The dynamics of renewable energy investment risk: A comparative assessment of solar PV and onshore wind investments in Germany, Italy, and the UK

Florian Egli[1]

Abstract: Building an energy system compatible with the Paris Agreement requires large-scale investment in renewable energy technologies (RET). Designing effective energy policies, therefore, requires an understanding of the dynamics of RET investment risk. This study draws on RET project data and 40 interviews with investors in Germany, Italy and the United Kingdom. We show that risk premiums and investment risk have declined for solar photovoltaics and onshore wind technologies in all three countries. Increasing technology reliability at a lower cost, data availability, better assessment tools and credible and stable policies were crucial elements of this declining investment risk. We identify the five most relevant risk types (curtailment, policy, price, resource and technology), show their relative importance over time and use network analysis of interview transcripts to identify the drivers behind the observed changes. While technology and policy risks have declined substantially over time, curtailment and price risks are becoming relatively more important. From these insights, we derive recommendations for policymakers aiming to accelerate the transition towards a Paris-compatible energy system.

---

[1] Energy Politics Group, ETH Zurich, Haldeneggsteig 4, 8092 Zürich, Switzerland.

1 Introduction

Redirecting investment flows to low-carbon assets and technologies is paramount to achieving the goals of the Paris Agreement (IPCC, 2014; Polzin, 2017). To achieve a Paris-compatible energy system, an estimated additional annual $536 billion, as well as a shift in investment patterns, is necessary to supplement the current policies from 2016 to 2050 (McCollum et al., 2018). The share of low-carbon investments in the total supply-side energy investment must grow from around 35% in 2015 to just below 80% by 2050. Among low-carbon energy generation technologies, solar photovoltaics (PVs) and wind are set to become the (combined) largest source of electricity in a Paris-compatible energy system by 2030 (OECD/IEA and IRENA, 2017).

To reach the levels of investment in renewable energy technologies (RET) required by the Paris Agreement, these technologies must become cost-competitive with fossil fuel–based technologies (FFT). Because RETs are more capital intensive than FFTs, reductions in the financing cost (the cost of capital) for RETs increase their cost competitiveness versus FFTs (Hirth and Steckel, 2016; Schmidt, 2014). Recent research shows that the cost of capital for RETs has decreased over time (Donovan and Li, 2018; Ecofys, 2016; Egli et al., 2018), which, in the case of solar PV and onshore wind in Germany, is partly due to lower risk premiums (measured via debt margins) (Egli et al., 2018). Economic theory predicts a positive link between risk and return (Merton, 1973), indicating that observed declines in RET risk premiums should coincide with a change in investment risk. Low investment risk, in turn, attracts private capital on a large scale, as many studies have found investment risk to be a main barrier to RET deployment (Agora Energiewende, 2018; Painuly, 2001; Steggals et al., 2017; Waissbein et al., 2013), specifically for large institutional investors (Kaminker and Stewart, 2012). While there is extensive literature on RET investment risk, there is little to no empirical data on the dynamics of RET investment risk over time and the drivers of that risk. This is surprising given that investment risk evolves over time as technologies develop (Kitzing et al., 2018) and the effectiveness of policies aiming to attract RET investments depends largely on their ability to reduce investment risk (Polzin et al., 2019).

The empirical literature on RET investment risk can be divided into two streams. The first aims to develop a better understanding of investor behaviour by shedding light on trade-offs, decision metrics (including risk) and biases. For example, these studies show that addressing investment risk tends to be more effective in inducing investment than increasing returns (Lüthi, 2010) and that, besides risk, investors are also driven by portfolio effects, a priori beliefs and path dependence (Masini and Menichetti, 2012; Wüstenhagen and Menichetti, 2012). The literature also shows that risk-return profiles are strongly affected by policy risk, but cross-country diversification can mitigate this risk (Gatzert and Vogl, 2016). Policy risk, in turn, is lower when policymakers have more autonomy from the political process (Holburn, 2012), and it differs according to the chosen policy instrument (Kitzing, 2014).

The second stream of research concerns empirical risk elicitation. These studies typically focus on a technology and/or a country and determine the most important investment risks through either choice experiments or surveys and interviews with investors. In general, they show that policy risk is important in solar PV (Karneyeva and Wüstenhagen, 2017) and onshore wind investment decisions (Steggals et al., 2017) in the European Union (Angelopoulos et al., 2016), as well as in less developed countries (Komendantova et al., 2012; Waissbein et al., 2013). Business-related risks such as financial risk (e.g., access to capital) and market risk (e.g., future power prices) are also important in mature markets like Western Europe, North America and Australia (Economist Intelligence Unit, 2011; Leisen et al., 2019).

In sum, there is evidence of the importance of risk in the investment decision. The literature also provides guidance to policymakers in specific countries regarding the relative importance of different types of risk for a given technology. However, there is no data on the evolution of investment risk over time. While Egli et al. (2018) established the dynamics of financing conditions over time, they did not evaluate this concept in markets other than Germany. Moreover, their study does not provide evidence as to whether the observed changes in risk margins were the result of changing investment risks or other factors such as better operational efficiency of banks or increased competition. This paper, therefore, proposes the following research question:

> Are there similar risk premium dynamics in markets other than Germany, and what are their drivers?

Understanding the dynamics of RET investment risk and its implications for financing conditions is important for at least two reasons. First, it brings more clarity to the drivers of changes in financing conditions, therefore potentially aiding policymakers to speed up the decrease in RET financing costs. Second, it demonstrates how RET investment risks may be affected by potential RET support policy phase-outs (Karneyeva and Wüstenhagen, 2017; Pahle and Schweizerhof, 2016) and may impact the cost competitiveness of RETs in consequence.

This paper follows three analytical steps: First, it identifies the most important components of RET investment risk (risk types) using the literature on investment risk and exploratory investor interviews. Second, it describes changes in risk premiums in Germany, Italy and the United Kingdom (UK) using project-level data and ranks the identified risk types over time based on investor interviews. Finally, this paper draws on the extensive experience of 40 RET investors to identify drivers of change and link those drivers to risk types using coded interview transcripts. The remainder of this paper is organised as follows: Section 2 introduces the research case and describes the methods used. Section 3 presents the results. Section 4 discusses research and policy implications.

2 Research Design

2.1 Case selection

In this study, the case selection was based on three dimensions: country, technology and project phase. To analyse changes in investment risk, we chose typical (or representative) cases, which allow us to study a phenomenon in detail (Seawright and Gerring, 2008). We focused on countries that were early adopters of RETs – namely Germany, Italy and the UK. From 2000 to 2005, these three countries accounted for over one-third of the cumulative global wind capacity, and from 2004 to 2014, the same was true for solar PV (IRENA, 2018). At the same time, the regulatory environments of these countries differed, meaning that each country had different risk exposure from an investor's perspective (Mitchell et al., 2006). While the focus of this paper is not on comparing policies, we have used this variation to identify the effects on policy risk. Germany serves as the base case, with a fixed-price RET support policy that was never changed retroactively. Italy used a fixed-price RET support policy, too, but it applied a retroactive policy change to large-scale solar PV in 2014 (Ramirez et al., 2017). The UK used a more market-based support policy by relying on quotas, tradable certificates and contracts for differences (Lipp, 2007; Mitchell and Connor, 2004).

The study focuses on solar PV and onshore wind technologies, the most deployed non-hydro RETs (IRENA, 2018). These technologies differ regarding their complexity of design and operation (Schmidt and Huenteler, 2016) and their resource volatility (i.e., irradiation versus wind speed), which may result in different investment risk profiles. Again, this study is not of a comparative nature, but it uses the technology differences to identify risk types that vary by technology.

Lastly, RET project phases typically include the planning and development phase, the construction phase and the operation phase (Breitschopf and Pudlik, 2013; Ecofys, 2016). Achieving the goals of the Paris Agreement will require tapping large pools of long-term capital. Large institutional investors typically seek low-risk and long-term projects (Nelson, 2015), and therefore, they tend to invest in commissioned and ready-to-operate (or operating) RET projects. In other words, they usually do not take planning and development or construction risks. For this reason, the present paper focuses only on the operation phase of RET projects.

2.2 Methods

The study draws on interviews with 40 investors – including 17 private-sector debt providers (13 commercial banks and 4 investment banks), 15 private-sector equity providers, 7 public-sector actors (4 public utilities and 3 public investment banks) and 1 consultant – as its main source of information (see Table A1 in the Annex for a full list of the interviewees). The interviews lasted approximately 60 minutes each and were conducted under Chatham House rule in person or over the phone between September 2017 and January 2018.[2] The interviewed investors had an average of 11 years of experience in the RET industry. As this paper investigates the dynamics of RET investment risk over time, it looks at investment risks in 2009, 2013 and 2017. Hence, this study spans a period of eight years, circumventing the 2007–08 financial crisis and covering a period of relatively stable interest rates (see Figure A1 in the Annex).

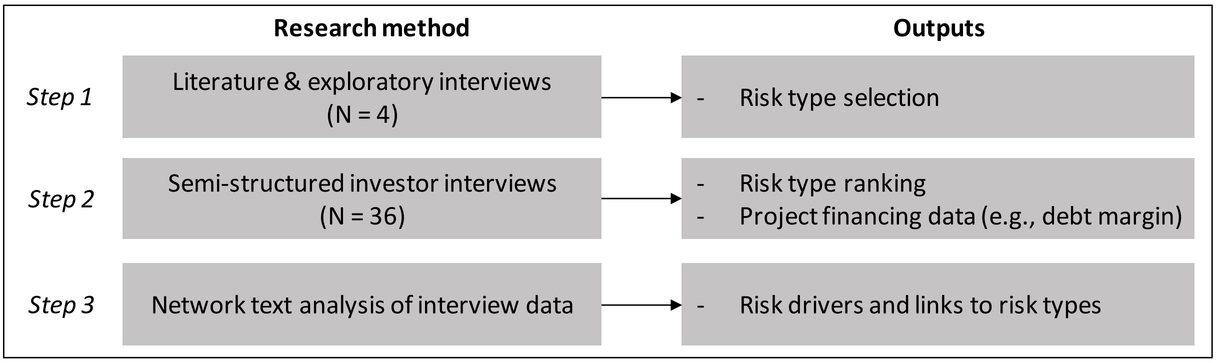

Figure 1. Methodological approach in three steps.

This study follows three methodological steps, illustrated in Figure 1. Two workshops with RET investors and academics in Utrecht (September 2017) and Berlin (April 2018) helped refine the selection of risk types in the first step and triangulate the findings of the second. In the first step, we identified the most important RET investment risk types, compiled a long list of RET investment risks from the literature (see Table A2 in the Annex) and used the exploratory interviews (N = 4) to identify the most relevant risk types given the country, technology and timeframe of the study. To determine the relevant literature, we conducted four Scopus searches of journal articles only,[3] scanned abstracts for relevance[4] and included further papers

---

[2] The Chatham House rule states that “participants are free to use the information received, but neither the identity nor the affiliation of the speaker(s) . . . may be revealed” (Chatham House, 2002).

[3] Search term 1: TITLE-ABS-KEY ("renewable energy" AND "investment risk" ANDNOT model) AND (LIMIT-TO (SRCTYPE , "j")) (N = 39);
search term 2: TITLE-ABS-KEY ((solar OR pv OR wind) AND ("investment risk" OR "RE risk") AND ("risk factor" OR "risk type")) AND (LIMIT-TO (SRCTYPE , "j")) (N = 5);
search term 3: TITLE-ABS-KEY (infrastructure AND "investment risk" AND ("risk factor" OR "risk type")) AND (LIMIT-TO (SRCTYPE , "j")) (N = 3);
search term 4: TITLE-ABS-KEY ((solar OR pv OR wind) AND ("investment risk" OR "RE risk") AND ("risk assessment" OR "risk management")) AND (LIMIT-TO (SRCTYPE , "j")) (N = 18).

[4] We excluded articles that consider only one investment risk, only one technology (except for solar PV and wind) or only non-investment grade countries.

and grey literature based on information obtained in the literature. To select the relevant risks from the long list, we tested several different categorisations and discussed whether they were mutually exclusive and collectively exhaustive in a team of three researchers (Morgan et al., 2000). Once we selected the risk types, we defined them together with the exploratory interviewees (see Table 1).

In the second step, we used the identified risk types and asked the investors we interviewed to rank them for 2009, 2013 and 2017 in order to identify their relative importance. Following the literature on retroactive sense-making biases, we evoked an anchoring event for 2009, 2013 and 2017 to make it easier for the interviewees to remember the point in time (Choi and Pak, 2005). We show the investors our definition for each risk type (as shown in Table 1). Depending on their investment experience, the investors were free to indicate whether their assessment was applicable to both technologies in all countries or differed according to technology or country. We aggregated the rankings by country and technology using the Borda count method (Emerson, 2013).[5] We also used the investor contacts established through our interviews to elicit project-level financing data for solar PV and onshore wind projects. This data was collected using the same method employed in Egli et al. (2018) – namely, investors named utility-scale projects corresponding to a reference project that they had realised or analysed in the past and provided project-specific financing data.

In the third and final step, we used a network analysis of the interview transcripts to identify the drivers of changes in investment risk. Interviewees were free to name and explain the main drivers that led to the changes in investment risk. Following Eisenhardt's (1989) approach, we continued holding interviews until no additional insights were provided. All interviews (N = 40) were transcribed verbatim. We used grounded theory to code the data and categorise the drivers. Glaser (1978) described coding as “a process that gets the analyst off the empirical level by fracturing the data, then conceptually grouping it into codes that then become the theory, which explain what is happening in the data” (cited in Walker and Myrick, 2006). Using the software MaxQDA, we coded all interview transcripts according to the risk involved, the country (if specified), the technology (if specified), the time (if specified), the direction of change (increasing, constant or decreasing) and the risk dimension (impact or probability). In total, we coded 869 segments (summarised in Figure 2).

---

[5] The Borda count method allocates points to an option based on the number of options ranked below it. Hence, if there was a choice between five risk types, the risk ranked first by an investor received five points.

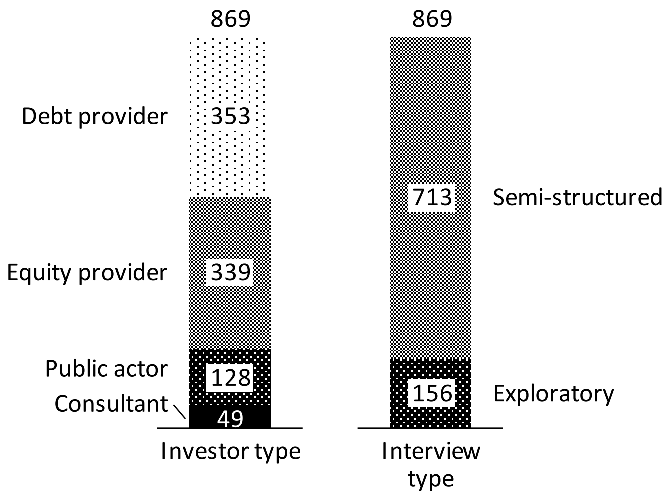

Figure 2. Number of coded segments according to investor type (left) and interview type (right).

For each statement, the coder then assigned a driver (if applicable). The coder developed these drivers iteratively to best fit the interview statements. In grounded theory, this procedure is termed “open coding” – the unconstrained comparison of incident (i.e., statement) to incident to generate categories (i.e., of drivers). This is an iterative process used to identify common patterns. We identified eight drivers with various sub-drivers (see Table A4 in the Annex). Once the drivers were categorised, we used MaxQDA to analyse the links between risk types and drivers. Specifically, we counted co-occurrences of different code types (e.g., risk type and risk driver) and developed a network that illustrates connections across all coded interviews. This enabled us to identify the most relevant drivers for each risk type by using the 869 coded segments.

3 Results and Discussion

In Section 3.1 of this paper, the evolution of risk premiums in Germany, Italy and the UK is discussed. Section 3.2 presents the most relevant risk types and shows the evolution of their importance over time. Section 3.3 identifies the drivers behind the changes and provides qualitative evidence to support the links between driver and risk type.

3.1 Changes in risk premiums

As shown in Egli et al. (2018), debt finance offers a clean way to operationalise project risk through debt margins. Debt providers typically charge a margin on top of a baseline rate for each credit they hand out. Because RET projects are usually financed in project finance structures in Germany, Italy and the UK, the risks associated with the credit are directly linked to the underlying project (Steffen, 2018). For riskier projects, investors typically demand higher debt margins as buffer. Figure 3 averages the data for Germany from Egli et al. (2018) over the anchoring year and the previous year and adds data for Italy and the UK (see Section 2.2).

It shows that project-specific debt margins decreased between 11% and 42% from 2008/09 to 2016/17, depending on the country and technology. In all three countries, the decline in debt margins was stronger for solar PV than for onshore wind. The debt margins of the two technologies were similar early on in Germany, while in Italy and the UK, the debt margins for onshore wind were lower than those for solar PV. In contrast to this overall decline, the debt margins in Italy remained roughly constant or increased from 2008/09 to 2012/13. This may be related to the looming concern about Italian policy credibility prior to the cut in large solar PV feed-in tariffs (FiT) in 2014 (*spalma incentivi*), which was ruled constitutional in 2017 (Steinhauer and Narducci, 2017).

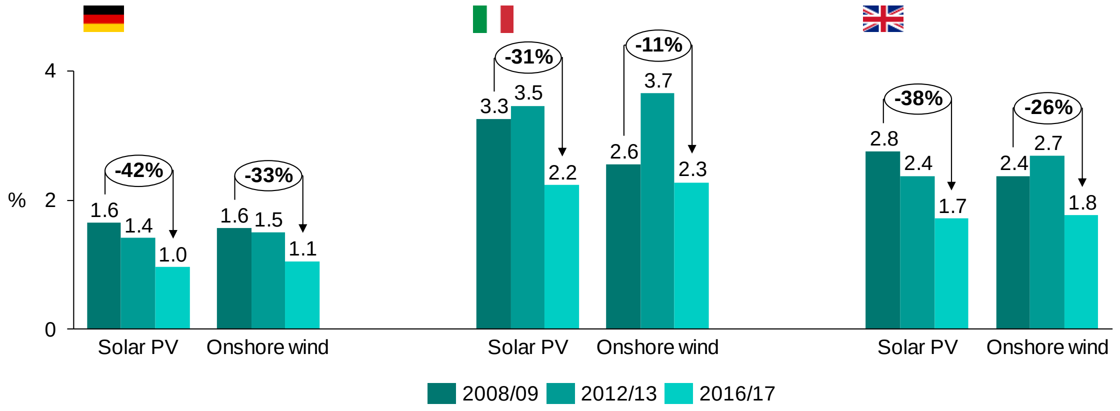

Figure 3. RET debt margins by country and technology (N = 79).

The evolution of other financial indicators that reflect investment risk (cf. Egli et al., 2018) – such as loan tenor, leverage ratio and debt service coverage ratio (DSCR) – is explained in Table A3 in the Annex. Longer loan tenors, increasing leverage ratios and decreasing DSCRs generally confirm the decrease in RET investment risk over time. To triangulate this finding, we asked investors about the general RET investment risk by letting them choose an asset class comparable to a RET investment in 2009, 2013 and 2017 (see Figure A2 in the Annex). While a comparable asset class in 2009 was a corporate bond of an established and listed company, today it is a low-risk infrastructure investment. The overall decline of risk premiums and the technology difference in that decline (stronger in solar PV than onshore wind) are consistent with other findings for Germany. As experience (the technology's track record) and corresponding data availability are key drivers in reducing risk, the fast deployment of solar PV in the period under study contributed to this faster risk reduction. In fact, as one investor put it, solar PV has become a commodity: "So, you see a deeper decrease in [the] perception of risk [for solar PV] because it is already considered a commodity". Onshore wind, in contrast, is a more complex technology to operate; as another investor explained: "With onshore wind, you have more moving parts and if there is a fault with the gear box, for example, it is possible that you have to demount the entire nacelle, leading to long out-of-service periods. . . . [With solar

PV, in contrast,] replacing one or two modules only leads to a row of modules not producing electricity".

In sum, risk premiums – measured with different indicators – and investment risk decreased substantially for solar PV and onshore wind in Germany, Italy and the UK between 2009 and 2017. This confirms and expands the findings of Egli et al. (2018) from Germany to Italy and the UK.

3.2 Risk types and dynamics over time

By screening the literature systematically to establish a long list of RET investment risks, we identified 22 relevant papers (see Table A2 in the Annex for a full list of papers and risks). Based on the scope of the study (investment grade countries and post-commissioning risks only; see Section 2.2) and using the exploratory investor interviews, we defined the five RET investment risk types most relevant for investment decisions. Table 1 provides definitions of these five risk types, which were elaborated in the exploratory interviews (see Section 2.2). The interview transcripts confirm that all five risks were mentioned frequently, with policy risks mentioned most frequently and curtailment risks least frequently (see Figure A3 in the Annex). Here curtailment risk refers to uncompensated and unexpected (i.e., not ex ante predictable at the time of the investment decision) curtailment.

Table 1. Definitions of risk types.

Risk type	**Definition**
Curtailment risk	The risk of lower revenues due to unexpected curtailment (e.g., grid bottlenecks).
Policy (reversal) risk	The risk of lower revenues due to a retroactive change in a cornerstone RET policy, taxation or other policy measures (e.g., retroactive FiT change).
Price risk	The risk of price volatility within a stable policy regime (e.g., merchant price exposure under a feed-in premium policy).
Resource risk	The risk of lower revenues due to inaccurate resource potential estimation (e.g., wind speed or solar irradiation).
Technology risk	The risk of lower revenues or higher maintenance costs due to the technology's novelty and unpredictability (e.g., faster degradation).

In this section, we report changes in the relative importance of these risk types. It is important to keep in mind that these are risk rankings and hence define the *relative* importance of one risk type versus another. Figure 4 shows changes in the relative importance of the five risk types between 2009 and 2017. Note that the figure includes risk assessments in which no technology was specified, as well as solar PV– and onshore wind–specific assessments. Overall, technology and policy risks declined the most, while price and curtailment risks increased the most and resource risk stayed approximately constant (all in relative terms). This pattern is confirmed when analysing the network data from the coded interviews. Figure A4 in the Annex shows that curtailment and price risks were typically mentioned when the interviewee talked about risks increasing in importance. Policy, resource, technology and general RET investment risks were usually mentioned in statements about decreasing risks.

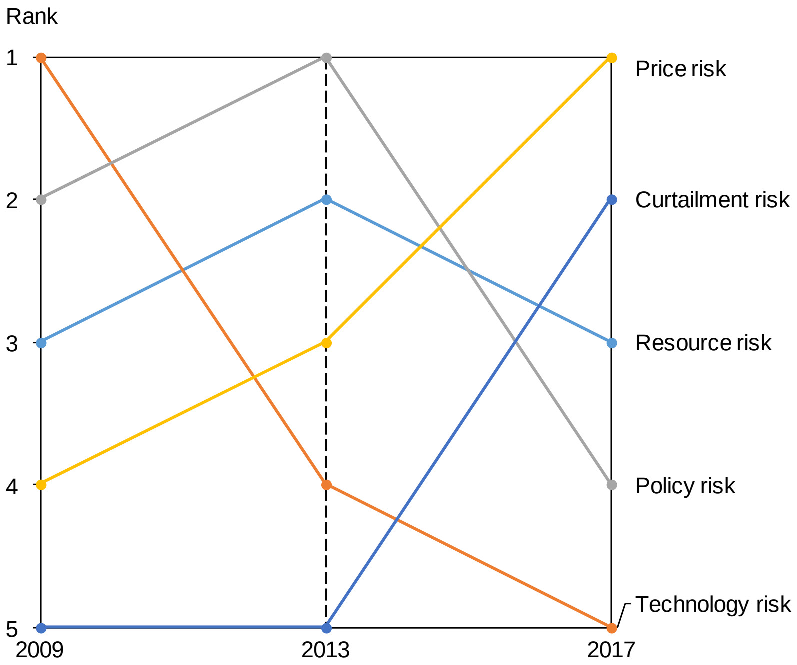

Figure 4. Relative importance of risk types (1 = most important; 5 = least important). Sample sizes are N = 32 for 2009, N = 37 for 2013 and N = 38 for 2017.

While Figure 4 shows aggregate changes, the interviews show that some risks vary by technology or country (policy context). To define which risk types vary based on which dimensions, we relied on the coded interviews. If interviewees mentioned a risk type together with a specific country (indicating a particularity of that risk type regarding the country), the evolution of the risk importance was charted by country (see Table 2). If interviewees mentioned a risk type together with a specific technology (indicating a particularity of that risk type regarding the technology), the evolution of the risk importance was charted by technology (see Table 3). Figure A5 in the Annex shows that, in the coded interview statements, resource and technology risks co-occur with technologies, while policy and price risks co-occur with countries. Curtailment risk does not appear in Figure A5, because it is still a relatively recent phenomenon. However, we infer qualitatively from the interview statements that curtailment risk depends on country (e.g., grid structure, RET share, remuneration policy) rather than technology. Tables 2 and 3 show the relative ranks of country- and technology-specific risk types for 2009, 2013 and 2017. The arrows indicate the direction of change over time.

Table 2. Risk ranks and changes in relative importance for country-specific risk types.

	Germany	**Italy**	**UK**
	2009 | 2013 | 2017	2009 | 2013 | 2017	2009 | 2013 | 2017
Curtailment risk	5th ↗ 4th ↗ 3rd	4th ↘ 5th ↗ 4th	5th → 5th → 5th
Policy risk	2nd → 2nd ↘ 5th	5th ↗ 1st ↘ 2nd	1st → 1st ↘ 2nd
Price risk	1st ↘ 3rd ↗ 2nd	3rd ↗ 2nd ↗ 1st	4th → 4th ↗ 1st

Table 3. Risk ranks and changes in relative importance for technology-specific risk types.

	Solar PV	**Onshore wind**
	2009 | 2013 | 2017	2009 | 2013 | 2017
Resource risk	4th ↗ 3rd ↘ 4th	1st → 1st ↘ 2nd
Technology risk	3rd ↘ 4th ↘ 5th	4th → 4th → 4th

Table 2 shows that investors ranked curtailment risk low in most years. However, this risk increased in importance over time in Germany, where RET shares of electricity generation are highest. The relative importance of policy risk differs substantially between countries. In Germany investors ranked this risk second in 2009 and 2013, but it had become the least important risk type by 2017. In Italy, in contrast, the relative importance of policy risk skyrocketed in 2013 and decreased only slightly from 2013 to 2017. In the UK, policy risk was ranked high throughout the entire time period. Meanwhile, investors identified an opposite trend in price risk, with increases across the board between 2013 and 2017 (no trend between 2009 and 2013).[6]

Technology-specific risk types are shown in Table 3. Investors ranked resource risk consistently high for onshore wind and low for solar PV – even as early as 2009. They ranked technology risk for solar PV lower over time, reflecting users' increasing experience with solar PV and the maturing of the technology. In 2017 technology risk was the least important risk type for solar PV, reflecting its modularity, which makes it less prone to technical failures on a system or plant level. In the case of onshore wind, investors ranked technology risk low from 2009 through 2017, indicating that the technology was already relatively mature and proven even in 2009. Due to its higher complexity than solar PV (see Section 3.1), there was, however, no decrease in the relative importance of technology risk for onshore wind over time.

3.3 Drivers of change

In the final step, we used evidence from the coded interviews to link drivers to the observed changes in importance of risk types (see Figure 4 and Table 2). This section discusses each risk type and its most important drivers, providing one or more representative quotes from the

---

[6] Note that the high ranking of price risk in Germany in 2009 was driven by one investor, who ranked price risk first for both onshore wind and solar PV. The investor's assessment was based on inflation risks in a nominal FiT and unrelated to the risk of exposure to merchant risk. "I looked at many inflation risks, because we thought that [the economic crisis] would lead to money being pumped into markets and the public sector, [which would lead] to inflation risks in the medium term [because] the FiT was fixed in nominal terms", said the investor.

interviews for each. Figure 5 shows the connection between risk types and driver categories based on code co-occurrences in the interviews.

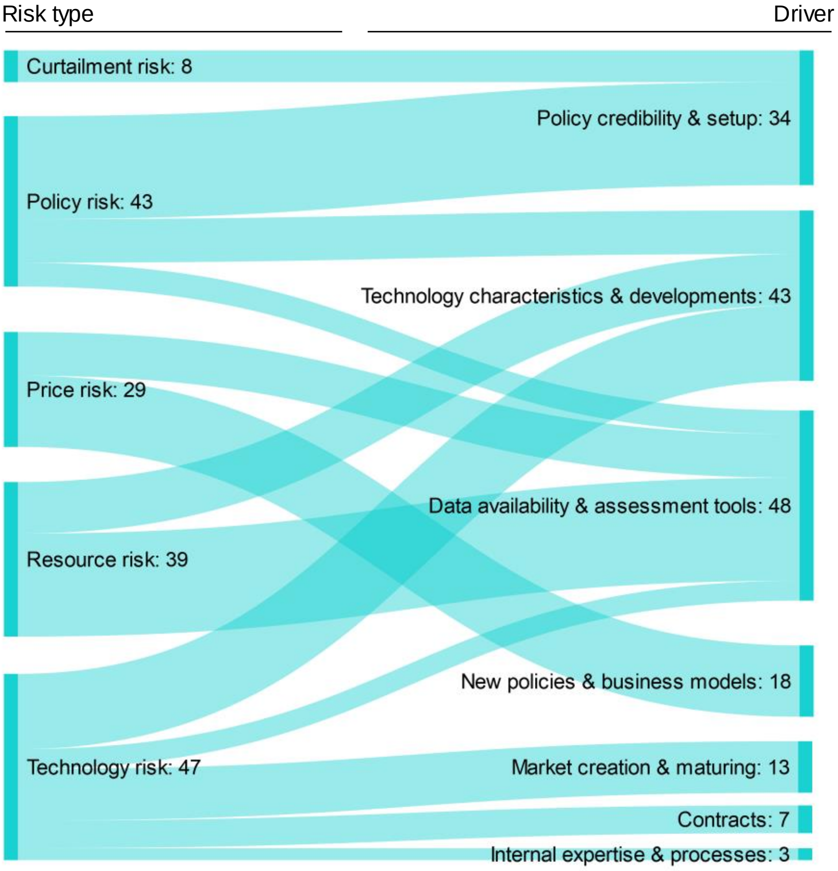

Figure 5. Risk types and corresponding drivers. Links with fewer than three co-occurrences are omitted. The width of the link is proportional to the frequency of co-occurrence.

Curtailment risk became relatively more important overall between 2009 and 2017 – a development mainly driven by Germany (see Table 2) – because the risk starts to materialise only at high levels of RET penetration. In Germany, for example, curtailment sharply increased with the expansion of RET generation (Schermeyer et al., 2018). As one investor explained, Germany experiences (at times) unexpected curtailment: “I have seen it with wind in Germany and really the trend there is as you have got more energy coming in at a given time, then you are finding that the grid operator is going to shut you down”. The main driver of curtailment risk is policy credibility and setup (see Figure 5), which determines, for example, whether RET generation can be fed into the grid with priority over other sources and whether curtailment (e.g., due to grid constraints) will be compensated by the policymaker. In Germany, since 2014, RET production must be sold at a zero subsidy if electricity prices are negative during six consecutive hours. In 2017 curtailment risk became a relevant factor to consider in investment proposals as a consequence (Linkenhell Perez and Küchle, 2017). In markets with less developed grids, curtailment becomes a factor at low but concentrated levels of RET penetration. However, for Germany, Italy and the UK, this is not an issue.

Policy risk was one of the most important risks in 2009 and 2013 and declined substantially in relative importance between 2013 and 2017 (see Figure 4). Developments in Germany, where policy risk declined rapidly relative to the other risks after 2013, largely drove this overall effect. In Italy, in contrast, policy risk became the most important risk in 2013 and remained relatively important in 2017. As mentioned previously, this is mainly due to the retroactive FiT changes implemented in Italy. Several investors brought up this point in the interviews. As one of them put it, “There were some legislative actions, that were perceived very critically by the market [participants]”. Another investor said, “With *spalma incentivi*, they enacted a reversal that was implemented more or less market compatible and with a sense of proportion by the lawmakers”. In the UK, policy risk was constantly ranked high, which may be a result of frequent policy changes and the inconsistency of the UK’s energy policy in a market-based and interventionist regime (cf. Keay, 2016). These changes in policy risk stem from three drivers: policy credibility and setup, technology characteristics and developments, and data availability and assessment tools (see Figure 5).

The credibility of policies and their future trajectory is a main reason that policy risk decreased in Germany relative to the other risks and increased in Italy. However, other factors also contributed. For example, investors understood policymakers better over time, so future policy adjustments became more predictable, thereby decreasing the policy risk. As one investor put it: “There is regulatory learning. You understand the regulator better, and you know what they are thinking”. This exchange of knowledge between investors and regulators may also have contributed to the design of the retroactive policy change in Italy that spared investors (mainly on the debt side) from large negative impacts. Some investors believe this change may also have occurred because the Italian banks were heavily invested in projects. Another factor contributing to the first driver is concern about policy costs being perceived as too high by the public. One investor explained: “The financial returns on the projects were absolutely crazy because the costs were falling so fast . . . and the policymakers just could not keep up. Actually, I do not even know if the policymakers realised how generous they were being”. This factor potentially increases the risk for retroactive policy change as policymakers are pressured by the public to lower policy costs.

To some extent, the second driver – technology characteristics and developments – has softened this concern. Rapidly decreasing technology costs have lowered the impact of potential policy changes as generation costs approach market prices. Many statements confirm this either directly or indirectly via power purchasing agreements (PPA) with the government gaining in credibility due to lower cost. One investor explained, “The risk decreased because of a lower delta between subsidies and market price". Another confirmed, "The risk is decreasing the closer we get to competitiveness and market prices". Both of these statements reflect a relative decrease in investment risk as the gap between subsidy price and market price narrows. In other words, investors are becoming less dependent on RET support policies as their outside options (such as selling electricity on the wholesale market) become more attractive. This is a direct effect of decreasing technology costs, to which subsidies respond. An additional indirect effect of decreasing technology costs is the increase in credibility of RET support policies as their cost decreases. As another investor described, "The closer we are to market prices, the higher the probability that the [PPA] contracts are fulfilled".

The third driver relates to difficulties in assessing wind resources, as more wind parks are being built and dedicated land area slowly fills up. In reaction, policymakers enact zoning changes, which extend the area where RET plants can be built. For onshore wind, an unexpected consequence is that wind turbines are often built in proximity to existing turbines, which causes wind turbulence and decreasing yield due to spatial interference. One investor explained the issue for Germany: "Nobody can guarantee you that the zoning does not change next door. . . . In 2016, our in-house lawyer spent most of his time suing wind parks that were built in proximity. . . . [Spatial interference from nearby wind parks] can lead to a 20–30% loss of production".

Price risk is the only risk that increased in relative importance from 2009 to 2013 and from 2013 to 2017 (see Figure 4). It was always relatively important in Germany due to potential inflation risks, and it has become more important in Italy and the UK over time (see Table 2). New policies and business models were the most important drivers of price risk and influenced another driver of price risk – data availability and assessment tools.

The move towards more market-based RET policies, including wholesale price exposure or premium auctions, is the main driver of price risk. For an investor, these policies introduce volatility in future cash flows and, therefore, increase risk margins (cf. Pahle and Schweizerhof, 2016). Since 2017 auctions have increasingly produced subsidy-free (i.e., zero premium) contracts in European countries for onshore wind and solar PV (Wronski, 2018). The introduction of price risk via auctions was noted as a risk driver by several investors. For example, one said: "Price risk is becoming more important. As we are in a bidding system, we have to take into account market prices more often". Another investor explained that securing financing potentially becomes more difficult in an auction system: "As you go into an auction as a developer, you need to present the sealed financing deal already. . . . For banks, this is a tricky game because of the many assumptions in the financing deal. For example, if the plant needs to be built within two years after winning the bid, [the bank] needs to estimate future technology and operating costs etc.". However, the risk initiated by auctions may also be temporary. In Germany an investor noted that the industry learns quickly and adapts to new policies: “For solar PV, we have seen auctions for a bit longer and hence everything is already a bit more settled and in order after the little storm that we saw”.

Due to increasing exposure to market prices, the profitability of RETs depends on future electricity prices. Assessment tools become less accurate due to this fundamental uncertainty, as one investor explained, “Because you calculate project [revenues] over a long time, while you fully look into a black box regarding the future price [of electricity]”. For example, the speed of electric vehicle deployment will have a major impact on future electricity prices. Another investor claimed that there is “just a lot of uncertainty on how these markets will develop in terms of electric vehicles coming on the grid . . . and whether storage will be there or not”. The shift to more market-based RET policies also creates an incentive to use private PPAs. This potentially increases risk because it exposes the investor to the business risk of the private counterparty and hence requires an additional examination of the counterparty’s creditworthiness. As one investor put it, “In a [private] PPA, I am actually in corporate finance again”.

Resource risk stayed approximately constant in relative importance between 2009 and 2017 (see Figure 4). It was of consistently high relative importance for onshore wind, and low relative importance for solar PV (see Table 2). The two main drivers of resource risk are technology characteristics (differences) and developments (new designs), and improved assessment tools due to increasing data availability.

Wind predictions are less precise than solar irradiation predictions, which makes resource risk more relevant for onshore wind. One investor explained: “Our solar PV portfolio is absolutely stable. . . . However, with wind resources, there is always an uncertainty that does not exist with solar irradiation, which is very stable, calculable and predictable”. The emergence of new wind turbine designs (higher masts) and complications in estimating wind speeds with other turbines close by (spatial interference) are also causing new problems for wind predictions. Installed onshore wind turbines have been growing consistently in capacity, rotor diameter and hub height (Fraunhofer IWES, 2019; Greentechmedia, 2018), which has also introduced new difficulties for resource estimation. As one investor noted, “I know a bit better how the wind blows 100 meters above ground, but this does not tell me the wind speed 160 meters above ground”.

However, at the same time, data on wind speeds (from existing turbines), including detailed spatial resolution, have become increasingly available. Subsequently, assessment tools and wind resource models have improved, leading to a drastic decline in resource risk. Typically, models are now able to estimate returns over a longer time and uncertainty has thus been narrowed (e.g., the difference between the often-used 90th percentile and the median has narrowed). One investor explained the decrease in risk: “[The] assessments became more accurate. . . . Hence, because the capital structure is mainly driven by resource uncertainty, there is clearly more debt available today compared to 2009”.

Technology risk experienced the most pronounced change in relative importance between 2009 and 2017 (see Figure 4). While it was the most important risk in 2009, it had become the least important by 2017, with most of the change occurring between 2009 and 2013. This change occurred mainly in solar PV (see Table 3), and it is linked to five drivers.

Technology characteristics and developments are the most important driver of technology risk. A successful technology track record (including data availability) is the main prerequisite for a lower technology risk. As one investor explained: “We just saw that the first parks going into operation in Germany around 2005 and 2006 ran consistently without problems for around eight years”. Such positive experiences lead to spillovers across the industry. An investor noted: “A lack of experience leads to a certain reservation. The broader the phenomenon of renewable energies, the more cases you have and the more exchange [of experiences] happens across all levels (e.g., board members, conferences)”.

However, for onshore wind, new turbine designs have also led to an increase in technology risk. Not only have resource estimations become more difficult as hub heights have increased, but unknown wind speeds and turbulences have also created technology risk (e.g., damages or interrupted generation). One investor explained: “We hesitate to finance new turbine types. At least, we require guarantees from the supplier that go beyond those we require for turbines with extensive operational experience”. Overall, the increase in technology risk from new technology designs remains marginal compared to the decrease in technology risk brought about by a technology’s successful track record.

The second-most important risk driver is market creation and maturing. A more mature market leads to service improvements, which lower technology risk (e.g., more efficient cleaning operations for solar PV, better operation and maintenance (O&M) contracts or cheaper O&M). For example, solar PV plants started using string inverters (decentral) instead of central inverters to reduce O&M risks. As one investor explained: “Besides the modules, the inverters are the second-most important topic. . . . To fix a central inverter, you need highly qualified staff. If you are in Sicily and need to wait for them to fly in from Germany, you may lose an entire day”. However, as the market matures, competition also increases in the supply chain, which can lead to quality issues. For example, wind turbine manufacturers were under strong pressure during a phase of rapid deployment in Germany, which led to manufacturing mistakes (such as using the wrong glues), lowering the quality of the turbines in French wind parks.

The third driver concerns the extension of contract scope and the standardisation of contracts. RET contracts have shifted from a performance guarantee (i.e., hours per year) to a production guarantee (i.e., megawatt hours per year), eliminating the risk of losses due to resource-poor times. One investor described this trend: “Meanwhile, producers moved to provide availability guarantees”. Similarly, contracts have started to include clauses to safeguard against uncompensated curtailment and are being drafted in a standardised way.

The fourth driver, more reliable assessment tools, also reduced technology risks, as more performance data was became available (see the section on resource risk for a description and quotations from investors). Finally, the fifth driver, internal capabilities, has resulted in lowered technology risk. As investors typically did not have experience with RET projects in the early years, they assembled skilled teams with the capability to assess the technological risks of onshore wind and solar PV. In turn, risk assessments became more precise and risk margins decreased. As one investor explained: “We hear from many investors that processes were streamlined, became faster, cheaper and more standardised”.

Further risk types, which are not specific to RETs but affect RET investment risk nonetheless, were also mentioned in the investor interviews. For example, the expansionary monetary policy in Europe has led to excess liquidity in the market, increasing competition for RET projects and hence lowering returns and risk margins. As one investor explained: “Changes in the markets due to the macroeconomic environment and the financial markets increased liquidity. Correspondingly, we see a strong yield compression, which leads to lower returns”. Additionally, the maturing investment ecosystem – together with more experienced investors – has created trusted relationships to facilitate RET investments. Investors like to do business with known partners. An investor explained, “That is our principle: whenever possible, we like ‘serial offenders’ [because] we can build on [an existing relationship]”. An investor noted that learning has happened on all levels to help bring technology costs down: “The developers learn a lot. The financial investors learn over time, and the regulators, too, learn over time. That total learning effect leads to decreasing levelised costs of electricity”.

4 Conclusions and Policy Implications

This paper makes four contributions to the field: First, we show that solar PV and onshore wind financing conditions improved in Germany, Italy and the UK between 2009 and 2017; this improvement was accompanied by lower risk assessments from investors. Second, we identify curtailment, policy (reversal), price, resource and technology risks as the five most important RET investment risk types. Third, we demonstrate that policy and technology risks became relatively less important over time, while curtailment and price risks became relatively more important (while resource risk stayed approximately constant). Resource and technology risks depended on the technology type, while curtailment, price and policy risks depended on the country (i.e., policy). Fourth, we identify the main drivers responsible for the changes in the importance of each risk type.

These findings allow us to put forth a stylised revenue model for RET investment risk. Technology-specific risk types impact the generation output (*Q*), whereas country-specific risk types impact the obtained price (*P*) or the ability to feed the produced electricity into the grid and therefore sell the production (γ). Equation (1) shows the three components of revenue (*R*); equation (2) gives the expected project revenues (*E(R)*); equation (3) indicates the bounds for two of the variables.

$$R_{(€)} = Q_{(MWh)} \times P_{(€/MWh)} \times \gamma \tag{1}$$

$$E(R) = \left[\overline{Q} \times \alpha \times \beta\right] \times \left[\delta \times E(P) + (1-\delta) \times \overline{P}\right] \times \gamma \tag{2}$$

$$\gamma, \delta = [0,1] \tag{3}$$

Equation (2) shows that the realised electricity output depends on the electricity generation capacity ($\overline{Q}$) and two parameters: the first (α) describes the deviation from the generation capacity due to technical failure; the second (β) describes the deviation from expected resource potential due to actual resource availability. Taken together, the first part of equation (2) describes expected electricity generation.

The second part of equation (2) depicts the expected price per megawatt hour for a simplified case in which a RET plant either operates in a FiT regime or sells electricity in a merchant market. The expected price depends on a fixed remuneration level ($\overline{P}$; e.g., FiT), the probability (δ) that this remuneration level is changed retroactively and the expected wholesale electricity price (*E(P)*) that the generation would be remunerated for in this case. In practice, a retroactive policy change may also be an increase in the tax rate or other RET-specific regulation that increases the cost of generation, as happened in Spain in 2015 for solar PV (Daley, 2014; Tsagas, 2015). The level of remuneration after a policy change may still be higher than *E(P).* Lastly, the curtailment factor (γ) represents the expected share of the generation that can be fed into the grid.

Both researchers and policymakers can use equation (2) as an analytical lens through which to look at RET investments. Researchers can then try to integrate risk metrics into models that use endogenous investment into RETs. For example, some of the presented risk metrics – such as debt margins or DSCRs – can serve as proxies for certain risk types. Integrating such dynamics into RET deployment models may serve to make them more realistic and to make trade-offs in policy designs visible. More research is needed to develop the mechanism through which the importance of different risk types changes and determine the precise impact that policy designs have on the risk types. Our research points to an important time lag between technical readiness and access to low-cost financing for a technology. As one investor put it, “The flip between emerging and mature [technologies] is not down to technology readiness level; it is down to commercial readiness level”. How technologies transition from technical to commercial readiness, and how this transition may be accelerated using smart policies to increase knowledge spillovers between investors and create a resilient RET investment ecosystem, is an interesting avenue for future research.

For policymakers, this research offers insights into the potential for accelerating RET deployment by reducing investment risk and thus RET financing costs. First, our results indicate that retroactive policy changes are costlier in early technology phases when the generation costs differ significantly from market prices. This has implications for policy credibility and stability, which is more important in the early phases of technology development. For latecomers this may mean that frequent policy changes in the past do not necessarily deter future investment. Second, our results point to the importance of sharing data and expertise in order to develop credible, powerful financial and technical models. RET lighthouse projects (large projects using new technology in cooperation with strategic partners) may, therefore, be crucial in establishing confidence in RET markets to bring down financing costs. However, the usefulness of such projects depends on their openness to sharing all data (financial and technical). Third, exposing RET projects to market risks may threaten RET investment, although RETs have reached cost competitiveness with FFTs. Importantly, risk should be phased in gradually, the success of which depends on the existence of a mature investment ecosystem. Only if such an ecosystem is present can the actors develop the products and structures to distribute and manage risk effectively with the technical knowledge required to assess the affected RETs.

5 References

Agora Energiewende, 2018. Reducing the cost of financing renewables in Europe. Berlin, Germany.

Angelopoulos, D., Brückmann, R., Jirous, F., Konstantinaviciute, I., Noothout, P., Psarras, J., Tesniere, L., Breitschopf, B., 2016. Risks and cost of capital for onshore wind energy investments in EU countries. Energy Environ. 27, 82–104.

Angelopoulos, D., Doukas, H., Psarras, J., Stamtsis, G., 2017. Risk-based analysis and policy implications for renewable energy investments in Greece. Energy Policy 105, 512–523.

Betz, S., Caneva, S., Weiss, I., Rowley, P., 2016. Photovoltaic energy competitiveness and risk assessment for the South African residential sector. Prog. Photovoltaics Res. Appl. 24, 1577–1591.

Bouhal, T., Fertahi, S. ed-D., Agrouaz, Y., El Rhafiki, T., Kousksou, T., Zeraouli, Y., Jamil, A., 2018. Technical assessment, economic viability and investment risk analysis of solar heating/cooling systems in residential buildings in Morocco. Sol. Energy 170, 1043–1062.

Breitschopf, B., Pudlik, M., 2013. Basel III and Solvency II: Are the Risk Margins for Investments in Pv and Wind Adequate? Energy Environ. 24, 171–194.

Chatham House, 2002. Chatham House Rule.

Choi, B.C.K., Pak, A.W.P., 2005. A catalog of biases in questionnaires. Prev. Chronic Dis. 2, A13.

Daley, S., 2014. Spain’s Solar Pullback Threatens Pocketbooks. New York Times.

Dinica, V., 2006. Support systems for the diffusion of renewable energy technologies - An investor perspective. Energy Policy 34, 461–480.

Donovan, C.W., Li, J., 2018. Do Listed Clean Energy Infrastructure Shares Make Financial Sense for Investors ? SSRN Electron. J. 1–44.

Ecofys, 2016. The impact of risks in renewable energy investments and the role of smart policies, EU DiaCore Final Report.

Economist Intelligence Unit, 2011. Managing the risk in renewable energy.

Egli, F., Steffen, B., Schmidt, T.S., 2018. A dynamic analysis of financing conditions for renewable energy technologies. Nat. Energy 3, 1084–1092.

Eisenhardt, K.M., 1989. Building Theories from Case Study Research. Acad. Manag. Rev. 14, 532–550.

Emerson, P., 2013. The original Borda count and partial voting. Soc. Choice Welfare 40, 353–358.

Enzensberger, N., Fichtner, W., Rentz, O., 2003. Financing renewable energy projects via closed-end funds—a German case study. Renew. Energy 28, 2023–2036.

Fraunhofer IWES, 2019. Turbine size.

Frisari, G., Hervé-mignucci, M., Micale, V., Mazza, F., 2013. Risk gaps: a map of risk mitigation instruments for clean investments, Climate Policy Initiative Brief.

Gatzert, N., Kosub, T., 2016. Risks and risk management of renewable energy projects: The case of onshore and offshore wind parks. Renew. Sustain. Energy Rev. 60, 982–998.

Gatzert, N., Vogl, N., 2016. Evaluating investments in renewable energy under policy risks. Energy Policy 95, 238–252.

Greentechmedia, 2018. Wind Turbines to See “Unprecedented” Growth in Size and Capacity.

Gross, R., Blyth, W., Heptonstall, P., 2010. Risks, revenues and investment in electricity generation: Why policy needs to look beyond costs. Energy Econ. 32, 796–804.

Hirth, L., Steckel, J.C., 2016. The role of capital costs in decarbonizing the electricity sector. Environ. Res. Lett. 11, 114010.

Holburn, G.L.F., 2012. Assessing and managing regulatory risk in renewable energy: Contrasts between Canada and the United States. Energy Policy 45, 654–665.

IPCC, 2014. Summary for Policymakers, Climate Change 2014: Mitigation of Climate Change. Contribution of Work- ing Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IRENA, 2018. Renewable capacity statistics 2017.

Justice, S., 2009. Private Financing of Renewable Energy: A Guide for Policymakers.

Kaminker, C., Stewart, F., 2012. The Role of Institutional Investors in Financing Clean Energy (No. 23), OECD Working Papers on Finance, Insurance and Private Pensions.

Karneyeva, Y., Wüstenhagen, R., 2017. Solar feed-in tariffs in a post-grid parity world: The role of risk, investor diversity and business models. Energy Policy 106, 445–456.

Kayser, D., 2016. Solar photovoltaic projects in China: High investment risks and the need for institutional response. Appl. Energy 174, 144–152.

Keay, M., 2016. UK energy policy – Stuck in ideological limbo? Energy Policy 94, 247–252.

Kitzing, L., 2014. Risk implications of renewable support instruments: Comparative analysis of feed-in tariffs and premiums using a mean–variance approach. Energy 64, 495–505.

Kitzing, L., Fitch-Roy, O., Islam, M., Mitchell, C., 2018. An evolving risk perspective for policy instrument choice in sustainability transitions. Environ. Innov. Soc. Transitions.

Komendantova, N., Patt, A., Barras, L., Battaglini, A., 2012. Perception of risks in renewable energy projects: The case of concentrated solar power in North Africa. Energy Policy 40, 103–109.

Komendantova, N., Patt, A., Williges, K., 2011. Solar power investment in North Africa: Reducing perceived risks. Renew. Sustain. Energy Rev. 15, 4829–4835.

Lei, X., Shiyun, T., Yanfei, D., Yuan, Y., 2018. Sustainable operation-oriented investment risk evaluation and optimization for renewable energy project: a case study of wind power in China. Ann. Oper. Res. 1–19.

Leisen, R., Steffen, B., Weber, C., 2019. Regulatory risk and the resilience of new sustainable business models in the energy sector. J. Clean. Prod. 219, 865–878.

Linkenhell Perez, C., Küchle, I., 2017. Einfluss der Sechs-Stunden-Regel auf die Erlöse einer Wind- und PV-Anlage.

Lipp, J., 2007. Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom. Energy Policy 35, 5481–5495.

Lüthi, S., 2010. Effective deployment of photovoltaics in the Mediterranean countries: Balancing policy risk and return. Sol. Energy 84, 1059–1071.

Masini, A., Menichetti, E., 2012. The impact of behavioural factors in the renewable energy investment decision making process: Conceptual framework and empirical findings. Energy Policy 40, 28–38.

McCollum, D.L., Zhou, W., Bertram, C., de Boer, H.-S., Bosetti, V., Busch, S., Després, J., Drouet, L., Emmerling, J., Fay, M., Fricko, O., Fujimori, S., Gidden, M., Harmsen, M., Huppmann, D., Iyer, G., Krey, V., Kriegler, E., Nicolas, C., Pachauri, S., Parkinson, S., Poblete-Cazenave, M., Rafaj, P., Rao, N., Rozenberg, J., Schmitz, A., Schoepp, W., van Vuuren, D., Riahi, K., 2018. Energy investment needs for fulfilling the Paris Agreement and achieving the Sustainable Development Goals. Nat. Energy 3, 589–599.

Merton, R.C., 1973. An Intertemporal Capital Asset Pricing Model. Econometrica 41, 867–887.

Mitchell, C., Bauknecht, D., Connor, P.M., 2006. Effectiveness through risk reduction: A comparison of the renewable obligation in England and Wales and the feed-in system in

Germany. Energy Policy 34, 297–305.

Mitchell, C., Connor, P., 2004. Renewable energy policy in the UK 1990-2003. Energy Policy 32, 1935–1947.

Morgan, M.G., Florig, H.K., DeKay, M.L., Fischbeck, P., 2000. Categorizing Risks for Risk Ranking. Risk Anal. 20, 49–58.

Nelson, D., 2015. The Untapped Potential of Institutional Investors, in: Donovan, C.W. (Ed.), Renewable Energy Finance: Powering the Future. Imperial College Press, London, pp. 273–305.

Neto, D.P., Domingues, E.G., Calixto, W.P., Alves, A.J., 2018. Methodology of Investment Risk Analysis for Wind Power Plants in the Free Contracting Environment in Brazil. Electr. Power Components Syst. 46, 316–330.

OECD/IEA, IRENA, 2017. Perspectives for the energy transition – investment needs for a low-carbon energy system.

Pahle, M., Schweizerhof, H., 2016. Time for Tough Love: Towards Gradual Risk Transfer to Renewables in Germany. Econ. Energy Environ. Policy 5, 117–134.

Painuly, J.P., 2001. Barriers to renewable energy penetration: A framework for analysis. Renew. Energy 24, 73–89.

Polzin, F., 2017. Mobilizing private finance for low-carbon innovation – A systematic review of barriers and solutions. Renew. Sustain. Energy Rev. 77, 525–535.

Polzin, F., Egli, F., Steffen, B., Schmidt, T.S., 2019. How do policies mobilize private finance for renewable energy?—A systematic review with an investor perspective. Appl. Energy 236, 1249–1268.

Ramirez, F.J., Honrubia-Escribano, A., Gomez-L??zaro, E., Pham, D.T., 2017. Combining feed-in tariffs and net-metering schemes to balance development in adoption of photovoltaic energy: Comparative economic assessment and policy implications for European countries. Energy Policy 102, 440–452.

Salvo, F., Ciuna, M., De Ruggiero, M., Marchianò, S., 2017. Economic Valuation of Ground Mounted Photovoltaic Systems. Buildings 7.

Schermeyer, H., Vergara, C., Fichtner, W., 2018. Renewable energy curtailment: A case study on today's and tomorrow's congestion management. Energy Policy 112, 427–436.

Schmidt, T.S., 2014. Low-carbon investment risks and de-risking. Nat. Clim. Chang. 4, 237–239.

Schmidt, T.S., Huenteler, J., 2016. Anticipating industry localization effects of clean technology deployment policies in developing countries. Glob. Environ. Chang. 38, 8–20.

Seawright, J., Gerring, J., 2008. Case Selection Techniques in Case Study Research A Menu of Qualitative and Quantitative Options. Polit. Res. Q. 61, 294–308.

Steffen, B., 2018. The importance of project finance for renewable energy projects. Energy Econ. 69, 280–294.

Steggals, W., Nelson, D., Stigliani, G., 2017. Financing clean power: a risk-based approach to choosing ownership models and policy/finance instruments.

Steinhauer, C., Narducci, R., 2017. Italian Constitutional Court Backs Feed-in Tariff Cuts – What's Next ? Chicago, Illinois, US.

Surana, K., Anadon, L.D., 2015. Public policy and financial resource mobilization for wind energy in developing countries: A comparison of approaches and outcomes in China and India. Glob. Environ. Chang. 35, 340–359.

Szabó, S., Jäger-Waldau, A., Szabó, L., 2010. Risk adjusted financial costs of photovoltaics. Energy Policy 38, 3807–3819.

Tsagas, I., 2015. Spain Approves "Sun Tax," Discriminates Against Solar PV, Renewable Energy World.

Waissbein, O., Glemarec, Y., Bayraktar, H., Schmidt, T.S., 2013. Derisking Renewable Energy Investment. A Framework to Support Policymakers in Selecting Public Instruments to Promote Renewable Energy Investment in Developing Countries. New York, NY.

Walker, D., Myrick, F., 2006. Grounded theory: An exploration of process and procedure. Qual. Health Res. 16, 547–559.

Wronski, M., 2018. Renewables 2.0: The Subsidy-Free Revolution.

Wüstenhagen, R., Menichetti, E., 2012. Strategic choices for renewable energy investment: Conceptual framework and opportunities for further research. Energy Policy 40, 1–10.

Xingang, Z., Jieyu, W., Xiaomeng, L., Pingkuo, L., 2012. China's wind, biomass and solar power generation: What the situation tells us? Renew. Sustain. Energy Rev. 16, 6173–6182.

6 Annex

6.1 Figures

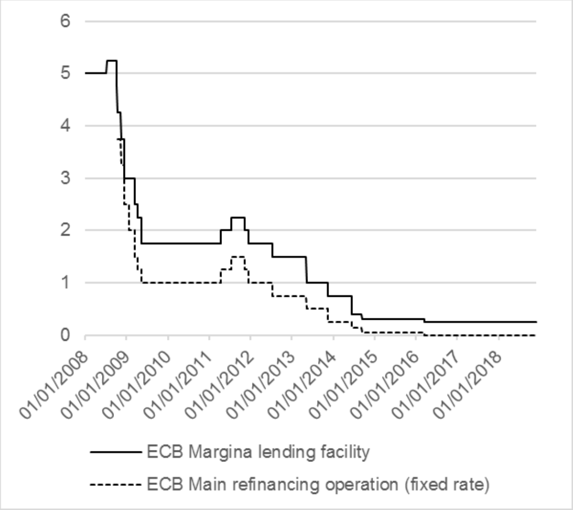

Figure A1: ECB interest rates

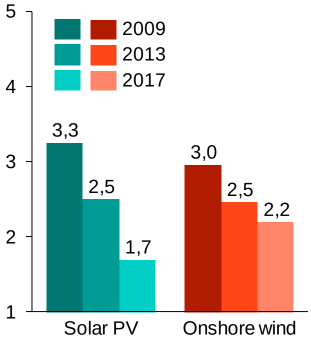

Figure A2: Overall RET investment risk by technology by selecting a comparable asset class for 2009 (N = 7), 2013 (N = 9) and 2017 (N = 10). 1 = 10-year government bond, 2 = low-risk infrastructure investment, 3 = corporate bond of an established and listed company, 4 = stock of a listed company, 5 = early stage venture capital investment.

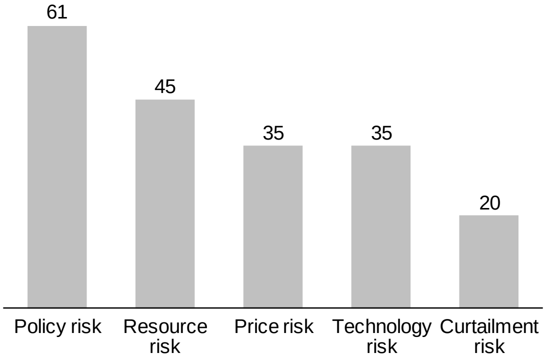

Figure A3: Risk type code frequency.

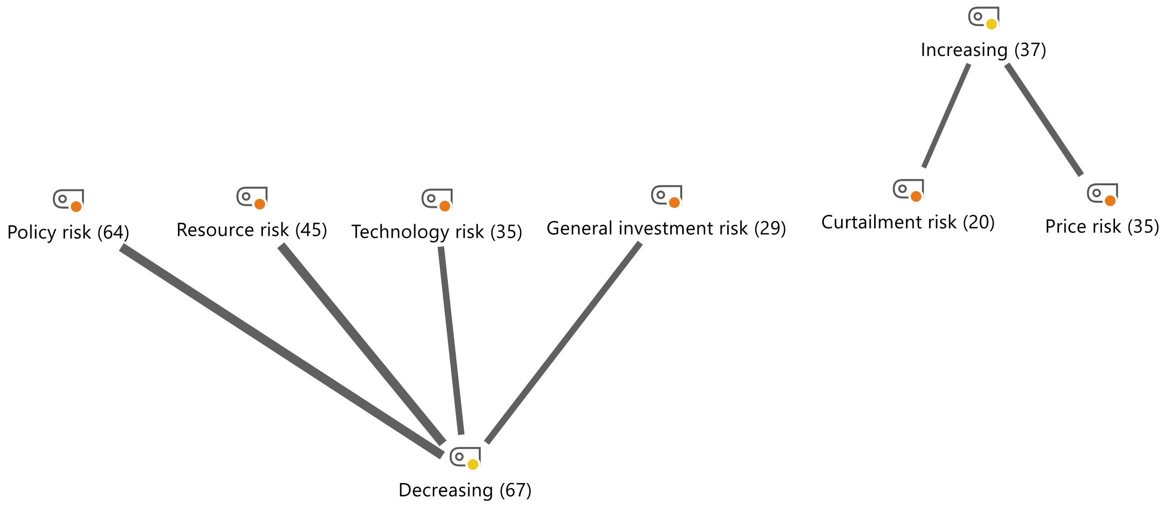

Figure A4: Risk types and direction of change. Co-occurrence of codes in coded segments across all investor interviews. Width of connection indicates frequency, total number of assigned codes in brackets. Figure shows only codes with at least five co-occurrences.

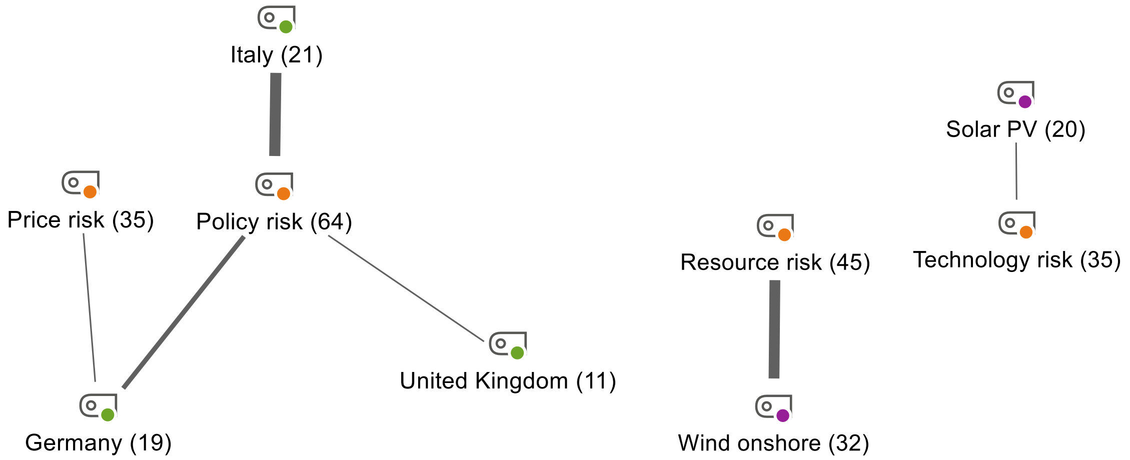

Figure A5: Country- (left) and technology-specific (right) risk types. Co-occurrence of codes in coded segments across all investor interviews. Width of connection indicates frequency, total number of assigned codes in brackets. Figure shows only codes with at least five co-occurrences.

6.2 Tables

Table A1: List of interviewees

ID	Interview type	Current organisation	Current position	Based in	RET investment experience (years)
1	Structured	Debt provider	Head of Division Energy & Utilities	Germany	12
2	Structured	Debt provider	Vice President	Germany	28
3	Structured	Debt provider	Associate Director Project Finance & Capital Advisory	Germany	7
4	Structured	Debt provider	Associate Director Infrastructure & Power Project Finance	Germany	9
5	Structured	Debt provider	Executive Director Project Finance Renewable Energies	Germany	21
6	Structured	Debt provider	Associate Director Global Infrastructure Debt	United Kingdom	5
7	Structured	Debt provider	Head Renewable Energies	Germany	27
8	Structured	Debt provider	Project Finance Analyst	Germany	11
9	Structured	Debt provider	Vice President Corporates & Small Business Project Finance	Germany	11
10	Structured	Debt provider	Director Structured Finance Power & Renewables	The Netherlands	11
11	Structured	Debt provider	Director Structured Finance Utilities, Power & Renewables	The Netherlands	11
12	Structured	Debt provider	Senior Manager Structured Finance Renewable Energy	Germany	19
13	Structured	Debt provider	Director Project & Structured Finance Utilities, Power and Renewables	Italy	11
14	Structured	Debt provider	Director Corporate Strategy	The Netherlands	19
15	Structured	Debt provider	Head of Renewable Energies	Germany	23
16	Structured	Debt provider	Head of Project Finance Origination Renewable Energies	Germany	8
17	Structured	Debt provider	Managing Director Project & Acquisition Finance	United Kingdom	12
18	Structured	Equity provider*	Head Risk Advisory	Germany	13
19	Structured	Equity provider*	CEO	Germany	10
20	Structured	Equity provider*	Founder and CEO	Germany	5
21	Structured	Equity provider	Principal	Switzerland	5
22	Structured	Equity provider	Partner	Switzerland	9
23	Structured	Equity provider	Director Infrastructure Equity Investment Team	Germany	12
24	Structured	Equity provider	Vice President Renewables	Switzerland	3
25	Structured	Equity provider	CIO	Germany	2
26	Structured	Equity provider	CEO	Germany	2
27	Structured	Equity provider	Associate Director Energy & Cleantech	France	12
28	Structured	Equity provider	Associate	United Kingdom	18
29	Structured	Public actor	Head Energy Services	Switzerland	12
30	Structured	Public actor	Deputy Head Energy Management	Switzerland	3
31	Structured	Public actor	CEO	Switzerland	7
32	Structured	Public actor	Head Portfolio and Asset Management Renewable Energies	Switzerland	8
33	Structured	Public actor	Vice President Origination and Structuring	Germany	6
34	Structured	Equity provider	Investments Director	United Kingdom	12
35	Structured	Public actor	Senior Investment Manager	Norway	11
46	Structured	Public actor	Economist	Luxemburg	15
37	Exploratory	Equity provider*	Head Risk Advisory	Germany	13
38	Exploratory	Equity provider	Partner	Switzerland	9
39	Exploratory	Equity provider	Principal	Switzerland	5
40	Exploratory	Other (consultant)	Head Hybrid Power Solutions	Germany	12

Table A2: RET risk types from the literature

Source	Risk types
(Breitschopf and Pudlik, 2013)	• Technology risks • Performance risks • Policy risks • Market risks • Resource risks
(Gatzert and Kosub, 2016)	• Strategic/business risks • Transport/construction/completion risks • Operation/maintenance risks • Liability/legal risks • Market/sales risks • Counterparty risks • Political, policy, regulatory risks
(Frisari et al., 2013)	• Political, policy, social risks • Technical, physical risks • Market, commercial risks • Outcome risks
(Steggals et al., 2017)	• Development risks • Construction risks • Operating risks • Resource risks • Curtailment risks • Price & offtake risks • Policy risks • Political risks • Currency risks
(Angelopoulos et al., 2017, 2016; Ecofys, 2016)	• Country risk • Social acceptance risk • Administrative risk • Financing risk • Technical & management risk • Grid access risk • Sudden policy change risk
(Waissbein et al., 2013)	• Power market risk • Permits risk • Social acceptance risk • Resource & technology risk • Grid/transmission risk • Counterparty risk • Financial sector risk • Political risk • Currency/macro-economic risk
(Dinica, 2006)	• Contract risks (i.e. demand risks in general) • Price risks
(Enzensberger et al., 2003)	• Technical risks (construction, technology) • Commercial risks (operation, market, financial) • Other risks (country, regulatory, social acceptance, force majeure)
(Szabó et al., 2010)	• Technology risk • Market risk • Regulatoy policy risk • Geopolitical risk • Stakeholder acceptance risk
(Economist Intelligence Unit, 2011)	• Financial risk (access to capital) • Business/strategic risk • Building and testing risk • Operational risk • Environmental risk • Political/regulatory risk • Market risk • Weather-related volume risk (i.e. resource risk) • Other risk

(Mitchell et al., 2006)	• Price risk • Volume risk • Balancing risk
(Bouhal et al., 2018)	• Investment risk • Resource risk • O&M risk • Inflation risk
(Neto et al., 2018)	• Resource risk • Price risk
(Betz et al., 2016)	• Resource risk • Technology performance risk (incl. degradation) • Price risk
(Kayser, 2016)	• Technology risk • Market and financial risk • Policy risk
(Lei et al., 2018)	• Construction risk • O&M risk • Policy risk • Technology risk
(Salvo et al., 2017)	• Resource risk • Technology risk • Financial risk • Policy risk • Theft and natural disaster risk • O&M risk
(Surana and Anadon, 2015)	• Resource risk • Technology risk • Financing availability risk • Project implementation (incl. planning, construction, O&M) risk • Grid & transmission risk • Counterparty risk • Power market (incl. price and policy) risk
(Justice, 2009)	• Country and financial risks • Policy and regulatory risks • Technical and project-specific risks (incl. construction, performance, environmental, O&M) • Market risk (i.e., price risk)
(Xingang et al., 2012)	• Competitive risk (e.g., market entry barriers) • Policy risk • Technology risk
(Komendantova et al., 2011)	• Regulatory risk • Political risk • Revenue risk • Technical risk • Force majeure • Financial risk • Construction risk • Operating risk • Environmental risk
(Gross et al., 2010)	• Price risks • Technical risks (incl. O&M) • Financial risks

Table A3: Other financial indicators.

Country	Technology	Period	CoC (%)	Debt margin (%)	Leverage (%)	Loan tenor (years)	DSCR	Bond yield (%)
DE	Solar PV	2008/09	4.7	1.6	80.0	15.8	1.18	3.6
DE	Solar PV	2012/13	3.2	1.4	81.7	17.2	1.18	1.5
DE	Solar PV	2016/17	1.4	1.0	87.5	18.6	1.13	0.2
DE	Onshore wind	2008/09	6.1	1.6	76.9	15.8	1.20	3.6
DE	Onshore wind	2012/13	3.2	1.5	75.1	17.0	1.17	1.5
DE	Onshore wind	2016/17	2.3	1.0	80.0	16.9	1.15	0.2
IT	Solar PV	2008/09	8.1	3.3	75.0	13.5	N/A	4.5
IT	Solar PV	2012/13	7.1	3.5	75.0	15.7	1.35	4.9
IT	Solar PV	2016/17	4.6	2.2	79.4	15.5	1.19	1.8
IT	Onshore wind	2008/09	8.9	2.5	75.5	13.5	1.40	4.5
IT	Onshore wind	2012/13	7.8	3.7	77.5	14.5	1.28	4.9
IT	Onshore wind	2016/17	4.3	2.3	82.0	18.0	1.21	1.8
UK	Solar PV	2008/09	6.5	2.8	75.0	15.5	1.40	3.9
UK	Solar PV	2012/13	5.0	2.4	72.2	13.5	1.49	1.9
UK	Solar PV	2016/17	3.0	1.7	77.5	17.5	1.33	1.2
UK	Onshore wind	2008/09	N/A	2.4	77.5	15.5	1.45	3.9
UK	Onshore wind	2012/13	4.8	2.7	75.0	13.6	1.54	1.9
UK	Onshore wind	2016/17	3.5	1.8	72.5	17.5	1.35	1.2

Note: For riskier projects, investors would typically decrease leverage (i.e. the amount of debt in a project) in order to safeguard against potential project losses that are borne by equity first and decrease loan tenors in order to reduce the risk exposure to a shorter period. The debt service coverage ratio (DSCR) is a measure of project cash flows available to pay debt obligations, namely the principal repayment and interest rate payments. Lower DSCRs can thus be interpreted as an indication for lower project risk.