Master Thesis U.S.E

Exploring investment enablers and barriers for mature and novel renewable energy technologies using the Delphi method.

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Abstract:

This paper investigates why certain renewable technologies have become more attractive for investors in recent years than other renewable energy technologies. This paper specifically investigates both technological and non-technological aspects of projects that have affected the risk perception of different investor types. This paper addresses the research question '*How do technology-specific, non-technology specific and investor-specific barriers and enablers shape the risk perception of different renewable energy technologies in the financial market?'* This question was approached by using interview data that followed the Delphi research design. The interviews were carried out with expert figures in the renewable energy financial market. The principal findings show that there are technological inherent issues in current novel renewable energy technologies that directly impact its cash flow and appropriate financing structure which impose entry barriers for certain investor types and small-scale project developers. An improved understanding of such technology-finance interactions can contribute to designing public policies that incentivise the correct type of finance designing on the technological requirement of the renewable energy project.

JEL-codes: G11, P18, Q42, B40.

Keywords: Renewable energy technology (R.E.T), Europe, public policy, private investor, financial risk, Delphi method, interview data.

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1. Introduction

This paper investigates why certain renewable energy technologies (RETs) are perceived as less risky and more investment friendly than other R.E.Ts. It examines the technology-specific and non-technology specific barriers and enablers that were, and for some R.E.Ts still are, present for different investor types throughout the financing of renewable energy technology projects.

Underinvestment in renewable energy technologies is a crucial obstacle in successfully addressing climate change. Without the necessary levels of financial capital, project developers cannot overcome the high upfront capital costs inherent in these technologies and hence economics of scale benefits cannot be received, a crucial aspect to mainstreaming any form of technology at an appropriate cost. Essentially, all scenarios aligned with the Sustainable Development Goals and the Paris Agreement include massive increases in low-carbon investments (McCollum et al., 2018). It is important to scale up various renewable energy solutions as incumbent R.E.Ts, such as wind and solar, have shown to suffer from intermittency problems. For example, solar may not produce enough energy during cloudy days for the demand at that moment, which is particularly troublesome during peak load times (Yekini Suberu et al., 2014). This temporary lack of energy supply due to weather conditions makes energy storage highly relevant and thus this thesis will also explore any potential current barriers that impede investors from scaling up storage solutions such as battery storage and green power to hydrogen.

In order to be competitive with the incumbent fossil fuel market, green energy companies, projects and technologies require larger amounts of investments than what the government can fund (Perez 2013; Mathews et al. 2010; Huberty & Zysman 2010). Financial intermediaries are needed for diffusing private financing for renewable energy projects and do so by primarily reducing information asymmetry between capital providers and receivers. Two principal functions of these intermediaries are brokerage, the matching of borrower and lender, and qualitative asset management, the using of short-term liabilities to finance long term assets (Merton, 1995). Through these functions, financial intermediaries, such as institutional investors and investment banks, can accelerate the energy transition by proving the necessary amount of financial capital to R.E.T projects.

The levelized cost of energy, which is the average net present cost of electricity generation for a generating plant over its lifetime, for the most popular renewable energy technologies, namely solar and wind energies, has been dropping significantly in recent years (IRENA, 2020). This decrease is due to lower capital expenditure costs through improvements in technology, but also through a financial experience curve, which involves the investors lowering capital costs for the borrower (Egli, Steffen and Schmidt, 2018).

We observe from literature that for projects to transition from the precommercial to niche to the fully commercialised stages there are a certain set of financial actors that must be involved. There is a need for venture capitalists, private equity, spin off, mezzanine and corporate debt finance in the niche stage with the same investors needed in the full commercialisation stage but with the addition of public equity (Polzin, 2017). Furthermore, state investment banks can play an investment enabling role for the private investors in these stages (Egli and Manuel, 2020).

Past literature has generally focussed on public policy instruments as a means to enable private investment into R.E.Ts. While feed-in tariffs have been shown to be more efficient than a bidding system (Dinica, 2006), it has also been shown by some scholars that feed-in tariffs can lead to low diffusion, while quota systems can be more attractive (Menanteau et al., 2003). Furthermore, feed-in tariffs may only be effective when the R.E.T is considered low risk for investors (Abolhosseini & Heshmati, 2014). Additionally, feed in tariffs have shown to have negative cost implications (Frondel et al., 2008). Given this dispute on the effectiveness of government public energy policy, it's important to review private investors perspective the on public policy, and also to discover any other investment enablers that these investors have encountered.

When venture capitalists are considering renewable energy investment, some barriers include a lack of application, growth, scalability and rapid payoffs (Hargadon and Kenney, 2012; Demirel and Parris, 2015). Barriers facing banks include time horizon preferences for loans and public policy dependence issues, while institutional investors face problems such as time horizon issues and regulatory risk (Polzin and Sanders, 2020). Other barriers are more systemic and include technological lock in and path dependency, further defined below (Masini and Menichetti, 2012, 2013; Hall, Foxon and Bolton, 2015; Lo, 2004).

Investment in renewable energies compared to fossil fuel technology results in significantly higher technological improvement yet it is remains underfunded relative to its performance gains (Schilling and Esmundo, 2009). Additionally, according to some scholars, there is potential for knowledge spillovers between renewable energy technology, which emphasizes the widespread effect and value of investments in renewable energy projects (Nemet, 2012; Verdolini, 2011).

There is a lack of research that investigates how different R.E.Ts' specific technical characteristics affects their risk profile in the view of the investor. There is also a lack of literature investigating how these certain technical characteristics may directly influence which investor type and financing structure is appropriate. Furthermore, there is little research on how certain non-technology specific investment enablers are more important for some investor types than others.

This thesis proposes that public policy may more effective if it targets the specific investor types that are appropriate for a technology due its technical characteristics and complexity. In this way, public policy can have a more nuanced and specific focus and may be more effective.

Although previous studies have discovered a finance experience curve in wind and solar energy (Egli, Steffen and Schmidt, 2018), the degree to which this curve is dependent on the barriers and enablers that are specific to the technology type is unclear. This analysis of the investor's perception of specific renewable energy technologies will allow us to discover which specific technical characteristics allow the investors to accumulate financial learning, leading to more favourable financing conditions for the technology in question. Little is known about what is driving this recent finance experience curve, and associated decline in capital costs, at an investor and technology specific level.

The main Research Question that this thesis attempts to answer is:

How do technology-specific, non-technology-specific and investor-specific barriers and enablers shape the risk perception of different renewable energy technologies in the financial market?

The following related Sub Questions are this presented:

- *How large of a role does previous investment experience have on the investor's perception of a renewable energy technology?*
- *How can technology-specific polices better target the investors that are more equipped to finance a particular technology?*
- *To what extent can investment enablers for one R.E.T be replicated in the financial scaling up of another R.E.T?*

Without understanding the technology-specific financial characteristics that each renewable energy technology possesses, we run the risk of applying blanket policies that may only lower the financial barriers associated with some technology types. Different technologies pose different financial structures, and so one size fits all energy polices do not succeed. For example, while onshore wind and solar differ in their design they are both more often financed with a project finance structure, whereas offshore wind, which is similar in design to onshore wind, was often financed rapidly on large cooperates balance sheets through a corporate financing structure (Steffen, 2018).

Similarly, if we do not consider the specific investor priorities, we risk applying blanket policies that do not incentivise all the necessary types of investors. The investors that are involved in the niche and commercialisation finance stages are a diverse group with different priorities and so polices that attempt a one size fits all approach are not sufficient. By identifying the specific investor obstacles and suggesting appropriate policies to remove them, this thesis suggests a pathway for accelerating the low carbon energy transition that we need if we are to maintain a world that is a maximum of 1.5 degrees Celsius higher than preindustrial levels (IPCC, 2022).

This paper defines *enablers* as any policy or other development that lowers risk or/and increases return for a certain investment and defines *barriers* as any policy or other development that increases the risk or/and lowers the return for a certain investment. This paper defines *mature renewable energy technology* as those technologies in which the initial faults and inherent technological problems have been addressed and removed. This paper defines *novel renewable energy technology* as those technologies in which some or all of the initial faults and inherent technological problems have not been addressed and removed. This thesis investigates what matters for different investor types when looking to invest in a renewable energy project by exploring their risk perception towards both mature and novel R.E.Ts. Thereafter, this thesis will propose public policy suggestions that better address the identified investment barriers for novel R.E.Ts.

In the following section, this paper will provide an expanded literature review, analysing past academic papers on the role of financial intermediaries in financial diffusion, risk perceptions in the renewable energy capital market, some general barriers that private investors face when considering novel renewable energy projects, path dependency, technological diffusion and knowledge spillovers, among other related literature streams. Then the paper will provide the theoretical framework followed by a description of the data collection process. The results section will then detail the principal findings. Finally, a discussion and conclusion will follow, summarising the main findings and stating the contributions to policy making, the financial market, and society as a whole.

2. Literature review

2.1. Financial intermediaries' role in the energy transition

Past academic papers have outlined the varying forms of financial intermediaries and what stages of the technological innovation they are best utilised due to the different risk internalising abilities of each investor type. Polzin, Sanders and Täube (2017) have established six stages, from basic R&D up to fully commercial, but as this study is focussed on mainstreaming renewable energy, we will focus on the last three stages after deployment, which are pre commercial, niche market and fully commercial. According to Polzin, Sanders and Täube (2017), the private investment best allocated to finance green energy technology at its precommercial stage is venture capitalists, angel investors and crowdfunding. In the niche stage the appropriate private investment is venture capital (VC), private equity, spin off, mezzanine, and corporate debt. In the fully commercial stage, the private financiers that are needed are the same as those needed in the niche stage but with the addition of public equity holders.

With their ability to reduce information asymmetries and upscale innovative technologies, it is crucial for financial intermediaries to increase their investment into renewable energy projects. Some of the investment priorities for venture capitalists, according to Hargadon and Kenney (2012) include growth, scalability, and rapid payoff, and therefore renewable energy projects, particularly those that utilise novel technologies, may not be an attractive investment for VCs. Even amongst types of venture capital financing, there has been evidence of different perceptions on investment barriers. For example, Croce, D'Adda, & Ughetto, (2014) find that bank venture capital funds prefer to finance firms with a lower financial distress risk compared to individual venture capitalists. An important barrier for banks offering debt finance to renewable energy projects is the seemingly unattractive risk/return profile. Banks traditionally offer loans that have a shorter maturity than the loans that renewable energy projects require. These longer loans are due to the inherent long-term nature of renewable energy project development. Furthermore, the bank's perceived risk of renewable energy projects is dependent on supportive public policy, which is often not as transparent or consistent as banks would like (Polzin and Sanders, 2020, Bürer & Wüstenhagen 2009; Lüthi & Prässler 2011; Lüthi & Wüstenhagen 2012)**.** Some of the renewable energy investment barriers that face institutional investors, such as pension funds and insurance firms, include lack of political support for the project in the long term, regulatory instability, lack of expertise in the technology, regulatory barriers, too long term horizons, shortage of data on the project, lack of appropriate investment vehicles, and slow capital stock turnover (Kaminker and Stewart, 2012; Polzin, von Flotow and Klerkx, 2016). This thesis will investigate if the overcoming of some of these investor specific barriers can explain the recent increase in investment levels in wind and solar projects.

2.2. Cognitive barriers

Under the market efficiency hypothesis, these previously mentioned investment barriers can be theoretically solved if the appropriate monetary instruments, such as subsidies and carbon pricing, level the playing field between carbon and renewable energy goods. This concept of market efficiency assumes that investors will rationally invest in renewable energy if it is cost optimal and the most profit maximising option from all the investment choices (Masini and Menichetti, 2012; Hall, Foxon, & Bolton, 2015; Lo, 2004). However, there are other types of barriers that reduce the effectiveness of these monetary instruments in incentivising investment into renewable energy. These barriers are cognitive and are studied within the behavioural finance literature. A significant cognitive barrier is information asymmetry which can be seen through an investor's acts of bounded rationality. According to Simon (1955), when there are limits to an investor's *"ability to gather and process relevant information"* on the asset under consideration, such as solar technology, investors will primarily seek satisficing, instead of optimal, solutions, resulting in the most profit maximising option not being chosen. This limit in gathering and processing relevant information that the other party has, such as the energy firm, is a form of information asymmetry. As a young innovative firm will possess more information about their technology than the external financiers, the firm will often not attain the desired finance, nor the desired costs of that finance such as the debt and/or equity costs (Myers and Majluf, 1984).

Information asymmetry plays a role in an investor's perception of radical, lesser-known and seemingly risky technology. Demirel (2015) shows that VC funds only cover a small portion of the financing gap for R.E.T companies as these funds only finance firms with R.E.T innovations with clear applications. Furthermore, within this sector in the UK, governments funds favour firms with patents and applied innovations, aligning with the investment priorities of venture capitalists. These investment agenda mean that there is still a substantial gap in financing for more novel and radical technology that suffers from the problem of information asymmetry due to the financiers not understanding as much about the technology as the other party, the renewable energy firm (Demirel, 2015). This leaves these types of firms to finance their projects themselves with internal resources that they may not have yet. This avoidance by venture capitalists of investments that contain information asymmetries can cripple the trajectory of creative innovation given the role of this financial intermediary type for *"economic experimentation"*. (Nanda, Young and Flemming, 2013) Banks have also been shown to suffer from this issue of information asymmetry when deciding on renewable energy investments (Demirel, 2015).

Other cognitive barriers include prior beliefs on technological risk (Masini and Menichetti 2012, 2013) and path dependency. The effect of path dependency can be seen when the *"private investor's resources and previous portfolio investments determine the value of its current transactions"* (Smit and De Maeseneire, 2004). Under uncertainty, as often with the case of renewable energy investments, path dependency of investments *"leads to unique investment opportunities that have a higher value to one specific investor than to the other"* (Smit and De Maeseneire, 2004). Financiers who have a history of fossil fuel investing may suffer from path dependence and therefore will continue to be locked-in their prior type of investing. Wustenhagen and Teppo (2006) find that venture capital path dependency can be explained by fact that *"VCs tend to invest in areas where they feel competent",* which is acts as function of their previous experience.

2.3. Spillovers

However, this previous experience may reduce the investors' risk perception if they can benefit from knowledge spillovers from previous investments into new investments. For example, experience in onshore wind may benefit investors when assessing the risk of an offshore wind project. Rosenberg (1994) emphasises that the *"transfer of concepts from one scientific specialty to another",* otherwise known as knowledge spillovers, is *"an important determinant of the rate and direction of scientific progress"*. Nemet (2012) executed a study into knowledge spillovers within the energy industry. By using the set of U.S. patents granted from 1976 to 2006, Nemet assessed the role of knowledge acquired from outside each energy patent's technological classification. The author found that important energy patents have drawn heavily from external prior art categorized as chemical, electronics, and electrical. Similarly, Noailly, J., & Shestalova, V. (2017) use patent citations to show that there are technical knowledge spillovers of wind technologies within its own field. Braun et al. (2010) showed that within the sector of wind energy there are technical knowledge spillovers between different wind technologies, which is known as intra-sectoral spillovers. Intra-sectoral spillovers were also found within the solar energy sector. However, the authors found that only wind, not solar, benefits from spillovers from technologically related non-wind energy sectors, which is known as inter-sector spillovers.

These technical knowledge spillovers are a form of positive externalities that originate from innovation Popp & Newell (2012). Given this evidence of knowledge spillovers between renewable energy technologies, it would appear that certain R.E.Ts may share some of the same technical aspects. Therefore, there may be financial knowledge spillovers in the form of common risk assessment and technical reporting. For example, a large investor company that has an investment history with electronics or fossil fuels may find that their risk assessment tools for these assets may be transferable in some capacity to a renewable energy technology such as onshore wind. Similarly, an investor who has a financing history with onshore wind parks may find that certain financial tools, such as risk assessment and technical reporting procedures, can be reused when starting to invest in offshore wind parks given the technical similarities between them as established by the knowledge spillovers literature. Thus far, this aspect of financial knowledge spillovers is understudied in the renewable energy technology sector and this thesis aims to explore this research gap.

2.4. Adaptive market hypothesis

Apart from cognitive barriers, there are also investment obstacles that can be borne from wider structural changes in the economy and finance market. Hall, Foxon, & Bolton (2015) argue that with *"the energy investment environment (policy, financial regulation, incentives, technology characteristics/ options, etc.)"* changing over time, incumbent firms and investors are forced *"to adapt to new conditions"*, while the structural changes *in "financial vehicles and wider capital markets affect the submarkets of energy finance"*. Changes in the energy environment may come in the form of policy risk. Policy risk, or regulatory risk, *"concerns the risk that unexpected changes to government regulations and policies will change the investment environment"* (Micale et al., 2013). Gatzert and Vogl (2016) has shown that lowering policy risk by diversifying investments over different countries can enable investment, while Holburn (2012) has found that investors view renewable energy projects as less risky when developed in countries where the relevant policy making process is independent from the political process of that country. Furthermore, Kitzing (2014) has demonstrated that different renewable energy policy instruments are more subject to policy risk than others, further suggesting heterogeneity in the risk perception of investors. Additionally, Karneyeva and Wüstenhagen (2017) have established that policy risk is particularly important in solar PV investment decisions, while Angelopoulos et al. (2016) have shown that policy risk is also important for onshore wind investment risk assessment.

These structural changes in the market coupled with the previously mentioned cognitive investment barriers result in a framework that considers more determinants of investing than the traditional market efficiency hypothesis. This alternative framework is known as the adaptive market hypothesis (Hall, Foxon, & Bolton, 2015).

2.5. The role of state investment banks

State Investment banks can assume a role in accelerating the energy transition through their early investment function. These banks kickstart this process by providing the necessary capital to cover large upfront costs that often exist in renewable energy projects. These provisions of financial capital de-risk the technology for private investors (Geddes, Schmidt, & Steffen, 2018). Furthermore, once a state investment bank has developed a positive reputation for R.E.T investment expertise, investors begin to view their investments as trustworthy and intelligent and so, through a signalling function, these banks leverage finance from previously disinterested private investors. Additionally, trustworthy state investment banks can assume the first-mover role, whereby the bank invests in new technology and by doing so gives private investors the confidence to into invest into subsequent projects that involve the same technology (Geddes, Schmidt, & Steffen, 2018; Mazzucato and Semieniuk, 2018). After using their specialist internal expertise to create and standardise innovative de-risking instruments, they can diffuse these instruments and knowledge throughout the investor industry. This sharing of knowledge assists in the financial learning of investors towards these less mainstream technologies, according to Geddes, Schmidt, & Steffen (2018).

2.6. Declining risk for solar and wind

Egli, Steffen and Schmidt (2018) show that the financing costs have improved for solar and onshore wind, meaning the risk perception of investors toward these projects has improved. These authors estimate that 41% of total solar PV LCOE reductions and 40% of wind onshore LCOE reductions between 2000–2005 and 2017 were due to lower financing costs. Through a multiple stage process, involving quantitative and qualitative analysis, these authors establish three components of these lower financing costs: lower capital expenditures (CAPEX) to be financed (strongest effect for solar PV), lower general interest rate (strongest effect for wind onshore), and financing experience. The last competent, financial experience is established through observing a lower debt margin, which is defined as the project specific margin on top of the refinancing rate of the debt provider, a longer loan tenor, and a lower required DSCR.

This thesis looks to build upon these findings by gaining further insights into how this lowering of financing costs, a proxy for a drop in investors' perceived risk, came about. This paper will examine this decreased risk perception over a larger range of investors, countries and technologies. This lowering risk perception towards R.E.Ts has led to large investment and deployment of solar and wind project and their associated economies of scale driven cost reduction (IRENA, 2020; Shields et al., 2021; Tran & Smith, 2018; Smart & Noonan, 2018; Cambell, 1995). Given this role of risk perception in enabling investment, it is important to understand all the factors that have been involved in reducing this perceived risk. It is expected to find the role of government aid, in forms such as tax cuts and subsidies, as a principal investment enabler, but this thesis will investigate if there are specific technological characteristics of a renewable energy that results in a specific financial structure. Furthermore, this thesis will explore if this resulting financial structure enables or stops certain investor types from investing.

2.7. Barriers for some novel renewable energy technologies

As mentioned previously, this paper defines *novel renewable energy technology* as those technologies in which some or all of the initial faults and inherent technological problems have not been addressed and removed. Past literature has highlighted some of the economic and technical problems associated with green power to hydrogen (P2H) as a storage solution technology. According to study by Saccani et al. (2020), in which P2H is compared with methane steam reforming with and without Carbon Capture, Utilization and Storage (CCUS), it was shown that P2H currently shows greater CAPEX and OPEX than methane steam reforming, thereby discouraging investments. In the past, Dixon (2007) and Felderhoff et al. (2007) both found that power to hydrogen has low cycle efficiency compared to other storage solutions, however, there is little recent work that estimates the potentially improved cycle efficiency of new P2H technologies and investigates its role in updated investor perception of this technology. Recently, Dolci et al. (2019) found that heterogenous national legal barriers can impede the use of P2H beyond mobility applications.

Past literature shows that the unreliable cash flows from Battery Energy Storage System (BESS) as a method of storage may be compensated by stacking revenue streams such as returns obtained from price arbitrage (Lombardi and Schwabe, 2017; Martins and Miles, 2021). This arbitrage is particularly attractive when electricity price differences between peak and off-peak periods are large (Lin and Wu, 2017). However, Gissey et al (2018) finds that the current merit order design of balancing and ancillary markets makes it difficult for the battery storage technologies to recoup their relatively high initial capital cost.

Regarding hydropower projects, Ullah et al. (2019) finds that a lack of government support as a barrier for scaling up projects, although this study is specific to Pakistan, while legal and regulatory processes for obtaining permits were cited as investment barriers in Poland (Kałuża et al., 2022). Studies on recent investment barriers related to technology-finance interactions in hydropower over a wider range of EU countries is missing from current literature.

Gunnlaugsson et al (2014) and Shannon (1975) both find that due to considerable concentration of minerals and gases, the geothermal wells and surface installations suffer from corrosion and scaling problems. Scaling issues involve mineral precipitates clogging pipes.

In sum, although some technical problems have been identified in these novel R.E.Ts, there is little research that contextualises these problems within the E.U. financial investment market.

There is also little recent research on how the impact of these technology specific investment barriers vary with investor type.

3. Theoretical framework

3.1. Risk and return theory

As this thesis investigates the enablers and barriers for investment into different R.E.Ts, its crucial to understand the relevance of fundamental risk and return and how it functions in the finance sector.

Risk management is a multi-step process and establishing context is the first step of this process. Establishing the context for risk management is important as it defines the domain of interest in which risk will be identified, the purpose of the risk management activities, specifies goals and criteria, an agenda for identification, develops an analysis of risks, and finally establishes which technological, human and organisational resources may be used to mitigate the risk. (Aven, 2016)

Second, an accurate identification of risks is needed to ensure that risks are managed in an effective manner. If an investor does not succeed in identifying all possible losses and gains then these non-identified risks and returns will become non-manageable (Greene and Trieschmann, 1984). If the investor does not account for them, then they will not take any actions related to them and the consequences could be very unexpected (Tchankova, L,2002). Through risk identification, the investor will be able to study the activities and places where its resources are exposed to risks (Williams et al., 1998). Sources of risk are elements of the organisational, or in this case, investment, environment that can bring positive or negatives outcomes, such as the quality of the manufacturer. Tchankova, L. (2002).

Once identified, the significance of the impact of the risk, such as the amount of loss, and likelihood of the risk is established. Combining these two elements enables the investor to quantifiably assess the risk (Aven, 2016). Finally, the investor may attempt to mitigate their risks by lowering or completing removing the risk factors so that they have less of a negative impact on their potential monetary return.

According to Wüstenhagen & Menichetti (2012) *risk and return have long been established as fundamental determinants of investments in finance theory,* explaining that investors compare investment opportunities by looking at their risk adjusted returns. Wüstenhagen & Menichetti (2012) adds that due to unaccounted externalities, the risk return ratio for renewable energy investments must be improved through either increasing the expected return through policies such as feed in tariffs or decrease the risk through instruments such as loan guarantees.

3.2. Market failure theory

Until recently, the financial risk in renewable energy projects had been too high and the expected return had been too low for significant investments.

The dominant energy sources are those derived from fossil fuels. In the past, externalities, such as the release of carbon dioxide leading to global warming, and air pollution, were not priced and hence for long-time fossil fuels were cheaper than their social cost (Owen, 2006; Andrew, 2008). This failure to integrate the negative externalities of carbon energy into its market price had led to an uneven playing field whereby renewable energy was the much more costly option because its price implicitly includes the higher costs of their external benefits (Owen, 2006).

This allowed fossil fuels to be established as the core energy production source, receiving the majority of funding, and meanwhile renewable energy technology had been severely under financed. Most bulk energy generation and distribution must reach a critical mass point of sufficient demand and usage in order to reap the benefits of the economics of network effects. This concept of network effects refers to when a business, or in this case an energy resource, is able to experience high growth and increasing returns to scale due to fixed costs being covered and a large number of users (Economides, 1993; Evans & Schmalensee, 2010). With a large enough number of users, which in the case of fossil fuels is almost the entire world population, the revenue generated can easily cover the remaining variable costs. Renewable energy also depends on these network effects and critical mass points to find mainstream success. However, due to underfunding, attaining these economic benefits had been difficult in the past.

Although fossil fuels are demerit goods, in that their overconsumption has harmful effects on society, they are still the mainstream source of energy (McCormick et al., 2007). In order to move away from these demerit goods, we not only need to more heavily price their externalities to reflect their true social cost, but we also must also continue to develop various renewable energy technologies as they are merit goods that, when consumed, produces benefits for society (McCormick et al., 2007). Solving the overconsumption of demerit energy goods and the under consumption of merit energy goods is a complex process that requires appropriate financing and effective public policy. Recently, certain renewable energy technologies have become more mainstreamed than others, such as solar photovoltaics, onshore wind and offshore wind. This thesis derives insights into why these technologies have found success in the financial market and why some other renewable energy technologies have remained underdeveloped. Specifically, this thesis examines the recent factors that have lowered the risk and/or increased the return for the more widely used renewable energy technologies that we recognise as mature.

3.3. Risk and return in the R.E.T industry

Beyond traditional risk and return management, Wüstenhagen & Menichetti (2012) propose a more advanced risk and return model. This proposed model accounts for bounded rationality, which concerns the irrational behaviour of investors faced with information asymmetry, policy instability, and path dependence, which concerns becoming stagnant in industries that dominate their portfolio such as oil and gas. These components combined with public energy policy, investor type and prior investment form the perceived risk and return of the specific investor which, in combination with portfolio diversification objectives, dictate whether or not an investment is made. The author argues that perceived risk, as opposed to standard risk, is more relevant in the renewable energy investment environment given the small amount of information available on different renewable energy technologies compared to their fossil fuel counterparts.

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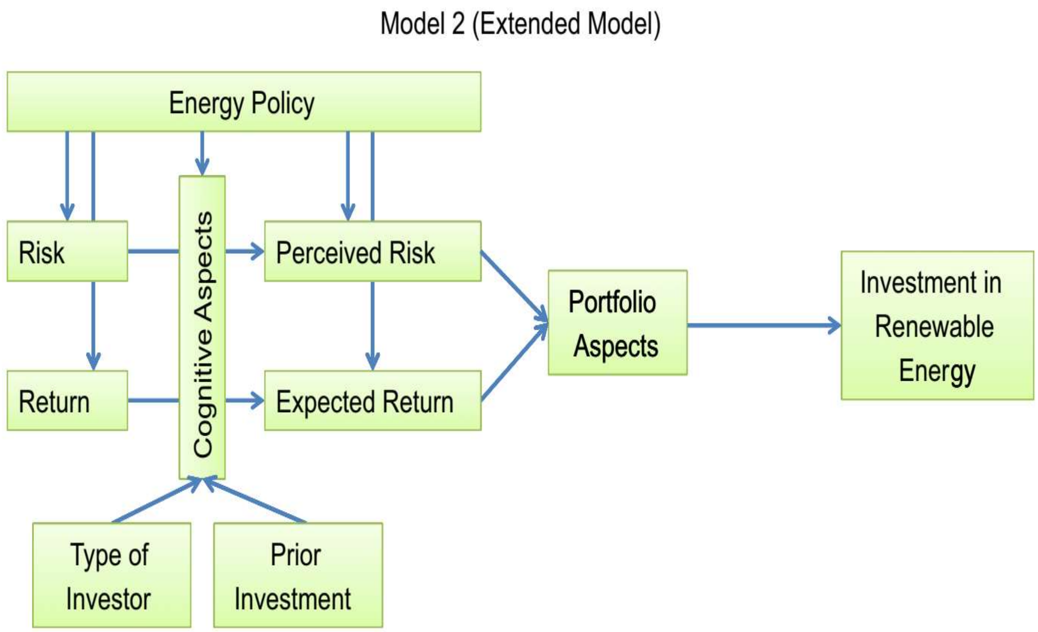

Fig. 4. A more differentiated model of renewable energy policy and investment.

Figure 1: Risk and Return model by Wüstenhagen & Menichetti, 2012

3.4. Proposed theoretical framework

This thesis will partially apply the conceptual framework by Wüstenhagen & Menichetti, (2012). *(Please see Appendix 4 for larger image)*

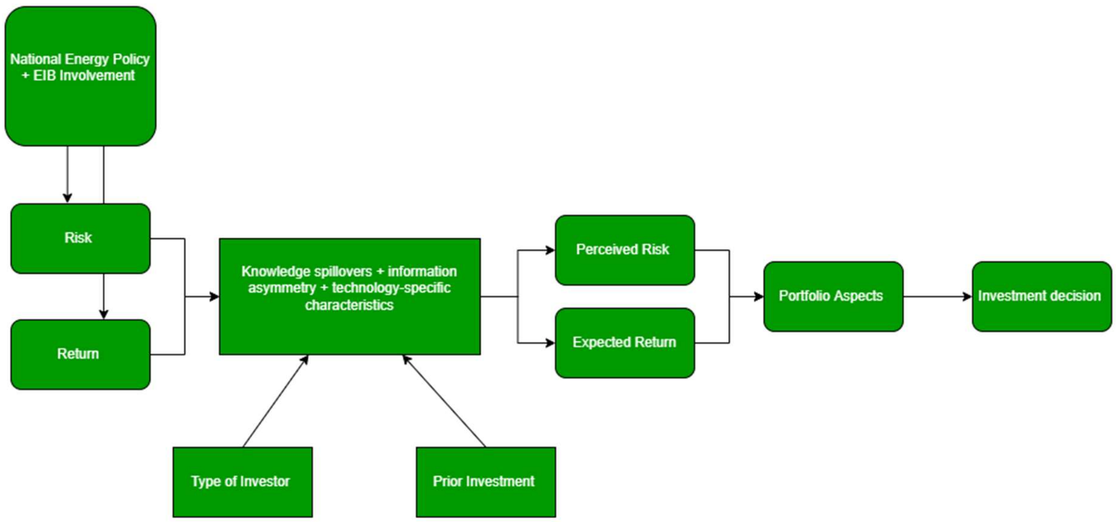

Figure 2: Proposed Risk and Return Model for Renewable Energy Technology investment

In my framework, the country-specific energy policy and the extent to which the EIB is involved as an early-stage investor will form a quantifiable risk and return estimate based on probability. Thereafter, the investor type, prior investment, potential knowledge spillovers between assets and past investments, information asymmetry, and technology-specific characteristics all interact to form the perceived risk and return of the specific investor. Like in the original framework by Wüstenhagen & Menichetti (2012), this perceived risk and return is combined with portfolio diversification consideration to decide if the renewable energy investment decision is made or not. Please find an explanation of each of the relevant terms below:

Knowledge spillovers: The application of knowledge gained from one technology into another.

Financial structure:

a. **Project finance:** Defined as *"an arrangement in which the money or loans put up for a particular project (often a property development) are secured on that project, rather than forming part of the general borrowing of the company concerned. In case of default, the lender has no recourse to the other assets of the company."* (Law & Smullen, 2008) Therefore, when projecting financing is used, the debt or equity provider cannot lay claim on the company's assets on their main balance sheet as a means of a collateral but rather they must trust in the cash flow of the actual project in which they invested as the means by which they will receive their return on investment, be it loan repayments or equity returns and/or dividends.

b. **Corporate financing**: Unlike with a project finance structure, in case of payment default, the lenders have a legal claim on all the assets of the company, which may be especially important for debt providers that are financing high risk projects. Furthermore, projects under stress can draw support from the positive cash flows of other successful projects within the company, which is particularly important to equity providers as their return on investment can be supplemented with cash outside of the project.

Information asymmetry: The limit in gathering and processing relevant information that another party possesses (Lambert et al., 2012). For example, a bank may be limited in its understanding of the technological feasibility of a novel renewable energy technology compared to the project developer. This thesis will investigate developments and policies that may have decreased this information asymmetry in recent years for certain renewable energy technologies.

Ticket size: The monetary value of the investment i.e. how much the investor is investing in a particular project.

Technology-specific characteristics: The technical aspects of a renewable energy technology such as cycle efficiency or large turbines. These technology characteristics may result in the project requiring a specific form of financing or being financially infeasible for certain investors. For example, increased technological complexity may increase the ticket size and therefore not suit project financing structures and shut out certain smaller scale investor types.

Type of investor: These include commercial and corporate banks, private equity investors, institutional investors, and public multilateral banks (e.g. EIB). Some investor types may be better suited to technologies than others, as will be explored in this thesis.

Prior investment: The previous assets in which the investor invested that they may or may not still have in their portfolio. Prior investment may stimulate investments through knowledge spillovers and/or limit investments through path dependence.

Perceived risk: The quantifiable objective risk of a project combined with investor-specific consideration such as information asymmetry, suitability to technology-specific characteristics, investor type, and prior investment history. This perceived risk can be driven by complexity, frequency and importance. The complexity of a technology can lead to information asymmetry between project developer and potential investor, leading to increased perceived risk in the absence of appropriate information-provision measures. The more frequent a risk is experienced, the greater the chance an investor can form risk mitigation strategies for it as it the learning process develops. The importance of the technology in question can dictate the significance of its risk compared to similarly risked but less important technologies.

Portfolio aspects: Portfolio aspects in the equity market are used to diversify investments so as avoid large simultaneous losses. Debt providers, such as banks, can also diversify their base of borrowers so that if one type of corporate borrower defaults there will be other loans that aren't affected (Markowitz, 1952). Investors often include both renewable energy and non-renewable energy assets in their portfolio in order to reduce risk through diversification (Markowitz, 1952). Investors also often diversify between renewable energy assets, such as including solar and wind in their portfolio, so as to reduce risk. This is known as diversification of plant-specific risk (Laurikka, 2008).

4. Methodology

For this thesis, data was collected from semi structured interviews that took place in 2019 and 2020. These interviews were taken as part of an EU research project INNOPATHS but weren't used. Private access to this interview data was granted by Utrecht University. Eighteen interviews took place. Fifteen different companies were interviewed, three of those companies were interviewed twice. One interview was not transcribed due to confidentiality reasons, but an extensive list of notes was taken as a summary of the interview findings. The seventeen transcripts and the one interview notes document are available upon request. The companies were based in the UK, Germany, Italy and The Netherlands.

These interviews explore the condition(s) under which a renewable energy technology is sufficiently feasible or too novel to be invested in. This question leads to an analysis of enablers and barriers, some of which are driven by technology-finance interactions. The interviews, which are between 30 and 60 minutes, focus on both mature and novel renewable energy technology investments. We define investments as the provision of both equity and debt, and therefore debt providing banks are recognised as investors. The participation was voluntary. Following the 'Chatham House rules', all statements will only be used fully anonymized, and participants can withdraw any time before publication of the resulting research.

This thesis has employed the Delphi research method as the means to answer the research question. According to Turoff & Linstone (2002), the Delphi method can be characterised as the following:
"a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem. To accomplish this structured communication there is provided: some feedback of individual contributions of information and knowledge; some assessment of the group judgment or view; some opportunity for individuals to revise views; and some degree of anonymity for the individual responses."

The Delphi method can be used when *"judgmental information is indispensable, and typically use a series of questionnaires interspersed with controlled opinion feedback"* (Dalkey & Helmer, 1963). The controlled interaction aspect of the Delphi method *"appears to be more conducive to independent thought on the part of the experts and to aid them in the gradual formation of a considered opinion. Direct confrontation, on the other hand, all too often induces the hasty formulation of preconceived notions, an inclination to close one's mind to novel ideas, a tendency to defend a stand once taken, or, alternatively and sometimes alternately, a predisposition to be swayed by persuasively stated opinions of others."* (Dalkey & Helmer, 1963)

Delphi studies have been shown to demonstrate validity and long-range accuracy (Dalkey & Helmer, 1963). Although Delphi research design is often used to *"to surface a consensus opinion"*, there have also been studies that shown the effectiveness of this method in showcasing *"differences of opinion in order to develop a set of alternative future scenarios"*, and also for developing concepts and frameworks (Dalkey & Helmer, 1963). Given these characteristics and functions, this thesis employed the Delphi research design as an effective method of developing a consensus opinion on investment attitudes in the renewable energy sector from a number of experts that operate in the field. Furthermore, this design allows this paper to use the consensus findings to develop a new risk and return framework that is specific to renewable energy investments. For an explanation of the variables examined in this Delphi research design, please see the theoretical framework section above.

The interviews were semi structured as they followed a clear set of questioning, but they didn't always follow the same order of questioning. The interviews were recorded with the interviewees' approval and transcribed verbatim to ensure correct interpretation. The first two interviews that took place, those being the first interview with Triodos and the interview with ING, particularly lacked structure as the beginning questions were very general such as *"what matters for you when looking at financing novel technologies?"*; thereafter the interviewer allowed the interviewee to speak freely without restricting them to specific areas. The subsequent interviews were much more structured and contained two separate parts. The first part investigated the past investment experience of the investor and the second part investigated what enabled their past and present investments and what prevented them from investing in other assets. This structure allows for the comparison and contrast of answers from different interviewees. The questions for part one were as follows:

> *1.Could you briefly describe your organization (e.g., type, size, core activities) and your role (e.g., hierarchy, main tasks, experience in years)?*
>
> *2. For the following list of technologies (not included here), please indicate whether you have looked at a potential investment and whether you have invested.*
>
> *3. Could you briefly elaborate on your market maturity description and describe the different stages of investability for these technologies?*

The questions asked in part two were as follows:

> *1. For the technologies that you have not considered at all; what would need to change for you to consider the technology as a potentially interesting market?*
>
> *2. For the technologies you considered, but did not invest in/insured; what were the main barriers?*
>
> *3. For the technologies you invested in/insured, what were key factors that enabled you to do so?*
>
> *4. In assessing investment potentials in different technologies, are there general factors you consider or is it technology specific?*
>
> *5. In assessing investment potentials; which of the following dimensions do you consider important?*
>
> *− Cost uncertainty*
> *− Revenue uncertainty*
> *− Project timeline*
> *− Market outlook*
> *− Internal processes (e.g., convincing the board, due diligence capacity, existing client relationship)*
> *− Other*

There were also interviews with two energy companies: Orsted, which develops offshore, onshore and solar projects, and Equinor, which is a petroleum refining firm that also operates renewable energy projects. These interviews followed the same narrative as the investor interviews such that they explored the energy companies' present and past energy development projects, as opposed to investors' present and past investments like in the other interviews. These interviews also attempted to seek the energy firms' opinion on why certain energy assets have been mainstreamed faster than others, in the context of financial enablers and barriers for investors. As two large energy firms, they have a lot of experience with different investors' attitude towards different renewable energy technologies and, thus, their insights are valuable for this research.

Almost all the interviews focussed on commercial energy generation projects and hence addressed the 'second valley of death' (the scaling up phase) and excluded demonstration projects. However, the interview with the Energy Demonstration Project department within the European Investment Bank naturally included enablers and barriers at the demonstration phase as well.

The interviewee selection criteria were based on involvement with renewable energy technologies. Financiers and energy companies were selected, the vast majority being financiers. Only firms based in Germany, Italy, France and the UK were selected. The selection ensures that there are no significant discrepancies in economic and financial capability that may affect our results.

The majority of the interviews were carried out by a Doctor Friedemann Polzin, an academic in the area of sustainable finance. The remaining interviews were carried out by other professionals on behalf of the EU INNOPATHS research project and so their credentials are presumed to be appropriate. The interviewees were all senior employees in established and reliable companies and organisations and hence their answers can be considered as informed and credible.

The majority of the interviews and resulting transcripts were in English although some were also in German. There were some missing words in the English transcripts that were filled through the listening of the audio file of the interview.

The investors and energy companies that were interviewed were as follows:

Investor Type	**Specific Investor Type**	**Organisations**
Banks	Corporate (Wholesale), Commercial	Triodos, ING, Rabobank, Deutsche bank, LBBW, HSH Nordbank, UniCredit, Bayern LB
Private Equity	Venture Capital, Family Office	Persistent (early VC), Platina Partners (family office)
Institutional Investors (asides from banks)	Pension funds Investors, Insurance Companies	PGGM (pension funds), ACS (insurance)
Public Investor Bank	Multilateral Financial Organisation	Energy Demonstration Projects department (within the EIB)

Energy Company Type	Organisation
Orsted	Mostly renewable energy power company
Equinor	Oil, gas, and renewable energy power company

Interviews are an appropriate approach to address the research question because they effectively *"explore the views, experiences, beliefs and motivations of individual participants"* (Gill et al., 2008). This research project relies on interviewees detailing their view on various renewable energy technologies and interviews can attain this detail through open ended questions.

The interviews contribute to this research by directly answering the main research question though various sub questions, such as those that focus on past investment experience and those that focus on technology-finance interactions. The research question is *How do technology-specific, non-technology-specific and investor-specific barriers and enablers shape the risk perception of different renewable energy technologies in the financial market?*

Instead of using NVIVO or another coding programme, the interviews were manually coded. Within this coding process, excerpts from the 19 interviews were categorised in order to find common themes and patterns. Open coding was used for creating basic labels such as "spillover", and then axial coding was used to group labels into single categories, such as "knowledge spillovers between renewable energy technologies". Finally, selective coding was used to group the single categories into core category sections, such as placing "knowledge spillovers between energy technologies" into the core category of "technology-specific investment enablers".

5. Results

Please see appendices 1, 2 and 3 for a summary of results.

5.1. Mature renewable energy technology

5.1.1. Non-technology-specific enablers:

All of the interviewed investors had invested in solar PV, onshore wind and offshore wind as their principal renewable energy investments. In order to investigate why these became their core focus for R.E.T investment, we explored the developments in the financial market that enabled these investments. From our interviews, we found some important investment enablers that aren't specific to the technical characteristics of the technology yet still leveraged their investment into these RETs.

5.1.1.1. Government financial aid

'Feed in tariffs' were found to be a crucial investment enabler for our private investor interviewees. We found that this price guaranteeing mechanism provided financiers with the confidence to provide their initial investment into the solar and wind technologies, with one bank investor claiming that *"this is how the banks became big in the field of renewable* *energies, so to speak, so that they could put a hook behind it".*[3] Other investors held the same view that a renewable energy investment *"was of course a very safe one for the project finance banks due to these feed-in tariff structures"*[4], as one investor stated, and it allowed allow green energy producers to be less dependent on the standard electricity grid price received, as another explained. This price guarantee enables investors to reduce their risk uncertainty. We also found that the Renewable Obligation Certificates scheme has enabled investment into renewable energy projects in the UK. These certificates function like a revenue guarantee mechanism whereby large-scale UK electricity suppliers are obliged to source an increasing proportion of the electricity they supply from renewable sources, hence making generators less reliant on the market demand on the grid.

Some investors informed us of other forms of government support that made their investment possible. One bank interviewee revealed that export credit agencies are particularly helpful when looking at onshore wind, and another interviewee explained the importance of governments setting up an *"investment fund for cooperatives for the pre-investments they have to do until financial close".*[2] This government financial support can de-risk investments for private financiers as the they have less of the project to finance and hence less to lose. Furthermore, the fact that government is offering this capital cost support can be perceived as a signalling effect as it legitimises the project's technology in the eyes of the private financier. As beneficial as the government can be in renewable energy mainstreaming, one bank interviewee highlighted moments when it can work against this scaling up of technology, such as when the German government creates *"two-gigawatt quantity tenders"*[4] for offshore wind projects which, according to the investor, is too large of a tender to realistically be successful.

5.1.1.2. Multilateral organisation financial aid

The European Investment Bank (EIB) also played a major role in leveraging these initial investments into solar and wind technologies. The interviewee, who works at the Energy Demonstration Projects department (EDP) in the EIB, highlighted this department's role in breaking the private investor hesitancy cycle which is characterised by private investors unwilling to invest in an unproven very novel technology. Therefore, the EDP's aim is to demonstrate to these investors that some of these technologies are commercially viable, so as to leverage private investment. Furthermore, according to the EDP interviewee, when a project developer has simply revealed that they are in talks with, or working with the EDP, private investors have taken notice of the project, meaning that the EDP assumes a signalling role also. However, it was found that the support that the EDP provides is limited by certain circumstances such as the need for the energy company to achieve a TRL 7 or 8 and also to generate 25% equity before the EDP can get involved at all. This equity requirement may shut out much smaller energy companies who cannot produce such equity margins resulting in them not being able to access the very helpful and crucial support of the EDP. Generally, the role of IFIs (International Financial Institutions), such as EBRD, Black Sea Trade and Development Bank, and the EIB is very important in certain geographical areas such as in Turkey, Romania, Bulgaria or Serbia where *"there is not enough liquidity in the local commercial banks"*[5] as one corporate bank interviewee revealed. The interviewee emphasized that, through their ability to *"communicate with the government, adapt laws and tax details"*[5], IFIs can create an investment environment favourable for emerging renewable energy projects.

5.1.1.3. Financial learning

This support of public financial aid allowed some investors to enter the market and begin their financial learning curve. Through the interviews, it was found that multiple of these private investors employed different strategies to learn more about renewable energy technologies that were novel at the time, including wind and solar, in order to reduce the information asymmetry between the technology producer and investor. This is important as information asymmetry increases the financier's perceived risk. One way that financial learning can be facilitated is through large renewable energy funds. According to a pension fund investor interviewee, as they are a large investor type, they were able to learn about multiple assets through large pure renewable energy funds, particularly those in 2006/2007. By investing in funds, institutional investors have *"a way to acquire or to get exposure to smaller assets"*[1]. This is important as institutional investors generally look to fund large ticket sizes and so these funds enable this investor type to finance these smaller scale technologies without bidding on the individual tickets, the interviewee added. With their large size, this finding shows that institutional investors can access financial learning through multi-asset fund investing. Learning about these assets requires *"sitting on the assets"*,[1] according to the interviewee, which over time allowed the investor to learn "*how expensive the vessels are, and what the main causes for the outages"*[1] or learn that one *"manufacturer is actually worse than the others are"*.[1] This finding suggests that financial learning was a process that simply required investors to cautiously learn by doing via siting on their investments and processing information in this new market. Information days about the technology with the manufacturer also helped this investment company to learn about the technology-inherent risk involved. Another institutional investor interviewee, from an insurance firm, revealed that partnering with certification companies allowed them to observe and learn about the technologies and their associated potential financial risks without actually investing nor insuring it yet. This insurance investor also revealed that their firm provide risk analysis knowledge from their insurance department to help investors both in and outside their company group to better price the risk of renewable energy assets they've insured in the past, suggesting that insurance companies may have potentially had a role in accelerating the financial learning curve of the current mature technologies of wind and solar.

One bank interviewee informed us of the bank's learning process when investing in offshore wind. According to the interviewee, when the bank initially got involved with offshore wind they found that due to the sheer size of offshore projects and the vast coordination between different technical aspects, there were a very large number of contractors involved such that nobody took responsibility and instead blamed the lull in progress on another contractor. As the interviewee explained, this bank encountered problems such as "*the foundations (not being) finished because the subcontractor hadn't finished your welding in anyway. And that's why the guy who's supposed to ram them into the ground couldn't do it yet"*.[5] Asides from this lack of responsibility-taking, working with so many contractors also *"takes far too long and is far too expensive"*[5] leading to heightened risk for the financier. In order to avoid this risk, this bank learned to narrow down the amount of contractors that they use by no longer doing "*one (contractor) for the foundations and one (contractor) for the turbines, but maybe one of them will do (all of) it (instead)"*[5], and then if they are *"somehow too late (in delivering their tasks), then I'll just go to them and they'll give me money"*,[5] and hence responsibility can be allocated better to less contractors. Although *"multi-contracting has not been completely abandoned in the offshore wind sector"*[5], this bank has narrowed the number of contractors from twenty to five. By realising the problems and costs associated with a very large number of contractors and thereafter learning to solve this issue by reallocating the project task to a smaller number of contractors, the bank was able to decrease the risk of their offshore projects and decrease the financial requirements for their investments. This is another example of learning-by-doing. An early-stage venture capitalist investor had a similar finding, revealing that the banks learned to aim for fully wrapped EPC contracts, meaning that a single creditworthy contractor was responsible for performing all engineering, procurement and construction tasks of the project. This allows financiers to seek renumeration from a single known party if they do not deliver what was agreed in the contract. However, this financial learning process was only undertaken by a small number of our interviewees, and we found that only when standardisation and guarantees were established that the majority of our interviewees began their large investments into the solar and wind industry, particularly the banks.

5.1.1.4. The role of the manufacturer guarantee

It was found that for the late-stage debt providers, guarantees of the manufacturer played a major role in enabling investments into solar PV (photo-voltaic) and wind projects. One bank interviewee emphasised the role of guarantees from large manufacturer companies, namely Siemens and Vestas, in alleviating financial risk for offshore wind projects. With construction guarantees removing the bank's construction risk and availability guarantees removing the banks operating risks, the bank was only left with the inherent wind risk, which concerns the risk of possible lower wind levels. Financiers have all started to work with Siemens turbines and Vestas turbines, *"perhaps not because they are somehow better, but because behind them are the guarantees, which are much more valuable"*[5], as stated by the bank interviewee. Another bank interviewee emphasised that the extension of the manufacturers certification for their offshore technology from maximum 20 to now 25 years *"makes a big difference"*[8], while an early stage venture capitalist interviewee stressed that without a manufacture guarantee, most banks won't provide the developer with debt financing anyway, suggesting a possible signalling effect of the guarantee. The bank interviewee added that "*the riskier the technology, the more the balance sheet, the financial strength of the manufacturer and the creditworthiness of the manufacturer must be able to cover the risk.*"[8] This suggest that the both the guarantee and the creditworthiness to support that guarantee was and still is an important factor for these investors when they look to invest in solar and wind technology. According to three of the investor interviewees, the spearheading of the market by Siemens and other large manufacturers helped enable investment as these large multinational firms are financially healthy enough to absorb the risks and provide guarantees on their technology.

5.1.1.5. Standardisation

Although government aid was found to be an important investment enabler for all investor types, financial learning played little role for our private banks and instead they entered into the solar and wind energy industries to a greater extent when standardisation was established.

In general risk assessment theory, standardization reduces overall transaction costs, such as information gathering and contracting. For late-stage investors, standardisation reduces the information asymmetry problem by allowing them to analyse information through common indicators and metrics hence providing the ability to compare projects of interest. Thanks to the financial learning process led by certain investor types, other investors could begin to enter the market with the comfort of standardised risk analysis. An Italian bank interviewee revealed that their bank enjoys standardised financial analysis for wind projects which allows them to compare project options and select the least risky and best performing. Furthermore, according to the interviewee, these standards mean that the bank can compare potential projects with those in which they have invested in the past. In this way, the bank will be more confident in financing a new project if it has the same or very similar performance metrics on the standardised financial indicators as a previous successful project. We found renewable energy investment funds also facilitated financiers to standardise their investments. One institutional investor interviewee revealed that by co-investing with another green energy investment firm into funds with multiple renewable energy assets, they were able to simultaneously scale up various solar PV and wind projects though standardised operations and maintenance (O & M) contracts within each technology group, hence lowering legal costs and risk uncertainty.

Similarly, an interviewee from a German bank emphasized that the standardisation of solar PV (photo-voltaic) and wind investment proposals, which has been accomplished through the learning of law firms, has enabled investment into these technologies. According to the interviewee, this standardisation determined "*the debt coverage ratios and guarantee requirements and what collateral is required*".[8] These standards allow the financiers to quickly and conveniently decide if this project is marketable and has an acceptable risk profile. An insurance firm interviewee emphasized the role of standardising certification schemes within a country in enabling investment into solar PV and wind. This institutional investor interviewee revealed that the manufacturer certification, such as TÜV and VD schemes, meant that manufacturers could *"be assessed as having similar quality and reliability."*[7] This certification means that financiers can reduce their risk by investing in projects that use certified manufacturers. Furthermore, the standardisation of technology reporting, such as that of wind reporting in Germany, has also enabled investment by establishing *"what should actually be included in a proper wind assessment"*[9] according to a German bank interviewee. This standardisation allowing financiers to decrease their information asymmetry by having clear points of comparison between wind performance reports.

However, some of the other investor interviewees stated that the investment terms in the proposal that the financier offers are actually becoming more favourable for the project developers through competition in the creditor market. For example, one energy company interviewee explained that project developers are now increasingly proposing more aggressive financial conditions of the investment that would be in their favour, such as a lower DCSR. The interviewee explained that thanks to the competition within the creditor market now for mature renewable technology projects, the developer's term sheet conditions may be accepted by another investor if they fail with their initial investor choice. An interviewee from a bank agreed with this view regarding wind projects, informing us that as the bank had to match new investors' lower accepted wind yield. For example, according to the interviewee, their bank *"started off looking at the 95% probability of wind yield"*[2], but as new investors entered the market they began providing financial capital for 90% wind probability and hence the bank had to also lend money on these conditions that are more favourable to the project developer. The interviewee explained that this competitive process also resulted in the bank increasing their loan tenure from 10 to 12 and eventually to 15 years. Another bank interviewee agrees that competition has lowered financing conditions for borrowers, stating that recently the vast *"availability of capital on the market*"[9], has been a crucial factor in decreasing the debt margin. This suggests that financial learning may be, at least partially, a result of competition in the mature renewable energy creditor market and that if this competitive process is still ongoing then in-house financial analysis standards must be dynamic and not static. Nevertheless, standards can significantly assist investors in making quick and easy decisions particularly when they enter new industries such as renewable energy as it removes the ambiguity of a new technology by presenting it in understandable financial standards, enabling comparison.

5.1.1.6. Country-specific factors

It was found that the country-specific legal and regulatory environment was, and still is, a large factor to consider when deciding to invest in solar or wind. One energy firm interviewee revealed that familiarity often enables investment from banks, stating that these investors aim for countries where they have already financed something that is "*the closest version to that technology, under the same regulatory or subsidy regime"*[14] and ideally *"with clients, you've worked with several times in the past".*[14] A German bank interviewee agrees with the investment enabling effect gained from the comfort of familiarity, stating that the contracts for difference (CFD) mechanism in France and partially in the UK offshore parks gave this German firm the confidence to finance in these countries, as this subsidy system is also used in Germany and so the financial risk is similar. This German firm found particular confidence in investing in France as the French have *"implemented the 2014 EEG almost word for word."*[4]

The legal and political landscape is also very important for investors when considering entering a new country. As one bank interviewee stressed "*there must be reasonable courts, even in the event of a dispute, the law must be enforceable*"[8], and with the question of ownership being at forefront of projects of this type, the *"land registry security is very important".*[8] The interviewee added that their bank doesn't invest at all in *"countries with a high corruption index or factor"*[8] as there are the *"risks of regulation, and on the other hand, corruption may mean that possible legal securities are not given."*[8] Another bank interviewee agrees with this finding, stating that a "*country's track record in fulfilling its contractual obligations*" is a crucial investment enabler and it then allows the lender to look at new future projects in that country also. Furthermore, it is important for the *"legal and regulatory system for this asset class (to be) stable and tested and predictable"*[3] as one bank interviewee added. The opinion of the capital market on certain countries is also very important and should be considered when looking at new investments. As another of our bank interviewees stated, *"if the capital market is of the opinion that we should not invest in a certain country, then we as a bank cannot offer our product there".*[9]

If capital market deems the country unsuitable for capital flows, the banks is unable sell some of the project in this country to other investors, which is often important as banks aren't always in a position to "*put everything (they) do on (their) own balance sheet*".[9] This finding stresses the importance of the country financial environment being capital market ready. A bank interviewee explained that the capital market also needs to be convinced of the legal system of the country through the assessment from usual well-known large law firms, emphasising that the lender must hire someone "*who not only knows the written word in the country, but also knows how the courts deal with it".*[9] These legal and political requirements are vital to *"achieve a calculable cash flow"*[9] because if a bank comes *"to the conclusion that the environment does not allow for a calculable cash flow due to the system, then it is also the immediate end of the project financing*",[9] as one bank interviewee said. Therefore, the legal and political situation of a country can either help enable or hamper investment into renewable energy technology. Asides from specific legal and political requirements, the country's past history with the technology of interest is also an important enabler. As one energy firm interviewee mentioned, banks *"consider countries where a lot of offshore wind has developed before as less risky."*[15]

5.1.2. Technology-specific enablers

From the interviews, investment enablers driven by the specific technical characteristics of a R.E.T were also discovered. Crucially, it was found that these technology-specific characteristics only enabled investment from certain investor types while hampering investments from other investor types.

5.1.2.1. Ticket size of offshore wind

According to our interviewees, there are little to no spillovers between onshore and offshore wind projects due to offshore wind's larger project size, high contingency costs and resulting risk profile, which has large implications on the size of the investment ticket. Some financiers found that the technical and management processes for offshore wind projects were too different to onshore for any significant spillovers between these project types. One bank interviewee revealed that there are *"remarkable differences in the risk profile (between offshore and onshore wind)"*[3] due to differences in *"the technology or the environment"*[3]. This interviewee also found *"that there can be significant differences in performance (between onshore and offshore wind technology)."*[3] Another interviewee from a different bank revealed that when developing an offshore wind project, you can't *"just drive there and put a tower on a concrete foundation"*[4] as is the case with onshore wind, instead offshore wind must be *"planned in a completely different way"*[4] depending on the length of the time period in which there are favourable weather conditions. The interviewee revealed that there are only *"173 days in the North Sea when you can do the maximum amount of work"*[4], and that outside this window of time, *"the swell is too high."*.[4] Furthermore, according to the interviewee, the time it takes to set a monopile in the water depends on how far it is being built from the coastline. Also, the use of installation ships for offshore wind projects introduces issues that onshore wind projects do not experience. For example, according to an interviewee, any delay in the operating of the installation ships due to bad weather accumulates to significant unplanned costs, with the investor specifying that in one project they paid 400,000 USD per day for leasing the ship, regardless of whether it was actually used. In this bank's view, due to these high contingency costs inherent in offshore wind, the reserve costs within project financing are very important.

An interviewee from an early stage venture capitalist company confirmed that the differences in risk profile between onshore and offshore are prominent, referring to the risk of the turbines corroding and*"1,000 other things that are different at sea"*[12] which make it a *"bit difficult to think in terms of (cost) modelling"*.[12] These contingency costs increase the financiers risk perception of offshore wind compared to onshore wind, while also shutting out smaller scale renewable energy developers who can't cover such variable costs.

Further findings from the interviews indicate that there are even differences in risk assessment between different offshore projects. It was found that construction risk for offshore depends on the distance from the turbine to the coastline. One bank interviewee noted that when projects are *"180 kilometres away from the coast"*[4] the bank cannot use the same project development companies that they worked with for the offshore projects that are much closer to the coastline, due to the need for different technical expertise. This suggests that the type of construction risks for offshore wind projects may be geographically specific. These findings demonstrate that investors are not able to use knowledge gained from previous onshore wind investments to enable investment into offshore wind projects. Therefore, smaller investors who could invest in onshore wind may not find offshore wind appealing due to the stark increase in risk profile. Apart from these higher contingency costs, the non-issue of noise generation and unsightliness has resulted in offshore wind turbines being built much larger than those in onshore wind projects, as one early venture capitalist firm interviewee revealed. The increase in turbine size and contingency costs make this investment ticket size larger than onshore wind.

However, it was also found that this difference in ticket size isn't necessarily an investment barrier. Although smaller investors cannot pursue such large tickets as it very difficult to absorb the financial risks associated with large projects, as explained by one of the bank interviewees, the large offshore wind tickets are appealing to the deep pocketed institutional investors who can deploy large amounts of capital. As one bank interviewee stated, the "*large size of offshore wind enables large debt and therefore encourages institutional investors to invest"*[11], adding that *"there were a lot of institutional investors being able to transact because tickets size (for offshore wind projects) were more of hundreds or one-fifty (million euro)".*[11] Therefore the technical characteristics directly impact which investor will invest, demonstrating a technology-finance interaction. Furthermore, the larger risk profile may mean that project financing is inappropriate, and that corporate financing is best suited for offshore wind projects, shutting out small scale energy companies who can't afford to provide the large collateral needed when using corporate financing. Given this higher risk in offshore wind compared to onshore wind, one corporate banak interviewee calls for a partial transfer of subsidies from onshore to offshore projects, also emphasising that offshore wind technology has a larger capacity factor too, and hence the subsidy would be more useful if used to fund offshore wind.

Apart from offshore wind specifically, it was found that some of our investor interviewees required large tickets to invest in renewable energy projects generally. For example, an interview from Deutsche Bank revealed that they do not provide debt for less than a 150-million-euro investment ticket, while UniCredit requires a ticket size of between 50 and 500 million euro, although they revealed that they use local banks to finance the smaller tickets within their internal leasing unit. The EDP unit, within the EIB, require a smaller ticket size of 7.5 million minimum in order to consider investment. Triodos actually fund both small and large tickets. According to an interviewee, this sustainably focussed bank uses smaller ticket funding for newer technology as it may not be successful. This smaller ticket financing also allows the bank to get to know the developer by getting *"a view on their ambitions (and) on what way their ambitions are realistic."*[2] However, as revealed by the interviewee, Triodos also do large tickets, particularly for offshore wind projects, with their sweet spot being from 2.5 million to 20 million euro. The technology characteristics can increase the ticket size, as demonstrated through my findings on offshore wind, until it reaches a size that is acceptable to the previously named banks.

5.2. Novel renewable energy technology

5.2.1. Technology-specific barriers

5.2.1.1. Battery

Battery storage is used to balance energy supply by storing any surplus energy that cannot be injected into the grid due to the possibility of causing power outages. When asked about their past or potential future investment into battery storage as a viable investment, we found that multiple of corporate banks interviewees found this technology unfeasible**.** Due to the rapid evolution of battery storage technology, project developers are faced with the fact that after 5 years of installing their battery storage system, a new technology that is *"ready for the market that can store electricity at half the cost"*[8] may emerge, making their technology non-competitive. This aggressive market dominance of the lowest cost technology is inherent in the merit order design of today's global energy system. Essentially this indicates that project developers only bid for short term tenders because they fear that their technology will be overtaken by another and therefore lose cash flow reliability after a certain amount of years. However, as our corporate banking interviewees revealed, debt financiers are not willing to provide financial capital for such a short period of time. For example, a financier won't provide project finance for the capital costs of 2-year battery storage projects as those 2 years may not be enough time to recover the capital costs through project cash flows. As one corporate bank interviewee stated debt providers *"cannot finance battery storage on the basis of balancing energy in the long term, because tenders are invited for short time slices."*[9] Even if the project developer was willing to accept a longer tender, it is still unlikely that the financier will recover their investment through the project's cash flows as a new and more cost efficient technology is likely to make the technology in which they invested obsolete and non-competitive, resulting in a lack of a *"long-term, predictable cash flow"*[9] as one interviewee put it. This inability to rely on long term cash flows means that project financing is unsuitable. This financing structure type is unsuitable because it limits the financier to claim the value of the project as collateral but cannot pursue the clients assets within their principal corporation(s). This infeasibility of project financing imposes important entry barriers for smaller scale developers and innovators who do have sufficiently valuable assets on their balance sheet to receive corporate financing from the debt providers. Furthermore, according one bank interviewee, a large portion of equity is required first to enable debt provision, resulting in small scale developers unable to receive funding.

This maturity mismatch is the core problem in scaling up battery storage globally that may not be solved until battery storage prices stabilize, giving confidence to project developers to operate longer contracts. The financial infeasibility of battery storage is a significant problem as solar and wind are intermittent power sources meaning they require back up stored energy when its cloudy or less windy, respectively. Furthermore, the opposite problem is also highly relevant which is the issue of balancing energy. Due to periods of low energy demand, solar and wind sometimes produce too large of an energy supply for the grid demand and this extra energy must disposed of as the grid can only accept so much unused energy before the excess voltage causes damage to the electronics within the system. There needs to be a storage system that can remove this excess energy so that it is not lost but rather can be stored and used later in periods of high demand.

5.2.1.2. Geothermal

Some technology-finance interactions were discovered in geothermal projects. One corporate bank interviewee stated *"geothermal energy simply has the supply risk. That means you could theoretically do it, but only when it's all drilled, when the discoverability (of the correct water source) is proven, even in the longer term."*[8] However, as the interviewee continued to explain, the drilling costs are one third of the total project costs and the drilling must be completed to prove that they have found the correct conditions in the earth for thermal energy. Therefore, the developer must cover the drilling costs with their equity capital, most likely their own internal equity, before banks engage with the financing of the project. Most project developers can't cover such a large upfront cost with their own financing and hence there is a technology-inherent barrier that stops the banks from investing. Furthermore, this interviewee emphasised that the economics of geothermal is highly dependent on finding the exact correct water temperature as water that is just a few degrees less results in the power generation becoming significantly more expensive. These drilling and water temperature technical characteristics are examples that clearly show that technology-specific characteristics can directly create financial barriers. As geothermal generation is limited to areas with the exact correct water temperature, finance may be better utilised if invested in innovating the distribution and end user downstream stages so that that geothermal energy is better transported from its limited amount of generation sites.

5.2.1.3. Hydropower

Although hydropower enjoys the second largest renewable energy production percentage in the EU, the interview research has uncovered some inherent technological issues with hydropower that are also found in other novel RETs, particulate geothermal (Renewable Energy Statistics, 2022). Therefore, this thesis considers hydropower to suffer from novel R.E.T investment barriers and must adapt its technology in order to improve its effectiveness, leading to its classification as novel in this paper.

Some of the corporate bank interviewees revealed some technology-finance interactions that create obstacles in upscaling hydropower in the finance market. Due to the nature of hydropower technology, it depends on the strength of the river and hence is geographically specific. As one investor revealed, hydropower isn't feasible in all of the Netherlands as *"in some places (in the Netherlands), the current is never high (enough)"*.[10] This finding implies that large areas of countries may be unsuitable for hydropower. This geographical limit may mean that financing would be better utilised in innovating the distribution and end user downstream stages to ensure more effective transportation from the limited amount of generation sites, as with geothermal. There is also a lack of warranties from contractors in hydropower as they are generally *"small-scale players in the market"*[2], as one bank interviewee explained, meaning that technical issues in the project may significantly affect the cash flow.

This interviewee explained that the unstable supply of energy makes hydropower problematic, stating that when the rain fills the rivers and hence increases the water supply to the plant, *"you can end up having all your water at once rather than spread over a nice period, which is what you tend to get with wind"*.[2] This unpredictability makes the need for energy storage highly relevant for hydropower given the potential over supply of energy to the grid. This also implies that if the financier doesn't have a storage solution such as a battery storage, for the financial reasons explained previously, then hydropower could potentially present yield losses as the operator will not be able to use the excess energy later when demand increases. Furthermore, with the effects of global warming perpetuating, the energy yield from hydropower may become more unstable with some areas drying up, while others are deluged more frequently. This unpredictable cash flow due to technology characteristics makes project financing an unattractive financial structure for both debt and equity providers, and the need to for corporate finance, and its larger collateral base, becomes more suitable. However, as explained previously, this may shut out smalls scale developers who cannot afford to collateralize their balance sheet assets for corporate financing.

5.2.1.4. Green power to hydrogen

Green power to hydrogen also has inherent technological weaknesses that make it financially unviable. One corporate bank interviewee noted that the *"cycle efficiency is quite low"*[11] which makes the need for *"an incentive scheme or a bigger company that says, okay, we want to push for this"*.[11] This finding highlights the technological weakness in power to hydrogen in providing an acceptable return on investment. This interviewee suggests the provision of larger tax breaks or subsidies for these kinds of promising technologies that are not yet at the technological stage to be economically viable without public support. One institutional investor confirms that for a main power source, it is too expensive, but that as a battery functioning to balance energy yielded from other technologies, it may become feasible. This technology was not spoken about very frequently by the interviewees.

5.2.1.5. Biomass

We found that the exposure of biomass projects to market volatility makes it a risky investment for investors. Multiple of the corporate bank interviewees agreed that the costs of biomass projects are too exposed to market dynamics. One interviewee noted that *"the purchase price for biomass correlates very strongly with the market prices of fuels in general, which are very volatile"*[8] resulting in an unpredictable cash flow projection when there are no fixed purchase contracts, such as a PPA (power purchase agreement). The interviewee continued to say that this alternative energy is also exposed to input price volatility, citing the fluctuating prices of grain types and concluding that this price volatility at both input and output stages makes biomass simply unsuitable for project financing. Another of the corporate bank interviewees confirmed this finding on price volatility, stating that biomass brings a *"market uncertainty into your house that you don't have with wind and solar"*[9]. The interviewee emphasized that this price volatility is not country-specific but is rather a global problem for biomass projects. When asked about the possibility of a long-term supply contract as a solution to this price volatility problem, the interviewee revealed that a bank will almost never *"get a supplier that you believe will survive for twenty years"*[9] because with biomass projects the lender typically encounters smaller and medium-sized recyclers which *"just have no possibility at all within* *the framework of a credit rating from a bank to show that if they promise you a price for twenty years, that they can also keep it."*[9] Another corporate bank interviewee confirmed this finding, stating that *"we can't say for sure that the parties who are there can, want to or will fulfil these contracts in the long term"*.[3] A fourth corporate bank interviewee confirmed that in their few biomass projects in the past they observed volatility in the form of hay and dung prices increasingly massively in Croatia, while, on the output side, they claim that there are no well-rated corporates in Eastern Europe and therefore PPAs are almost only creditworthy if signed by the government or by a state-owned enterprise. An interviewee from one of our more sustainably focussed banks noted that the status of biomass as an alternative clean energy should be carefully scrutinised under certain circumstances. The interviewee noted that in the UK they are depleting their domestic biomass sources so fast that importing biomass from North America and other countries will soon be required, introducing carbon emissions from transport and hence making the net zero carbon status of biomass energy untrue. This finding suggest that the net zero status of biomass energy is geographically specific as it only carbon-free when farmed and used in the same country without the use of non-renewable transport methods.

5.2.1.6. Proof of technology

Additionally, we found some discrepancy in our investor interviewees' views on investing in unproven technology. For instance, HSH Nordbank, Triodos, Platina Partners and PGGM all require the technology to be proven in order to consider investment. Our HSH Nordbank interviewee told us that the bank defines a proven technology as *"one that has been used successfully in this form of application several times and over a longer period of time, let's say two years."*[3] This interviewee explained that once the technology is proven and so is producing *"its output as (they) have planned, then a legal and funding framework will typically emerge that will promote the whole thing (and) the banks will be very eager to get involved. But the technology is, so to speak, the key to the whole thing."*[3] By contrast, Persistent, Rabobank and the EDP, within the EIB, all do not require the technology to be proven before investing. For instance, Persistent, being an early-stage VC firm, stated that they only require enough collateral to take on the risk that unproven technology presents, adding that established manufacturers such as Samsung are able to provide an acceptable level of collateral in these cases. The EDP has a core function to invest in projects at the demonstration stage and so, naturally, these technologies are not proven yet, while Rabobank are known to invest at an earlier stage than most other corporate banks, particularly in the wind energy sector. The other interviewees did not mention proof of technology as either an enabler nor barrier and hence we can't assume their investment policy as it pertains to proof of technology.

6. Discussion of results and analysis

The research question guiding our enquiry was: *How do technology-specific, non-technology-specific and investor-specific barriers and enablers shape the risk perception of different renewable energy technologies in the financial market?* In this section, we reflect upon this research question and interrogate our findings with previous insights from the literature on investors' attitude towards both mature and novel R.E.Ts. We investigate how investors have begun to perceive solar PV, onshore wind and offshore wind projects as less risky and/or having a more attractive return. Egli, Steffen and Schmidt (2018) have shown empirically that financing conditions, such as lower debt margin and DSCR, and longer loan tenor length, have relaxed significantly for all three technologies, demonstrating a decline in the risk that the investors perceive these technologies to have. This decrease in risk is highly correlated with the reduction in LCOE due to economies of scale driven benefits gained from increased widespread investments. To investigate this decrease in risk perception and associated large increase in investments levels, we explored technology-specific and non-technology specific risks which both can have varying effects on different investor types.

6.1. Mature renewable energy technology

6.1.1. Non-technology specific

6.1.1.1. Public finance

From our interviews we discovered that the provision of public finance partially decreased the risk of investments into these R.E.Ts, hence enabling them initially through contracts for difference and obligation certificates. These findings on the risk mitigation function of feed in tariffs are aligned with the research of Dinica (2006) and Abolhosseini & Heshmati (2014). Geddes, Schmidt, & Steffen (2018) find that state investment banks can assume help accelerate the energy transition through their early investment function by covering large upfront costs. We add to this literature by discovering that the EDP, within the EIB, and other International Financial Institutions have an important role in providing liquidity in areas such as Turkey, Romania, Bulgaria or Serbia where there is not enough liquidity in the local commercial banks. We also discover that the IFIs are crucial in their function of communicating with the governments, adapting laws and tax details so that an investment-friendly environment is created for R.E.Ts.

6.1.1.2. Information asymmetry reduction

According to Simon (1955), when there are limits to an investor's ability to gather and process relevant information on an asset or project, such as offshore wind parks, investors will primarily seek satisficing, instead of optimal, solutions, resulting in the most profit maximising option not being chosen. This form of information asymmetry can hamper investments into unclear yet crucial investments that are needed for the energy transition.

Demirel (2015) shows that most investors prefer to pursue investments that present clear information in order to reduce the risk that they take on. This investment agenda can result in there being a substantial gap in the provision of financial capital to renewable energy technologies in their early stages. We found that financial learning by some investor types has decreased this information asymmetry in the solar and wind energy industries, through learning about how the technology works and its associated risks. We discovered that thanks to their large size institutional investors were able to kickstart this financial learning process. For example, we found that by leveraging their size to co-invest in large pure renewable energy funds and partner with certification companies, these investor types were able to get exposure to smaller less known assets without individually bidding on them. This exposure allowed them to learn about these asset risks and returns though a process known as learning-by-doing. However, financial learning was not discussed by the vast majority of our investors, but instead the later introduction of standardisation was seen as a principal enabler. R.E.Ts undergo the process of financial learning and eventually certain standards are formed. We found that half our bank interviewees, all our institutional investor interviewees and our private equity interviewee found some form of standardisation, namely standardised financial analysis, standardised reporting and standardised manufacturer quality, to be very helpful in lowering their risk perception of solar and wind energy projects. Standardisation formalises the financial risk assessment so that companies may compare projects with an industry standard such as an acceptable level of DSCR. This availability of an industry standard benefits investors as they have a clear piece of information to look for with which they can either accept or reject projects. Furthermore, it was found that by standardising which indicators should be included in the technology's performance reports, the investor is able to compare and contrast projects' attractiveness in common metrics. Without standardisation, the investor is tasked with interpreting various non-standardised forms of information metrics on different projects, some of which they may not understand and hence their decision to invest may become crippled with uncertainty even if the technology is, in reality, financially viable.

6.1.1.3. Country-specific factors

We found that investors consider the political and legal landscape of a country to have a powerful effect on their perception of the risk of an investment. The investors mentioned the existence of legitimate courts, an enforceable legal system and land registry security as principal law-related enablers. A lack of these legal necessities, due to factors such as political corruption, will create an unreliable investment environment, leading to the capital market losing faith and hence will impede an investment into a project in a country. These findings are supported by Holburn, (2012) who found that investors perceive renewable energy projects as less risky when operated in countries in which the policy making process and associated legal environment is independent from the political process of that country. Without a reliable legal and political system, investors fear that there is risk of policy instability, which Karneyeva and Wüstenhagen (2017) has found is specifically important in solar PV investment decisions, while Angelopoulos et al. (2016) have shown that this policy risk is also important for onshore wind investments. Furthermore, we also found that investors prefer to invest in countries in which a familiar public policy regime exists, such as a similar subsidy structure, and also where a similar technology had been developed before.

6.1.2. Technology-specific enablers

6.1.2.1. Investment ticket size

Through our interviews, we found that large ticket sizes driven by a project's technological characteristics can be an investment enabler or barrier, depending on the investor type. We found that this technology-finance interaction is particularly prominent in the offshore wind sector. Thanks to its remote nature, offshore wind turbines can be built very large resulting in large ticket sizes. Apart from the fundamental turbine size difference to its onshore counterpart, offshore wind also accumulates more contingency costs such as shipping complications and water corrosion. These large turbines combined with the extensive contingency costs makes offshore wind an attractive investment for deep pocketed investors, such as institutional investors, who have the size to absorb the risk as long as the ticket size is large enough. However, this large ticket can also impose investment barriers for smaller financiers who cannot afford to provide such large amounts of financial capital. This large ticket size makes it difficult to finance this project type with project financing due to the large collateral that is required. Therefore, corporate financing becomes more appropriate, and some smaller energy companies who cannot afford to provide the collateral in a corporate financing structure will be unable to enter the offshore wind sector. This lack of spillovers between onshore and offshore wind projects due to differences in risk profile results in different financing structures being appropriate. This lack of spillovers is in contrast to previous research by Braun et al. (2010) who found that within the sector of wind energy there are technical knowledge spillovers between different wind technologies, known as *"intra-sectoral spillovers"*.

6.2. Novel renewable energy technology

6.2.1. Technology-inherent enablers/barriers

We found that due to their certain technological features, some novel R.E.Ts, they are still financially unattractive for most investors. In geothermal energy projects, drilling must be completed first before banks commit to financing as it is only after the drilling when they know if the correct water is found, a sharp contrast to the oil drilling process. Therefore, banks require energy companies to finance these high drilling costs themselves or use external equity providers which is very often not possible given the large amount of equity that would be required. Furthermore, even if water is found, the slightly lower temperature of water results in a significant increase on the cost of the electricity generation which is unattractive for financiers. These findings add value to the literature on geothermal technical issues, such as those studies by Gunnlaugsson et al (2014) and Shannon (1975), by establishing how geothermal technical issues relate to its financial feasibility and appropriate investment structure, in the eyes on the private investor.

Regarding hydropower projects, we found slow currents and inconsistent energy yields due to rainfall make these projects unappealing for the investor because of unpredictable fluctuating cash flows. Furthermore, this unreliable cash flow will only worsen as some bodies of water dry up and others flood due the effects of global warming. This cash flow issue as a result of the inherent technical characteristics of hydropower projects is a new finding that adds to the literature on hydropower's financial issues such the regulatory problems found in Poland by Kałuża et al. (2022), and lack of government financial aid found in Pakistan by Ullah et al. (2019).

Technology-driven financial problems were also found in biomass projects. According to our investors, the input and output price risk due to market exposure means that expenses in biomass projects are unpredictable and hence the net cash received is inconsistent. Regarding green power to hydrogen, we found there to be low cycle efficiency issues that makes this technology too expensive for application as a main power source and low cash flow. This finding is aligned with those findings by Dixon (2007) and Felderhoff et al. (2007)

Finally, concerning battery storage projects, we found issues of maturity mismatch between the financier and the project developer. Project developers only accept short term tenders given the short-lived competitiveness inherent in battery storage technology, yet financiers need more time to make their investment worthwhile resulting in a lack of financial capital flowing into battery storage projects. This short-lived competitiveness is due to ongoing rapid technological evolution of this technology; frequently making older models obsolete. This maturity mismatch would suggest there is no opportunity for developers to stack their revenue streams as a means to supplement battery storage cash flow as the projects often don't receive the initial necessary external financial capital. This finding brings into question the significance of revenue stream stacking as a means to make battery storage financially feasible as found in the research of Lombardi and Schwabe (2017) and Martins and Miles (2021).

All of these technology inherent problems clearly result in financial issues. The cash flow issues associated with hydropower, green power to hydrogen, and biomass projects makes project financing less reliable as project financing inherently uses project-specific cash flow to pay back investors, whether it be loan payments to banks, or dividends to equity providers. Instead, investors will most likely prefer to limit the financing structure that they offer to corporate financing through which they can claim the corporation's balance sheet assets as collateral, hence reducing their financial risk. Apart from specific technology characteristics we found that some of our late-stage financial capital provers do not invest in unproven technologies at all, while our earlier stage investors, namely the EIB, Rabobank, and early VC firm Persistent, invest in both unproven and proven technologies.

7. Implications for policy makers

After an intensive analysis of the findings, we have formulated some suggestions for policy makers.

First, given this higher risk in offshore wind compared to onshore wind, a partial transfer of subsidies from onshore to offshore projects is suggested. As one interviewee pointed out, offshore wind technology has a larger capacity factor than onshore wind, and therefore the subsidy would actually be more useful if used to fund offshore wind. Regarding geothermal, this paper suggests that governments, or IFIs, begin to subsidise the drilling cost so that these projects don't remain stagnant due to equity constraint, as explained previously. On the other hand, as geothermal generation is limited to areas with the exact correct water temperature, finance may be better utilised if invested in innovating the distribution and end user downstream stages so that that geothermal energy is better transported from its limited number of generation sites. This recommendation also applies to hydropower projects given their limited geographical scope. This paper also suggests that governments attempt to establish a price guarantee for the fuel input for biomass projects and its outputted products that are sold on the market. This price guarantee would reduce investor risk as the project wouldn't be exposed to unpredictable market price dynamics. Regarding green power to hydrogen projects, it is recommended that governments, and perhaps IFIs, invest heavily into improving the low cycle efficiency problem with this technology. Once this issue is solved, or at least addressed, green hydrogen to power could prove to be a reliable main source of energy through its balancing of the frequent oversupply of solar and wind energy.

Finally, it is recommended that governments invest heavily into battery storage R&D so that the optimal technological storage model can be reached, and aggressive technological evolution managed such that storage solutions do not become obsolete in a short number of years. This stabilised state of technology will solve the maturity mismatch between financiers and project developers because the project developers will bid for longer tenders. Finally, given the large enabling role of standardisation for late-stage debt providers that was found, governments should invest their time more heavily into developing standardisation schemes. Instead of waiting on institutional investors to undergo financial learning through large R.E.T funds and for risks to thereafter emerge, establishing standards may speed up the financing by introducing the confidence that late-stage debt providers need to invest.

8. Limitations

First, the number of interviewees is small, only 15 in total; however, as panels of subject matter experts, their contributions are considered as a partial off-set. Furthermore, these interviews were performed in 2019 and 2020 and although updated versions on policies and figures that the interviewees mention were researched, it is still possible this thesis may have overlooked some of these updated versions. Additionally, given the evidence of investor specific attitudes to different enablers and barriers found in the study, it would have been better to have a broader range of investor types, for example more early-stage investors like the early-stage venture capital investor Persistent. Finally, each interview, some more than others, had parts where the participants would talk about a theme that was generally irrelevant to this paper's research.

9. Conclusion

The question that was answered in this paper was *How do technology-specific, non-technology specific and investor-specific barriers and enablers shape the risk perception of different renewable energy technologies in the financial market?* In conclusion, it has been discovered that there were technology and non-technology specific investment enablers for mature renewable energy technologies, solar PV, onshore wind and offshore wind. The non-technology specific investment enablers included public financial aid, financial learning, manufacturer guarantees, standardisation and country specific legal and political systems. The technology specific enablers were the large ticket sizes of offshore wind projects driven by large turbines, and technological complexity, resulting in an investment enabler for large investor but perhaps an investment barrier for smaller investors. Within this finding, we conclude that there is a lack of knowledge spillovers from onshore wind to offshore wind due to the higher risk profile and higher contingency costs of offshore wind projects. Regarding investment barriers, we found certain cash flow uncertainty driven by specific technological aspects to be a principal investment barrier for investors. These findings are valid as they are taken from interviews with experts from large established firms in the renewable energy market. Further research could investigate the possibility of knowledge spillovers between other similar renewable energy technologies, such as solar CSP and solar PV. Further studies could also investigate if the investment enablers and barriers found in this study are also found outside of the European financial market. Overall, the findings suggest that the investment enablers and barriers for both mature and novel R.E.Ts has been shown to be partially driven by technology-specific characteristics, and also impact certain investor types differently. A better understanding of technology-finance interactions can contribute to designing policies that incentivise the right type of finance depending on the technology requirements of low-carbon transitions.

10. Points for further discussion

Given the increasing uptake and ever decreasing LCOE of the mature RETs and solar PV and wind, it poses the question as to why we still have government support for these projects. For example, given the increased demand for the electricity from these mature RETs, does there still need to be Purchase power agreements and contracts for difference provided by the government. If these RETs are approaching cost competitiveness with the fossil fuel industry, then why do subsidies still exist for these technologies and why haven't they been reallocated to the more novel RETs. These are important and exciting avenues for future research.

11. Quotation references

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2. Triodos
3. HSH Nordbank
4. Bayern LB
5. UniCredit
6. EDP (EIB)
7. ACS
8. LBBW
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10. Rabobank
11. ING
12. Persistent
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13.Appendices

Key:

"Bank" is in reference to an interviewee from any bank that is not the EIB

Appendix 1: Non-technology specific investment enablers for mature RETs

Key Enablers	Where along the curve?	Specific enabler (organisation name)	Frequency
Government Aid	Signal	UK's ROCs (PGGM, Triodos), Feed-in-Tariffs (HSH, Deutsche, Bayern LB), Credit Export Agencies (Orsted, UniCredit), Government pre-financing (Triodos)	7 (1 institutional investor, 5 banks, 1 energy company)
EDP (EIB) aid/ other IFIs	Signal	Fills financing gap (EDP), Signalling role to other investors (EDP), Liquid provision by IFIs (UniCredit)	2 (1 public investor bank, 1 bank)
Financial Learning strategies	Tipping point	Partnerships with certification firm (ACS), Multi-asset funds (PGGM), Sitting on assets/Learning-by-doing (PGGM, UniCredit), Risk analysis knowledge sharing (ACS),	3 (2 institutional investors, 1 bank)
Role of Manufacturer	Tipping point/Megatrend (differs per tech?)	Guarantee (LBBW, UniCredit), Risk stabilising/Bringing costs down (LBBW, HSH, Persistent)	4 (3 banks, 1 early stage vc)
Standardisation	Megatrend	Standardized financial conditions, e.g. DSCR (Platina Partners, LBBW, PGGM, UniCredit, Triodos), Standardized manufacturer quality through certification (ACS), Standardized wind reporting (Deutsche Bank)	7 (4 banks, 1 private equity , 2 institutional investors)
Country-Specific Regulatory/Political Environment	Tipping point/ Megatrend *Depends on the political geography*	Same/Similar subsidy regime (Orsted, Bayern), Political/Legal Environment (LBBW, HSH, Deutsche Bank)	5 (1 energy firm, 4 banks)

Appendix 2: Technology-specific investment enabler/barrier for mature RETs

Lack of spillovers between Onshore and Offshore wind projects

Differences	Organisations	Frequency	Implications for financing structure	Implications for investor type
Different risk profile/performance due to different technology and environment	HSH	5 (4 banks, 1 early-stage VC)	Makes project financing less appropriate. Makes corporate financing more relevant.	Larger tickets of offshore are more appealing to institutional investors
Offshore is riskier due to weather conditions, delay issue with ships result in high costs, multi-contracting	BayernLB			
Corrosion risk with offshore wind	Persistent			
Construction risks for offshore wind varies depending on how close the project is to the coast	BayernLB			
Offshore wind has larger ticket size	Triodos, ING			

Appendix 3: Technology specific investment barriers for novel RETs

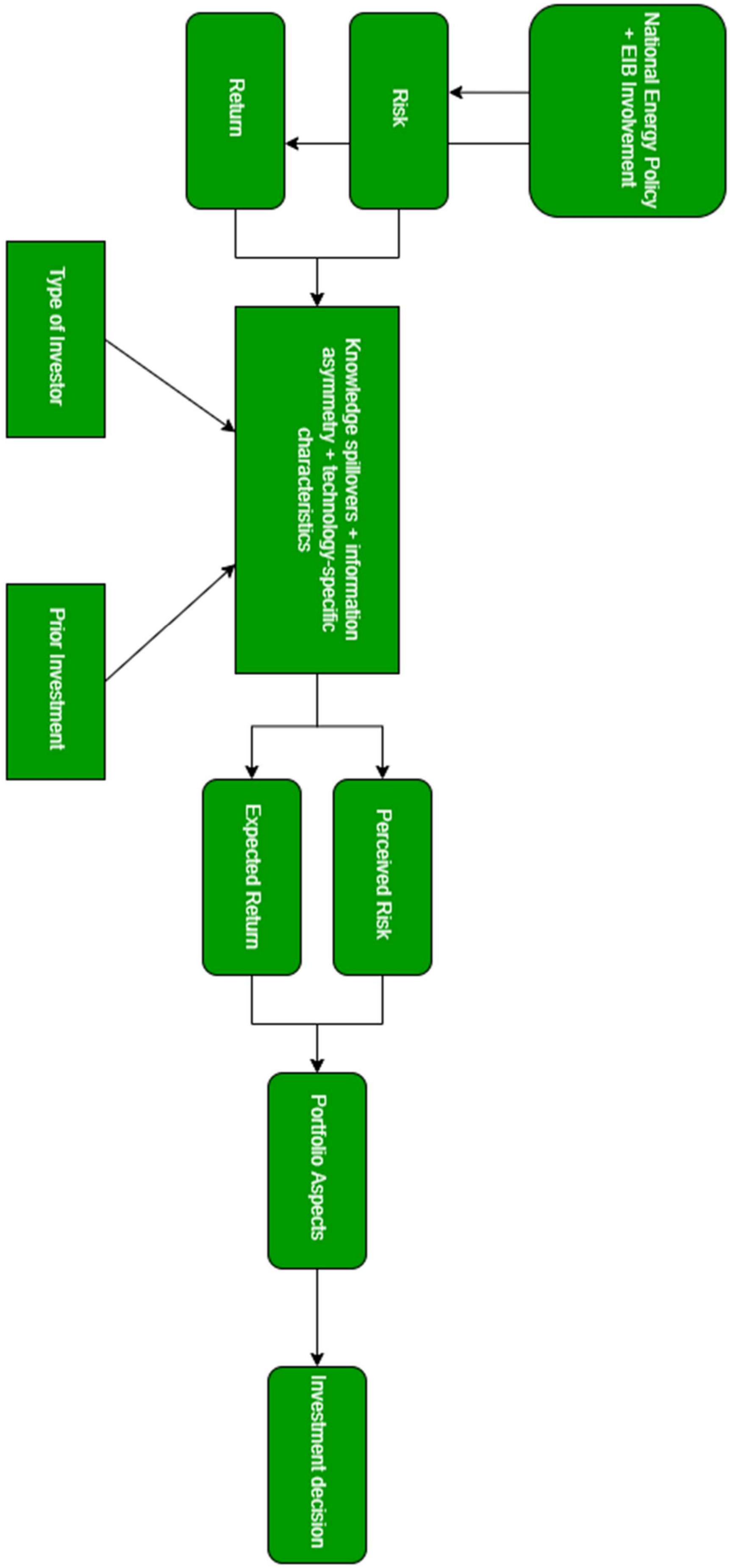
Technology Type	Barrier (organisation name)	Frequency	PUBLIC POLICY SOLUTION
Geothermal	High drilling costs require large equity financing first (Deutsche Bank), Effect of incorrect water temperature on electricity generation cost (Deutsche Bank)	1 (1 bank)	Should the government fund this drilling cost if nobody else will (due to risk?)

Hydropower	Slow river current (Rabobank), Inconsistent energy yield (Triodos), Large number of involved parties (Triodos), Unable to secure warranties from small scale contractors (Triodos)	2 (2 banks)	Governments can provide collateral for these small-scale contractors?
Biomass	Input and Output price risk exposure (LBBW, Deutsche Bank, UniCredit), Biomass becoming non-carbon with importing aspect (Triodos)	4 (4 banks)	Governments can establish a guaranteed price for both input fuel and output biomass product?
Green Hydrogen to Power	Too expensive as main power source (PGGM), Cycle efficiency is too low (ING)	2 (1 bank, 1 institutional investor)	Government should invest heavily into the cycle efficiency innovation to increase the efficiency and hence make it a more attractive investment for upscaling
Battery Storage	Rapid reduction in production cost due to technological evolution (LBBW, Deutsche Bank), High equity requirement (ING)	3 (3 banks)	Governments should invest heavily into battery innovation so as to reach the stabilised technology quality, so it doesn't keep

			becoming obsolete?

Proof of technology	**Organisation**	**Frequency**
Doesn't invest in unproven technology	HSH Nordbank, Triodos, Platina Partners , PGGM	4 (2 banks, 1 private equity, 1 institutional investor)
Invests in both proven and unproven	EDP (EIB), Rabobank, Persistent	3 (1 early-stage public investor bank, 1 bank, 1 early-stage VC)

Appendix 4: Proposed Theoretical Framework (on next page)


National Energy Policy + EIB Involvement
Risk
Return
Type of Investor
Prior Investment
Knowledge spillovers + information asymmetry + technology-specific characteristics
Perceived Risk
Expected Return
Portfolio Aspects
Investment decision