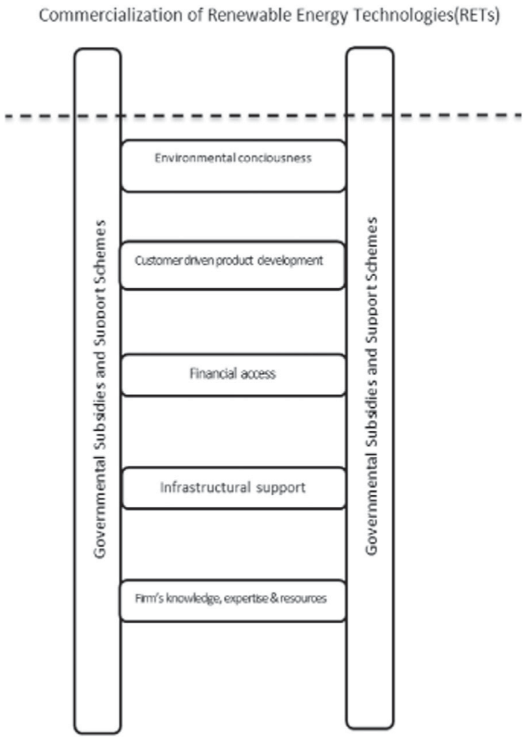

Fig. 6. Commercialization Ladder.

affecting their commercialization process. Moreover, the current study has been conducted in the Finland, where the market dynamics, technology development and business environment are different from other countries. Therefore, the findings of the study may not be generalizable in the broader context and to other parts of the world.

8. Conclusion

Finland's technological excellence, energy security concerns, sizeable renewable energy resources, research and development culture, and the emerging demand for clean energy solutions worldwide make the cleantech sector a natural choice. The government has stated its interest in promoting the sector and making it the engine of the economy. To this end, the country has achieved reasonable success in technology development aspects. However, the commercialization of these technologies has remained problematic. The objective of this study was to investigate how different RETs can be effectively commercialized in Finland. This research tried to address the question by exploring the drivers and barriers affecting the process of commercialization. The study shows that the factors driving the sector are market dynamics, strong research and development infrastructure, technological know-how, environmental awareness and supportive public policies. However, there are number of challenges the country needs to address if it really wants to attain its vision of becoming the sector's market leader. It is recommended that the key to success lies in improving financial mechanisms, encouraging collaboration, providing support in internationalization and developing infrastructural facilities for the industry. Based on the findings, the study presents a comprehensive framework for the commercialization of RETs in Finland.

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Renewable energy sources in power generation in Pakistan

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ABSTRACT

Pakistan, as an underdeveloped and populous country requires an uninterrupted source of energy to keep its development on track and provide its citizens with a reasonable standard of living. Conversely, the country is unable to fulfil its domestic energy requirements and is undergoing an acute energy crisis. Electricity is a sector that has suffered the most from the energy shortages. The gap between demand and supply is met through blackouts and, at times, the country plunges into darkness for more than 10–12 h a day. This crisis, that the country is currently facing, did not occur overnight. The root cause of this debacle goes back in history and can be attributed to decades of mismanagement, poor planning and negligence.

This article provides a comprehensive overview of the electricity sector in Pakistan and the issues it is beset with. In addition, an analysis of the energy policies that the country has announced over the years, as well as the impact that they have had on the electricity sector, is presented. It is concluded that Pakistan's existing energy mix is not sustainable due to the excessive reliance on imported fossil fuels, rising electricity generation cost and increase in power generation related emissions.

This paper develops a roadmap and proposes the energy sources that can fulfil the country's rising energy requirements, whilst being sustainable at the same time. The roadmap identifies and highlights the primary tasks that the country must undertake to reach its vision of meeting its energy needs and integrating renewable energy sources in the power generation.

The recommendations of this paper will provide guidelines to the decision-makers and policymakers, with an insight on how the energy technology and resource development should be carried out, which sources should be given priority and how the issues should be resolved, both in the short and long-term.

Contents

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1. Introduction

Energy plays a pivotal role in the formation and sustainment of modern economies. It is central to practically all aspects of human welfare including access to basic necessities, agriculture, health care, employment, education and sustainability. Energy is considered to be crucial to the economy and a central component in a country's success. As a developing country, Pakistan requires a large amount of energy to fulfil its household and industrial needs, as well as to keep the country's development on track. However, the country is struggling to ensure the sustained supply of energy and is currently facing the worst energy crisis of its history [1].

1.1. Objective and structure of the study

The objective of this study is to provide an overview of the prevailing energy situation, present the main challenges and key issues behind the unprecedented energy crisis and to propose practical strategies and policies to address the issue. This paper develops a roadmap and proposes energy sources that can fulfil the country's rising energy requirements, whilst being sustainable at the same time. The roadmap identifies and highlights the primary tasks that the country must undertake to reach its vision of meeting the rising energy needs and integrating renewable energy sources in the power generation. This paper attempts to address the following key questions 1) What are the key factors behind the prevailing electricity crisis? 2) Is the existing generation mix sustainable in the long run? 3) Can renewable energy sources (RES) play a role in mitigating Pakistan's abysmal electricity crisis? 4) Which sources should be given priority and how the issues should be resolved, both in the short and long term?

This paper is structured into 12 main sections. The first half briefly discusses the state of energy, demand forecasts and existing sources of power generation. The following section addresses the origin of the crisis and challenges that the country is beset with. The next part explores the sources and potential of power generation from renewable energy sources. The subsequent section of this study presents the energy policies that the country has implemented over the years and discusses their impact on the electricity sector. Finally, the last part identifies the actions that are necessary to improve the existing energy systems. The recommendations are based on the SWOT analysis, which is conducted to highlight the key challenges and opportunities that exist.

2. State of energy and existing sources of power generation

Pakistan is an underdeveloped and populous country with over 190 million inhabitants in 2014 [2]. The per capita energy consumption is low compared to the rest of the world. The average per person energy consumption is 1/20th of the developed world, 1/9th of the OECD countries, 1/5th of the global average and less than half of the underdeveloped countries, as shown in Fig. 1 [3,4]. According to Asian Development Bank (ADB) the availability of energy is considered an underlying factor behind the low level of consumption [5].

According to Aslam et al. the overall energy consumption in Pakistan has increased in recent decades, like many developing economies, and is expected to follow the same trend [6]. The primary energy supplies have witnessed a soaring growth of over 90% in recent decades, from 34 million tons of oil equivalent (MTOE) in 1992 to 64.7 MTOE in 2012, as shown in Fig. 2 [7]. The indigenous production remained around 45.2 MTOE, leaving a shortfall of 20.5 MTOE to be covered through energy imports [8].

Electricity is the sector that has suffered the most from energy shortages. The country has failed to produce the required amount of electricity to meet the domestic consumption requirements. The gap between electricity demand and supply has been stretched and the shortfall reached 4500 MW in 2010, 6620 MW in 2012 and remained over 5200 MW in 2013, which, on average, constitutes over 50% of the country's total generating capacity of that time (see Fig. 3) [9–11]. The total installed capacity for 2014–15 is 23,928 MW whereas, during the peak periods, the demand is expected to be around 23,242 MW [12]. In actuality, the installed generation capacity perfectly matches with the demand. However, due to issues such as high petroleum prices, availability of indigenous energy sources, circular debt and the transmission and distribution (T&D) losses, the actual generation capacity is expected to remain lower than the installed capacity. The maximum generation capacity is projected to be 18,499 MW, leaving a shortfall of at least 4743 MW during high demand periods [12]. Khalil et al. states that the electricity demand in Pakistan varies on a seasonal basis and peaks during the summer time [13].

The gap between demand and supply is met by blackouts, at times, the country plunges into darkness for over 12–14 h in cities and around 18 h in villages [14]. The deficiency of electricity has caused the industry to cripple. This situation has forced industrialists and agriculturalists to opt for alternative means of electricity generation. According to Pasha et al. self-generation is two and half times more expensive than electricity coming from the grid, and requires additional repair and maintenance costs [15]. Expensive electricity contributes to the higher prices of final product or services. This consequently impacts businesses' ability to compete in the local, as well as international, arena. Many of the businesses were not able to recover from this and eventually had to shut their operations down [5]. Others have shifted their industries to the neighbouring countries [16]. According to BNU [17], the energy crisis has hampered the country's economic growth and has cost Rs. 1272 billion during 2011–12. The economy has witnessed a decline of 2–3% in the GDP [5,18] and 12–37% loss

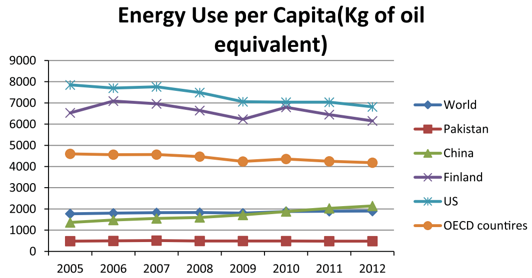

Fig. 1. Comparison of per capita energy consumption.

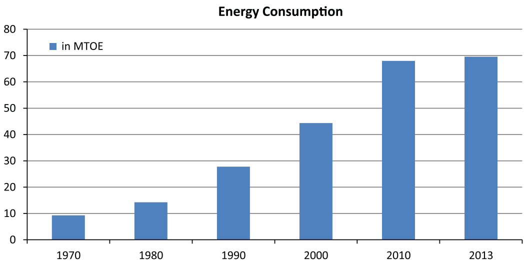

Fig. 2. Pakistan energy consumption from 1970 to 2013.

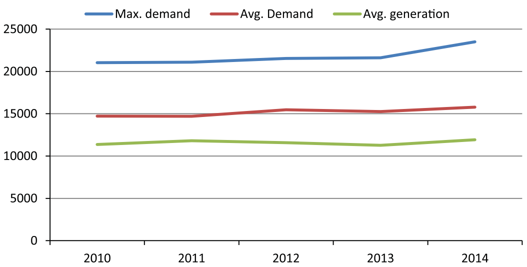

Fig. 3. The average shortfall in MWs.

in the total industrial output during 2010–2011[19]. The Asian Development Bank [5] affirms that over the last 5 years, the power shortage has reduced investments by 7.5%. According to [17], the disproportion between the energy sector receipts and payments has further added 5–6% of the GDP to the fiscal deficit. Moreover, the higher unemployment, the dwindled international competitiveness, low exporting volumes, poor standards of living and disruption in the routine life are some of the many ripple effects, it have caused.

3. Energy patterns and demand forecast

Similar to the overall energy consumption, the demand of electricity has increased in recent decades and is likely to intensify in the foreseeable future. According to Qasim et al. during the first decade of the 21st century, the demand increased at the rate of 8% [20]. From the Fig. 4, it is explicit that the demand is estimated to increase manifold, which will only escalate the situation and make the crisis worse. The demand is projected to increase at the rate of 8–10% in forthcoming years. The country would require 54,000 MW by 2020 and 113,000 MW by the end of 2030 to meet its electricity requirements in full [21]. The projected electricity demand for 2015 is over 23,000 MW [22].

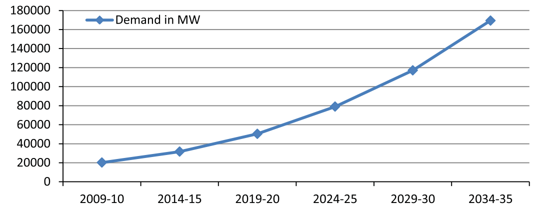

Fig. 4. Electricity demand forecasts from 2011 to 2035.

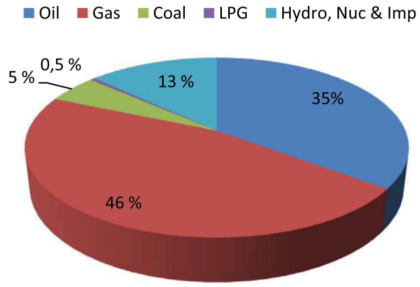

Fig. 5. Total primary energy supplies by source in 2014.

The rapid urbanization, expansion in the agricultural and services sector, use of modern appliances, little or no awareness about energy conservation or efficiencies, projected rise in population and the government's commitment to extend the electricity to the remaining parts of the country are some of the factors that will cause the demand to escalate [22,23]. Leiby argues that, to achieve the increase of this magnitude, it is inevitable for the government to bring new sources of power generation on stream, and encounter the challenge that can threaten its long-term development [24].

4. Existing sources of power generation

The overall energy mix of Pakistan is tilted towards thermal generation, where hydrocarbons constitute 87% of the total primary energy supply (TPES). Among these thermal sources, natural gas accounts for almost 46%, whereas, oil and coal contributes 35% and 5% respectively. Hydel and nuclear are the renewable forms of energy generation, constituting the combined share of 13% in 2014 (Fig. 5) [101]. Like the country's overall energy mix, the electricity generation is also dominated by fossil fuels with an accumulative share of 61%, followed by hydel 33%, whereas nuclear and other imported sources accounts for 5.6% [22,102]. For the first time in history, 2013–14 witnessed 0.2% contribution from wind energy in the overall electricity generation (Fig. 6) [11].

4.1. Natural gas

According the Energy Information Administration (EIA) Pakistan's natural gas reserves accounts for 282 trillion cubic feet (Tcf), with 24 Tcf of recoverable reserves [25]. Historically, natural gas has remained a prime source of power generation in Pakistan. Its production has increased from 2.04 billion cubic feet per day (Bcf/d) in the 1989–99 to 4.24 Bcf/d in 2012–13, a rise of over 50%. The total annual production in 2012 was 1.55 Tcf (32 MTOE), almost half of the country's primary energy supplies for the corresponding year. The reliance of this magnitude makes natural gas an integral component of Pakistan's energy mix. The concerning thing for the country is that its indigenous reserves of natural gas have already peaked and it is facing constraints in increasing the level of

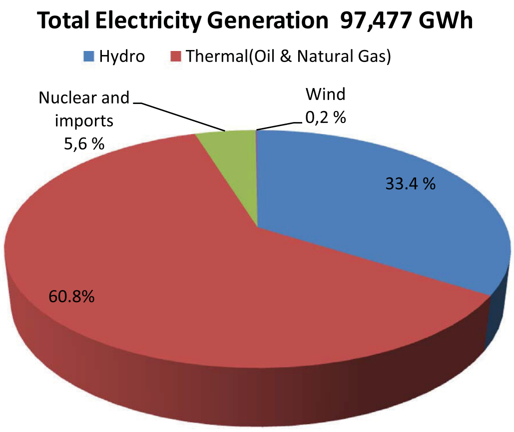

Fig. 6. Total electricity generation by fuel type in 2015.

production. Very few new discoveries have been made in the past and those that were discovered did not have sizeable reserves [26,27]. The country is set to exhaust its existing resources in 17 years at the existing utilization rate [28]. However, in actuality, the consumption is expected to increase four times, causing the depletion earlier than projected [26].

To fulfil the energy requirements, Pakistan needs to import natural gas from foreign sources either by constructing a gas pipeline or LNG terminals. Two natural gas pipeline projects: Turkmenistan, Afghanistan, Pakistan and India (TAPI) and Iran–Pakistan (IP) gas pipeline have been discussed over the past decade. However, none were realized due to various geopolitical and security reasons [29]. Pakistan established its first LNG terminal, which is capable of handling 4.5 million tons of LNG per year, at Port Qasim Karachi. The terminal has started its operations very recently and received its first LNG cargo, carrying 145,000 cubic feet of LNG, in March 2015 [30]. However, the existing capacity of the LNG terminal is very small compared to the country's needs.

4.2. Oil

Oil plays an integral part in the country's TPES, with over one third of all energy generation coming from this source [7]. Pakistan's overall resource potential is estimated to be 22 million barrels [31], which is insignificant compared to its gigantic needs. According to EIA, during 2013, Pakistan's total production of crude oil was 80,000 barrels per day (bbl/d), whereas the consumption remained over 455,000 bbl/d [25]. The limited domestic production and heavy consumption has enforced the country to import most of the oil that it consumes. According to Sustainable Development Policy Institute, 83% of all the oil consumed in the country comes from energy imports [18]. Oil is an expensive commodity and importing petroleum products is a huge burden on the country's fragile economy. According to Ministry of Finance [32], Pakistan's petroleum import bill was over $10 billion in 2012, constituting over 40% of all the imports.

4.3. Hydro

Historically, hydro has been a main pillar for low cost renewable form of energy generation in Pakistan. During 1960, approximately 70% of all the generated electricity came from hydel. In 2014, hydro accounted for roughly 30% of all the electric generation, approximately 7000 MW [33] and 9% of the total primary energy supplies [22]. Pakistan is a big country with plenty of lakes, rivers and waterfalls that can be tapped for the production of hydel energy. The potential of energy generation from hydro is enormous and a number of new sites have been marked for the installation of hydel based electricity generation installations (this is detailed in Section 5.4).

4.4. Nuclear

Pakistan acquired nuclear technology in the 1970s. However, it was not until three decades later that the country started to generate electricity from nuclear technology. In 2001, a total of 325 MW was added into the system [34]. Historically, the development of nuclear technology has been on the slow side. By the end of 2014, nuclear technology provided 650 MW of electricity and accounted for 2% in the country's primary energy supplies. Realizing its massive potential and probable role in the country's energy generation, the GOP has decided to boost the share of nuclear and have instructed the Pakistan Atomic Energy Commission (PAEC) to develop an infrastructure to produce approximately 9000 MW of energy by 2030 [35].

4.5. Coal

Pakistan is endowed with enormous coal reserves. According to [27,36], Pakistan's total resources are estimated to be 185 billion tons, with 2.07 billion tons of proven reserves. The majority of Pakistan's known coal reserves are located in the Thar region, the province of Sindh. Despite an enormous resource base, Pakistan has failed to utilize coal for the energy generation. The share of coal in the total primary energy supply is a mere 7% [7], which is small compared to its potential. It is believed that the country's coal resources are not of the finest quality and contain a higher content of sulphur and ash [37]. However, it is argued that despite being low in quality, it is still good enough to serve the domestic energy requirements [36].

5. Origin of crisis

Pakistan is undergoing an acute electricity shortage. The crisis that the country faces today did not occur overnight. The current state is the result of decades of poor planning, policymaking, lack of foresightedness, ineffective management and corruption. The following section briefly discusses some of the issues that have brought the country to its existing state.

5.1. Poor planning

Pakistan is a populated country with over 190 million inhabitants. The swift industrialization, electrification of villages, steady economic growth and increase in living standards are some of the major factors that have escalated the energy requirements over the years [38]. From 1960 to 1970, the demand has grown at the rate of 10% per annum, whereas a moderate rise of 5–6% was observed from 1990 to 2000. The demand further escalated during the first decade of the 21st century, with an increase of 10% on a yearly basis. On the other hand, the supplies have lagged behind the demand, leaving a massive gap between the energy generation and consumption. The availability of electricity was fairly good until the last decade. The crisis started to exuberate in the year 2000 and got worse after 2006, when the gap equalled half of the country's generating capacity [109]. The inadequate planning and poor understanding of the electricity market brought the country and its people to the situation of despair.

5.2. Historical background

The root cause of the crisis can be traced back to the 1980s, when the threat of electricity shortage became imminent. In 1980, Pakistan had approximately 2600 MW of installed electricity generation capacity, which was enough to fulfil the requirements of that time. When the need to bring new electricity generation sources emerged, the decision was made in favour of developing thermal based power generation facilities across the country. During that period, the prices of oil per barrel were fairly low, around 17$, and establishing an oil based power generation appeared as an obvious choice. In addition, oil based plants are relatively easier to build, the development process is quicker and costs less money. They can generate electricity within no time [39], in contrast to the hydro based plants, which require years to build and start the generation.

The measure, in itself, was an indication of the poor understanding and little or no awareness about the market fundamentals and dynamics. The decision helped to overcome the energy issues in the short-term but had negative implications in the long run. The price of oil was bound to go up and, once it did, having little or no indigenous resources of oil, the import of oil remained the only choice. The mounting prices of oil became a serious burden on the economy and a significant portion of the GDP was spent on covering the energy import cost. The roller coaster prices and increasing energy requirements had a negative impact on the weak economy. As such, the country had to pay the hefty amount for the purchase of oil, which subsequently reduced the generation capacity of the plants and, as a result, supplies started to lag behind the demand.

5.3. Inefficient consumption of natural gas

The domestic production of natural gas started in 1955 and, since then, it has remained an integral component of Pakistan's energy mix. In 2013, almost half of the country's energy requirements were met through this source [12]. Likewise, the significance of natural gas in the electricity generation cannot be overlooked. Approximately 29% of all the electricity produced in the country comes from domestically extracted natural gas [22,33]. As discussed in Section 4.1, Pakistan has exhausted 49% of its recoverable reserves [40] and the remaining resources are expected to deplete in less than 17 years.

Considering the limited domestic reserves and increasing reliance on natural gas, the efficient utilization of this resource was required to avoid gas shortages. In contrast, in 2005, the government of Pakistan recklessly chose to make natural gas available for transportation purposes. The decision was made to reduce the consumption of oil in the transportation sector by providing natural gas as an alternative fuel for vehicles. The choice was not bad in itself, however, the policymakers failed to realize that the domestic resources are already limited and, without ensuring additional supplies, the situation will only get worse.

The policy had a negative effect on the overall energy situation. Having compressed natural gas (CNG) available at less than half of the oil price, over 80% of the vehicle owners converted to CNG. As a result of this policy, Pakistan became a country with the highest number of CNG vehicles driving on the roads after Iran [41]. However, the measure had a devastating effect on the overall electricity generation as supplies were diverted towards the fuel stations. Consequently, less gas was available for the power generation [42]. Due to the limited production and overly burdened natural gas sector, the electricity generation had to use expensive furnace oil. [12,43] exhibits that the share of natural gas in the total generation went from 68% in 2005–06 to 23% in 2013 and, conversely, the generation from oil increased to 35% from 31% during the same period.

5.4. Hydro generation

One of the prime reasons for the present day electricity crisis is the country's inability to maintain the share of hydropower in the electricity mix. Traditionally, hydro has remained the premier source of power generation in Pakistan. During 1980, more than half of all the electricity generation came from hydel. Due to the government's inability to develop new generation plants and track the demand, the overall share started to slide and reached 31% in 2015 (Fig. 7). On the other hand, the share of expensive thermal production increased from 42% to 65% during the same period [102].

Hydro is an ideal choice for a developing country like Pakistan. This is because it is cheap, abundant, indigenous and a renewable source of energy generation. The cost of hydel generation is around Rs. 2–3 per kW h, whereas electricity generation with natural gas costs Rs. 4–6 per kW h. The cost is higher, Rs.15-18, for the companies who generate electricity on Residual Furnace oil (RFO) and High Speed Diesel (HSD), almost five times that of hydel generation [17,44].

Despite all of the lucrative benefits that hydel offers, no noteworthy facilities were developed after the construction of Mangla and Tarbela dams in the late 1970s. The last considerable investment was made in the form of Ghazi Brotha dam in 2002, which brought the 1450 MW generation capacity on stream. It has been over a decade now and no notable investment has been made in this sector. From 2004 to 2012, the overall capacity has increased by a mere 16%, whereas the demand has grown by 27.5%. Talks of developing Kalabagh dam (3600 MW) and Diamer Bhasa dam (4500 MW) have remained in the air for a long time but none of the project has been realized due to political [45] and financial issues [46].

5.5. Transmission capacity

In addition to the stretching gap between the demand and supply, the existing distribution infrastructure is also a huge hurdle in the transmission of electricity to the end consumers. The electricity demand for 2014 was over 23,000 MW. However, the existing infrastructure can only ensure the effective and reliable dissemination of 11,500 MW to 12,500 MW, which is less than half of the total requirements [47]. Transmission of anything over 12,000 MW, for the longer period of time, increases the likelihood of a breakdown in the distribution network [48]. The collapse in transmission network occurs frequently, especially during the summertime when the demand peaks. During the high demand periods, the distribution companies tend to supply the maximum available electricity to the grid. However, the inefficient, old and poorly managed infrastructure cannot handle the burden and this result in its breakdown. The bottleneck of the network adds to the demand-supply gap and further aggravates the crisis.

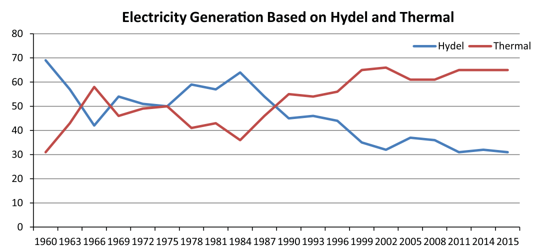

Fig. 7. Decreased share of Hydel in electricity generation from (1960–2015) in Percentage.

5.6. Inefficient support schemes

The energy and power sector has always been subsidized in Pakistan. Like many developing countries, the actual cost was never transferred to the people and subsidies covered a sizeable portion of the generation price. The government provides a huge amount of money in the form of subsidies to the distribution companies to cover the difference between the generation and sale price [49]. The rationale behind the financial support is to reduce the burden on consumers. The increased share of thermal in power generation has elevated the electricity generation cost in Pakistan. On the current electricity generation portfolio, the incurred price is around Rs. 14.95 per kW h, while the realized tariffs for the household and industrial users are Rs. 8.66 kW h and Rs. 11.21 kW h, respectively. The government is subsidizing Rs. 5.10 for households and Rs. 3.74 per kW h for the industrial users [40].

Over the past five years, the government of Pakistan has paid approximately $ 3 billion a year in terms of subsidies [50]. Furthermore, it is argued that the subsidies are not well directed and are less beneficial to those who need it the most [5,18]. According to State Bank of Pakistan (SBP), the users that consume a high amount of electricity (more than 700 kW h) receive Rs. 6600 in subsidies, compared to the lifeline users (consuming 100 kW h a month), who receive less than Rs. 450 a month [50]. According to [18], only 0.3% of all the subsidies go to the deserving segment of society.

The situation was not like this until the 1970s, when the international petroleum prices followed the upward trend and subsidies started to become a serious burden on the country's GDP. Back then, the government decided against the adjustment of domestic prices, presuming that the increased tariff would impact the life of a common person. As time progressed, the petroleum prices continued to climb and the burden of subsides became unbearable for the government. The decision of not regulating the local prices in accordance with the international market reduced the revenues of the institutions involved in the power sector. For instance, the Water and Power Development Authority (WAPDA), a state owned institution responsible for electricity generation, failed to invest in the development and maintenance of power generation facilities and infrastructural setup.

The power policy of 2013 stated the aim of eliminating the subsidies in phases and to transfer the actual cost to the end users. This support will only be given to the deserving segment of society, i.e., the lower 20% of the population in terms of GDP per capita. It is estimated that this measure will reduce the deficit to 0.4% of the GDP from the existing 2% [5]. The first half of 2014 witnessed a reduction in subsidies and escalated prices. The cost increased by 160% from the fiscal year 2008–09 to October 2014 [51]. However, It is widely believed that the full elimination of subsides may not be as easy as it sounds. The removal will increase the per unit price to the substantial level and could possibly result in inflation, public anger, dissatisfaction with the government performance and a situation leading to public riots and instability of the government.

5.7. Circular debt

Pakistan's power sector is operated by both the state owned and private sector. The involvement of private actors in the state owned network did not occur until the mid-1990s, when the government announced the first power policy in 1994 to encourage private sector involvement in the power generation. Since then, the contribution from private power producers has increased on a yearly basis. Asian Development Bank (ADB) states that, in 2014, more than 56% of all the generation came from independent power producers (IPPs) [5]. The government purchases electricity from the IPPs and supplies to the end users through distribution companies.

The issue of circular debt emerges when the government is unable to pay back the money that it owes to the private producers. Once the payment is delayed, it becomes difficult for the private producers to operate their plants on the optimal capacity (Fig. 8). Reduced capacity further stretches the gap between demand and supply, making the situation even worse. Practically, the system should work in a loop - the revenue from the sale of electricity should balance the amount that the government owes to the IPPs and so forth. However, in actuality, the receivables are less than payables and the bulk of the money has to come from the government to cover the inefficiencies. The following are some of the prime reasons for the circular debt in Pakistan.

Pakistan's existing infrastructure is old, inefficient and has huge transmission and distribution (T&D) losses. According to Javaid et al. almost 22% of the electricity gets wasted during dissemination [21]. The ratio is high for a country that is already struggling to keep the generation up with the requirements. According to Malik, T&D in Pakistan is fairly high compared to the global average of 8.8%, while the distribution losses in China, the OECD and Korea are accounted as 8%, 7% and 4%, respectively [52]. [53] states that over half of all the distribution losses in Pakistan are caused by non-technical factors such as billing problems, administrative issues and electricity theft. Patel and Zhao claims that companies can retrieve only 76% of the money that consumers owe them [54]. Planning Commission [55] affirms that the line losses and power theft cause the loss of over Rs. 150 billion per annum over the last five years. According to [53], in Punjab, 13% of all the electricity gets wasted because of this theft. This percentage is even higher in Sindh and KPK, with the respective share of 35% and 36%.

The imbalance between the receipts and payments cascades through the whole energy generation network, from the fuel providers to the electricity generation companies in public sectors and IPPs. This results in the increase of load shedding. In 2013, the amount of circular debt crept over Rs. 500 billion [56]. The government decided to pay off the debt in order to let the IPPs and generation companies' work to their full capacity. However, due to inefficiencies, within a year, the amount had again reached Rs. 300 billion [57]. Despite all of the government's efforts to increase tariffs and eliminate subsidies, the equilibrium between receipts and payments cannot be achieved unless the issue of circular debt is resolved on a priority basis.

6. Unsustainable energy mix

The current generation mix is highly skewed towards the thermal, with oil and natural gas leading the production. The existing energy portfolio is not sustainable in the future due to the increase in generation related emissions (see Fig. 9) and the likely rise in the electricity prices (Fig. 10), which would make it unaffordable for the masses.

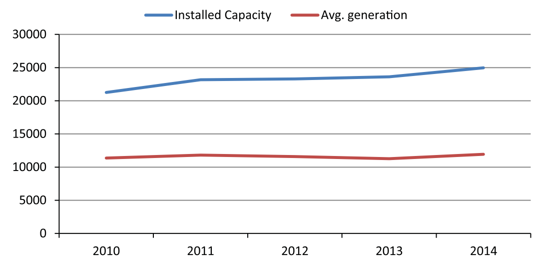

Fig. 8. The gap between installed capacity and avg. generation in MWs.

The rising level of carbon (CO_2) emissions is a great concern for the environment in Pakistan. According to Kafaitullah, the energy sector contributes over 80% of all the CO_2 emissions in Pakistan [48]. In 2010, Pakistan produced 164 million metric tons (MMT) of carbon emissions, out of which 42 MMT came from electricity, approximately 25% of all the emissions [58]. In 2013, the overall emissions have reached over 166 MMT [108]. If cleaner means of energy generation are not adopted and generation remains thermal dependent, the emissions are likely to boost in the foreseeable future. By the end of 2030, the carbon related emissions are projected to reach 123 MMT, a threefold growth from 2010. Likewise, the share of nitrogen (NO) and sulphur (SO_2) related emissions are also estimated to increase by four and seven times, respectively. Conversely, if the country opts for generation from renewable energy and other cleaner sources of production, the emissions are projected to decrease by 50% in CO_2, 60% of SO_2 and 61% in NO [59].

The high cost of electricity generation is another factor that makes the portfolio unsustainable. The reliance on expensive fossil fuels for the generation is likely to increase the per unit price in the future. According to the survey conducted by Sustainable Development Policy Institute (SDPI), more than 80% of people in Pakistan are not willing to pay an extra cent for electricity, even if it eliminates the crisis completely [18]. The prices are already so high that any further increase would make it unaffordable in the long run. The estimation of [39] suggests that, by 2020, the cost of electricity generation from the renewable energy sources will be less than half of the thermal based generation in Pakistan.

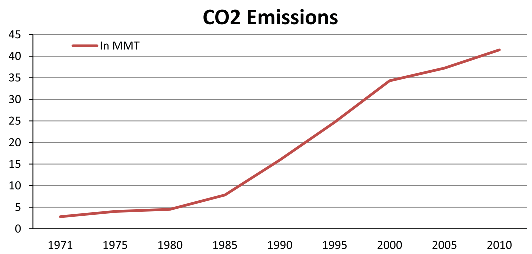

Fig. 9. Electricity related CO_2 emissions in Pakistan.

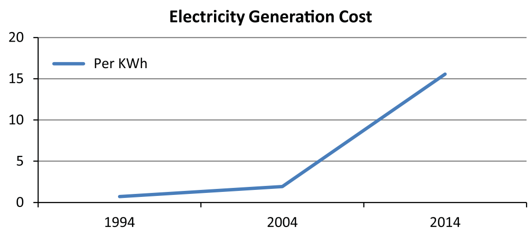

Fig. 10. Electricity generation cost per kW h in Rs.

7. Electrification from RES

The share of Renewable Energy Sources (RES) in the present energy mix is negligible. The scarcity of the indigenous hydrocarbon resources, excessive dependence on fossil fuels, volatile fuel prices and environmental concerns leaves the country with no other option but to focus more on the development of indigenous and abundant RES for the energy generation.

RES are emerging as one of the fastest growing sources of energy generation across the globe. REN21 states that the renewables accounted for approximately 10% of the global energy mix in 2012 and their share is likely to reach 15% by 2040. According to Global Wind Energy Council [60] from 2004 to 2011 the annual investment in renewables has increased by 30%. Electrification from the RES is gaining momentum worldwide. Renewable Energy Network's [59] figures shows that the global electricity generation capacity from RES exceeded 1.5 TW in 2013, an overall increase of 8% from the previous year. The increasing political and investment support programmes have enabled technologies to thrive and play a notable role in meeting electrification challenges in an environmentally friendly manner. In 2013, RES accounted for an estimated 26.4% of the world's power generating capacity and more than half of the new electricity generation installations worldwide [61]. For six consecutive years, renewables have remained the single largest source of electricity generation in the EU and the trend is likely to continue [59].

As discussed in Section 2, Pakistan is beset with serious issues of sustaining its energy supplies. The energy demand is expected to grow, while the projections from the supply side are not optimistic. The country needs to take drastic steps to ensure that the electricity generation balances the demand. In order to do so, Pakistan must explore its indigenous and abundant renewable energy sources. RES surely have the potential to supplement future needs in a sustainable and effective manner. The following section briefly discusses the renewable sources and their potential in Pakistan.

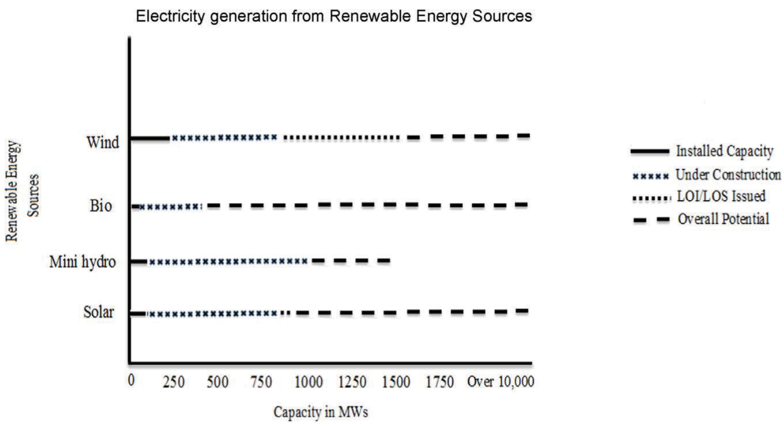

Fig. 11. Actual and potential energy generation from RES in Pakistan [105].

8. Renewable energy sources in Pakistan

The RES may well be the long-term solution to Pakistan's abysmal energy crisis. Pakistan holds a land area of approximately 800,000 km^2 with plenty of sunshine, wind and water. Being an agrarian country, there is an abundance of agricultural residues, crops and waste that could be effectively utilized for energy generation purposes. Pakistan is a populous country with over 190 million inhabitants. According to [60], more than 30% of the population does not have access to electricity at all. The [61,62] states that 44% of the rural households and over 40,000 villages across the country are not yet connected to the main grid. Harnessing the potential of solar, wind, biomass and hydro can very effectively meet the energy needs of the rural areas, as well as contributing to the economic development of the country (see Fig. 11) [63]. The following section explores and discusses the different RES with their potential.

8.1. Solar

Energy acquired from sun radiation is known as solar energy. According to the needs, the radiations can either be transformed into heat or electricity. The two widely acknowledged procedures of generating electricity are known as the solar photovoltaic and solar thermal conversion. Solar photovoltaic (PV) cells convert the heat into electricity straight away, whereas solar thermal uses thermal collectors to generate a stream by heating the liquids and subsequently making the electricity like a standard stream turbine power plant. Solar energy has gained worldwide acceptance and the technology is experiencing a staggering growth. According to EPIA [65], over the last decade, the solar PV has witnessed the highest growth of 28%, second only to wind energy. Over the last five years, the worldwide capacity of solar PV has increased by 55% [59]. In 2014, the solar PV has witnessed the highest worldwide growth in terms of installed capacity.

Pakistan lies on the sunny belt and has the significant potential of solar energy. The United States National Renewable Energy Laboratory (NERL), in collaboration with the Alternative Energy Development Board of Pakistan (AEDB), conducted an assessment to measure the solar energy potential in Pakistan [66]. The report states that the country is situated in the region where most of the days are long and sunny with high solar radiations and insulation, which, in practice, is ideal for the development of solar energy projects. On average, the country receives 15.5 × 1014 kW h of solar radiations per year with most of the areas having 8–10 h of sunlight a day [67]. The assessed potential is around 1600 GW annually, more than 40 times the existing power generation capacity [68]. According to Chaudhry et al., the Baluchistan province is one of the best in terms of solar irradiation potential, with 8.5 h of average sunlight per day and 20 MJ/m^2 of solar insolation [69]. In addition, the deserts in Punjab, Sindh and Cholistan have high solar energy development potential. Furthermore, these regions are infertile and could hardly be used for an alternative purpose, thus making this place an ideal for the solar installations.

Despite these favourable conditions and huge potential, the solar energy in Pakistan is in its earlier stages of development. During 1980s, the government of Pakistan realized that solar energy could play a vital role in meeting the country's requirement in the long run and installed 18 photovoltaic systems with a combined capacity of 450 kW h [70]. However, due to the lack of technical understanding and poor management, these installations did not generate the desired results and were abandoned.

In 2003, the government of Pakistan established AEDB to accelerate the development of renewable energy technologies (RETs) and ensure technical and managerial support to tackle obstacles [71]. The AEDB has provided electricity to over 30 villages and around 17,000 houses by using solar PV technology in rural areas of Punjab. Similar projects are under way to power 3000 villages and 12,000 houses in the province of Sindh and Baluchistan. The government of Pakistan (GOP) has initiated a mega project, Quaid-i-Azam solar energy generation, the first of its kind, which will produce electricity from the solar PV on a commercial basis. The project is expected to generate 100 MW of electricity in the beginning. However, the capacity is anticipated to increase up to 1000 MW with the help of public and private partnership [72]. The project has come on stream in 2015 [103]. Moreover, in order to accelerate the development of solar, in the 2014–2015 budget, the GOP has waived all of the duties and taxes on the imports of solar technology [73]. This measure will slash the cost and increase the number of solar installations across the country.

8.2. Biomass

Traditional biomass has been used as a primary source of energy generation for thousands of years. IEA defines biomass as any organic, decomposable matter derived from plants or animal available on a renewable basis [74]. Biomass includes wood, agriculture crops, herbaceous, woody energy crops, municipal organic wastes and manure [104]. Bio energy is the most widely used form of energy. In 2014, the share of biomass was 10% of the world's total primary energy supplies [75]. The consumption is relatively high in developing countries, where traditional biomass accounts for over 80% of the total energy generation. According to REN21, over two and a half billion people rely on traditional biomass for cooking and heating purposes [59]. The use of biomass is likely to increase in the future and global bio energy production is estimated to reach 3000 TW h by 2050 [76].

Biomass also has huge potential in Pakistan. Pakistan is an agricultural country and around 62% of its population lives in villages and rural areas [77]. The majority of populace in these areas is directly or indirectly involved with agriculture and agricultural related professions. The traditional biomass, such as fuel woods, cow dung and agriculture residues, are the principal source of energy generation in these areas [78]. According to Amjad el al., there are over 160 million animals in Pakistan with a growth rate of around 9% annually [79]. On average, each animal drops 10 kg of dung every day. The utilization of the dung alone, in an efficient manner, can serve the heating and cooking needs of more than 50 million people, which is roughly 40% of all rural population [46]. However, at the moment, most of these resources are utilized as an unprocessed fuel. According to Mirza et al., households utilize 1500 kg of dung, 1200 kg of crop residues and over 2300 kg of fuel woods [64]. The consumption of resources in a traditional way is 25% less efficient and produces gases that are harmful to humans.

Biomass is one of the renewable sources that are being developed at a rapid pace. So far, the Pakistan Council of Renewable energy technology (PCRET) has installed 5357 bio gas plants (with a net generation capacity of 12–16 million m^3/day) on a cost sharing basis [112]. The AEDB, in collaboration with different organizations from the USA, Germany and Denmark, has estimated the potential of bagasse and waste for power generation in Pakistan. The estimation shows the potential of 1800 MW from bagasse and 500 MW of from waste [48,50]. However, it is widely believed that considering the quantity and readily availability of resources, the current development is nothing compared to the potential [46,47].

8.3. Wind

Globally, the development of wind power has gained momentum. Currently, the worldwide production of wind power, mainly onshore installations, has reached 282 GW in 2012, with an average growth rate of over 25% over the last five years. The total global wind capacity doubles every three years and the cumulative market is predicted to reach 900 GW by 2020 [80]. A study conducted by Wind Energy Council [60] concludes that an effective utilization of just one fifth of the economically viable wind resources can easily meet the world's electricity consumptions by seven times over. Currently, more than 83 countries are using wind power and its development is most advanced in China and the USA, followed by Germany and Spain [81]. According to European Wind Energy Association a number of European countries generate over 10% of electricity from wind [82].

Likewise, Pakistan is endowed with enormous resources of wind power. Pakistan's Alternative Energy Development Board (AEDB), in cooperation with National Renewable Energy Laboratory (NREL), USAID and Pakistan Meteorological Department (PMD), has developed the country's first wind map [83]. The assessment has shown propitious wind power potential in different regions including Sindh, Baluchistan and some areas of Punjab. The commercially exploitable wind sources are estimated as 346 GW [84]. The AEDB has identified a number of sites to install wind generation facilities, across the country, with the help of the private sector. One such site is the Ghoro- Keti Bandar wind farm - an area that stretches along the shoreline of Sindh province and has an average wind speed of 7 m-s at 50 m above the ground level. The power density is calculated as 400 w/m^2 with a capacity factor of 25% [85]. In these conditions, a place becomes ideal for the installation of large-scale commercially viable wind farms. The assessed potential of the site is over 60 GW [86].

However, despite its substantial potential, its actual contribution to the total primary energy supply is negligible. To this end, 2014 has witnessed the highest input of 106 MW from wind power [12], which is less than 0.2% of the total electricity consumption [33]. The addition of wind in the country's energy mix is a result of the positive intent that the government has shown in the development of this resource. The AEDB has now issued licenses to numerous companies and a number of new projects have been set up by domestic and international companies. The government plans to develop at least 30 GW of power generation from wind by 2030 [87].

8.4. Hydro

Energy generation from moving water is known as hydro or hydel power. Evidently, hydro is the largest source of renewable energy generation, with the potential of competing with the conventional source of energies like oil, gas and coal. According to REN21 one-fifth of the worldwide electricity supply and 87% of the electricity generated from renewable energy sources (RES) comes from hydro [59]. Globally, the technical potential of hydro is unlikely to constrain further development, as hydro is technically mature, can compete on prices and is being deployed at a rapid pace. Currently, more than 160 countries are using hydropower and its development is advanced in some of the richest and environmentally conscious states such as China, Brazil, Canada, the USA and Norway [81]. According to Altinbilek et al., the true potential of hydro is yet to be realized, as one third of the realistic hydro potential remains to be utilized [88].

Hydro also plays an important role in Pakistan's electricity generation. The country's total electricity generation capacity is 23,000 MW, out of which 6500 MW is produced by hydro, constituting 34% of the total generation capacity [7]. The country's total hydel potential is estimated as 100 GW, with the identified sites of 59 GW [89]. The public and private sector has installed over 300 micro and mini hydroelectric power plants in the areas that are not connected to the national grid [90]. Recently, the government initiated a plan to build small-scale hydropower projects in the northern areas of Pakistan. Moreover, WAPDA has planned to generate at least 16000 MW of electricity from hydel by 2025 [33].

9. Power generation polices in Pakistan: a synopsis

Since 1990s, the government of Pakistan has formulated and implemented a number of policies to cope with the rising energy needs of the country. The first comprehensive policy was announced in 1994, with the intention of involving the private sector in a state dominated power infrastructure [91]. The aim was to offer lucrative packages and globally competitive incentives, eliminate extra procedural steps and provide a favourable investment climate to gain investors' interest in the development of power generation projects. The stated policy prompted interest from investors and generated a favourable response. However, almost all of the investments were proposed in the thermal based power generation projects. A year later, the government of Pakistan announced a power policy with the objective of inviting the private sector to invest in hydel generation. Hydro, being the cheapest and abundantly available form of electricity generation, can provide great benefits to a country like Pakistan [92].

Considering the rising energy needs and the state's inability to keep up the sector on its own, in 1998, the government of Pakistan announced a new power policy. The purpose was to restructure and privatize the thermal based power generation facilities, transmission and distribution network and denationalization of state owned utilities. It projected the government's intention to encounter the rising electricity requirements through developing a competitive power generation market in Pakistan [93]. The proposed policy framework was developed to interest the private sector and entrepreneurs by offering them the lowest per kWh tariff. The government intended to play a proactive role by making sure that the initial projects were based on indigenous coal and hydel. However, the policy failed to entice the desired objectives and participation from private actors remained inadequate [94]. The failure led the government to revisit its policies and devise new plans to allure the private sector interest, while ensuring that the prices remains at an affordable level.

The power policy of 2002 carried the vision of private-public partnership in the power sector. The policy not only focused on the development of indigenous renewable energy and human resources but also, stated a target of developing at least 1500 MW of renewable energy generation (non-hydro) by 2020 [95]. However, the policy failed to provide a comprehensive framework and plan for the development of indigenous renewable resources [67]. In 2006, the country announced its first ever renewable energy policy, which emphasized the development of small-scale hydro, solar photovoltaic and wind power projects in Pakistan [96]. The key objectives were to ensure energy security by utilizing indigenous resources, spreading the electricity to the villages and rural areas and protecting the environment by reducing emissions. Five years later, the government announced a new policy, the midterm framework of 2011. In its core, this policy carried the same objectives as the policy of 2006, with placed focus on indigenous resource development and reiterated the AEDB's objective of meeting at least 5% of energy requirements through renewable by 2025 [97].

Despite all of these measures and policies, to date, the supply of energy has lagged behind the demand and the shortfall has reached a level where load shedding has become a routine matter. The latest power policy was announced in 2013, with the aim of tackling the gap between demand and supply in a sustainable and cost effective manner. The main objectives are to reduce the cost of electricity generation, increase revenue collection by reducing trade and distribution losses and focus on the development of indigenous resources. The policy aims to bring the shortfall to 0 MW by the end of 2017 [98]. The following table 1 presents a summary of all the energy policies introduced by the country.

10. Discussion

Pakistan's energy sector, which is a pivotal contributor to the overall economic growth, is undergoing an acute energy crisis, especially with regard to electricity. The root cause of this debacle goes back in history and can be attributed to decades of mismanagement, short-sightedness and negligence. Traditionally, the demand has witnessed a quick rise, while supplies have remained dearth. The power generation and transmission infrastructures were primarily owned and managed by the state governed institution, Water and Power Development Authority (WAPDA). WAPDA was responsible for the distribution of electricity, maintenance, upgradation of power infrastructure and installation of additional capacities. Malik [52] states that the institute performed fairly well until the 1980s, when demand and supply grew abreast. The first major signs of supplies lagging behind the demand appeared in the early 1990s, when demand exceeded supply by 15–20%. The government took immediate actions and decided to bridge the gap by establishing thermal based power generation plants. The installation of the additional capacity of thermal seemed an obvious choice, as it required less time and resources to develop.

The policy turned out to be a double-edged sword for Pakistan. The approach yielded reasonable outcomes in the short-term, as supplies were quickly brought on stream. However, the plan produced disastrous consequences in the long run, as the government solely relied on the thermal generation and failed to focus on the cheaper, indigenous and sustainable source electricity generation, as shown in Fig. 12 [99,106]. The prices of oil started to rise in the international market, which subsequently raised the electricity generation price in Pakistan. Instead of transferring the actual cost to the consumers, the government started to give a hefty amount in the shape of subsides to keep the prices stable.

Realizing the limited resources and inabilities to meet the generation requirements, the government involved the private sector in power generation. The participation of the private sector in large, state owned, infrastructure was the first step in the right direction. However, unfortunately, the government failed to engage the private actors in an efficient way. Almost all of the investments to date are made in thermal based power generation plants and renewable energy sources based IPPs accounts for less than 2% of the total electricity generation [12]. The government's failure to entice the investment in cheap and indigenous renewable sources led thermal dominating the generation. Moreover, the transmission and distribution losses, electricity theft, issues of non-payment and energy related subsidies further contributed to the capacity constraints.

The majority of the policies that were intended to improve the situation hardly made any sense. The budget of 2014–15 allocated over Rs. 200 billion for brining 1300 MW capacity on stream by developing the projects that are in the pipeline; 80% out of which are natural gas based. The policy completely overlooked the fact that the country is already facing a gas shortage. According to [100], around 70% of all the existing gas based installations are not able to work to their full capacity. Unless the supplies of gas are ensured, the plans are unlikely to improve the condition [50].

To this end, the performance of the state based institution requires improvement. The policies from 1994 to 2013 failed to achieve the stated targets. The renewable energy policy of 2006 and 2011 aimed to accelerate the development of renewable energy sources in Pakistan. The goal was to attain at least 5% of electricity generation from renewable energy sources. Likewise, the policy of 2011 stated that the share of RES would increase to 15% by 2015. However, after almost a decade, the policy has failed to achieve the objectives and the share of renewables in electricity generation is less than 1%.

Similarly, the power generation policy of 2013 stated an ambitious target of eliminating the gap between generation and consumption by the end of 2017. However, considering the sector's performance, the resource base and the gap between demand and supply, it is unlikely that this objective will be achieved. At the moment, the situation looks quite bleak and the crisis seems to have been prolonged at least until 2020, if not any further. It can only be improved if the government takes immediate action concerning spreading the resources base and ensuring ample supplies of natural gas [6,39].

The government of Pakistan is now in the process of implementing net metering in Pakistan. The crisis has enforced individuals and industries to make self-arrangements for the power generation. This measure will allow excess electricity to be transmitted to the grid. Once implemented, the Solar PV generation is likely to play a key role in the success of this initiative [110]. However, to this end, the diffusion of solar system is in its early phases. The widespread adoption of solar is very dependent on the successful promotion, market mechanisms and incentives for the consumers [111]. The main barriers in the adoption are lack of public awareness, trust in the technology and high upfront installation cost. The stakeholders involved in the process should play their parts in encouraging the use of environmental friendly and cheap sources of power generation. Moreover, the government should introduce innovative micro-financing measures to increase the affordability for the consumers.

It is also explicit that no real efforts have been made in developing local capabilities and encouraging research and development tasks at the local level. Almost all of the renewable

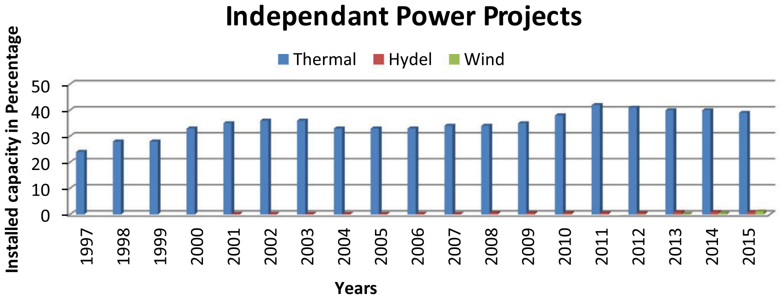

Fig. 12. Independent power projects based on thermal, hydel and wind.

energy systems are imported in Pakistan, which increases the cost. During all these years, very little has been done to encourage collaboration between the state, industry and academia to promote cooperation and develop technologies at the local level. A step taken in this direction will provide employment, promote local industry, develop competitiveness and help achieve objectives in the long run.

In an effort to seek for the development of renewable energy for power generation in Pakistan, an internal micro-environmental analysis should be conducted to evaluate the relevant strengths, weaknesses, opportunities and threats (SWOT) [107]. SWOT analysis has been widely utilized for the strategic planning purposes by industry and academia. SWOT analysis helps highlight the strengths and weaknesses of the prevailing energy system. It also allows us to explore the opportunities that the country can capitalize on, and the indication of the potential threats that can delay achieving the set goals. The SWOT analysis will help to propose actions and measures that can be suggested in the roadmap. The main findings of the SWOT analysis are illustrated in Fig. 13.

11. Recommendations

The power sector of Pakistan is in a state of complete chaos: the per unit electricity generation prices are extremely high, the transmission network is facing bottleneck, the demand is superseding the generation and the transmission and distribution losses are colossal. The demand of electricity is expected to increase, whereas the supply side is facing serious constraints. The existing resource base is expected to shrink, putting an additional burden on the already weak generation system (Fig. 14).

The lack of indigenous hydrocarbon resources and the energy crisis at hand provides a great opportunity for Pakistan to develop the indigenous sources including renewable energy that renders excellent potential for meeting the country's long-term energy needs. The existing low prices of oil in the international markets are no less than a blessing for importing countries like Pakistan. The decrease in prices has reduced the cost of electricity generation, as well as the amount that the government pays to the distribution companies in the form of subsidies. The reduction of over 50% of the energy export bill offers an excellent opportunity for the government to initiate new projects with the help of the private sector and bring new generation capacities on stream. Based on the comprehensive analysis of the electricity sectors, the following are some of the major issues and recommendations for the policy-makers in Pakistan.

The most important step is to eliminate load shedding and ensure the smooth and uninterruptable electricity supplies to the population. This matter can be resolved by addressing the issue of circular debt and upgrading the transmission network on the priority basis. T&D losses ought to be brought down, revenue collection must be increased, and the investment should be made in the transmission infrastructure. The upgradation of dissemination network and the addition of new generation facilities should be done simultaneously. A priority should be given to the development of hydro generation, as the source is abundantly available and generation cost is very nominal (Table 2).

To this end, the vision of increased electricity generation from renewable sources is very dependent on the right level of involvement from the private sector. The government should offer lucrative packages, incentives and purchase guarantees to trigger the investment in this sector. In addition, the state should play a

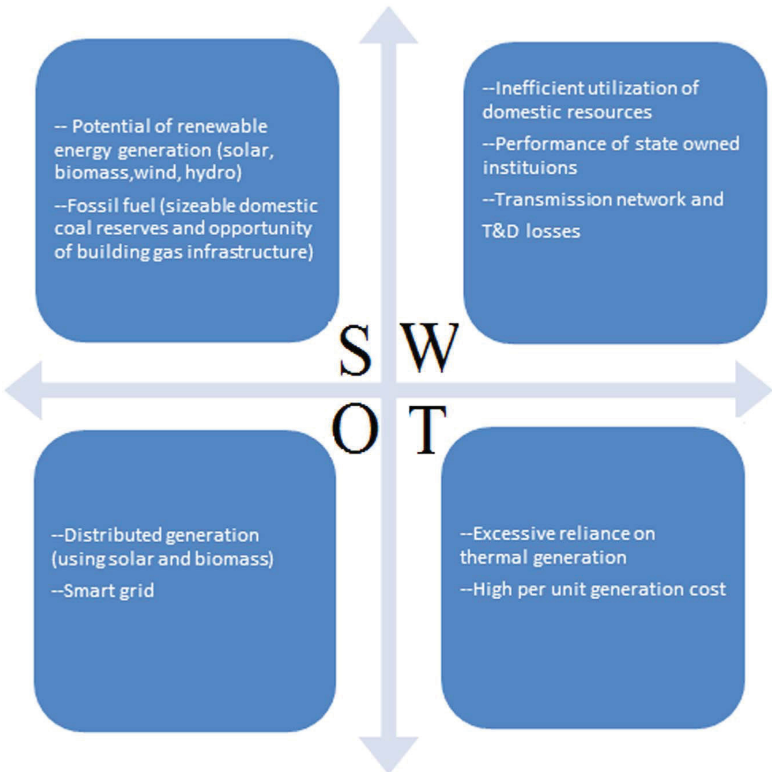

Fig. 13. SWOT analysis of Pakistan energy sector.

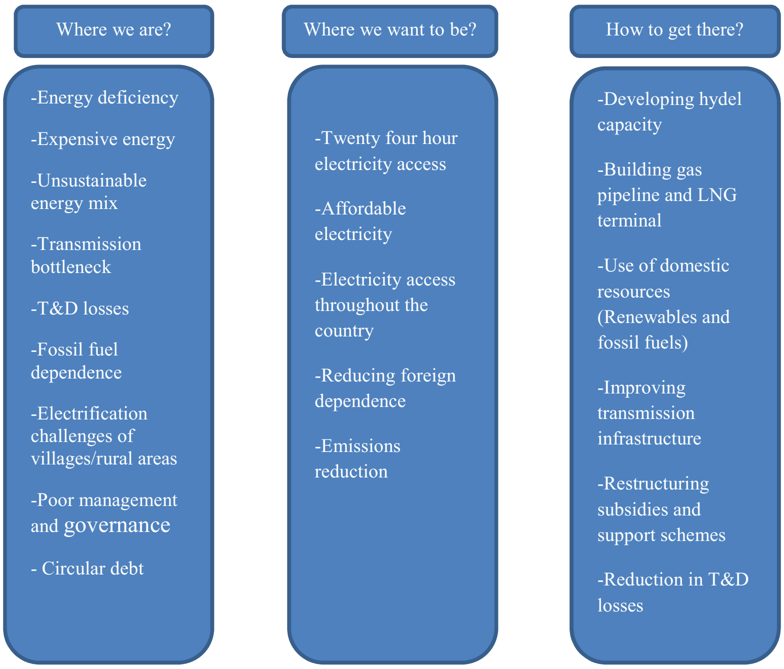

Fig. 14. Assessment of Pakistan's electricity sector.

Table 1
Summary of power generation policies in Pakistan.

Policy	Key objective(s)	Year
Policy Framework and Package of Incentives for Private Sector Power Generation Projects in Pakistan	To increase the private sector involvement in the state dominated power infrastructure	1994
Policy Framework and Package of Incentives for Private sector Hydel Power Generation	To encourage private sector investment in hydropower projects	1995
Policy for New Private Independent Power Projects	Privatization of thermal based power generation facilities, transmission network and denationalization of state owned utilities.	1998
Policy For Power Generation Projects	Developing indigenous energy sources with the involvement of the private sector	2002
Policy for Development of Renewable Energy for Power Generation	Development of small scale hydro, solar photovoltaic and wind power projects in Pakistan	2006
Alternative and Renewable energy policy	Reiterated the interest of renewable energy development	2011
National Power Policy 2013	To meet rising electricity requirement in a cost efficient manner, reduce T&D losses and development of renewable sources	2013

Table 2
Roadmap for renewable energy development in Pakistan.

Milestone	Time frame[a]	Outcomes/objectives	Measures required
Eliminate load shedding	Short-term	Zero hour load shedding	Addressing the issue of circular debt (detailed in Section 5.7)
Developing sustainable energy mix	Medium/long-term	Emission reductions and reduced per unit price	Developing independent power generation plants on natural gas and local renewable energy sources
Five percent of the total generation from RES(excluding large hydro) by the year 2025	Long-term	Inclusion of renewable energy in the generation mix	Encouraging the private sector to invest in RE generation by offering lucrative packages, incentives and purchase guarantees
Sixty per cent electricity from hydel sources	Medium/Long-term	Cheap and emissions free electricity generation	Building small-scale hydel capacity and construction of proposed Neelam Jhelum, Dasu and Diamir-Basha dams
Electricity access throughout the country	Long-term	Connecting villages to the national transmission grid	Extending the transmission network to the villages and rural areas, in phases
Smart grid/Net Metering	Medium-term	3000–4000 MWs in the National transmission system	Fostering the development of net metering to get additional supplies from the domestic, commercial and industrial sector
Distributed generation	Medium/ Long-term	Standalone generation plants across the country	Encouraging private actors and community organizations to develop solar and bio based generation plants in the areas where local potential is available and national grid is non-existent. Innovative financial mechanisms and public awareness

[a] Short-term: 2–5 years, Medium: 5–10 years, Long-term: 10–15 years.

proactive role and encourage local and private sector players to develop small-scale power generation plants in the rural areas, which can fulfill the electricity requirement of the local community without adding extra burden on the national grid.

12. Conclusion

The existing energy crisis is the result of a lack of foresight, flawed policies, poor decision-making and lack of seriousness to address the issue on the government's behalf. The issue cannot be resolved without the strong commitment of the government and steps taken in the right direction. The study has presented a comprehensive overview of the Pakistan energy industry and has provided decision-makers and policymakers with an insight into how the energy technology and resource development should go from here onwards. A technology roadmap is developed to address the key issues such as supplies of energy, rising energy prices, electrification of the rural areas and development of indigenous energy sources.

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The role of personal and institutional factors in influencing academics' tendency to engage in commercialization of academic research

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Abstract

The commercialization of academic research has gained significant attention in the recent past. The existing literature has highlighted a number of factors influencing university-industry collaboration and commercialization of academic research. This study seeks to explore the role of personal and institutional factors in shaping academics' tendency to engage in the commercialization of research. The research is based on primary data collected from 891 academics working in Finnish universities. The findings highlight that researchers' intentions to commercialize, their entrepreneurial orientation, the effect of working in multidisciplinary teams, their prior commercialization experience and their familiarity with the Technology Transfer Office (TTO) positively impact their decision to commercially exploit research results. Time allocated for the research and excellence in research do not have an impact, whereas the effect of services offered by the TTO—tested through the moderation effect—is neutralizing, signalling that the services offered by TTOs are yet to reach to a level where the interaction could enhance the positive impact and improve the likelihood of commercialization. The result of discipline dummies highlight that academics' working in biotechnology have higher tendency of engaging in commercialization activities. This research has several theoretical and policy implications.

Keywords: Commercialization; University-Industry collaboration; Academic entrepreneurship; Technology transfer offices; Finland

1. Introduction

Universities and educational establishments are pivotal to a country's success and competitiveness in the international arena (O'Shea et al., 2005). Universities have traditionally been considered as institutions responsible for the education and training of the workforce, which can contribute to industry. However, in the past few decades, the university's traditional role has been challenged (Etzkowitz, 1983) and this public-sector institution is now expected to take on an additional role, referred to by Sutz (1997) and others (Etzkowitz and Leydesdorff, 1999; Mazzoleni and Nelson, 2005) as the third mission, which contributes directly to economic activity rather than being limited to education and training alone. The extension of the university's role into this new domain appears natural to some (Geuna, 1998) since universities, as institutions, are the recipients of a significant amount of public and private funding and enjoy the luxury of hosting some of the brightest and skilled minds in their respective fields. Thus, it becomes inevitable for a country to allow its institutions to work in isolation and not to take advantage of complementarities that may arise from their interactions (Ankrah and Al-Tabbaa, 2015). Evidence suggests that both universities and industry can benefit from this interaction (Zucker and Darby, 2001). Universities can directly contribute to society, can have new equipment and laboratory facilities, access to additional financing, the possibility to share ideas, collaborate with colleagues working in companies as well as providing students and young researchers with opportunities to gain exposure by working in industrial settings (Cyert and Goodman, 1997; Larsen, 2011; Lee, 2000). Similarly, for companies, collaboration can improve their public image, ensure access to complementary research, reduce the cost of research and development, ensure sustainable competitive advantage and improve financial performance (Bell, 1993; Cohen et al., 2002; Grant, 1996). However, there have been concerns about the idea of integrating commercialism into the academic sector (Rosenberg and Nelson, 1994). Historically, academics have enjoyed the independence of choosing the topic they deemed important and their work has been freely available in the form of publications. The commercialization of academic research can damage the open dissemination of knowledge (Poyago-Theotoky, 2002) and may narrow the focus of research to areas that have potential to produce commercial gain (Azoulay et al., 2009). Research conducted by Blumenthal et al. (1996), Walsh et al. (2007) and Louis et al. (2001) has supported the claim that researchers have been found to maintain secrecy, are reluctant to share their findings in order to protect potential commercial gains and are likely to take on research topics that are closer to the interests of industry

(Larsen, 2011). Scholars such as Nelson (2004) and Murray and Stern (2007) maintain that collaboration for commercial gain can be detrimental to science and to the production of knowledge for societal good.

The issue of university-industry collaboration and the commercialization of academic research was highlighted during the last half of the twentieth century when a number of initiatives were undertaken in the United States to translate the knowledge produced in universities to ensure commercial gain (Mowery et al., 2001; Sampat, 2006)—among these measures, the Bayh-Dole Act of 1980 received particular attention (Aldridge and Audretschab, 2011). This Act strengthened the universities' position by introducing a favourable ownership structure and encouraging them to commercialize their research in order to benefit economically from research results (Franklin et al., 2001). In response to this new legislation, a number of universities in the US made structural changes to reap the benefits (Mowery and Sampat, 2005). The success of this initiative, in the form of improved linkages with industry and financial benefits, led universities across Europe and elsewhere to follow a similar path, assisted by supportive legislation and policy frameworks (OECD, 2003; Phan and Siegel, 2006).

University-industry collaboration and the commercialization of academic research has become an interesting topic for researchers and the literature on this subject has expanded (Kirchberger and Pohl, 2016; Perkmann et al., 2013; Phan and Siegel, 2006; Rothaermel et al., 2007). The emphasis has been on exploring the factors that distinguish between universities that are more active in terms of collaboration and those that have achieved only limited success in identifying factors that can ensure the successful transfer of university knowledge. Universities are complex organizations (Bercovitz and Feldmann, 2006) and the successful commercialization of academic research is very much dependent on the academics working in the university setting as well as a supportive organizational structure (Clarysse et al., 2011). In attempting to understand this phenomenon, researchers have investigated this emerging paradigm using different lenses from organizational studies (Ambos et al., 2008), strategic management (Powers and McDougall, 2005), psychology (Jain et al., 2009), biology/genetics (Nicolaou et al., 2008) and entrepreneurship (Guerrero and Urbano, 2014).

From an organizational perspective, extant research has particularly focused on the development of the technology transfer office (TTO) and the resulting impact on the transfer of knowledge

(Ambos et al., 2008; Feldman et al., 2002), demographic factors and the location of the university (Chapple et al., 2005; Leitch and Harrison, 2005), the quality of the university (D'Este and Patel, 2007), the extent of faculty involvement (Jensen and Thursby, 2001) and the influence of external factors (Friedman and Silberman, 2003). On the other hand, research that has focused on individuals as the unit of analysis has placed greater emphasis on the role of personal characteristics (O'Shea, Rory ; Allen, Thomas ; O'Gorman, Colm ; Roche, 2004), expertise (D'Este et al., 2012), status (Link et al., 2017), attitude (Krabel and Mueller, 2009), entrepreneurial capacity (Clarysse et al., 2011), previous training (Bercovitz and Feldman, 2008) and motivation (Perkmann et al., 2013). The extant research has helped us to develop the understanding of this important domain and has highlighted the key roles played in university-industry collaboration and commercialization. However, most of the research has been conducted in the context of the United States and the United Kingdom; very limited empirical evidence has been presented from other European countries (Rothaermel et al., 2007). In particular, very few studies have emerged in the context of Finland (see, for instance, Ejermo and Toivanen, 2018 and Nikulainen and Palmberg, 2010).

The context and dynamics in Europe are very different than those in the US and the UK. The different economic models adopted by the countries presents distinct opportunities and challenges for the institutions. The universities operating under the Anglo-Saxon model, adopted in the US and the UK, are encouraged to generate their own revenues by commercializing education and research, compared to the continental Europe and Nordic countries, adopting social market economy and welfare model, in which universities are largely funded by the state. The differences in intellectual property rights and ownership structure, within European countries and the USA, (Meyer, 2003a) necessitates additional evidence to be presented from more European countries to better understand the phenomenon as well as to provide empirical evidence that can assist in policy formulation at the local level. Furthermore, in some cases, existing studies have produced inconsistent results —see, for instance, in the case of age, gender, excellence, impact of industry funding and experience (Ambos et al., 2008; Audretsch, 2000; Azagra-Caro, 2007; D'Este and Patel, 2007; Gulbrandsen and Smeby, 2005; Powers and McDougall, 2005; van Rijnsoever et al., 2008)—therefore, presents inconclusive and at times a confusing picture. An additional testing of these important factors offers an opportunity to explore the mechanism and boundary conditions of these relationships to better understand this phenomenon. This study contributes to the existing body of knowledge by investigating the moderating effect of organizational support on the individual's propensity to engage in the commercialization of academic research by integrating new constructs, that have largely remained unaddressed in the past, and puts forth fresh empirical evidence from a different context. In particular, the study highlights the impact of team structure, time allocation and the support available from TTOs with regard to the commercialization of academic research. The findings of this research have both theoretical and practical implications.

The remainder of this paper is structured as follows. Section 2 presents the conceptual background and hypothesis development. Section 3 sheds light on the methods used in the study, followed by Section 4 on analysis and results. Section 5 presents the discussion, while Section 6 examines the theoretical and practical implications. Finally, Section 7 discusses the limitations of the study and provides suggestions for future research.

2. Conceptual Background

University-industry collaboration and the commercialization of academic research have emerged as important areas of research (Kirchberger and Pohl, 2016). Due to their complex nature and the interaction of different actors, players and stakeholders involved in the process, the phenomenon has been studied from a range of perspectives. A review of the literature shows that earlier studies conducted in this area were primarily qualitative in nature, placing greater emphasis on the impact of policy frameworks introduced by governments and the influence this had in changing universities' organizational structures and the development of TTOs. In contrast, with the exception of studies on resource dependency theory, strategic choice, ambidexterity theory, stakeholder theory, social network theory, organizational learning, dynamic capabilities and institutional theory (Ankrah and Al-Tabbaa, 2015; Markman et al., 2008; Miller et al., 2014), quantitative studies are more inclined towards establishing causal relationships and investigating the factors that could have an impact, rather than using theoretical frameworks.

The underlying objective of these studies is to answer the question as to why some universities become more entrepreneurial than others and what makes academics commercialize their research. According to Jacob et al. (2003) and Feldman and Desrochers (2003), universities that have highlighted commercialization and identified it as a core objective in their missions are more successful in the commercialization of research. Friedman and Silberman (2003) associate a university's success with its location, stating that universities in close proximity to high-tech firms are more likely to commercialize. Powers and McDougall (2005) found that a university's resources and financial capital are positively associated with commercialization activities. Baldini et al. (2006) suggest that the likelihood of realizing commercial potential from research increases if a university has established a TTO. Carlsson and Fridh (2002) have attributed the success of the TTO to its age, asserting that older TTOs are more likely to be successful in commercialization activities. Di Gregorio and Shane (2003) linked commercialization success to the prior experience of the TTO. Powers and McDougall (2005) maintain that with the passage of time, TTOs develop routines and tasks that improve the commercialization outcomes. According to Siegel et al. (2004), the limited business and technical skills of a TTO hinder successful collaboration with industry. Link and Ruhm (2009) suggest that high-quality research universities are more likely to be successful in commercialization activities. Coupe (2003) argues that additional financial resources dedicated to academic research will have a positive impact on university patents. Di Gregorio and Shane (2003) state that having high-quality research staff improves the likelihood of commercialization. Universities that have collaborated with industry in the past are more likely to replicate this behaviour and to become involved in commercialization activities in the future (Arvanitis et al., 2008). Feldman and Desrochers (2004) submit that departments with a tradition of collaborating with industry are better at recognizing commercial opportunities for their research. O'Shea et al. (2005) suggest that narratives of successful commercial ventures in the past will accentuate the likelihood of future successful commercialization endeavours.

However, having a supportive organizational structure does not alone guarantee that universities will become successful in achieving the desired results because, as individuals, academics are an important part of the system. Roberts and Peters (1981) have linked commercialization behaviour with the background characteristics of the individuals involved. Baldini et al. (2007) highlight that the tendency to engage in patenting and licencing is influenced by the researcher's perception of the value it brings and the effort it requires. Argyres and Liebeskind (1998) suggest that campus-wide norms towards commercialization impact on industrial collaboration and commercialization activities. Bercovitz and Feldman (2008) affirm that scientists who were trained in institutes where commercialization and collaboration is perceived as a positive activity will have a higher propensity to commercialize during their careers. Tartari et al. (2014) found that having higher academic status, such as being a professor, positively impacts one's tendency to engage with industry and to commercialize research. D'Este and Patel (2007) assert that individuals who have established themselves in a field are likely to gain benefits from this and are better positioned to create contacts with industry. Vohora et al. (2004) extended this argument, stating that companies are comfortable when collaborating with someone who has a good reputation and academic standing. Jensen and Thursby (2001) suggest that personal contacts between researchers from educational establishments and from industry play an important role in collaboration and commercialization activities. Göktepe-Hulten and Mahagaonkar (2010) found that academics might patent in order to signal their achievements to their peers and to gain a reputation among their colleagues. Rasmussen and Borch (2010) found that academics with industrial backgrounds are more likely to produce results that can generate commercial value. Wu et al. (2015) emphasized that researchers who become involved in the commercialization process after disclosing it to the TTO are more likely to be successful. The literature suggests that although commercialization behaviour among academics is less driven by financial incentives (Colyvas et al., 2002; D'Este and Perkmann, 2011), however, a properly designed incentive structure for academics and TTO staff can improve collaboration and commercialization activities (Siegel et al., 2003).

2.1 Hypothesis Development

2.1.1 Researcher's Intentions

The successful transfer of research to commercial ventures is an intricate process that requires all pieces of the puzzle to fit. The final outcome may be affected by a number of elements, although the decision to commercially exploit research results depends on one fundamental factor: the researcher's attitude towards commercialization (Krabel and Mueller, 2009). A study conducted by Wu et al. (2015) found that researchers with a favourable attitude towards commercialization are likely to become involved in commercialization activities. In an academic setup, which can largely be described as an independent working environment, the decision to commercially exploit research depends on an individual's desire to engage in such ventures. Involvement in entrepreneurial activities and the creation of new ventures may not be a random act but something that people choose and intend to do (Shaver and Scott, 1991). The relationship between intentions and behaviour is deeply rooted in social psychology literature (Ajzen and Fishbein, 1980). This literature suggests that an individual's behaviour reflects the intentions he or she holds. Intentions correspond to a state of mind that directs the individual's attitude and interest in a particular action (Bird, 1988; Krueger et al., 2000). If the intentions are non-existent, the behaviour will not take place (Ajzen, 1985).

Researchers who intend to commercialize are bound to have a favourable attitude towards commercialization. The researcher's current involvement in a primary field of research may be influenced by his or her own interest in the subject, the interests of a superior (usually the project head or the supervisor), the availability of financing, the desire to respond to corporate needs or the opportunity to commercialize. It is expected that academics whose primary choice is influenced by the opportunity to commercialize will undertake measures leading to the commercial exploitation of academic research. In contrast, academics who pursue research with intentions other than engaging in commercialization activities should be less likely to form commercial ventures in the future. Based on this it is hypothesized that:

H1: Academics whose engagement in current field of research is influenced by opportunities to commercialize are more likely to engage in the commercial exploitation of research.

2.1.2 Prior Experience

It is evident from the literature that prior experience positively impacts academics' propensity to engage in future entrepreneurial ventures (D'Este and Patel, 2007). According to Venkataraman (1997) and Shane (2000), an academic entrepreneur may lack the skills and knowledge necessary to identify and exploit commercial opportunities. Academics are generally trained in an environment that requires a specific set of skills linked to the dissemination of knowledge in the form of teaching and conducting research for scientific purposes. The non-commercial nature of educational establishments makes it somewhat challenging for academics to acquire the skills necessary to embrace this objective. Therefore, those who have commercialized in the past are more likely to overcome these issues and are in a better position to generate commercial outcomes compared with their counterparts who lack previous experience. The learning effect in the form of understanding complexities, improved understanding of the risks and knowledge of complementary assets enable the individual to engage in an entrepreneurial venture in the future. Casper (2013) highlighted the role of personal contacts in establishing entrepreneurial ventures. Experienced researchers are more likely to have a larger network that can be helpful for commercialization (Giuliani et al., 2010). The study conducted by Bekkers and Bodas Freitas (2008) found strong evidence that prior experience positively influences academics' propensity to engage in future endeavours. Similarly, a study conducted by Van Dierdonck et al. (1990) found that people with prior experience of entrepreneurial activities are more likely to engage in commercialization activities. On this basis the following hypothesis has been formulated:

H2: Academics with prior experience of being involved in a commercialization activity are more likely to engage in the commercialization of academic research in the future.

2.1.3 Excellence in Research

Publications are important criteria for assessing academics' standing in their respective fields. A higher number of publications can generally be linked to an individual's excellence in his or her area of research. The use of academic research for a successful commercial venture depends on the novelty and applicability of the research in the industrial setting. Academics who are experts in a field are more likely to produce research results that are worth using for the pursuit of commercial gain (Powers and McDougall, 2005). Expertise and knowledge facilitate access to the commercial potential of a project. Furthermore, academics with good scientific standing are more likely to attract attention from their industrial counterparts (Nilsson et al., 2010). According to Zucker and Darby (1996), the top scientists were found to be more active in pursuing commercialization ventures. Academics with a high number of publications stand out in their fields and are more likely to be in contact with companies for the purpose of developing collaborations. Their breadth of knowledge and networks of personal contacts enable them to secure external grants and private funding, the results of which are often used for practical and commercial purposes. A study conducted by Gulbrandsen and Smeby (2005) found a positive relationship between patenting and publication activities. Therefore, it is hypothesized that:

H3: Academics with excellence in research are more likely to engage in commercialization activities.

2.1.4 Entrepreneurial Orientation

The literature on entrepreneurship emphasizes that individuals vary in terms of their propensity to engage in entrepreneurial activities. An individual's choice to become involved in an entrepreneurial endeavour may not be a random act, but is influenced by a number of factors, such as genetics, education, past experience, interest, the opportunity to identify and exploit opportunities and risk-taking propensity (Bouchard et al., 2004; Nicolaou et al., 2009; Shane and Venkataraman, 2000; Stewart and Roth, 2001; Vohora et al., 2004; Wright et al., 2004). Individuals with an entrepreneurial orientation have a higher tendency to be swayed by opportunities and will be more likely to engage in them. Academics with an entrepreneurial orientation will be better at identifying commercial opportunities and are likely to be driven by their intrinsic motivation to engage in a commercial venture. A study conducted by Clarysse et al. (2011) on researchers in the UK found that entrepreneurial capacity is by far the most important factor impacting the individual's propensity to engage in entrepreneurial activity. Therefore, it is safe to assume that keeping other things constant, compared to their counterparts, individuals with an entrepreneurial orientation are more likely to engage in commercialization activities.

H4: Academics with a higher degree of entrepreneurial orientation are more likely to become involved in commercialization activities.

2.1.5 Time allocation

Time can be a determining factor in one's efforts to engage or disengage in any activity. Academics working in a university setting often experience time constraints as they are expected to engage in teaching, research and administrative tasks. The percentage of expected time allocation is divided on the basis of their job responsibilities and the terms of their contract with the university. Academics who are more inclined towards research are expected to be better placed in terms of producing high-quality research. It is evident that the commercialization of research is a daunting task and requires serious efforts from the inventor before it is able to yield the desired outcomes (Mustar, 1998). Efforts and follow-up require time and researchers who are caught up in activities other than research are less likely to devote time to commercialization-related matters. In addition, commercialization activities are not usually considered in performance evaluations; academics are generally judged on the basis of publications, teaching and administrative activities. Therefore, uncertainty related to outcomes and high opportunity costs may disincentivize researchers, who may consequently refrain from being involved in any venture that could impact their performance and damage their position in the university. In contrast, researchers who are less bound by teaching and administrative activities have more time for research and are in a comparatively better position to engage in commercialization activities. Based on this it is hypothesized that:

H5: Academics who spend more time on research and are less bound by teaching and administration activities are more likely to be involved in commercialization activities.

2.1.6 Multidisciplinary Teams

A number of studies have attributed success to the accumulation of knowledge generated through the interaction of multidisciplinary teams (Van Der Vegt and Bunderson, 2005). The literature suggests that new knowledge is socially constructed and that interaction between people from diverse backgrounds generates the opportunity to produce new knowledge. Bozeman and Corley (2004) maintain that the rising number of co-authored publications highlights increased collaboration for the purposes of scientific research, which supports the claim that new knowledge is the product of collaboration. Jones et al. (2008) studied publication behaviour by investigating scientific articles published over the last three decades and found that research based on collaboration among researchers from different universities has intensified and that academics involved in such collaboration produce the highest impact papers. Libaers (2015) further argues that collaborative research often has an increased likelihood of generating commercial results. However, collaborations are not always homogeneous in nature and may differ based on the characteristics and backgrounds of the contributors. Research conducted in multidisciplinary teams may lead to better opportunities to generate commercial output as the individuals involved in the collaboration may hold diverse information, knowledge and expertise that can facilitate the commercialization process (Nicolaou and Birley, 2003). Working in multidisciplinary teams can provide an opportunity to collaborate and network with academics from diverse backgrounds, and the interaction can result in learning and sharing new methods and perspectives.

The influence of multidisciplinary teams on performance is well highlighted in business studies. However, the development of academic commercialization as a result of research conducted by multidisciplinary teams has largely remained unaddressed. The existing literature emphasizes the effect of the interdisciplinary backgrounds of the individuals' involved, referred to as boundary spanning, but it is yet to establish the effect that the nature of teams has on commercialization activities. The literature on boundary spanning suggests that academics with interdisciplinary backgrounds are more likely to engage in commercialization activities (D'Este et al., 2012). Based on the above arguments, it is expected that academics working in multidisciplinary teams are more likely to become involved in commercialization activities. Therefore, it is hypothesized that:

H6: Academics working in multidisciplinary teams are more likely to engage in the commercial exploitation of academic research.

2.1.7 Familiarity with the TTO

The TTO in the university setting has been found to have a positive impact on academic engagement and commercialization outcomes generated by the university. TTOs have been established to facilitate linkages between industry and academic institutions by assisting with contract research, filing patent applications, forming spin-off companies and initiating discussions with public and private partners for the industrial application of research (Bercovitz et al., 2001). In addition to being directly involved in facilitating commercialization and collaboration, the work of TTOs often involves arranging campus-wide activities including lectures, seminars and sessions to create awareness, enabling the exchange of information between academics and technology transfer staff and discussing the potential commercial applications of research. The objective of these measures is to create an environment in which academics become accustomed to and feel comfortable with commercialization activities. A study conducted by Meyer (2003) states that activities undertaken by TTOs have a positive influence on academics' intention to engage in commercial activities. Bercovitz and Feldman (2008) found that researchers who were trained in universities after the development of TTOs were more likely to have a positive attitude towards commercialization. Therefore, it is expected that, compared to their counterparts, researchers who are familiar with TTOs are more likely to commercialize. On this basis, it is hypothesized that:

H7: Familiarity with the TTO positively influences academics' propensity to commercialize their research.

2.1.8 TTO Support Capacity

TTOs are involved in offering diverse services to facilitate university-industry collaboration and the commercialization of academic research. The positive impact that a TTO has on the commercialization of research and on revenue generation for the university is evident (Lester, 2005). However, the efficiency of TTOs varies across universities. A number of studies have questioned the performance of TTOs and the actual role they have played in the commercialization of academic research (Chapple et al., 2005; Lockett and Wright, 2005). A study conducted by Jones-Evans et al. (1999) found that TTO staff often lack the resources and expertise required to facilitate the process in an efficient and effective manner. Research conducted by Siegel et al. (2003) found that TTOs are often understaffed and lack the knowledge and practical skills necessary to facilitate university-industry collaboration and the commercialization of academic research. If the TTO is not efficient in its operations, it is plausible that the interaction will be unlikely to positively influence commercialization outcomes. As discussed in section 2.1.7, a TTO works on multiple fronts, from cultivating the culture of entrepreneurship among university scientists by promoting commercialization activities to facilitating on different fronts, such as arranging financing, negotiating contracts and providing support in the preparation of business plans. Bercovitz and Feldman (2008) articulate that the establishment of a TTO may signal a university's commercial intentions and serve as an indication of its support for commercialization activities. However, the direct effect of the TTO can only be assessed after considering the impact these services actually have on the commercialization process. If technology transfer units are efficient, the interaction with TTOs should enhance the likelihood of a successful transfer and the exploitation of academic research. Therefore, it is safe to assume that those who interact with the TTO should have a higher likelihood of engaging in a commercial venture compared to those who have not benefited from their services. On this basis, the following hypothesis has been formulated:

H8a: Interaction with the TTO should boost the likelihood of the successful exploitation of academic research for commercial purposes.

To specifically measure the effect of TTO services and their impact in enhancing commercialization outcomes, their effect on academics' intentions to commercialize and on entrepreneurship orientation is assessed. If the TTO provides its services in an efficient manner and performs as expected, it should further strengthen the impact on intentions and entrepreneurship orientation in relation to the commercialization of research. This is hypothesized as follows:

H8b: The interaction with the TTO should positively influence academics' intentions to commercialize academic research.

H8c: The interaction with the TTO should strengthen individuals' entrepreneurial orientation towards the commercialization of academic research.

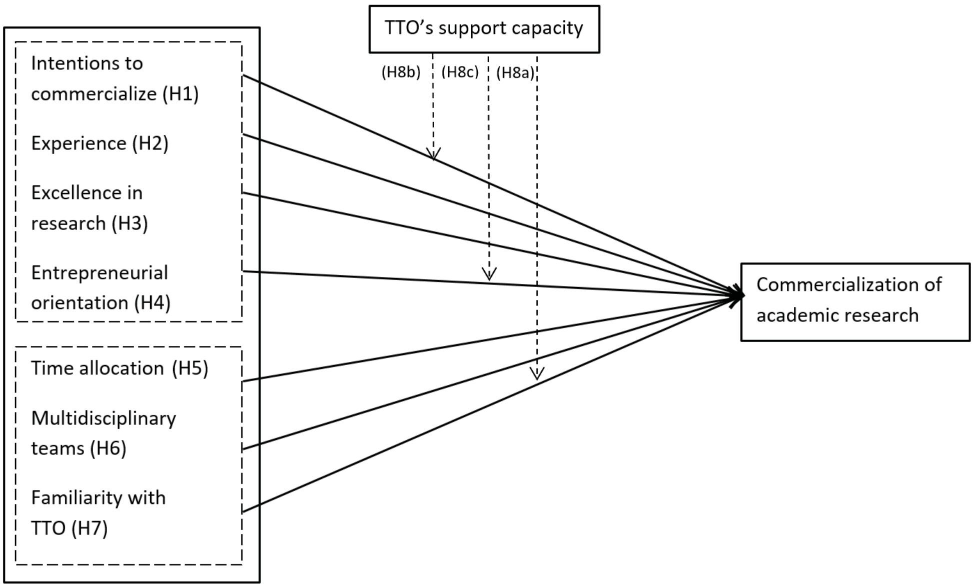

Figure 1: Conceptual model of the study

3. Methodology

3.1 Data Collection

This study is based on data collected from researchers working in Finnish universities, polytechnics, research institutes and industry. A web-based survey was carried out and 13,746 questionnaires were distributed in April 2017. The survey included text explaining its purpose and ensuring anonymity and confidentiality. A reminder was sent three weeks later. The questionnaire requested information about the researcher's background, education, expertise, field of study, funding sources, motivation and challenges faced in collaboration and commercialization activities and the role of TTOs. A total of 4,735 completed questionnaires were received, corresponding to a response rate of 34.4%. This research is based on a sub-sample drawn from this comprehensive data set. Bearing in mind the objective of this research—to study the effect of personal and institutional factors on the commercialization of academic research—the data set has been limited to researchers who are associated with universities. The respondents were filtered on the basis of their responses to the question of whether they were working in a university, polytechnic, research institute, company or at any other place. The institutional email address also provided an indication of the researcher's workplace. Since the dependent variable is whether or not research results were commercially exploited, the respondents were narrowed down to those who corresponded to this category, leaving a final sample of 891 respondents.

A number of tests were then performed to check the reliability of the collected data. To address the issue of non-response bias, the results of the early respondents were compared with those of the later respondents. An independent samples t-test was performed comparing the early respondents (N = 605) to the later respondents (N = 286) in terms of their intentions to commercialize (p = .711) and familiarity with the TTO (p = .752). The lack of significant difference between the groups signifies that non-response bias was not an issue. Common method bias concerns the issue of respondents' systematic answers to questions. Harman's single factor test was applied to check the extent to which the data may have been influenced by the issue of common method bias. This test yielded positive results, confirming that the included factors yielded an eigenvalue of greater than one. The first factor explained 23.19% of the variance, affirming that the results do not point to a single factor accounting for most of the variability in the data. This confirms that common method bias is not a concern for the present analysis.

3.2 Measures of Constructs

3.2.1 Dependent Variable

The dependent variable, commercialization of academic research, is based on the question in which respondents were asked whether they had decided to commercially exploit their research results. Those who had were coded as 1, whereas those who had not were coded as 0.

3.2.2 Independent Variables

In order to measure the researchers' intentions to commercialize, the respondents were asked to state the importance of the factor 'opportunity to commercialize research' in their choice of orientation towards their primary field of research. The scale ranged from 'Not at all important' (1) to 'Very important' (4). To measure their previous experience, the number of patent applications in which respondents had participated was considered. Those who selected zero were coded as 1, whereas 1–5 applications, 6–10 applications, 11–20 applications and 20+ applications were coded from 2 to 6, respectively. Excellence in research was measured based on the number of scientific articles they had published in peer-reviewed journals. The selection choice was 0 publications, 1–9 publications, 10–19 publications, 20–49 publications, 50–100 publications and 100+ publications. Respondents with zero publications were coded as 1 whereas 100+ published articles were coded as 6. To measure the researchers' entrepreneursial orientation, the following constructs were included in the questionnaire: 'I take on facilitating the creation of new entities outside of my organization', 'I take on starting new business units', 'I take on reaching new markets or the creation of new communities'. The construct used to assess the entrepreneurial orientation was adopted and modified from the studies of Covin and Wales (2012) and Thompson (2009). The respondents were asked to choose from 'Never' (1) to 'Constantly' (7). The final variable was constructed as an average of these three items (Cronbach alpha .76). To gauge the effect of time allocation, the respondents were asked to distribute their working time among research, teaching and administration and other tasks. Respondents who allocated more than two-thirds of their time to research were coded as 1, while those whose job responsibilities required more time to be spent on teaching and administration and other tasks were coded as 0.

In order to examine the impact of the multidisciplinary team, the respondents were asked to state whether their research teams featured researchers from different scientific fields. Those who chose yes were coded as 2, while the others were coded as 1, referring that the work was not conducted in multidisciplinary teams. To measure familiarity with the TTO, the respondents were asked whether they were familiar with the services of TTOs. The respondents who were not at all familiar with TTOs were coded as 1, whereas those who were somewhat familiar, rather familiar or very familiar were coded as 2, 3 and 4, respectively. In order to assess the TTO support capacity, the respondents were asked to report how well their TTO matched their need for its services: 'facilitation of the commercialization of research results', 'support for the entrepreneurial activities of the researchers', 'education in commercializing research results', 'facilitation of the acquisition of external funding', 'support in preparing business plans, evaluations of the commercial potential of findings', 'support in organizing intellectual property rights issues', 'support in preparing patent applications', 'identification of commercial users for findings and negotiation of a licencing contract'. The respondents were asked to select from 1 to 4, with 1 being very poor, whereas 2, 3 and 4 were labelled as rather poor, rather well and very well, respectively. The Cronbach alpha yielded the value of .93, affirming the reliability of the incorporated constructs.

3.2.3 Control Variables

Several control variables were considered in the estimation model. Age is considered to have a negative impact on the individual's tendency to engage in commercialization activities, i.e., the likelihood of engaging in commercialization activity decreases with age (D'Este and Perkmann, 2011). The age of the respondents was calculated based on year of birth. Those aged between 0 and 40 years were coded as 0, while those aged between 41 and 90 years were coded as 1. A number of studies have found that being male is likely to have a positive impact on commercialization (Azagra-Caro, 2007). Therefore, this was added into the model as a control variable. Females were coded as 2 while males were coded as 1.

The impact of time since being awarded their last degree, industrial financing and the role of the researcher in the team were also considered. The respondents were asked to state the year in which they obtained their highest degree. The number of years since receiving their last degree was then calculated based on the information provided. Academics are usually more inclined towards commercialization during the early stage of their careers, so a five-year time period was set as a dummy variable (Bercovitz and Feldman, 2008). Those who corresponded to this category were coded as 1. To measure the academics' role in the team, respondents were asked if they were currently the head of a single team or several teams or had been the head over the last five years. Those who corresponded to this category were coded as 1. To measure the effect of industrial financing, the respondents were asked to state how much of their total research funding is provided by companies. The respondents who indicated a total of 50% or more were coded as 1, while the remainder were coded as 0. It is expected that if more than half of a researcher's time is covered by financing from industry, this may influence the likelihood of engagement in commercial activities (Gulbrandsen and Smeby, 2005). Individuals belonging to different disciplines may vary in their propensity to engage in commercialization (Arvanitis et al., 2008). To gauge the impact of the discipline, research fields were taken into account in the estimation model.

4. Analysis and Results

This section presents the descriptive statistics (Table 1), the correlation matrix (Table 2) and the results of the regression analysis (Table 3). Correlations were run between the variables to test their relationships with each other. The correlation matrix highlights that there was no issue of multicollinearity. Considering the dichotomous nature of the dependent variable (responses in the form of a binary number), binomial logistic regression was applied for the analysis. To measure the sensitivity of the studied constructs, regressions were performed in four models (see Table 3). Model I includes variables related to the individual characteristics of the researcher: researchers' intentions to commercialize, entrepreneurial orientation, excellence in research and previous experience. All the variables included in Model I are highly significant and positive. Model II includes variables relating to the allocation of time and the effect of working in multidisciplinary teams. The results in this model indicate that time allocation has no significant impact, whereas working in multidisciplinary teams does have a significant and positive effect. Model III includes variables that estimate the effect of the TTO by measuring the impact of familiarity with the TTO and the interaction effect of TTO support services on the researcher's intention, entrepreneurship orientation and familiarity with the TTO. The results in this model indicate that familiarity with the TTO does have a positive and significant impact on the decision to exploit research results for commercial purposes. However, when tested for the interaction effect using the TTO support capacity as the moderating variable, the *p* value increased, referring to the fact that interaction with TTOs neutralises the positive effect of familiarity with the TTO. Similarly, testing the moderation effect of the TTOs' support capacity on intentions to commercialize and entrepreneurial orientation yielded comparable results. The final model included control variables exploring the effect of age, sex, time since last degree and researchers' status, as well as the effect of industry funding and the field of science the academics are associated with. Model IV indicates that intentions to commercialize ($b=.411$; $p\leq.001$) and entrepreneurial orientation ($b=.322$; $p\leq.001$) are strongly significant and positive in all four models. These results are in line with the H1 and H4 hypotheses, supporting that researchers' intentions and entrepreneurship-related characteristics do have a positive influence on their decisions to engage in the commercial exploitation of results. The effect of excellence in research ($b=.144$; $p>0.1$) was insignificant in the final model; therefore, H3 is not supported. Previous commercialization experience was found to have a positive and significant effect ($b= .206$; $p\leq0.05$), affirming H2 that researchers with prior commercialization experience are more likely to engage in future commercial endeavours. However, with regard to H5 (the effect of time allocated for research on the commercial exploitation of the results), no support was found in the model ($b=.212$; $p>0.1$). H6, which was developed to measure the effect of working in multidisciplinary teams, was significant and positive, thus confirming that academics working in a team with researchers from different backgrounds are more likely to commercially exploit the results ($b=.453$; $p\leq0.05$). H7, H8a, H8b and H8c considered the impact of the TTO on commercial exploitation of the results. The variable 'familiarity with the TTO' was significant and positive ($b=.288$; $p\leq0.05$). Therefore, H7 is supported, highlighting the fact that the availability of the TTO office in an educational establishment does have a positive effect on commercial activities. However, introducing the TTO's support capacity as a moderating variable actually diminished its positive impact ($b=.161$; $p>0.1$); thus, H8a is not supported. The effect of the TTO's support capacity on individuals' intentions to commercialize and its impact on developing entrepreneurial orientation was evaluated by measuring the interaction of these variables with the TTO support capacity. The regression results for TTO support capacity on intentions to commercialize were ($b=-.047$; $p>0.1$) and entrepreneurial orientation ($b=.070$; $p>0.1$). Therefore, no support was found for H8b and H8c.

	Minimum	Maximum	Mean	Std. Deviation
Intentions to commercialize	1	4	2,33	,892
Entrepreneurial orientation	1	7	2,42	1,335
Excellence in research	1	6	3,99	1,403
Previous experience	1	5	1,66	,851
Time allocation	0	1	0,33	,471
Multidisciplinary teams	1	2	1,73	,435
Familiarity with TTO	1	4	2,63	,727
TTO's support capacity	1	4	2,37	,786
Age	0	1	0,67	,447
Sex	1	2	1,71	,441
Time since last degree	0	1	0,20	,398
Role in team	0	1	0,80	,403
Industry funding	0	1	0,17	,379

Table 1: Descriptive statistics

Correlations

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Intentions to Commercialize	1																		
2	Entrepreneurship orientation	**.330**	1																	
3	Excellence in research	**-.100**	.008	1																
4	Previous experience	**.213**	.088	**.336**	1															
5	Time allocation	.045	**-.124**	**-.240**	**-.099**	1														
6	Multidisciplinary teams	**.094**	**.156**	**.130**	-.029	-.017	1													
7	Familiarity with TTO	**.261**	**.247**	**.147**	**.253**	**-.108**	**.096**	1												
8	TTO support capacity	**.102**	-.038	**-.113**	-.010	**.069**	-.014	**.082**	1											
9	Age	-.033	**.074**	**.480**	**.186**	**-.262**	.025	**.154**	**-.072**	1										
10	Sex	.008	.027	**.093**	**.182**	-.034	**-.073**	**.099**	.014	-.005	1									
11	Time since last degree	.050	-.043	**-.465**	**-.168**	**.255**	-.008	**-.136**	.065	**-.465**	-.038	1								
12	Role in the team	.004	**.193**	**.452**	**.163**	**-.328**	**.092**	**.156**	-.058	**.374**	**.066**	**-.329**	1							
13	Industry funding	-.002	.002	**-.114**	-.053	**.110**	-.058	-.044	**.068**	**-.072**	-.019	.047	**-.127**	1						
14	Bio technology	.056	-.032	**.156**	**.132**	.055	**.165**	**.066**	.019	.029	.006	-.025	.055	**-.094**	1					
15	Nano technology	.057	-.036	**.120**	**.215**	-.010	.046	**.070**	.011	-.053	.044	.038	.023	-.056	**.177**	1				
16	Energy& Enviro technologies	**.129**	.057	-.044	.031	.002	-.036	.065	.052	-.015	.052	-.015	.031	.000	**-.077**	**.186**	1			
17	Smart digital technologies	**.071**	**.153**	**-.145**	-.020	-.058	-.007	**.105**	.035	.009	**.108**	-.022	-.005	-.014	**-.225**	**-.159**	-.027	1		
18	Social Innovations	-.026	**.159**	**-.131**	**-.234**	-.060	**.117**	-.060	-.011	.045	**-.195**	.000	.022	-.016	**-.189**	**-.160**	**-.081**	**.347**	1	
19	Results commercially exploited	**.256**	**.271**	**.140**	**.192**	-.027	**.155**	**.222**	-.037	.039	**.085**	**-.085**	**.166**	-.053	**.153**	.050	-.011	.001	-.039	1

Table 2: Correlations. Correlations are significant at $p < 0.05$ (marked in bold)

Model	Model I		Model II		Model III		Model IV	
	B	S.E.	B	S.E.	B	S.E.	B	S.E.
Intentions to commercialize	0,470***	0,091	0,446***	0,092	0,389***	0,094	0,411***	0,097
Entrepreneurial orientation	0,342***	0,059	0,332***	0,06	0,318***	0,062	0,322***	0,064
Excellence in Research	0,256**	0,057	0,191***	0,059	0,179**	0,059	0,114	0,073
Previous experience	0,206***	0,096	0,297**	0,098	0,252**	0,099	0,206*	0,104
Time allocation			0,153	0,162	0,185	0,164	0,212	0,175
Multidisciplinary teams			0,555**	0,178	0,524**	0,179	0,453*	0,185
Familiarity with TTO					0,304**	0,109	0,288*	0,113
Familiarity with TTO by TTO's support capacity					0,172	0,127	0,161	0,129
Intentions to commercialize by TTO's support capacity					-0,073	0,113	-0,047	0,115
Entrepreneurial orientation by TTO's support capacity					0,057	0,076	0,070	0,076
Age							-0,400⁺	0,209
Sex							0,292	0,183
Time since last degree							-0,274	0,232
Role in team							0,539*	0,23
Industry funding							-0,120	0,204
Bio technology							0,510**	0,184
Nano technology							-0,050	0,223
Energy and Environmental technologies							-0,230	0,17
Smart and Digital technologies							-0,065	0,174
Social Innovations							0,062	0,213
Negalkerke R square	0,181		0,195		0,208		0,238	
Classification correct	65,90 %		66,70 %		68,10 %		69,40 %	
N	891		891		891		891	

***$p \leq .001$, **$p \leq .01$, *$p \leq .05$, $^{+}p \leq .1$

Table 3: Binomial logistic regression

5. Discussion

This study has sought to investigate the impact of individual and institutional factors on academics' tendency to engage in the commercial exploitation of academic research. The results reveal that intentions to commercialize and entrepreneurial orientation are two of the strongest individual-level factors influencing the academic's likelihood to engage in the commercial exploitation of their research. The literature suggests that intentions to undertake an action affirm the individual's favourable attitude towards the behaviour (Ajzen and Fishbein, 1980) and direct future actions (Krueger, 1993). Academics' inclination towards a field of research, influenced by the opportunities to commercialize, is an antecedent to their engagement in the commercialization of research. The entrepreneurship literature considers entrepreneurial orientation to be an important determinant in measuring an individual's propensity to engage in the creation of new business ventures. The findings of the present study are in line with those of Clarysse et al. (2011), who studied the factors influencing the commercialization of academic research in the United Kingdom and found entrepreneurship capacity to be a significant factor in choosing to undertake commercialization activities. Excellence in research did not have a significant impact in the final model. This effect becomes insignificant once controlled for the role in the team, highlighting that if an academic takes a leading role, i.e., being head of the team, excellence in research becomes less relevant. One plausible reason for this effect could be that a higher number of publications signifies academic standing in the field and enables researchers to create linkages with their counterparts in industry in order to initiate collaboration (Zucker and Darby, 1996). This effect may be superseded by higher status, thus becoming less important.

The results related to prior commercialization experience support the findings of previous studies that report its positive impact on future commercialization activities (Bekkers and Freitas, 2008). The effect of working in multidisciplinary teams was also found to have a positive impact on the commercial exploitation of research results. Previous studies have found the positive effect of the individual's interdisciplinary background on commercialization activities (D'Este et al., 2012). However, the impact of working in multidisciplinary teams has largely remained unaddressed. This study has found empirical evidence to support the suggestion that work conducted in a multidisciplinary team setting is more likely to be commercialized. One probable reason for this could be that academics working in the team come from different educational backgrounds, have different experiences and may differ in terms of their attitudes towards commercialization. The synergy effect created through the heterogeneity of the individuals may help identify the commercial potential of the research and offer better linkages and networks with industry, which may be helpful when applying academic results to a commercial setting.

This study also tested the relationship between the time allocated for research and commercialization. However, no empirical evidence was found to support the proposition that academics spending more time on research are more likely to be engaged in commercialization activities. If these results are viewed in light of research conducted by Libaers (2012), where no relationship was found between time spent on teaching and commercialization activities, it can be inferred that the decision to engage in commercialization activities is less likely to be influenced by the time academics are required to allocate in compliance with their job requirements. The existing literature shows that academic involvement in the commercialization of research is less influenced by financial and economic motives (Colyvas et al., 2002) than it is by the desire to establish prominence and standing in researchers' respective fields (D'Este and Perkmann, 2011). It is also evident that researchers working in the academic sector receive less financial remuneration than their counterparts working in industry. Academics sacrifice higher salaries in favour of the autonomy and independence they enjoy in the academic sector and they quench their creative thirst by working on topics they consider interesting and important. In a context where work is driven by passion and interest, time becomes somewhat irrelevant and this is possibly the reason for its insignificant impact.

This research also supports the findings of previous studies demonstrating that the presence of TTOs in universities positively impacts the commercialization of academic research (Bercovitz and Feldman, 2008). To measure the effect of the services offered by the TTO, the interaction effect of the TTO's support capacity with regard to familiarity with the TTO, intentions to commercialize and entrepreneurial orientations was assessed. A typical TTO works on many fronts that ranges from encouraging academics to engage in commercialization activities by promoting them on campus, to establishing linkages with industry and providing support for patenting and licencing activities. The results of this study demonstrate that TTO services are yet to reach the point where the interaction could enhance the positive impact and improve the likelihood of commercialization. This finding is striking in that, rather than facilitating the commercialization process, the interaction with the TTO actually neutralises its original impact. These findings are in line with previous studies that found similar explanations for limited TTO performance (Siegel et al., 2004, 2003).

The effect of age was found to be negative, meaning that young academics are more likely to be engaged in commercialization activities. The effect of gender on commercial exploitation was insignificant. In this regard, the findings of this research offer a different perspective to studies that found being male significantly improves the chances of commercialization of academic research and are in line with (Gulbrandsen and Smeby, 2005). The present study did not find any evidence to support the assertion that academics are likely to engage in commercialization activities during the early period of their academic careers, as suggested by Bercovitz and Feldman (2008). With regard to academic status, this study affirms the findings of Link et al. (2007) that researchers with higher status are more likely to engage in commercialization activities. This may be due to their knowledge and networks, as suggested by Boardman (2008). Financial support from industry does not have any impact on the decision to commercially exploit research results. When considering the discipline dummies, it is evident that academics associated with biotechnology have a higher likelihood of commercially exploiting results while researchers working in energy and environmental technologies are not active in commercialization. Biotechnology is consistently found to be a research-intensive industry, which is highly commercializable and requires scientific knowledge in the development of technology (Kenney and Goe, 2004). The results of this study have both theoretical and practical implications, which are discussed in the following section.

6. Theoretical and Practical Implications

This research has contributed to the existing body of knowledge on the commercialization of academic research by examining the role of personal and institutional factors in influencing academics tendency to engage in commercialization. In particular, by presenting empirical evidence from Finland, the study has highlighted the effects of team structure, TTO support capacity, entrepreneurial orientation, time allocation and researcher’s intentions. The study has several practical implications. Relative to gross domestic product(GDP), Finland is one of the leading countries when it comes to research and development activities (Eurostat, 2017). Despite being small, Finland is continually ranked among the highest-ranking countries on different innovation indexes. However, it lags behind when it comes to knowledge diffusion (Global

Innovation Index, 2017). Despite having good research facilities in universities and contacts with industry, the country has struggled to ensure that commercial gains are generated from these interactions (Shakeel et al., 2017). The demise of the telecommunications sector and financial crises have forced the country to focus on developing new sectors that can sustain economic growth in times to come. The rise of Industry 4.0, the integration of IT with contemporary technologies and the increased reliance on automation and digitalization require Finland to reconsider interaction between institutions and facilitate the flow of information. In an era when economies are increasingly becoming knowledge-based, future industrial growth will be more dependent on knowledge and skills and less reliant on heavy infrastructure and traditional industrial setups. Recent advancements in novel technologies suggest that technological progress is associated with scientific developments. Thus, the role of university researchers in advancing tacit knowledge through which technologies enter a commercial domain is central (Yusuf, 2008). The findings of this study suggests that researchers working in the energy and environmental technologies are not active in commercial exploitation of academic research. There is a need to emphasize on improving the collaboration and facilitation the transfer of knowledge from university to industry in this sector.

In addition, the education system in Finland is under constant pressure to change. Traditionally, being public-sector institutions, universities have received funding from the state. However, the dynamics are changing and universities are required to generate revenue to ease the burden on public financing. This study has sought to highlight the areas that policy-makers need to focus on before university-industry collaboration can magnify the gains for both sectors. The study also highlights the immediate need to revamp the functionality of TTOs. Universities should place emphasis on deploying human and financial resources and should focus on providing training to ensure positive outcomes. The focus should not only be on ensuring the successful transfer of technologies, but also on creating awareness among young researchers and promoting an environment that is conducive to commercialization activities. Furthermore, the scenario in which an increasing number of future PhD graduates in Finland will have to seek employment outside academia highlights the dire need to train young researchers to undertake this challenge by becoming ambidextrous and proficient in both academic research and its commercial application. The study also provides useful insights for companies interested in collaborating with university academics by highlighting the personal and institutional factors that are central to the commercialization of academic research, which can provide a good starting point for collaboration.

7. Limitations and Future Recommendations

This study has some limitations that offer interesting areas for future research. This research has considered commercialization activity without taking commercialization channels into account. As highlighted by D'Este and Patel (2007), individuals may vary in terms of their intentions and ambitions when it comes to the selection of appropriate channels for commercialization purposes. Therefore, it might be an interesting avenue of future research to consider the different factors impacting the choice of channels. Similarly, entrepreneurial orientation has been considered an antecedent to engaging in commercial activity without taking into account the effect of opportunity identification and opportunity exploitation (D'Este et al., 2012). The effect of time allocation on research had no impact on commercialization activities, it would be interesting to examine whether it has a similar effect in different contexts.

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Venture capital's value-added contribution in the development process and commercialization of renewable energy technologies

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Abstract

Venture capital can play an important role in assisting companies to successfully commercialize their technologies. New technology development is a resource intensive process. Venture capital not only provides companies with the finances they need but also can assist in addressing the challenges faced throughout the development process. This study seeks to explore venture capital's non-financial value-added contributions to renewable energy technologies companies in Finland. This qualitative study was based on four case study companies operating in renewable energy technologies. The purposive sampling approach was adopted to select the cases. The data collection was conducted through semi-structured interviews, while within- and cross-case analysis approach was adopted to gain a deeper understanding, as well as to identify similarities and differences, between the case companies. The findings of this study highlight that venture capital's strongest contribution was in setting portfolio companies' strategic orientation and ensuring access to external resources, whereas a moderate level of assistance was observed in providing an opportunity to collaborate with other portfolio companies, market knowledge, teambuilding, and improving the image of a company. Weak support was found in the case of internationalization and seeking additional finances, while they did not contribute at all on the technology development front. The study emphasizes the importance of having clear and open communication between the venture capital and portfolio companies.

Keywords: Venture Capital; Non-financial; Value-added contributions; Commercialization; Finland

1. Introduction

Commercialization of a technology is a complex and multifarious phenomenon. A number of technologies and products fail to gain their fair share of the market due to challenges they face during this process (Chiesa & Frattini, 2011). The process becomes even more cumbersome for start-ups and small- and medium-sized companies (SMEs), restrained as they sometimes are by their limited financial and human resources (Nicholas, Ledwith, & Perks, 2011). A venture capital (VC) can play an important role is bridging this gap by providing the required financing, business development skills, knowledge and understanding to ensure the growth of a company (Large & Muegge, 2008). The readily available capital for investment, prior experience of working with similar companies, and network of partners and collaborators makes a VC a sought-after choice for partnership. There is ample evidence to support the assertion that VCs have played a vital role in companies' success across the globe (Haines, Madill, & Riding, 2003; Kaplan & Strömberg, 2003; Kerr, Lerner, & Schoar, 2014; Samila & Sorenson, 2010). However, the idea that having a VC on board is a sure recipe for success may not always hold up, as there are a number of instances where partnering with a VC did not yield the desired outcomes and the collaboration resulted in the failure of the companies (Busenitz, Fiet, & Moesel, 2004; Gaddy, Sivaram, Jones, & Wayman, 2017).

A considerable amount of research has been done to explore various aspects of the collaboration between businesses and venture capital firms. The existing literature has helped in developing an understanding of what VCs are (Wright & Robbie, 1998), how they operate (Zider, 1998), and what factors are considered important when making an investment (Gompers & Lerner, 2001). An alternative stream of research has explored the valuable offerings provided by VCs, such as bringing in the necessary capital (Bottazzi & Da Rin, 2003) assistance in the recruitment process (Hellmann & Puri, 2002), finding collaboration partners (Hsu, 2006), and improving the legitimacy of the company (Zimmerman & Zeitz, 2002). However, researchers have also presented evidence that collaboration with VCs can adversely affect a company's performance due to lack of industry-specific specialization, high technology risk, and accelerated exit plans (Anokhin, Wincent, & Oghazi, 2016; Dimov & De Clercq, 2006; Ghosh & Nanda, 2010; Guler, 2007).

A review of the literature reveals that the extent of VCs' involvement and the value-added contributions to its portfolio companies varies across contexts and industries (Wustenhagen & Teppo, 2006). The extant research has studied contributions in different industries such as high-tech (Bertoni, Colombo, & Grilli, 2011; Florida & Kenney, 1988; Maula, Autio, & Murray, 2005), information technology (Dushnitsky & Lavie, 2010; Hogan & Hutson, 2005), and healthcare (Rosiello & Parris, 2009; Silverstein & Osborne, 2017); however, the literature focusing on the role of VCs in the context of renewable energy technologies (RETs) is rather limited (Bjørgum and Sørheim, 2015). This limited research has explored contributions from either the perspective of portfolio companies or the VCs, but few have considered the viewpoint of both actors. This approach has helped us in developing our understanding of the contributions made by VCs. However, there has been an inherited limitation with such an approach: most of the findings reported are based on the perceived value addition from either the companies' or VCs' side. This study distinguishes itself by considering the perspectives of both VCs and the RET companies. The approach can help us explore the phenomenon in detail and enable us to highlight important factors that may have remained unaddressed. Moreover, the context chosen for the study also offers interesting perspectives and insights.

1.1 Context of the study

Finland is one of the leading countries for research and development (R&D) in the energy and environment sector. Despite being small, its share in the global cleantech market is over 1%, twice its contribution to the global GDP. The demise of the telecommunications sector and financial crises have forced the country to focus on developing new sectors that can sustain economic growth in the future. Clean technologies offer an excellent opportunity for a technologically advanced country such as Finland to become a key player in this emerging market. According to Statistics Finland (2018), the combined turnover of the industry was around $40 billion USD in 2016, and it employed over 50,000 people and is expected to create 40,000 new jobs by the year 2020 (Cleantech Finland, 2014). The Global Innovation Index (2017) ranked Finland among the leading countries on innovation input, public R&D and innovation culture; however, it lags behind when it comes to commercialization. The successful commercialization of technologies is very much dependent upon the technical, regulatory, and market-related factors. The process becomes even more cumbersome if the technology in question is disruptive in nature and requires the alteration of existing structures. Renewable energy technologies are disruptive in nature, require huge amount of investments, face uncertain market conditions, rely on infrastructural and regulatory supports, and usually have a long payback time. A study conducted by Shakeel, Takala, and Zhu (2017) found that the limited availability of financing, market dynamics, infrastructure support, challenges in internationalization, and market-oriented technology development are some of the major issues causing slow commercialization of RETs in Finland. VC can play an important role in addressing some of these challenges by providing value-added contributions throughout the development process.

Moreover, the start-up ecosystem in Finland is continually attracting investors' interest. According to Finnish Venture Capital Association (FVCA), the year 2018 witnessed the highest amount of VC funding to date, amounting to 203M € (FVCA, 2018).Statistics arranged by Statista (2018) showed that in proportion to its GDP, Finland took a leading position in European venture capital investments during 2013–2017. This scenario offers an excellent opportunity to explore the state of the VC industry in Finland and the extent to which VCs adds value to their portfolio companies, if any. This article, therefore, seeks to explore the role of VCs' value-added contribution in the context of RETs in Finland.

The remaining sections of this paper are structured as follows. Section 2 presents a review of the literature. Section 3 discusses the methods adopted in this study, while section 4 provides details of the case companies included in this study. Section 5 presents analysis, and section 6 is dedicated to the discussion and conclusion. Section 7 discusses the limitations of the study and provides suggestions for future research.

2. Literature review

VCs' non-financial value-added contribution has become an important area of research. Scholars have explored the extent, the nature of contributions and the effect they have on a company's performance. The literature suggests that partnering with a VC could have a mixed effect on a company's performance; however, a vast majority of the research concluded that the effect is positive (Haines et al., 2003; Samila & Sorenson, 2011). According to Kaplan & Strömberg (2003), partnering with a VC improves start-up performance. As Bjørgum and Sørheim (2015) and Maula, Autio, and Murray (2005) maintained, though, in addition to hefty financial requirements, innovative technology-based companies necessitate contributions in areas such as networking, industry-specific expertise, understanding of foreign markets, technology know-how, or excellence in business administration. There are many examples of cases where a VC has provided value-added input to the companies that has helped them in fostering the innovation process (Busenitz et al., 2004; Gorman & Sahlman, 1989; Large & Muegge, 2008; Sapienza, 1992; Sapienza, Manigart, & Vermeir, 1996).

Hsu (2006) divided these contributions into three categories: improving the structure and governance of start-ups, business development, and improving the legitimacy of the company. Gorman and Sahlman (1989) pointed out that VCs supports companies in finding supplementary financing, strategic development, operational planning, management recruitment, presentation to potential customers and suppliers, and resolving compensation concerns. Florida and Kenney (1988), as well as Von Burg and Kenney (2000), affirmed that VCs can provide strategic, financial, and legal guidance. Cumming and MacIntosh (2002), Gorman and Sahlman (1989), and Hellmann and Puri (2002) suggest that VC helped entrepreneurs with hiring, finding clients, and suppliers.

In their analysis of 20 peer-reviewed articles, Large and Muegge (2008) reported that a VC's non-financial value-added contribution can be divided into internal and external fronts. The internal contributions are related to recruitment, strategy, consultation, operations, mentoring, and mandating, whereas external ones are connected to legitimisation and outreach. Bocken (2015), Gompers and Lerner (2001) claims that uncertainty and information asymmetry are often the reason that causes incumbent firms to fail. VC helps in bridging this information gap by providing assistance in critical decision-making and planning processes. Aoki (2000), Burt(1992), and Lindsey (2002) further suggests that VCs can serve their portfolio companies as information intermediaries, ensuring privileged business networking, access to information, and minimising the overall cost attributed to identification of partners for collaboration. Research conducted by Gorman and Sahlman (1989), Kaplan and Schoar, (2005), and Macmillan, Kulow, and Khoylian (1989) highlighted that VCs mentor entrepreneurs, participate in the strategy planning process, and use their experience and knowledge to ensure a company's growth (Gorman & Sahlman, 1989; Kaplan & Schoar, 2005; Macmillan et al., 1989). Kortum and Lerner (2000) suggested that VCs are often well-connected and their access to relevant industry knowledge can help companies improve their decision-making processes, seeking collaboration, and setting up partnerships.

Nonaka, Toyama, and Konno (2001) suggested that start-ups, being in the earlier stages of development, often lack routines and established procedures. A VC can help companies to professionalise their working practices, customs, human resources and management practices (Cyr, Johnson, & Welbourne, 2000; Hellmann & Puri, 2002), and corporate governance (Baker & Gompers, 2003). Hsu (2004) argued that the start-up often struggles to establish the trust required in setting up collaborations and seeking the desired partnerships. De Clercq, Fried, Lehtonen, and Sapienza (2006) suggested that collaboration with a VC positively affects a company's reputation and trust, which can be critical for partners and stakeholders in being willing to collaborate. Furthermore, Fried and Hisrich (1995) emphasised that a VC's moral support and improving discipline in their portfolio companies helps to improve the company's operational performance.

Frank et al. (1996) suggested that a high number of company failures are linked to the so-called 'valley of death', when the cost of running a business is generally high and revenues are low. A VC, having a pool of financing at their disposal, can assist companies in overcoming financing issues at this critical stage of development (Gompers & Lerner, 2004). Kelly and Kim (2018) found that a VC's financial support has helped companies in accelerating development, as well as ensuring successful commercialization. Research conducted by Bertoni and Tykvova (2012), Caselli, Gatti, and Perrini (2009), Dubocage, Rivaud-Danset, and Redis (2012), and Hellmann and Puri (2002) reported VCs' value-added contributions in technological, managerial, financial support, and industry-specific networking. Listing a company to the stock exchange, mergers or acquisitions, and getting the evaluation right is often a difficult proposition for companies. Using their expertise, experiences, and knowledge, VC can help companies in ensuring successful and profitable exits. A study conducted by Lahr and Mina (2016) showed that partnering with a VC improves a company's patenting process.

3. Methodology

The objective of the study (VCs' value addition to RET companies), the exploratory nature of this research, and the aim of studying a phenomenon in its natural setting makes an in-depth qualitative case study the appropriate approach for this research. Yin (1984) emphasized that a case study methodology can be applied in various contexts, having multiple units of analysis, and utilizing divergent means for data collection and investigations. The purposive sampling technique was adopted to identify cases for the study. The technique is useful when a researcher is particularly interested in the identification and selection of information-rich cases related to the phenomenon of interest (Ritchie, Lewis, McNaughton, & Nicholls, 2013). Since this study seeks to explore VCs' value-added contributions to their portfolio companies, it was only appropriate to select case companies that have acquired financing from venture capital firms. To identify such cases, we explored venture capital firms operating in Finland. First, a list containing the names and websites of portfolio companies was prepared. Second, the selected portfolio companies' websites were explored to ascertain which of these are involved in RETs. Companies that were not involved in RETs were excluded at this stage. The selected companies and venture capital firms (that have invested in the company) were contacted to explain the purpose of this research and seek their participation in the study. The selected RET companies matched the following criteria: a) portfolio companies agreed to be a part of the study b) those venture capital firms that had invested in the companies also agreed to be participate. Only companies where the company and the venture capital firm both agreed to participate were selected as cases. Altogether, we have included four companies in our study, each accounting for an individual case. Baxter and Jack (2008) and Stake (1995) affirmed that the integration of multiple firms helps in understanding the similarities and differences between the cases and thereby qualifies this study as a multiple case study. Furthermore, Eisenhardt and Graebner (2007) supported the adoption of multiple case studies, as this design ensures valid and reliable findings.

The data collection was conducted in the form of semi-structured interviews by two researchers. The average duration of the interviews with the companies lasted approximately an hour, whereas the

VCs' interviews took around one hour and fifteen minutes. The respondents were either the founder, CEO, or board of the directors for the companies and thus had a fair understanding of the company's history, operations, plans, and strategies. The respondents selected from the VCs were either the managing partners of the firm, who have extensively collaborated with the case company, or are serving on the board of directors of the portfolio company.

Interviews were divided into two stages. In the first phase, interviews with the case companies were conducted. The companies were asked questions concerning the contributions made by venture capitals on different accounts, concerns they had, and the challenges they faced. The interviews were transcribed and the summary was shared with the interviewees to avoid any misunderstanding, as well as to ensure that their point of view was correctly understood and represented. Interviews with the VC representatives were conducted in the second phase. They were asked to share their understanding of the portfolio company, contributions made by them to the company, and the challenges they had faced while working with the company. The companies and the venture capitals were both assured of secrecy and anonymity within this study. Both companies and firms were assured that no information would be exchanged between the participants.

All interviews were recorded and one researcher took notes during the interviews. A data triangulation technique was adopted to ensure accuracy and reliability while obtaining a detailed understanding of the situation. The sources utilized to supplement the primary data included the companies' websites, news articles, press releases, industry analysis reports, and information published on the VCs' websites. This approach has helped us gain an in-depth and comprehensive understanding of the overall process. The within- and cross-case analysis approach was adopted to analyze the cases. This approach has helped us in gaining a comprehensive understanding of each case and provided an opportunity to identify similarities and differences by comparing the case companies. Relevant excerpts are added in the analysis to gain a deeper understanding of the context, as well as to establish links between data and analysis (Anderson, 2010).

4. Case companies

Case Company A is one of the world's most advanced manufacturers of ceramic anode supported solid oxide cells. The innovative technology, offered by Company A, can operate in lower temperatures than its competitors at reduced costs, giving it an advantage over its competitors. The cell design and stack modularity allows the technology to be used in few kilowatt-hour (kWh) systems to multi- megawatt (MW) systems. Moreover, the technology can be used in multiple settings, such as residential and commercial uses, as well as transportation and energy storage solutions.

Case Company B offers dynamic compensation solutions for power quality, energy efficiency, and grid connections to renewable energy solutions. Company B's technology, such as active filters, Statcoms, and Static Var Compensators (SVC), save energy, increase productivity and capacity, as well as satisfy the requirements set for the grid connections. The company operates on a global scale, with successful investments in South America, Africa, Asia, and Europe.

Case Company C focuses on developing and commercializing solid oxide fuel cell (SOFC) systems in a range of 50–300kW for distributed power generation. The technology offered is capable of providing cost competitive and environmentally sound power generation solutions that radically improve reliability of energy supply, efficiency of primary energy use, and makes it possible to increase the use of renewables in the energy mix. The company designs SOFC systems for power security, competitiveness of lifecycle costs, grid and fuel flexibility, and minimal emissions. The company operates in both local and international markets.

Case Company D is an innovative company operating in the field of wave energy technologies. The company produces wave energy converters with minimal impact to the environment while offering viable economic opportunities at local deployment sites and communities. The technology offered is capable of working at low temperatures and under harsh climate conditions, giving it an edge over competitors. This company also operates on a global scale.

5. Analysis

As discussed in Section 2, VCs' contribution can be observed on different fronts. Table 1 presents the VC value-added contributions observed in the case companies. To understand the extent of contribution and the nature of engagement, we have scaled the contribution from insignificant, to moderate, and high. Insignificant refers to minimal to no contribution, while high signifies that the VC has contributed significantly. Engagement refers to whether a VC has been directly involved in the process, contributed indirectly, or not played any role in the studied area.[1]

5.1 Technology development

Technological competencies is one of the value-added benefits that a VC brings to a company (Large & Muegge, 2008). However, in our study, we hardly seen any VC activity that directly or indirectly

[1] For instance, High (Extent) and Active (Engagement) in the case of 'strategic orientation' means that the VC has been actively involved in setting the strategic orientation of the company and has significantly contributed on that front. Insignificant (Extent) and Neutral (Engagement) in the case of 'technology development' shows that the VC has neither been active nor contributed on this front. Moderate (Extent) and Indirect (Engagement) in the case of 'internationalization' means that the VC has moderately contributed, but has not been directly involved in internationalization. For instance, the VC have advised the portfolio company to participate in one of their events abroad, where the portfolio company partnered with a local consulting company (that later helped them in finding customers).

benefitted the technology development. This may be due to the fact that RETs require tacit knowledge and understanding to develop a technology further. Especially in cases where a technology is new and advanced, it is very likely that only people with a specialized set of skills, who are working with the technology, have an actual understanding of the functionality of the technology, as suggested by a VC:

> *"It is their [portfolio company's] job to ensure that the technology is operational and functioning, as desired. We have very little knowledge or understanding about how technical aspects of the technology can be improved; therefore, we do not have much to contribute from our side".*

The nature of the technology and the technical understanding needed to make a valuable contribution towards the technology's development is the key reason why we witnessed no contribution by the VC in this area. As affirmed by a CEO, commenting on the VC's input on the technology development front,

> *"No, they are not able to comment on the technology itself and they have never done it. It is very technical and only few people could be in position to do that. However, they might have their opinions about its application or design, but they are not going into the technical details".*

5.2 Strategic orientation

Improving the strategy and setting company's strategic orientation is found to be one of the key contributions by the venture capital. Technology-based start-ups are often formed by a team of technical experts, who generally lack business acumen. The portfolio companies ranked VCs' contribution in this domain of high importance. The CEO of one case company affirmed,

> "*If we think about how to develop business, secure enough funding, contact right people for services and to partner with, I believe the contribution of venture capital has been the most important. I would say that we [our team] did not have that background. My previous job was design-related consultancy, which was purely technical and did not require any skills in business or management. VC has bridged that gap. We have developed a clear strategic focus*".

The CEO of another case company stressed a similar contribution:

> *"The positive [thing for us] was that the structure of company's management has improved. We started to have our ordinary board meetings, management team meetings, and operational planning meetings in a planned manner. Overall, the company's strategy planning process became much more formal, as it should be, and better organized. That was the biggest*

improvement from management's point of view. Resource planning, allocation, distribution, and these sorts of activities got more attention".

The VC affirmed,

"*It is of great importance to set the right trajectory… it is a continuous work. Many of our companies … let us say … run on low resources. With smaller resources, they need to achieve something that their competitors are attaining with much higher resources. Therefore, it is essential to have the right resources allocated for research and development, management, communication, and marketing. We put effort into resourcing the company in a manner that the team can work things out for themselves [on their own]. For us, it is important to assist our companies in setting the strategic focus. For instance, which one could be an interesting market to explore, which market segment and customers to hit, how to work in the market in the long run, how to make a business plan work, and so forth".*

5.3 Teambuilding

Teambuilding is one of the domains where venture capital tends to contribute (Gorman & Sahlman, 1989). The contribution may come in the form of recruiting new people, making changes to top management, or re-structuring the core team. Recruitment was not been the primary focus in the studied cases as suggested by a VC:

"We do not generally interfere in a company's recruitment process. The core team of our portfolio companies are technical experts working together on something for quite some time. We do not pick up a person and place them in the company. It may affect the whole team. Rather, it should be that they [the team] decide who they want to hire and to work with in their team".

The VCs are mostly active in assisting with profiling and suggesting what sort of person could be suitable, which sectors to look at, how many resources should be dedicated, and how a compensation plan should be devised. For instance, in one case company, the VC realized that the company was performing well and there was now a need to employ full-time staff to work on sales and marketing to boost the company's sales. The managing partner of the VC firm stated,

"*We are now in discussion with the portfolio company that they [the portfolio company] needs people to develop their sales team. We will advise them on having the right level of compensation, as it is essential to hire and retain people with the right skillset. However, they [the team] will conduct the hiring process*".

Although, VCs may also refer someone to their portfolio company if they feel they may be suitable. As explained by the VC:

"We, at times, do suggest [new team members to] our portfolio companies if we come across someone who could be suitable for the company. They could be someone who has applied for the job at another company [other portfolio companies], or is someone with whom we have worked with in the past and know that they possess good merits. However, we never interfere or force a company to hire. It is up to them [the team] to decide if they need a person of that skillset and decide if they would add value to the team".

However, in one of the case companies, the VC was directly involved in the recruitment process, as there came a time when they needed to establish an office in Finland. Since the venture capital firm is based in Finland and had a fair understanding of the local market and professionals, the VC helped the portfolio company in setting up the office, built a competent team and discussion around their compensation packages. Similarly, in another case company, the suggestion was made that the company should hire a CEO who is experienced in developing company operations, processes, can acquire external finances, and has expertise in taking the company to the commercialization phase. At the same time, the existing CEO, who is an expert engineer and knowledgeable in technology development, could have more time to spend on improving the technology, reducing the cost, and making it more efficient. As affirmed by the CEO of that company,

"*Actually, I am a technical guy, I am more interested in the technological aspects, and I thought my skills are needed there. Hiring someone else as a CEO would give me time to get engaged with the technology team more and use my skills there*".

This new CEO was proposed by the VC.

5.4 Collaboration

Working with a VC can offer an excellent opportunity to collaborate with other portfolio companies, who are in relatively similar stage of the development cycle and operating in a similar market. In the studied cases, the venture capital provided two of its portfolio companies with an opportunity to collaborate with each other to develop a technology further, share their experiences, and learn from each other. Since both of the firms are dealing with similar technologies, the interaction and collaboration could create a synergy effect. As stated by the VC,

"Together they can develop the technology further, optimize the system, bring efficiencies, use distribution networks, and can cut the cost down better than any other way possible."

However, the collaboration should be a voluntary act and companies involved in collaboration should themselves decide if they want this type of cooperation. As stated by a VC,

"*We always encourage our portfolio companies to interact, we usually introduce teams to each other and leave it to them to collaborate should they choose and find feasible ways to do* *so. After all, it is their business and they should be making the final decision. There is no point in making them do something that they do not value*".

5.5 Internationalization

Internationalization is another important front where a VC can help companies (Lockett, Wright, Burrows, Scholes, & Paton, 2008). Due to the small local market, Finnish technology companies have very little choice except looking for customers and projects in the international market. As stated by one of the case companies,

"*Our first deliveries were not in Finland but to Asian countries. For us, the life has been the other way around. We could not really find customers in the local market, so we started the other way around. We got our references abroad and now finally are getting sales in Finland, years after our inception".*

Furthermore, in the case of RETs, certain regions have more potential of generating energy compared to the others. Likewise, there are some countries where there are supportive policies in place that make some RETs commercially viable. A CEO of a case company stated,

"*We are always mapping out the potential areas where our device can work at an optimal level, where there is interest in renewable energy, and the prices of electricity are high. These regions offer chances of success and making profits. However, they are usually far from our home market, and we often require assistance to reach these markets*".

One of the venture capital firms studied had good connections internationally. The VC participated in a business fair in China and took the CEO of a case company to explore business opportunities there. The CEO stated,

"*We participated in the event and figured out that the Chinese market would be interesting for us to find perspective customers as well as to get our devices manufactured. The Chinese [companies] would be able to do it at the [needed] scale, effectively, and at a lower cost, so we started putting effort into that market. We hired the services of a local consultant who helped us in identifying potential partners*".

In the case of another company, the VC used their connections to find partners in the Asian market to expand their operations.

5.6 Financing

Venture capital helps companies in meeting their financial needs through investment. However, there is generally a limit to this investment. More often than not, venture capitals are not the sole financers of their portfolio companies. The company may need to arrange additional financing from different sources, such as banks, business angle networks, crowd sourcing, and grants. The start-up stage requires companies to have adequate financing to meet their hefty financial needs. VCs can help companies in arranging this additional financing. As observed in one case company, which acquired financing from two venture capitals. The second VC was involved in the process through contact initiated by the first VC. The first venture capital firm knew the managing partner of the second VC and discussed the opportunity to co-finance the company. In the case of another case company, VC helped the company in applying for an EU grant. The VC informed the company about the funding possibility and shared details about consultancy firms who could help prepare the application package. The assistance helped the company secure 12M €, which, as stated by the VC and affirmed by the company's CEO, "*would not have been possible to secure without the VC's input and collaboration*". Similarly, in another case company, VC held discussions with a multinational firm and invited them to invest in the portfolio company.

5.7 Access to resources and services

Access to the resources necessary to perform various tasks is also a valuable contribution that a VC brings to the table. A VC work with a number of companies that are, more or less, in a similar developmental cycle and have similar needs; therefore, the resources utilized for one portfolio company can be valuable for other companies too. Having past experience of working with similar companies ensures that the portfolio company can immediately find the required resources without needing to go through an extensive market search process. It reduces the time, effort, and associated transactional costs. As one CEO stated,

> *"Consultants often come through the VC side. They are working for several companies. [Therefore], once they recognize that someone is good, they [VC] will tell you that this firm has succeeded with such and such thing. Then you can contact them if you are looking for someone with the similar expertise. I think it is very important to get these ideas about where to try, where to look, whom to talk to. Once you have a proper contact, it provides a certain level of trust and surety that we are working with professionals. For instance, we have recently contacted a lawyer for some work and we have gotten this contact from the VC. Many such contacts have come from the VC".*

The CEO of one case company iterated,

> *"The VCs have very good contacts…running so many companies simultaneously, they see what is going well, what works, what does not … and of course, they recommend these good contacts to us and to the other portfolio companies. The last consultant that we used for filing an application for funding from the EU came through the VC's contact".*

5.8 Market knowledge

Asymmetric information is one of the key challenges that a start-up and SMEs face. This becomes even greater in the case of RETs, as the market is in the early stages of development. The companies are usually running low on resources, and success is often connected to supportive policies and infrastructure support. This makes it somewhat challenging for a company to prepare themselves for the challenges that may ensue. The venture capitals being well-connected to the industry and having knowledge of the market can provide valuable information and mitigate the effect of such asymmetries. For one case company, when the CEO initially discussed the idea with the VC, to seek financing and partner with them, the VC suggested that the company should accelerate the development of their technology, as they were aware of other companies who were already working on similar technologies, and being late to the market can trigger severe competition. The CEO stated,

> "*They [VC] thought that we are actually late in the market; for one, they were aware of couple of other companies who were developing similar technologies. Secondly, it was their assessment that the market of these technologies is just about to open up and if we are not quick, we might lose big opportunities*".

The market knowledge of the VC encouraged the company to hasten the process and develop the technology quicker and better than their competitors.

5.9 Legitimization

Improving the image of the company and increasing their legitimization is also an important aspect that VCs contribute to. Being a start-up and having a technology that is not tried and tested, it becomes difficult for young companies to acquire the trust of perspective financers, customers, and partners. The VC can help companies in bridging this trust deficit. Having a VC on board, in itself, signals that the company has potential and the technology may offer a unique value proposition. The CEO of one case company, on discussing the legitimization effect, stated,

> "*Yes, it improves. I would say because it is always easy to acquire an additional investor if there are already investors on board. If somebody has already invested, people think that maybe it is worth investing and we should invest as well… I think it is a natural behavior. If nobody is buying or going to a resultant, it [would] require additional efforts to invite customers in comparison to a restaurant, which is nearly full of people all the time, it will automatically attract customers' attention*.

Similarly, the CEO of another case company stated,

> "*We are a young company and we do not have too many resources. Companies [customers] usually wonder if we will have the resources to carry out larger projects. We have signed some big projects when the company's overall worth was 3M €; we got one project worth 1M*

> *€. In these kinds of situations, it helps when you can say that we are backed by a venture capital fund that has a 50M € fund. So do not worry, we will be backed up".*

In such situations, having a VC on board is certainly helpful. However, in some cases, it may not have the desired effect. It is no secret that a VCs' investment in a portfolio company is for profit-seeking purposes and they are constantly looking for the right time to generate revenue from their investment by redeeming their share or selling the firm to a third party. This situation may be concerning for perspective partners if they are looking for long-term collaboration or partnership.

> *"When we are looking for partners, where our aim is to establish a long-term partnership, having a VC may send mixed signals. When they [perspective partner companies] see that we have a venture capital on-board, they realize that the relations are not going to be the same in the long term. When the business starts to pick up, the venture capital will sell the business to somebody and the whole business environment will change".*

6. Discussion and conclusion

Section 5 briefly discusses the extent to which VCs have benefitted their portfolio companies. The analysis highlights that setting companies strategic orientation is one of the contributions that is highly valued, both by the case companies and the venture capitals. The core team of case companies are a team of technical experts, who are mostly active of technology development front. The understanding required to keep business operations running optimality, taking care marketing and management-related issues are often lacking. The VCs having rich experience and expertise in working with such ventures can help bridging this gap. Moreover, companies operating in renewable energy face challenges those are different from the conventional tech industry. Some of the RETs are in the relatively earlier stages of development, have high fixed costs, and require longer periods of time to develop. In the case of Finland, the additional challenge is the small domestic market. The companies need to go international from a very early stage. A VC can provide the market knowledge, network, and contacts needed to make these big steps in markets that are far from their country of origin.

Moreover, the analysis revealed the importance of having clear and open communication between the portfolio companies and the venture capitals regarding how the business should move forward. We have observed that the companies and the VC may have differing expectations of each other. A company, collaborating with VC, may come under the impression that now financing, finding partners, strategy, and business-related activities will be taken care by the VC, and the team can focus on the technology development aspects. As affirmed by one of the portfolio company's CEO,

> *"Currently, if I estimate I spent 80% of my time on funding-related issues, which is ... maybe ... important or required, but I am not a funding expert. I am a technical person. If we talk about the added value of a VC, one would assume that they [venture capital] would have a wide network of additional investors that they [are] continuously working with, a network of companies that you [portfolio companies] can potentially collaborate with. A network which could help in internationalization and finding partners to discuss exit opportunities with. One would expect the VC to take care of such things, which has not happened in our case"*.

Likewise, on the issue of cooperation,

> *"The policy of the VC has been that they are not putting companies to cooperate, or let us say they are not pushing companies to cooperate. If you look at their portfolio companies, there could be a lot of synergies between the companies. [Portfolio] companies would benefit if there were more cooperation. [However], from the VC perspective, I would say they see those [portfolio companies] as separate items in their portfolio. The companies may cooperate with each other if they see a self-interest in doing so*.

On the other hand, the VC may have a different account of the things, as stated by the managing partner of a venture capital,

> "*It is their company and they should decide if they want to collaborate with someone or not. We simply introduce companies and share information. [The] teams should be able to work together ... and that is important. We do not believe that we should force any company to work with anyone unless they see it by themselves"*.

Furthermore, when it comes to creating trust, collaborating with a VC has a dual effect. A VC can help in establishing confidence with the customers who are afraid of companies' resources; however, they can also lead to insecurities for those who are looking for establishing long-term relationships with the company.

7. Limitation and future studies

This study is based on a comparative case study design, where we have selected four case companies that acquired financing from different venture capitals. It would be interesting to increase the number of cases to explore the VC's value-added contributions towards their portfolio companies. Similarly, the extent and the contributions made by the venture capitals may vary based on their profile, experience, and area of expertise. Therefore, it would be worthwhile to conduct a study with increased number of venture capitals and case companies. One of the limitations of this study concerns the time in which this research was carried out. The VCs and portfolio companies' collaboration is ongoing.

It is probable that some of the VCs' contributions will come at later stages, after this study has been conducted; therefore, it could not have been reported. Moreover, this research is conducted in the context of one specific industry (i.e. RETs). The findings of this study may be generalizable to industries that are disruptive in nature and share similar characteristics. However, generalization on a broader level should be done with caution.

Table 1: Overview of the contributions

	Company A		Company B		Company C		Company D	
Contribution	**Extent**	**Engagement**	**Extent**	**Engagement**	**Extent**	**Engagement**	**Extent**	**Engagement**
Technology Development	Insignificant	Neutral	Insignificant	Neutral	Insignificant	Neutral	Insignificant	Neutral
Teambuilding	Moderate	Direct	Insignificant	Neutral	Moderate	Indirect	Moderate	Direct
Collaboration	Moderate	Direct	Moderate	Indirect	Moderate	Indirect	Insignificant	Neutral
International-ization	Moderate	Indirect	Insignificant	Neutral	Insignificant	Neutral	Insignificant	Neutral
Financing	Insignificant	Neutral	High	Direct	Insignificant	Neutral	Insignificant	Neutral
Access to Resources	Moderate	Direct	Moderate	Direct	Insignificant	Neutral	Moderate	Direct
Market Knowledge	High	Direct	Insignificant	Direct	Moderate	Direct	Moderate	Direct
Strategic Orientation	High	Direct	High	Direct	High	Direct	High	Direct
Legitimization	Moderate	Indirect	Moderate	Indirect	Moderate	Indirect	Moderate	Indirect

Extent = Insignificant, Moderate, High **Engagement** = Direct, Indirect, Neutral

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Towards the establishment of renewable energy technologies' market: An assessment of public acceptance and use in Pakistan

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Adoption of renewable energy technologies is a complex and intricate process affected by a multitude of factors. The objective of this study is to examine the factors influencing consumers' intention to use renewable energy technologies for household usage in Pakistan. In order to understand the adoption behaviour, we have extended the actual framework of the theory of planned behaviour by integrating three additional factors, i.e., environmental concern, cost, and awareness. The findings of this research are based on primary data collected from 244 households in the twin cities of Islamabad and Rawalpindi through survey questionnaires. The proposed hypotheses were then tested and analysed using structural equation modelling. The results reveal that factors such as subjective norm, perceived behavioural control, and attitude positively influence consumers' intention to use renewable energy technologies in Pakistan, whereas cost has the opposite effect. Interestingly, awareness and environmental concern were found to be insignificant. The results of this study highlight the need to increase environmental awareness, frame innovative financing mechanisms, and address the benefits that renewable energy technology offers, all through an integrative and coherent effort. *Published by AIP Publishing.*
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I. INTRODUCTION AND BACKGROUND

Over the past few decades, environmental and climate change issues have taken the centre stage in political and economic debates around the globe. The excessive use of hydrocarbons for energy generation purposes has severe effects on the environment, nature, and society as a whole. Efforts are being made to ensure a smooth transition from conventional fuels to renewable sources for energy generation purposes. However, the successful and smooth transition from one energy source to another is very much dependent upon the efforts at multiple levels and on the input of all the stakeholders involved in the process (Kern and Smith, 2008).

Entrepreneurs and energy technology companies are important elements in this transition process since without the availability of affordable and reliable energy technologies, the transition of the energy system and the attainment of related environmental targets will remain only a dream. Therefore, invention, diffusion, and adoption of technologies by consumers all become important. However, for a technology which is high-tech, is radical in nature (requires changes in existing institutional and technical infrastructures), and belongs to an industry which is in the earlier phases of development, it may be challenging to achieve successful commercialization in isolation (Shakeel *et al.*, 2017). Story *et al.* (2011) affirmed that a single company is rarely

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capable of ensuring the successful commercialization of a technology. The diffusion of such technologies often requires cooperation between individual actors, organization, and support from other stakeholders. Actors surrounding the innovator companies can impart knowledge and provide access to relationships and other resources that are important for commercialization. Similarly, the role of consumers in facilitating and accelerating this transition cannot be overlooked. Consumers, as end users, must make the final choice between conventional and environmentally friendly solutions. Therefore, their understanding of the issues and their awareness (AW) regarding the alternatives become an important topic. Environmental and economic policymakers emphasize consumers' responsibility and the role they can play in achieving environment-related targets. According to Aarikka-Stenroos *et al.* (2014), successful commercialization requires innovation in promoting interaction and communication between individuals and communities. Therefore, consumers' actions and behaviour towards renewable energy sources have become pivotal in achieving energy-related targets and in the attainment of a sustainable future.

Pakistan, as a populous and developing country, requires ample supplies of energy to meet its domestic energy requirements and keep its development on track. However, despite being endowed with enormous resources and energy generation potential, the country has not been able to meet its primary energy needs and has experienced acute energy crises (UNDP, 2014). Electricity is the sector that has suffered the most from the energy shortages. The gap between demand and supply is managed through routine power cuts. The duration of power cuts can be 8–10 h a day in the cities and 10–14 h a day in rural areas, depending upon the generation capacity and the energy demanded (GIZ, 2016). This inability to ensure the necessary energy supplies has hindered the country's economic development and has impacted the social life of its inhabitants. The restricted supplies of electricity from the grid have left households and businesses in disarray, leaving them with no other choice but to install an alternative energy generation system in homes and workplaces. This prolonged absence of grid electricity has led to the development of whole new markets for alternative energy generation systems—including rechargeable devices, storage batteries, uninterruptible power supplies (UPSs), power generators, and solar photovoltaics (PVs). To this end, a standard household generally relies on a UPS, an oil-fired power generator, and/or rechargeable devices for access to electricity when power from the grid is turned off.

Pakistan is blessed with enormous renewable energy potential, and the use of renewable energy technologies (RETs) for the power generation can help to reduce import costs and decrease emissions, offering a long-term solution. Despite the significant energy generation potential, the use of sustainable energy technologies such as solar PV is not always a preferred choice. A number of factors are attributed to the low adoption of RETs worldwide including the cost, use of the technology, lack of supportive policy frameworks, and low levels of environmental awareness (Karakaya and Sriwannawit, 2015). However, there have been hardly any studies conducted in the context of Pakistan to understand the drivers encouraging or discouraging consumers to opt for or abstain from RETs. Extant research has primarily focused on the availability of different energy sources and their potential (Ghafoor *et al.*, 2016), the state of the energy generation sector (Shaikh *et al.*, 2015), the impact on industry and the economy (Shahbaz and Ali, 2016), emission reduction (Yousuf *et al.*, 2014), energy security (Sahir and Qureshi, 2007), analysis of government initiatives and policies (Shakeel *et al.*, 2016), studies of the barriers that the sector is facing (Rafique and Rehman, 2017), and the way forward (Amer *et al.*, 2016). However, studies from the perspectives of technology companies and consumers have largely remained unaddressed. In the absence of relevant information, it becomes difficult for companies, policymakers, and other stakeholders to formulate effective strategies and devise measures to encourage customers to use renewable-based solutions, consequently enhancing the adoption of such technologies. This study attempts to bridge the gap by investigating the factors influencing consumers' intentions (INTs) to use RETs for household purposes. The remaining sections of this paper deal with: (a) the theoretical framework and hypothesis development, (b) the methodology of the study, (c) the results and analysis, (d) the discussion, (e) the conclusion and implications, and (f) the limitations and suggestions for future research.

II. THEORETICAL FRAMEWORK

Previous research has argued that consumers' decision-making is a complex phenomenon, and an actual purchase decision may have been influenced by several divergent factors, such as economic, social, and psychological factors (Olshavsky and Granbois, 1979). To understand the complex nature of consumers' purchase decisions, several theoretical frameworks have been applied by researchers, for example, social cognitive theory (SCT), self-efficacy theory (SET), the theory of reasoned action (TRA), and the theory of planned behaviour (TPB) (Ajzen, 1985; Ajzen, 1991; and Fishbein and Ajzen, 1975). Among these frameworks, TPB remains prominent and widely adopted (Madden *et al.*, 1992). TPB envisages an individual's intention to engage in certain behaviours. The TPB considers that individual behaviour is driven by behavioural intentions, corresponding: (a) attitude (ATT) towards a behaviour, meaning how positive or negative an individual feels about the behaviour of interest, keeping in view the outcomes of that particular behaviour, (b) subjective norm (SN) refers as a social influence to perform or not to perform certain behaviours, (c) perceived behavioural control (PBC) considers an individual's subjective evaluation of how easy or difficult one feels to engage in certain behaviour, based on one's perceived enablers or impediments to that behaviour (Ajzen, 1991) (see Fig. 1). TPB has been applied to various aspects of consumer research, such as online buying (George, 2004), environmental and green behaviour (Kumar and Chandra, 2018), and organizational studies (Chen *et al.*, 2017). There is a consensus among researchers that the use of any particular technology is largely influenced by different multidimensional factors with economic, social, and regulatory dimensions (Leucht *et al.*, 2010). The adoption of RETs becomes even more complex due to the high cost of the technology, the long payback period, and the societal impacts it promises to have. Several studies have applied the TPB framework to examine the influence of different factors on sustainable energy technology adoption behaviour, and these studies acknowledge that this model is suitable and assumes rational behaviour (Alam *et al.*, 2014; Chen, 2016; and Korcaj *et al.*, 2015). Acknowledging the suitability and robustness of TPB for examining the consumers' intention to use RETs in Pakistan, we have extended this model by integrating three contextual factors, namely, environmental concern (EC), cost, and awareness. Environmental concern can be regarded as the degree to which consumers are aware of the problems of environmental degradation, cost is the total price the consumer pay for the purchase of the technology, and awareness is the degree to which consumers are aware of the RETs and their benefits. The integration of these contextual factors enabled us to make the framework comprehensive enough to investigate the factors that may play an influential role in shaping consumers' intention to use RETs. Section III discusses the hypotheses, and Fig. 2 presents the framework.

III. HYPOTHESIS DEVELOPMENT

A. Environmental concern

Environmental concern (EC) is the degree to which people are aware of environmental problems and are concerned about solving them. An increasing number of people around the world are becoming conscious of the environmental impact of their daily consumption

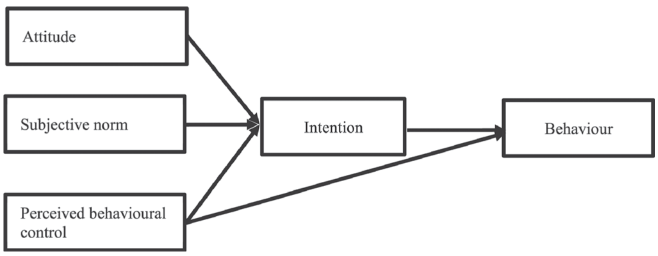

FIG. 1. Theory of planned behaviour.

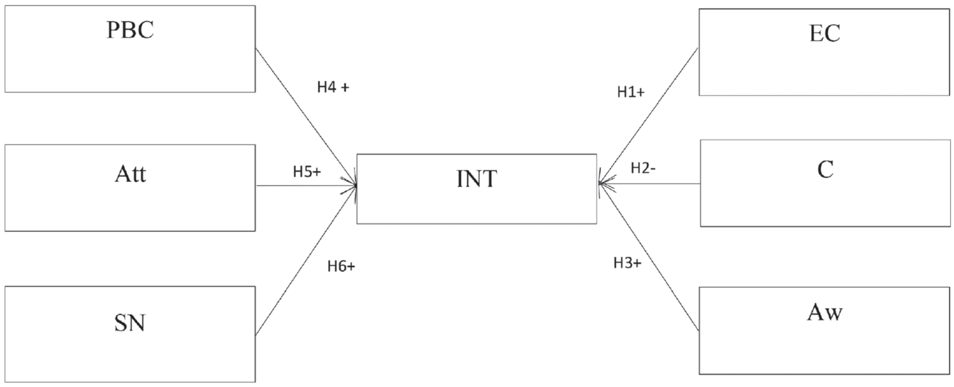

FIG. 2. Renewable energy intention research model (TPB extended for this study).

behaviour and wish to minimize the damage it causes (Fujii, 2006). Individuals who show such concerns also made efforts to protect the environment and demonstrate a favourable attitude towards green purchases (Tan, 2011). Growing attention has been paid by researchers to examining consumers' EC and the influence this has on their decisions to buy sustainable products. Dienes (2015) affirmed that EC is a major determinant of consumers' pro-environmental intentions, influencing their intention to purchase environmentally friendly products. It is further argued that people who show concern about environmental damage tend also to be cautious about their energy usage and to hold favourable attitudes towards the use of RETs (Lin and Syrgabayeva, 2016). Zhang *et al.* (2015) found that energy conservation becomes a self-perceived responsibility of consumers who are concerned about the environment. Hartmann and Apaolaza-Ibanez (2012) affirmed that environmentally conscious consumers view energy conservation more favourably. According to Liu *et al.* (2013), the sensitivity of consumers towards climate change issues can influence their intention to adopt RETs. Urban and Scasny (2012) argued that EC has an influence on consumers' desire to save energy. Based on the arguments, we expect that consumers' EC will favourably influence their intention to use RETs. Therefore, it is hypothesized that

H1. *Consumers' environmental concern will positively influence their intention to use RETs.*

B. Cost

Consumers evaluate price information to determine the monetary sacrifice related to the purchases they make (Dodds *et al.*, 1991). Cost (C) is perceived as one of the principal barriers to the adoption of RETs (Ghosh and Ghosh, 2018). The overall cost of RETs has decreased over the years (Chu *et al.*, 2016); however, it is yet to reach at the level where it can compete with existing solutions (Shakeel *et al.*, 2017). RETs are believed to be expensive, requiring high initial installation costs (Claudy *et al.*, 2013). Several studies have found a negative relationship between the cost and the adoption of RETs (Park and Ohm, 2014 and Yaqoot *et al.*, 2016). Zografakis *et al.* (2010) revealed that consumers are reluctant to pay additional price for RETs. Research conducted by Powers *et al.* (1992) affirmed that the higher the cost of the technology, the higher the consumers' reluctance to use it. Hansla *et al.* (2008) found that consumers' willingness to pay for green electricity decreases with the increase in its cost. In their study, Traber and Kemfert (2009) also found that despite the advantages that a renewable energy technology can offer, its association with high cost represents a huge impediment to its adoption. More recently, the studies conducted by Eder *et al.* (2015), Kardooni *et al.* (2018), and Luthra *et al.* (2015) in the developing world context identified capital cost as a major obstacle in the adoption of RETs. Based on these arguments, we hypothesize that

H2. *There is a negative influence of cost on consumers' intention to use RETs.*

C. Awareness

Awareness (AW) is an important factor in consumers' decisions to adopt a new technology (Howard and Moore, 1982). In the context of RET use, awareness can be regarded as consumers' knowledge and understanding about the technology and the advantages and disadvantages that the use of technology may have regarding costs, savings, efficiency, and related matters (Van Raaij and Verhallen, 1983). According to Zografakis *et al.* (2011), awareness is an important factor in determining consumers' RET adoption decisions. Alam *et al.* (2014) concluded, in their study conducted in the Malaysian context, that awareness is positively related to consumers' intention to use renewable energy sources. Von Borgstede *et al.* (2013) explained that the reason for adoption may be the technological benefits or the environmental offering the technology has. Ek (2005) stated that consumers who are fully aware of how their actions can lead to the reduction of carbon footprints may take measures to change their current way of life and adopt technologies and other means to contribute positively towards the environment. Therefore, it can be deduced that an effort should be made to increase consumers' awareness about the availability of technologies and to reiterate the benefits the use of these technologies may yield and the positive environmental impacts they may have (Islam, 2014). However, due to poor education and understanding, people may not always be aware of the need for saving energy and protecting the environment (Wang *et al.*, 2014). This lack of awareness can be a critical factor with a negative influence on consumers' adoption of new technologies (Sathye, 1999). Given the importance of awareness in renewable energy adoption, it is therefore hypothesized that

H3. *There is a positive influence of consumers' awareness on their intention to use RETs.*

D. Perceived behavioural control

Ajzen (1985) explained that perceived behavioural control (PBC) is the belief of an individual in his ability to perform any behaviour. PBC directly influences the intentions of an individual and indirectly influences his or her behaviour. If an individual is not capable of performing any behaviour, the corresponding intentions will not be formed. In the context of RETs, PBC is related to how easy or difficult a consumer believes it would be for him or her to adopt the technology. One aspect that can influence an individual's PBC is related to the technicalities associated with the use of the technology. PBC has been found to positively influence consumers' purchase of environmentally friendly products (Ham *et al.*, 2015).According to Korcaj *et al.* (2015), to use a renewable energy source, an individual must have access to the resources required for the purchasing and installing a RET and the use of a RET. Studies reveal that PBC is positively related to consumers' energy conservation intentions (Alam *et al.*, 2014). Wang *et al.* (2017) argue that PBC plays an important role in consumers' vehicle choices with respect to energy. Tan *et al.* (2017) found that PBC had a positive influence on Malaysian consumers' use of energy-efficient appliances. Halder *et al.* (2016) found that PBC was a strong determinant of consumers' intention to use bioenergy in Finland and India. Based on these arguments, it is therefore hypothesized that

H4. *Perceived behavioural control positively influences consumers' intention to use RETs.*

E. Attitude

Attitude (ATT) is an important element of the TPB that refers to the evaluation of any behaviour by an individual as favourable or unfavourable (Ajzen, 1985). Attitude can be regarded as consumer's positive or negative feelings towards the use of RETs. The origin of these positive or negative feelings may be based on the outcomes and benefits expected from their use, which may be environmental, economic, or social. The extant literature shows that attitude is positively related to consumers' intention to use RETs. Consumers believe that green energy helps to prevent climate damage and global warming, decreases our dependency on conventional energy, and improves air quality (Hartmann and Apaolaza-Ibanez, 2012). Tan *et al.* (2017) argued that attitude is a powerful predictor of household energy use. Attitude has also been found to be a strong predictor of consumers' ecological behaviours, such as recycling and fuel conservation (Kaiser and Gutscher, 2003). Greaves *et al.* (2013) found a strong relationship between employees' attitude towards the environment and their energy saving behaviour. In addition, Tan *et al.* (2017) affirmed a positive relationship between attitude and consumers' intentions to purchase energy-efficient household appliances. Attitude has also been found to be positively associated with consumers' intentions to reduce energy (Fujii, 2006). Ha and Janda (2012) found that attitude has a strong effect on consumers' purchase intention toward energy-efficient products. Moreover, Afroz *et al.* (2015) reported the positive influence of attitude on consumers' intention to purchase environmentally friendly vehicles. All these arguments lead to the formulation of the following hypothesis:

H5. *There is a positive influence of consumers' attitude on their intention to use RETs.*

F. Subjective norm

A subjective norm (SN) is defined by Ajzen (1991) as a perceived social pressure to perform or not to perform certain behaviours. The SN can be regarded as an influence or pressure from friends, family members, and peers, resulting in the use of RETs. The SN or normative social influence has been identified in earlier studies as a significant factor influencing consumers' energy and conservation behaviour. For example, Hori *et al.* (2013) found a positive relationship between SN and consumers' energy saving behaviour. Subjective norm indeed exerts a positive impact on consumers' energy saving and carbon reduction behaviour (Chen, 2016). Rogers *et al.* (2012) suggested that the success of community renewable energy projects depends on fostering new social norms for energy generation. Ozaki (2011) argued that social norm influences consumers' adoption of green electricity. Moreover, Gadenne *et al.* (2011) revealed a positive relationship between SN and consumers' environmental and energy saving behaviour. In their study, Ozaki and Sevastyanova (2011) reported that SN is an important motivational factor in encouraging the purchase of sustainable energy technologies. Similarly, Liu *et al.* (2013) found that consumers would be likely to undertake a similar action if their neighbours chose to use a RET. Most recently, Jayaraman *et al.* (2017) found a positive influence of SN on consumers' purchase intentions regarding PV panels. The findings of these studies reflect the fact that consumers are likely to be influenced by the opinions and actions of other people. Therefore, it is rational to assume that this may also hold true in the context studied here. Based on this, we hypothesize that

H6. *There is a positive influence of subjective norm on consumers' intention to use RETs.*

IV. METHODS

A. Measures and data collection

The scale items for measuring the awareness, cost, and PBC are adopted from the study by Alam *et al.* (2014). Scale items related to the EC variable are obtained from the studies of Bang *et al.* (2000) and Hartmann and Apaolaza-Ibanez (2012). Scale items for measuring attitude and intention to use (INT) are adopted from the studies of Chou *et al.* (2015) and Yazdanpanah and Forouzani (2015). All the scale items were measured on a Likert scale from 1 (strongly disagree) to 5 (strongly agree). The data were collected during the months of March and May in 2017, using the convenient random sampling technique in the twin cities of Islamabad and Rawalpindi, Pakistan.

B. Data analysis and results

The Statistical Program for Social Scientists (SPSS 20.0) was used to analyse the demographic data of the respondents. However, for model fit analysis, we used the structural equation modelling (SEM) of partial least squares (PLS) approach, using SmartPLS 3.0 application software. PLS is a widely used variance-based SEM technique which is used for examining the relationships among latent variables. The PLS method is efficient, is less stringent, does not make data distribution assumptions, and works well with a small sample size (Hair *et al.*, 2011). In addition, since this study aims to examine consumers' intention to use RETs, PLS, which is intended for predicative analysis, is more suitable than covariance-based techniques (Reinartz *et al.*, 2009).

C. Sample characteristics

A total of 244 questionnaires were filled out by the respondents. The majority of respondents (37, 15.2%) were 36–40 years of age. There were more male respondents (148, 60.2%) than female respondents. A total of 144 respondents (59.0%) were married. Respondents were mostly bachelor degree holders (131, 53.7%). Only two respondents (0.8%) had income levels less than 5000 PKR, whereas 59 (24.2%) had income levels above 60 000 PKR (see Table I).

TABLE I. Demographic characteristics.

Characteristics		N	Percentage (%)
Age (years)			
	18–20	16	6.6
	21–25	41	16.8
	26–30	36	14.8
	31–35	27	11.1
	36–40	37	15.2
	41–45	23	9.4
	46–50	23	9.4
	51–55	21	8.6
	56–60	10	4.1
	Above 60	10	4.1
Gender			
	Male	148	60.7
	Female	96	39.3
Marital status			
	Married	144	59.0
	Unmarried	98	40.2
	Divorced	1	0.4
	Widowed	1	0.4
Education			
	Primary	3	1.2
	Secondary	22	9.0
	Bachelor's degree	131	53.7
	Master's degree	84	34.4
	PhD	4	1.6
Income (in Pakistani rupees)			
	Less than 5000	2	.8
	5001–10 000	4	1.6
	10 001–15 000	14	5.7
	15 001–20 000	16	6.6
	20 001–25 000	14	5.7
	25 001–30 000	26	10.7
	30 001–35 000	19	7.8
	35 001–45 000	31	12.7
	45 001–50 000	29	11.9
	50 001–60 000	30	12.3
	Above 60 000	59	24.2

D. Descriptive statistics, correlation, and discriminant validity of measures

As shown in Table II, the descriptive statistics of the data were checked using the mean and standard deviation, and the interrelationships between the variables were checked using Pearson's correlation test. In addition, the discriminant validity of the data was assessed using the square root of the average variance extracted (AVE).

E. Measurement model

A confirmatory factor analysis (CFA) test was performed to assess whether the data collected to test the model in this study resulted in an adequate fit. To test the internal consistency of the items for each variable, we used composite reliability (CR) (Fornell and Larcker, 1981). Moreover, the discriminant validity and convergent validity of the measures were also checked. Discriminant validity is the degree to which two or more measurement items for the factors are not theoretically interrelated (Paulraj *et al.*, 2008). Convergent validity refers to the degree to which measurement items are theoretically related to each other (Fornell and Larcker, 1981). Convergent validity was assessed using the item loadings and the average variance extracted (AVE). As shown in Table III and Fig. 3, values of AVE for each construct higher than 0.50 indicate that more than 50% of the variance was accounted for by latent variables. The square root of AVE for each latent construct was larger than its correlation with other constructs, thus supporting the discriminant validity (see Table III) (Fornell and Larcker, 1981). Overall, the measurement model results demonstrate adequate validity and reliability.

F. Structural model and results of the hypotheses

After achieving adequate validity and reliability of measures, we evaluated the structural model (see Fig. 3) and tested the hypothesized relationships (see Table IV). The first step in assessing the structural model is to compute the R^2 statistic that demonstrates the amount of variance of the dependent variable explained by the independent variables in the model. The value of R^2 is 0.680, which is above the value of 0.35 suggested by Cohen (1988), and indicates considerable significance for the interpretation. Moreover, to discover whether the structural model has satisfactory predictive relevance for all the constructs, the cross-validated redundancy measures (Q^2) were computed using blindfolding in PLS. The value of Q^2 is 0.404. Multicollinearity is not a problem, and the variance inflation factor (VIF) indices are below the threshold value of 10 (Field, 2009). Bootstrapping is used in PLS to estimate the accuracy of the measurement model (Roldan and Sanchez-Franco, 2012). We adopted a bootstrapping method for sampling tests on the basis of 5000 bootstrapping, to calculate the path coefficient and generate *t*-values. Based on this criterion, the path coefficients of the hypothesized relationships show the strength of the relationships between the independent and dependent variables. For example, the path coefficient result did not support hypothesis 1, and therefore, we reject the hypothesis that EC positively influences consumers' intention to use RETs ($\beta = 0.089$, $p > 0.01$). Regarding the second hypothesis, we accept it because the effect of cost on consumers' intention to use RET is found to be negative ($\beta = -0.213$, $p < 0.01$). The influence of

TABLE II. Correlations and discriminate validity ($p < 0.01$). Values of square root of AVEs are shown diagonally in parentheses.

Sr.	EC	C	AW	PBC	ATT	SN	INT
EC	***(0.84)***						
C	−0.242	***(0.89)***					
AW	0.063	0.192	***(0.86)***				
PBC	0.265	−0.105	0.150	***(0.78)***			
ATT	0.420	0.039	0.499	0.475	***(0.87)***		
SN	0.273	−0.131	0.157	0.552	0.556	***(0.83)***	
INT	0.113	−0.325	0.214	0.664	0.630	0.565	***(0.82)***

TABLE III. Factor loadings and convergent validity.

Constructs	Items	Standard loadings	CR[a]	AVE[b]
Environmental concern				
e1	I am concerned about pollution	0.771	0.827	0.706
e2	I am concerned about climate change	0.904		
Cost				
c1	The use of RET incurs high repair and maintenance costs		0.880	0.787
c2	The purchase of RET requires high installation costs			
Awareness				
a1	I am aware of the availability of renewable-based solutions in the market and their usability	0.806	0.890	0.731
a2	I am aware of RET's benefits	0.922		
Perceived behavioural control				
Pbc1	I have the resources, knowledge, and ability to use RET	0.772	0.813	0.600
Pbc2	Using RET is entirely within my control	0.818		
Pbc3	I am confident that I would use RET in the future	0.716		
Attitude				
at1	Using a RET would be beneficial	0.870	0.857	0.750
at2	Using a RET in my house would be a wise idea	0.843		
at3	Using a RET in my house would be pleasant	0.851		
Subjective norm				
n1	People who are important to me think that I should use RETs in my home	0.832		
n2	I will use a RET if my colleagues think I should	0.794	0.869	0.688
n3	I will use a RET if people in my social network do (friends, relatives, neighbours, etc.)	0.861		
Intention to use				
i1	I intend to use a RET in the future	0.825	0.858	0.669
i2	I plan to spend more on RET than on conventional energy	0.836		
i3	I will strongly recommend that others use a RET in their house	0.792		

[a]AVE = (sum of squared factor loadings)/(sum of squared factor loadings) (sum of error variances).
[b]CR = (square of the sum of the factor loadings)/[(square of the sum of the factor loadings) + (square of the sum of the error variances)].

awareness on consumers' intention to use RETs is insignificant (β = 0.175, $p > 0.01$), and therefore, we reject hypothesis 3. While PBC (β = 0.309, $p < 0.01$), attitude (β = 0.299, $p < 0.01$), and SN (β = 0.248, $p < 0.01$) all positively influence consumers' intention to use a RET, we accept hypotheses 4, 5, and 6.

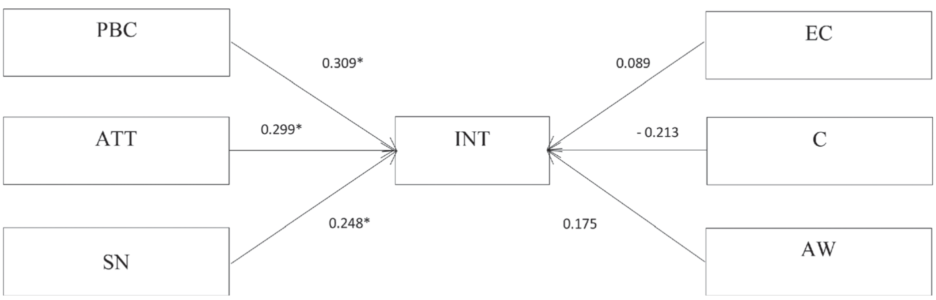

FIG. 3. Path coefficients (structural model).

TABLE IV. Hypothesis results.

Hypothesis	Hypothesized path	B	*t*-value	Label	*P*	VIF	R^2	Q^2
H1	EC → INT	0.089	1.424	Reject	0.155	1.249	0.680	0.404
H2	C → INT	−0.213	2.880	Accept	0.004	1.096		
H3	AW → INT	0.175	1.631	Reject	0.103	2.230		
H4	PBC → INT	0.309[a]	3.315	Accept	0.001	2.369		
H5	ATT → INT	0.299[a]	3.555	Accept	0.000	1.393		
H6	SN → INT	0.248[a]	2.788	Accept	0.005	2.873		

[a] $p < 0.01$.

V. DISCUSSION

A. Environmental concern and intention to use RETs

It is widely believed that the use of RETs can improve the environment and can help in reducing generation-related emissions. Based on the previous literature, it was hypothesized that a similar effect may occur in Pakistan's market also. However, unlike other studies that have found a positive influence of EC on consumers' intention to use RETs (Liu *et al.*, 2013 and Zhang *et al.*, 2015), this study did not reveal a significant influence. One possible reason may be related to the principal purpose for which these energy systems are bought by consumers. The environment-related factor may take priority for consumers in countries where the technology is used as an alternative to gain long-term economic benefits, reduce utility bills, or contribute positively towards environmental objectives. In a country like Pakistan, environmental and pollution-related matters are usually not a priority for consumers when making such decisions. This may be due to the fact that these matters have hardly been on the government's agenda, and attempts have seldom been made to make people aware of environmental issues, their responsibilities, and the role they can play in improving the environment.

B. Cost and intention to use RETs

The statistical results support our hypothesis, and the data reveal the negative effect on consumers' intention to use RETs. Renewable energy-based solutions are costly compared to traditional energy generation systems, and the added cost of purchase becomes an impediment to their adoption. For instance, currently, installation of solar PV for household users costs roughly five or six times more than other energy generation systems available in the market such as UPSs or oil-fired power generators. Moreover, the price is much too high for the average household to pay for the purchase in a lump sum. This finding supports the results of earlier research by Kardooni *et al.* (2018), Luthra *et al.* (2015), and Yaqoot *et al.* (2016), where the cost was found to negatively influence consumers' intention to use RETs. This indicates that cost is an important barrier and plays a critical role in consumers' intention to use a RET.

C. Awareness and intention to use RETs

The statistical results reveal that awareness does not have a significant influence on consumers' intention to use RETs in Pakistan. Our study contradicts the research findings of earlier studies in the literature that found a positive influence on the use of RETs (Alam *et al.*, 2014; Islam, 2014; and Zografakis *et al.*, 2011). One possible reason for this is that people are not yet fully aware of RETs and the benefits they offer. An earlier study by Wang *et al.* (2014) highlighted that awareness may not play a significant role, due to poor understanding of consumers concerning the usefulness of renewable energy sources. The market for RETs in Pakistan is not as established as that for the competing existing energy generation systems used by households. There is limited awareness about the vendors, technology, and installation services that can be trusted and that can deliver in the long run.

D. Perceived behavioural control and intention to use RETs

Our findings indicate that PBC positively influences the intention to use RETs. The results correspond to the findings of earlier research that PBC positively influences consumers' intention to use a renewable energy source (Alam *et al.*, 2014 and Tan *et al.*, 2017). For example, solar PV is more technical and complex than existing energy generation solutions available such as power generators or UPS. The lack of availability of technical experts, repair and maintenance costs, and the possession of very little or no prior experience of the technology may all make the adoption of such technologies troublesome. Consumer's knowledge about the technology and their perception of its usability in the long run are crucial factors in building trust and confidence in the technology.

E. Attitude and intention to use RETs

Attitude is found to positively influence intention to use RETs. Studies conducted by Afroz *et al.* (2015) and Tan *et al.* (2017) have also found a positive influence of attitude on consumers' intention to use RETs. The positive effect is due to the long-term economic and social benefits offered by these technologies. RETs can generate electricity over a long period without entailing additional costs. In addition, the use of such technologies also provides a solution to the basic problem that the users of oil-fired or gas-fired power generators face everyday, i.e., the issue of noise and smoke generated by the engine while operating. The use of solar PV installations helps in mitigating this constant noise which has become a significant concern for users.

F. Subjective norm and intention to use RETs

The results show that Subjective Norm (SN) does have a positive influence on consumers' intention to use RETs. The findings of this study are consistent with earlier research of Jayaraman *et al.* (2017) and Chen (2016) where SN and behaviour were found to have a positive influence on consumers' intention to use RETs. In a society like Pakistan, the influence of social groups and family members plays an influential role in decision-making. The society is very much integrated, and inputs from the close friends and relatives are considered important. The decision may also be influenced by the experiences peers have had of using the technology. Trust in the technology is rather limited due to the fact that the adoption of RETs is in its early stages. Input from peers may influence the decision if they have used a RET in the past or are currently using one. A positive experience with the technology automatically creates trust in the mind of the consumer who tends to give importance to the opinions and suggestions of others. This social influence may work as a stimulus and may encourage consumers to opt for the technology.

VI. CONCLUSION AND IMPLICATIONS

The objective of this study is to investigate the factors influencing consumers' intention to use renewable energy technologies for household purpose. This study seeks to address this challenge by studying the key factors influencing the adoption and diffusion of renewable energy technologies and by investigating the extent to which they play a role in a local context. An attempt has been made to explore the impact of these factors in the context of Pakistan and to see how these factors encourage or discourage consumers with regard to opting for these solutions. We have extended the TPB framework by integrating different contextual factors. Based on an in-depth literature review, it was hypothesized that factors such as environmental concern, cost, awareness, perceived behavioural control, subjective norms, and attitude may influence consumers' intention to adopt RETs in Pakistan. The data were collected and analysed using structural equation modelling (SEM). The results revealed interesting findings with important managerial and policy implications. Perceived behavioural control, subjective norm, and attitude of the consumers all have a positive influence on their intention to use RETs. However, environmental concern and awareness are found to be insignificant, whereas cost has a negative effect.

This study has many implications for policymakers, companies engaged in the renewable energy technology business, and other stakeholders involved in the process. Based on the findings of this study, it is suggested that there is a need to adopt an integrated approach, and a coherent effort should be made by all stakeholders at various levels of society to raise the level of environmental awareness. Government, private companies, Non-profit organizations (NGOs), and other stakeholders should place more emphasis on devising policies that highlight environmental concerns and the reduction of emissions as key objectives. Seminars and workshops should be organized at university and college levels to make young people aware of this important subject and to ensure that environmental values are given consideration when purchase decisions are made in the future. In addition, sustainability-related studies should be integrated into the educational curriculum from the very beginning, in primary and secondary schools, so that students become aware of these issues and it becomes part of their routine to take steps which have a positive bearing on the environment. Awareness campaigns should be launched by the government using social, print, and electronic media to highlight the need for energy conservation, reducing carbon emissions, and maintaining a sustainable way of life.

Similarly, this study also offers important insights into the companies and state departments interested in the commercialization and enhanced diffusion of these technologies. RETs are still in the earlier phases of development, and their high cost, technical complexity, and the lack of trust in the technologies hinder consumers from opting for these solutions. There is a great need to disseminate information on what exactly these technologies can offer and how they are better than the existing solutions. If consumers are well advised and made aware of the long-term social, economic, and environmental benefits these technologies offer, this may increase people's interest in the technologies. Companies engaged in the sale and installation of RETs should emphasize services and packages to make consumers' purchase decisions easier. For instance, consumers' concern about the availability of experts, the durability of the technology, and repair and maintenance costs can be addressed by offering post-sale services in the form of warranties, repair and maintenance at reduced prices, and periodic visits to the installation site to ensure that the equipment is working at the optimum capacity. This will build consumer trust and confidence in the technology. It is also recommended that companies should launch marketing campaigns and hire professional sales personnel to highlight the economic benefits to the buyer, e.g., utility bill reductions or possible reductions that can be achieved using smart meters.

The government should develop strong and interactive relationships with industry to ensure that policy initiatives are generating the desired results. Information should flow both ways, i.e., input should be obtained from the stakeholders, and government's measures should be discussed to ensure the implementation in the right manner. It is also recommended that companies should look beyond the traditional model of sales and purchase if they want to successfully commercialize these technologies in Pakistan's market. The companies should alter their business model and offer the RETs at a low up-front cost. The remaining amount shall then be collected in the form of monthly installments or by offering a power purchase agreement (PPA), where customers are charged based on the power generated by the RETs.

VII. LIMITATIONS AND FUTURE RESEARCH

There are several limitations of this study that should be taken into account. First, the sample size limits the generalizability of the findings of this study. The data were collected from cities, which are by definition urban in nature. The demographic factors such as income, level of education, access to information, and awareness about the issues may be different compared to the same factors for people living in rural parts of the country. Moreover, the renewable energy industry is complex and is affected by a number of variables, and therefore, the number of factors investigated in this research may represent a limitation. The observed relationships might have been better understood by integrating additional factors such as trust, knowledge, relative advantage, complexity and/or ease of using a renewable energy source, environmental and social responsibility, moral obligation, and the use of technology for personal/individual or group/collective purposes. Therefore, an interesting topic for future research would be to investigate the impact of some of these variables on consumers' adoption behaviour. Another important aspect that is lacking in this research is the investigation of the impact of some demographic aspects such as the income or level of education on the intention to adopt. We believe that studying the moderating effect of these variables may yield interesting findings. Finally, in this study, we have taken capital cost into consideration; however, the cost and benefit analysis and the estimations based on the Levelized Cost of Energy (LCOE) may also provide interesting insights. This can be an interesting aspect to be considered in the future research.

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