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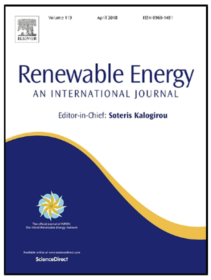

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Barriers to Investment in Utility-scale Variable Renewable Electricity (VRE) Generation Projects

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Abstract

To effectively mitigate climate change, variable renewable electricity (VRE) is expected to substitute a great share of current fossil-fired electricity generation. However, VRE investments can be obstructed by many barriers, endangering the amount of investments needed in order to be consistent with the Paris 2°C target. To help policy-makers better understand and assess these barriers, an integrated framework was developed. It establishes a clear connection between barriers identified in literature and the investment decision-making process, based on the project life of VRE assets. Barriers in this framework are defined as factors hindering the realization of a positive final investment decision (FID), which can lead to investment withdrawal.

Based on this research, we argue that addressing so-called "symptomatic" barriers alone is hardly effective when the "fundamental" barriers remain untouched. It also demonstrates that monetary and fiscal policies can have side-effects on VRE investments. We suggest that a comprehensive policy framework to support VRE should not be solely limited to the narrow context of climate and energy policy, and the electricity market. It should be incorporated in a broader context including monetary and fiscal policies. When re-designing these macroeconomic policies, their potential negative impacts on VRE investments should be considered.

Key words:

Variable renewable electricity; Barrier; Investment; Decision-making; Energy policy

1. Introduction

To effectively mitigate the worst impacts of climate change, the Paris Agreement agrees to limit the increase in global average temperature to 2 °C above pre-industrial level and seeks to further limit the temperature increase to 1.5 °C (UNFCCC, 2015). This requires a significant contribution of renewables in the global electricity generation portfolio to decarbonize the power sector (OECD, 2016). In particular, variable renewable electricity (VRE), which is electricity converted from stochastic energy flows (e.g. wind and solar), is expected to play an indispensable role in substituting electricity generation from fossil fuels. The 2 °C scenario of the International Energy Agency (IEA) indicates that the combined penetration of wind and solar in global electricity supply has to increase from 4% to 25% between 2013 and 2040 (IEA, 2015). In some regions like the European Union (EU), this figure may be as high as 37% by 2040 (IEA, 2015). Hence, a sustainable and robust growth of investments in VRE is needed for the foreseeable future.

Driven by climate policies (including renewable energy support) and increasing cost reduction associated with technological learning and economies of scale, a strong growth trend for global VRE investments has been witnessed since 2000 (Wustenhagen and Menichetti, 2012; UNEP and BNEF, 2016). During 2004-2015, annual investment in new VRE assets increased from 38.1 billion USD_{2015} to 270.6 billion USD_{2015}[1], resulting in an increase of total installed VRE capacity by a factor of 13 (from 51 GW to 669 GW) (REN21, 2015; UNEP and BNEF, 2016). It is estimated that a cumulative investment in VRE amounting to 4444 billion USD_{2015} between 2016 and 2035 is the minimum level needed to be consistent with the 2°C climate target (IEA, 2014a; UNEP and BNEF, 2016). However, concerns still exist to whether sufficient VRE investments can be realized. Investment in power generation assets, in general, feature sunk capital costs and uncertainty surrounding future returns and costs (Lundmark and Pettersson, 2012). VRE investments, as a result of their specific techno-economic characteristics, can be distinguished from investments in conventional fossil-fired power plants in two main aspects. Firstly, because VRE projects tend to have a higher capital-intensity (measured by capital expenditures (CAPEX)'s share in total operating expenditures (OPEX) and CAPEX) than fossil-fired plants, they are more exposed to capital constraints and the cost of capital (WACC) (de Jager et al., 2011; Waissbein et al., 2013; Henrich, 2014; Donovan, 2015; Ondraczek et al, 2015). Secondly, featuring variable, uncertain and location-dependent outputs, VRE projects are more exposed to downside revenue risks (i.e. actual revenue received below the expected revenue) (Zane et al., 2012; Hirth et al., 2015). Not only facing these two inherent disadvantages, VRE investments can be obstructed by many other barriers. They either reduce the economic appeal of the investment project, or hinder the process of accomplishing necessary steps before final investment decisions (FID) can be made

[1] Original data are given in nominal value. Deflators (http://stats.areppim.com/calc/calc_usdlrxdeflator.php) are used to obtain their constant USD_{2015} value.

(OECD, 2016). These barriers have been discussed in a wide range of literature, but in a fragmented manner. They tend to focus on only one type of barrier to VRE investments or limit the scope of their discussion from a single perspective. For instance, Hirth et al. (2015) and Munoz and Bunn (2013) respectively demonstrate that the current EU electricity market design may be detrimental to the business case of VRE investments from the revenue perspective and the risk-return perspective. From the cognitive and institutional perspective, Masini and Menichetti (2013) show that biased perceptions and preconceptions defer the decision-making process for VRE investments, favoring the existing energy production model based on fossil fuels. Drawing from a case study, Jami and Walsh (2014) conclude that the lack of public participation may contribute to the rejection of VRE investments. It seems that based on the current knowledge of literature, a comprehensive overview is missing that connects different barriers and their underlying contributors. This adds difficulty to diagnose and address these barriers. This paper aims to deliver a literature review-based analysis that can provide such overview, through developing an integrated framework to analyze barriers to VRE investments as identified from literature. In such framework, we define barriers to VRE investments as factors hindering reaching a positive FID, which can end up with investment withdrawal. Hence, a clear link can be established between barriers and the decision-making process for VRE investments. This serves as the basis to identify and analyze barriers. The scientific contribution of this paper lies in two main aspects. Firstly, the existing body of both empirical and theoretical literature is limited when pertaining to investment decision-making in power plants and renewable energy, e.g. Wustenhagen and Menichetti (2012); Groot et al. (2013). Often, these literature sources tend to be detached from the project life of VRE asset. Complementing existing literature, this paper bridges the project life and the investment decision-making process. Thus, it offers deep insights for different stakeholders and the scientific community on how VRE investment decisions are made in practice and what factors affect the decision-making process. Secondly, findings of this paper can feed into the discussion of how barriers to VRE investments can be effectively tackled. This helps to safeguard necessary VRE investments consistent with the 2 °C climate target.

This paper is organized as follows: In Section 2 an integrated framework is developed to represent the decision-making process for investments in VRE assets from a project developer's perspective, given its essential role in making a FID. This is performed through connecting the investment decision-making process with the project life of VRE assets. Section 3 applies the integrated framework to analyze and combine key barriers to VRE investments identified from existing literature, based on the division of the decision-making process into several stages. The survey of relevant literature is based on a few targeted keywords, such as "investment decision-making", "renewable energy" and "barrier". A snowball method is also used to facilitate the literature survey process. This allows the identification of other literature sources from the reference list of a surveyed paper and the identification of new papers citing the surveyed paper.

To include literature from different fields that are related to VRE investments, we do not take a specific view to select and assess literature, i.e. an explorative approach is adopted. A total number of 140 literature sources are reviewed (see table 1), which consist of peer-reviewed journal papers (60), other academic literature sources (29) and non-academic literature sources (51)[2]. In section 4, a synthesis of the review-based analysis is given, including policy implications drawn for policy-makers. We point out the recommendations for further research in section 5.

Table 1. Summary of reviewed literature sources

2. Development of the integrated framework

The development of the integrated framework for the research was mainly drawn from literature that describes the project life of a VRE asset. The project life of a VRE asset typically consists of several project steps that follow a temporal sequence. They are pre-feasibility study and site prospecting, VRE resource assessment, environmental impact assessment (EIA) and permits acquisition (e.g. land, building, grid connection), off-take arrangement and support scheme application, capital access, engineering and equipment procurement and contracting, construction and commissioning, commercial operation and maintenance, and decommissioning[3] (Tetra Tech, 2011; WB and CIF, 2013; ADB, 2014; Deloitte, 2014). Since the step of engineering and equipment procurement and contracting and the step of construction and commissioning involve the commitment of the majority of costs throughout the project life, the implementation of these two project steps marks the actual start of the investment. This implies final investment decision (FID) must be made prior to these two steps (Deloitte, 2014). Investments will only be committed once the FID is made. Therefore, using the FID as a demarcation, the project steps before FID comprise the investment decision-making process. Each project step naturally formulates a decision-making step. Empirically, the decision-making process serves to confirm that the investment case considered is a good investment for the project developer, i.e. with a satisfying economic outcome under a sufficiently high confidence interval (Groot et al., 2013). To streamline the decision-making process, the recognized decision-making steps were further grouped into two sequential principal stages before the decision outcome of the FID: stage prior to capital access (i.e. project development stage) and capital access stage.

[2] To better capture first-hand and up-to-date information, a number of non-academic literature sources (51 in total) are also used. Many of them are widely-cited, and they come from official government documents, well-acknowledged organizations and other primary sources (e.g. IEA, World Bank, Bloomberg New Energy Finance). Peer-reviewed reports (e.g. IEA-RETD) are also included among them.

[3] Depending on projects and countries, the sequence of project steps may be slightly different. For instance, VRE resource assessment can be performed earlier than site selection and prospecting, and off-take arrangement can be earlier than permits acquisition. Note that some project steps can also be implemented in parallel (Tetra Tech, 2011).

VRE investments are subject to many unknown events affecting capital and time expenditures associated with each project step and future cash flows of the investment project. To inform successful decision-making, project developers should be able to evaluate the viability of the project under these unknowns. Based on the measurability of knowledge, Zeckhauser (2014); Diebold et al. (2008); Stirling (1994) distinguish these unknowns into three states: risks/known unknowns (with specified outcomes and probabilities), uncertainties/unknown unknowns (with specified outcomes and unspecified probabilities) and ignorance/unknowable unknowns (with unspecifiable outcomes and probabilities). Although it is uncertainties and ignorance that are mostly encountered in VRE investments, it is common practice to treat uncertainties as risks via assigning a (subjectively) estimated probability distribution function and be wary about ignorance (Wickham, 2006; Kitzing et al., 2014; Zeckhauser, 2014). Hence, in this paper the term "risk" is used to generalize the three states of unknowns, and it is specified to downside risk. In traditional finance theory, the assumption of perfect information and full-rationality implies that investment decision-making should be informed by the statistically measurable risk (Baker and Nofsinger, 2010; Hampl and Wustenhagen, 2013; Pistorius, 2015). However, behavioral and psychological literature points out the subjective perception of risk in reality, reflecting bounded rationality, can strongly affect investment decisions, depending on the developer's judgment and attitude towards risks (Hampl and Wustenhagen, 2013; Wustenhagen and Menichetti, 2012; Masini and Menichetti, 2013). Furthermore, due to high unknown and unknowable risk level associated with complex VRE investments, their actual risk is *a priori* hardly measurable. Consequently, risk has to be treated with a high degree of subjectivity, which is subject to different psychological, behavioral and institutional attributes (Hampl and Wustenhagen, 2013). To take these into account, we deem it useful to add "preliminary risk scanning" as an additional stage, to the very beginning of the decision-making process. This enables to capture the process of moving the project from investment intention (or formulation of the investment intention) to development action.

Figure 1 presents the developed integrated framework for the VRE investment decision-making process, which consists of three main stages. We will elaborate on these three stages below and how they move forward towards reaching the FID.

Figure 1. Integrated framework for VRE investment decision-making process

- Stage 1: Preliminary risk scanning

Before deciding whether to start the development of a potential VRE project, the project developer is expected to preliminarily scan[4] the risk profile of the project. If risks are perceived too high for the developer to accept or handle, the project will be rejected (Masini and Menichetti, 2013).

- Stage 2: Project development

This stage concerns establishing the layout of the project and thoroughly assessing the economic feasibility of the investment (Deloitte, 2014). It consists of four sequential project steps. Although not comparable to the upfront capital costs required to start the investment, each step of the project development still involves sizable investment and time. Therefore, the project developer must decide whether to move the project forward at the beginning of each step. The decision-making process is assisted by an iterative process of economic appraisal for the investment project in parallel to the project development (Springer, 2013). The investment decision would be rejected if any step of the project development is unrealizable, either due to an undesirable result of the economic appraisal or other factors (e.g. unaffordable costs or complex administrative procedures associated with a step). This minimizes potential losses.

This iterative process also improves the quality of the economic appraisal and reduces its unknown level. This is because as more steps of the project development are proceeded, more accurate data and information inputs regarding the future cash flows of the project will be disclosed (Groot et al., 2013; Springer, 2013). Consequently, the unknown state of project risks tends to switch from unknown unknowns to known unknowns. However, the unknowns of risks do not necessarily decrease. To thoroughly take project risks into account, the iterative economic appraisal can be based on a probabilistic discounted cash flow (DCF) approach. Key performance indicators (KPI) of this approach can be based on either net present value (NPV), internal rate of return (IRR), benefit-cost ratio (BCR)[5], or discounted payback period (DPBP). KPI selection depends on the preference of the project developer, but in principle a minimum required rate of return (i.e. financial hurdle rate) in the form of discount rate should be met (Groot et al., 2013). In the early steps of the financial appraisal, a higher risk-adjusted discount rate can be used to estimate the expected value of these KPI, reflecting the state of high unknown unknowns. In the late steps with more data available, Monte Carlo simulation or statistical mean-variance analysis can be used to give the cumulative probability distribution of the KPI (Park, 2015). The resulting at-risk value of KPI (value at a given percentile or minimum value at a given confidence level) can effectively inform the developer whether to proceed with

[4] Note that preliminary suggests that more comprehensive risk assessment need to be conducted to support later stages of investment decision-making. They are incorporated in the iterative process of economic appraisal paralleled to the project development stage in this integrated framework.

[5] BCR is the ratio between the present value of the future cash flows and the upfront capital costs. Sometimes it is also referred to as profitability index (PI).

the next project step (Ye and Tiong, 2000). The corresponding minimum criterion[6] is that the NPV-at-risk value should be above 0, the IRR-at-risk value should be above the discount rate, the BCR-at-risk should be above 1, and the DPBP-at-risk value should be below the lifetime of the project. Otherwise, the project would be rejected due to the lack of economic appeal.

- Stage 3: Capital access

After passing through the project development stage and the iterative process of economic appraisal, the decision-making process would enter the capital access stage. Final investment decision would only be accepted if the project developer is able to access sufficient affordable capital to finance the investment. Otherwise, the project would be rejected. Once the final investment decision is accepted, the project developer can start the investment.

3. Review-based analysis of barriers to VRE investments

The integrated framework provides a basis to identify and analyze barriers to VRE investments from the reviewed literature. It enables to connect barriers with different investment decision-making stages, where barriers increase the likelihood of the investment project being rejected. Barriers for each decision-making stage and their attributes are analyzed in the following sections.

3.1 Barriers at preliminary risk scanning stage

Barriers at this stage mainly increase the project developer´s risk perception towards the VRE investment project, which can lead to rejection of the investment. Risk perception is a joint function of both risk judgement and risk attitude (Ricciardi, 2008). The former represents the cognitive/mental process of defining the risk levels of the project, while the latter reflects the affective/emotional attitude towards the judged risk (Weber and Hsee, 1998; Van Winsen et al., 2011). Three types of risk attitude can be distinguished: risk-seeking, risk-neutral and risk-averse. If the project developer is risk-averse, the impact of risk judgment can be amplified and it leads to a higher risk perception (Weber and Hsee, 1998). Therefore, risk perception increases either through increased risk judgement or increased risk averseness.

Risk perception can be influenced by actual risk factors for VRE investments, which can occur at different steps of the project life (Hampl and Wustenhagen, 2013). De Jager and Rathmann (2008), Oxera (2011), Hampl and Wustenhagen (2013) and Waissbein et al. (2013) have provided different but similar classifications for these actual risk factors. They include policy risks, public acceptance risk, technology risk, permit risk, construction risk and electricity market

[6] Threshold values for different KPI under the minimum criteria are consistent, which reflect the situation of the required rate of return being just met. Note that it is possible that firms or project developers may set additional cut-off criterion for one or more KPI beyond the minimum criterion, which to some extent reflect their bounded-rationality.

risk, to name a few. Most of them will be treated as barriers in later sections of this paper. Here we focus on psychological, behavioral and institutional attributes that can give rise to additional risk perception, which constitute barriers to VRE investments (Gruning and Moslener, 2016). These attributes include ***path dependence, the lack of knowledge and experience, the lack of confidence, the lack of sustainable strategic value, and individualistic worldview and culture.***

3.1.1 Path dependence

Path dependence suggests past investments in fossil-fired plants can impact today's decision-making for investment in VRE projects (Wustenhagen and Menichetti, 2012). It has implications for VRE investments at energy system and firm level, both of which can increase the risk perception for potential VRE project developers. At a system level, historical development of fossil-fired plants and complementary infrastructure has displayed multiple comparative disadvantages for VRE technologies (Lehmann et al., 2012). In particular, increasing the uptake of VRE requires large-scale development of flexibility resources, e.g. grid infrastructure, demand response, storage and flexible fossil-fired plants. The lack of flexibility in the current energy system may lead to technological lock-in and increased risk perception for VRE investors. At a firm level, risk perception towards VRE investments of incumbent firms that were heavily involved in fossil fuel investments may be affected by their historical activities (Wustenhagen and Menichettil, 2012). This seems particularly true for large utilities that own large fossil-fired plants and associated infrastructure (Barth and Siebenhuner, 2010). Even when government tightens the environmental standard, these utilities tend to retrofit and upgrade existing plants instead of switching to VRE technologies, to avoid the write-off large sunk costs (Barth and Siebenhuner, 2010).

3.1.2 Lack of confidence

The lack of confidence and misinformation about VRE can increase the risk perception towards VRE investment (Huijts et al., 2012). Masini and Menichetti (2013) distinguish two types of confidence related to VRE investments: technology confidence and policy confidence. Technology confidence reflects the project developer's personal belief about the technological performance of VRE. Compared with fossil-fired electricity generation, VRE technologies are less established and often perceived as less mature (Masini and Menichetti, 2013). Skepticism about the reliability and adequacy of VRE technologies increase the risk perception of project developers (Barth and Siebenhuner, 2010). This is often exacerbated by misinformation about VRE technologies created by the fossil fuel lobby (Valentine, 2011; Smink et al., 2015). Policy confidence reflects the developer's personal belief in the effectiveness of policy that aims to stimulate and streamline VRE development (Masini and Menichetti, 2013). The lack of long-term credibility, stability and visibility in policy can reduce such policy confidence.

3.1.3 Lack of knowledge and experience

The lack of knowledge regarding VRE technology and its operation can increase the perceived risk towards VRE investment, because the perceived unknown level increases in absence of sufficient knowledge (Masini and Menichetti, 2013; Huijts et al., 2012). Consequently, even risk-seeking investors may feel unable to hedge against VRE technology risk (Masini and Menichetti, 2013). If the knowledge gap fits the developer' personal biases towards VRE technology, it may further reduce the confidence level in VRE investment (Masini and Menichetti, 2013).

Experience enables a better estimate and management of the actual risk level. Through learning by doing, experience in early adoption of VRE technology creates knowledge, which indirectly affects risk perception (Huijts et al., 2012). It also directly reduces the perceived risk due to increased familiarity with the technology. Based on an empirical survey of European investors, Masini and Menichetti (2013) point out that investors with greater experience in the renewable energy sector tend to favor renewable energy technology over fossil-fired technology. This suggests that lack of experience may increase the risk perception towards VRE investment.

3.1.4 Lack of sustainable strategic value

Firms with a stronger sustainable strategic value tend to be more accepting and hold a less risk-averse attitude towards VRE investments (Groot et al., 2013; Gamel et al., 2016). A large government ownership often increases the sustainable value and financial robustness of firms, reducing the risk perception (Groot et al., 2013). For instance, in Germany municipal utilities tend to weigh environmental motives higher than commercial utilities in investment decision-making (Barth and Siebenhuner, 2010; Nelson et al., 2016). This suggests that the lack of sustainable strategic value constitutes a barrier to VRE investments.

3.1.5 Individualistic worldview and culture

Risk perception for VRE investment can be affected by the worldview and culture of investors. Chassot et al. (2014) prove that investors holding an individualistic worldview favoring a free-market tend to affectively amplify their risk perception towards VRE investments under high regulatory exposure than other investors. Similarly, Weber and Hsee (1998) show that, due to social diversification, investors from a collectivist culture (e.g. China) tends to hold a lower risk perception than their peers from a individualistic culture (e.g. United States, Germany) for the same investment option. Therefore, an individualistic worldview and/or culture can hinder VRE investments.

3.2 Barriers in an iterative economic appraisal process

In this paper, the (expected) NPV of the VRE project and its at-risk value using the probabilistic discounted cash flow approach are adopted to perform the economic appraisal process. Therefore, barriers are here defined as attributes that reduce the absolute NPV of VRE investments or its relative value to fossil-fired plants. Attributes increasing the variance of NPV can also be deemed as barriers to VRE investment, which tend to reduce the NPV-at-risk value[7]. Figure 2 shows an illustrative example of the probability density function for NPV and the NPV-at-risk value at 5 percentile (or 95% confidence level). The NPV-at-risk value here represents the minimum NPV value with 95% probability. It can be generated through a Monte Carlo simulation, which draws repeated random samples of input parameters for the NPV calculation and statistically analyzes the calculation result. This requires defining the probability distribution for each input parameter and their correlations.

Figure 2. Probability density function of NPV and NPV-at-risk at 5 percentile

Source: adapted from Ye and Tiong (2000)

The NPV can be calculated via the following formula:

$$NPV = -I + \sum_{i=1}^{L} \frac{(B_i - C_i)}{(1+r)^{-L}} \quad (1)$$

Where:

I: Upfront capital costs;

B_i: Annual revenue;

C_i: Annual operating &maintenance costs and tax payments;

r: Discount rate;

L: Project economic lifetime;

Formula (1) shows that barriers can result in a lower NPV or NPV-at-risk value through negatively influencing any of the input parameters of the calculation. In other words, barriers can influence either the expectancy of the economic lifetime, upfront capital costs, discount rate, annual tax payments or annual revenue of the VRE investment.

3.2.1 Underestimation of project economic lifetime

Underestimating project economic lifetimes tends to result in underestimated project NPV. Branker et al. (2011) report that although the manufacturers' guaranteed lifetime for solar PV system is usually 20-25 years, working lifetime well beyond 25 years is increasingly shown in

[7] Under a higher variance, the probability distribution function for NPV becomes wider. Thus, the NPV-at-risk value at a given percentile tends to decrease. Note that a lower expected NPV also reduces the NPV-at-risk value, because it shifts the entire probability density function leftwards.

practice. Once the guaranteed lifetime has passed, the system would still generate electricity at negligible cost. Therefore, a more credible value on the economic lifetime should be provided by industries that fully considers the trade-off between the actual working lifetime and the system degradation rate (Branker et al., 2011). If the guaranteed lifetime is used to determine the project NPV, it can give rise to misconception.

3.2.2 High unit upfront capital costs and capital-intensity

Despite the ongoing effects of technological learning and economies of scale, to date the upfront capital costs per unit of installed capacity for VRE world-wide are generally still higher than that of gas-fired power generation (see figure 3). In terms of firm capacity[8], unit upfront capital costs are even more expensive due to the variable nature of VRE. The unit upfront capital costs of onshore wind and PV have experienced significant cost reduction in past years, while a reversed trend has been observed for offshore wind since 2000 (Schwanitz and Wierling, 2016; Sovacool et al., 2017). Half of the increased costs can be explained by increased depth and distance to shore and increased commodity price, while the rest can be largely ascribed to increased offshore turbine price due to limited competition between manufacturers (Voormolen et al., 2016). Quality control for locational-specific mega-turbines, increased construction costs associated with disjointed turbine design and construction, the lack of standardization and fragmented construction industries may also limit the cost reduction for offshore wind (Sovacool et al., 2017).

Figure 3. Unit upfront capital costs for investments in different fossil-fired electricity and VRE generation technologies

Source: Data derived from IEA (2016)

VRE investments also face higher capital-intensity than fossil-fired electricity generations (Finon, 2013; IPCC, 2011; Hirth and Steckel, 2016). For instance, the capital-intensity for gas-fired generation and coal-fired generation is typically 0.4 and 0.45, while it is 0.8 for onshore wind and even higher for solar (Helms et al., 2015). This tends to negatively impact the NPV of VRE investments, as more costs are paid upfront rather than being discounted in the future.

3.2.3 Non-accelerated tax depreciation policies

Tax depreciation policies affect the distribution of annual tax payment of VRE assets. A higher depreciation rate enables the project to claim higher after-tax net revenue in its early operating

[8] Firm capacity represents the percentage of the nominal capacity of a power plant that can be served as guaranteed power supply with a certain level of system reliability (Sijm, 2014).

lifetime, which increases the NPV. This is in the case of accelerated depreciation that prescribes a depreciation time shorter than the project lifetime (Richardson, 2008). On the contrary, non-accelerated depreciation policies (e.g. straight-line depreciation) decrease the economic appeal of VRE.

3.2.4 Expected revenue insufficiency

Expectancy of insufficient annual revenue reduces the absolute NPV of VRE investments and its relative value to fossil-fired electricity generation. At worst, the project will be rejected if it fails to break even, i.e. NPV<0. Since the revenue received by VRE is the sum of the market revenue of selling electricity, the revenue of auxiliary products and subsidies from support policy schemes, fundamental causes for revenue insufficiency are related to unfavorable electricity market conditions or unfavorable policies:

- Unfavorable electricity market conditions

The market revenue of VRE is contingent on conditions of the electricity market. In a liberalized electricity sector, the revenue from electricity sales in the spot market usually constitutes the largest source of market revenue, depending on the electricity spot price and sales volume. A ***very low regulatory price-cap*** can decrease the spot price (de Vries and Hakvoort, 2013). Frew et al. (2016) also report that the ***spot price is often depressed by overcapacity*** due to the disconnection between the spot market and administratively-determined higher reliability standards. This gives rise to a market failure (Hogan, 2013; Hogan, 2017). Exacerbated by the large increase in VRE capacity but the limited market exit of surplus baseload capacity and the post-recession low demand, severe overcapacity has been identified in various regions, e.g. Germany and Australia (Auer and Hass, 2016; BMWi, 2015; Jotzo and Mazouz, 2015). This decreases revenue for all generators including VRE. VRE may, however, be more sensitive to a lower spot price compared to other generators. The short-run marginal cost (SRMC)-based price settlement in the spot market seems to not favor VRE characterized by close-to-zero SRMC. Firstly, due to the so-called "***merit-order effect***", there is a tendency of spot price decrease when VRE generation replaces the marginal thermal plant used to set the price (Chaves-Avila et al., 2015). Secondly, with increased VRE penetration, the spot price during periods of VRE generation tends to be further reduced because of the "***decreased temporal correlation effect***" between VRE and demand (Hirth et al., 2015). These two effects have already been demonstrated by many empirical and model-based studies (see Munoz and Bunn, 2011; Wurzburg et al., 2013). ***Decreased electricity sales volume*** of VRE also causes market revenue reduction. It occurs during curtailment resulting from ***limited flexibility*** of the power system to absorb surplus VRE generation (Zane et. al, 2012). System inflexibility can also be amplified by the overcapacity of baseload plants, since it increases the must-run generation level.

Besides providing electricity products, VRE is also able to provide balancing capacity products in the balancing market (Van Hulle, 2015; Hirth and Ziegenhagen, 2015). In particular, the downward balancing services provided by VRE are cost-effective because no opportunity cost is involved (Hirth and Ziegenhagen, 2015). However, ***biased market conditions*** in terms of low time resolution and early gate closure time create an entry barrier for VRE to provide reliable balancing services (Hirth and Ziegenhagen, 2015). This reduces potential revenue streams for VRE. Similarly, an unfavorable imbalance settlement system for allocating system balancing costs can reduce VRE's revenue. For instance, a two-price system penalizes any imbalance of electricity delivery from schedule, even if such imbalance counteracts the system imbalance (Scharff, 2015). This punishes VRE more often due to the difficulty in forecasting (Baker and Gottsterin, 2012). It also discriminates against smaller market participants, which often include VRE, since large market participants are more capable of netting their imbalances (Vandezande et al., 2010).

- Unfavorable policies

Relying on market revenue alone, currently it seems less likely for VRE to recover its high upfront capital costs (Janerio et al., 2016). This can be largely explained by unfavorable Energy & Climate policies that ***fail to create a level playing field*** for VRE to compete with fossil-fired electricity generation in the market. Firstly, due to the ***incomplete internalization of negative externalities*** (e.g. climate change, air pollution, energy dependency) associated with fossil-fired electricity generation, VRE's value in avoiding these externalities is not fully reflected in electricity pricing (Neuhoff, 2005). This represents a fundamental market failure. Emission standards regulation is often criticized for legitimizing pollutant levels below the prescribed emission limits without pricing their external costs (Outka, 2012). Even when there are externality-pricing schemes (e.g. pollution tax or cap-and-trade), the price level is often insufficient to fully internalize all external costs. An often cited-case is the EU emission trading scheme (ETS). Its carbon price (per Tonne CO_2) only oscillated between 6.4-8.6 $Euro_{2015}$[9] in 2015, compared to a social cost of carbon (SCC) at 108 $Euro_{2015}$ estimated by the Stern Review and a minimum carbon price required at 61 $Euro_{2015}$ to make VRE investments break-even (Stern, 2007; Deutsch et al., 2014). Secondly, ***explicit and/or implicit subsidies for fossil fuels***, as market distortions, also reduce the revenue of VRE relative to fossil-fired electricity generation (REN21, 2015). The total global subsidies for fossil fuels amount to 516 billion USD_{2015} in 2014, equivalent to a negative carbon price of 116 USD_{2015}/Tonne CO_2 (IEA, 2015)[10]. This subsidy can be substantially increased, if costs associated with military operations and diplomatic activities to secure overseas fossil resources are included (Outka, 2012). Thirdly, due to historical

[9]EEX European emission allowance auction (EUA) market data (https://www.eex.com/en/market-data/emission-allowances/auction-market/european-emission-allowances-auction#!/2016/06/20)

[10] Original data are converted into their constant USD_{2015} value.

prioritization of development, fossil fuel industries as incumbents have large ***vested interests*** in maintaining their competitive advantages over VRE in terms of subsidies, existing physical infrastructure and incomplete internalization of externalities (Effendi and Courvisanos, 2012). They also have more political power and lobbying capacity to hinder potential policy efforts that aim to establish a level playing field for VRE (Smink et al., 2015).

Support policy schemes for VRE investments can be justified by compensation for the positive externality of technology spillover, a market failure, and the unlevelled playing field (Fischer and Preonas, 2010; Auer and Burgholzer, 2015; Andor and Voss, 2016). These schemes target VRE investments either based on each unit of electricity production or installed capacity. They play an essential role in enabling VRE investments break-even. Hence, ***insufficient support levels*** can lead to revenue insufficiency. Often it is caused by ***constrained government budgets***, especially under austerity measures of fiscal policy (Galgóczi, 2015; Del Rio et al., 2015). For instance, Van der Elst and Bosch (2012) observed that limited budgets under the Dutch SDE+ scheme have led to under-bidding for support application. Many investment decisions will be finally rejected, once the project viability becomes clear (Van der Elst and Bosch, 2012). A similar case is also reported for PV projects in China (SEMI PV Group, 2011).

Negative interactions between the electricity market and policies and between different policies, if not minimized, may also contribute to revenue insufficiency. Two mechanisms are often reported for such interactions. One mechanism is that ***in absence of an ex-post cap adjustment mechanism***, VRE support schemes reduce the demand for emission permits under a cap-and-trade scheme (Richstein et al., 2015). This results in a decreased carbon price and electricity spot price, as observed in the EU ETS (Fischer and Preonas, 2010; Koch et al., 2014). The other mechanism is related to the direct distortion effect of various ***production-based support schemes*** (e.g. feed-in tariff, feed-in premium and tradable green certificates) on the electricity market, which leads to a depressed spot price (Oliveira, 2015). Both interaction mechanisms increase the support level required for VRE investments.

Besides revenue insufficiency, revenue volatility also negatively affects the financial appraisal, since it tends to lower the NPV-at-risk value. Three factors contributing to revenue volatility of VRE investments are often reported in the literature. Firstly, due to the ***merit-order*** and ***decreased temporary correlation effects***, spot price volatility tends to increase with increased VRE penetration in the electricity market. Secondly, price volatility is an inherent characteristic of ***quantity-based policies*** for pricing externalities (e.g. cap-and-trade scheme) or supporting VRE (e.g. tradable green certificate) (Coulon et al., 2015). These are expected to increase the revenue volatility of VRE investments. Large price volatility has been observed in the EU ETS and the Swedish/Norwegian green certificate market (Koch et al., 2014; Fagiani and Hakvoort, 2014). Last but not least, revenue volatility also depends on the ***type and features of support schemes***.

Under the same mean value of annual total revenue, feed-in premiums (with fixed premiums on top of the spot price) result in higher volatility than feed-in tariffs (with guaranteed price) (Kitzing, 2014). However, design features such as price floor and cap may limit the higher volatility associated with feed-in premiums (CEER, 2016; Angelopoulos et al., 2016). Tradable green certificates can result in the highest revenue volatility for VRE investments (Fontaine et al., 2016). Although feed-in tariffs provide the most stable revenue, they are increasingly replaced by other support schemes to stimulate improved market integration. For instance, the EU will prohibit the use of feed-in tariffs to support new VRE installations from 2016 onwards (EC, 2014).

3.2.5 High discount rate and additional strict cut-off investment criteria

The discount rate is the minimum required rate of return demanded by the project developer, and it represents the present time-value of future cash flows. A high discount rate can be considered a barrier to VRE investments, since it leads to low or even negative NPV. Based on survey and literature data, Oxera (2011) reports the range of (pre-tax) real discount rate used by investors in the United Kingdom for different VRE technologies, against that for Natural Gas Combined Cycle (NGCC) (see figure 4). Although only reflecting the situation in the United Kingdom, it shows that VRE investments might face a higher discount rate than fossil-fired electricity generation. As VRE investments are comparatively more capital-intensive, their NPV calculation is more sensitive to high discount rates. Therefore, a higher discount rate further exacerbates the comparative disadvantages.

Figure 4: Discount rate ranges for investments in different VRE technologies and NGCC

Source: data derived from Oxera (2011)

The discount rate should at a minimum reflect the ***weighted costs of capital (WACC)*** or financing costs of the underlying VRE investment. Therefore, the discount rate increases with the WACC. Companies commonly determine WACC based on the capital asset pricing model (CAPM), which adjusts the risk-free rate based only on systematic risks – risks correlated with overall macroeconomic conditions and business cycles (Oxera, 2011). Due to relatively underdeveloped capital markets, less stable macroeconomic conditions and state of political environments, and higher inflation, VRE investments in developing countries usually face a WACC substantially higher than that in developed countries (Waissbein, 2013; Ondraczek et al., 2015). Angelopoulos et al. (2016) also reports that in the case of onshore wind investments throughout different European countries, the WACC is highest in Greece and Croatia (12%), while lowest in Germany (3.5-4.5%).

The CAPM assumes sector/firm/project -specific unsystematic risks (e.g. revenue volatility associated with input estimates, weather-related resource risks, technology risks) can be fully diversified away without additional costs. In practice this is hardly the case for VRE investments (Fougner, 2011). One explanation is the lack of insurance coverage due to insufficient loss data and high complexity due to the involvement of several project partners, which is particularly the case for offshore wind projects with relatively short track records (Gatzert and Kosub, 2016). Financial theories suggest that unsystematic risks should not be compensated to avoid double counting, since they are already covered through adjusting for the cash flows in the probabilistic DCF approach (Edner and Paulsson, 2013). However, in practice risk premiums adjusted for unsystematic risks are often added on top of the WACC (Jagannathan et al., 2016; Oxera, 2011). Such a practice of "***Fudge factors***" artificially increases the discount rate[11], potentially reducing the NPV of VRE investments and increasing the support level needed. A typical example is the use of a risk-adjusted discount rate to compensate for the revenue volatility (an unsystematic risk) associated with different VRE support schemes, as mentioned by Kitzing (2014). This can result in a higher discount rate for feed-in premium schemes than that for feed-in tariff schemes at the same mean revenue level. Finon (2013) also argues that in the SRMC-based spot market the self-hedging ability to price volatility is very limited for capital-intensive VRE investments, because of the large gap between their SRMC and long-run marginal costs (LRMC). This increases the risk of unrecovered upfront capital costs (downside risk) and, consequently, the discount rate (Finon, 2013).

In presence of many unsystematic risks that are unmeasurable unknown unknowns (e.g. policy uncertainty risks, social acceptance risks, spot price uncertainty risks), fudge factors can be partly, if not fully, justified. Risk premiums that are fed into the discount rate increase with the level of risk perception. In particular, ***policy uncertainty risks due to discontinuity of existing support schemes and the lack of long-term policy visibility*** can have substantial and long-lasting impacts on the risk perception towards VRE investments, which increases the risk-adjusted discount rate (WB and CIF, 2013; De Jager and Rathmann, 2008; Jacobs et al., 2016). For instance, the imposition of retroactive tariff reduction for existing VRE projects almost shut down new VRE investments entirely in Spain in 2013 (UNEP and BNEF, 2014). As demonstrated by Luthi and Prassler (2011), wind project developers in the EU and the US also rank legal security as the most important factor in their investment decision-making (Klessmann et al., 2013). In addition, insurance coverage for policy uncertainty risks barely exists (Gatzert and Kosub, 2016). If project developers are incapable of managing the perceived highly unknown levels associated with VRE investments, they may use a very high discount rate or ***additional***

[11] Note that if capital providers also adjust their required rate of return to unsystematic risks, their fudge factors will be fed in to the WACC. It will result in an even higher discount rate.

strict cut-off investment criteria (e.g. high IRR and short PBP) to exclude the investment decision.

3.3 Barriers at project development stage

Barriers at this stage hinder the completion of necessary project development steps, and they can be split into two elements: high development costs (section 3.3.1) and lack of social acceptance (section 3.3.2).

3.3.1 High development costs

Before access to external capital, costs associated with different project development steps have to be covered by the developer's own financing resources (WB and CIF, 2013). Therefore, high development costs can be a barrier to VRE investments. ***High development costs may exacerbate revenue insufficiency***, as the project developer tends to demand a higher level of support to compensate for the reduced profit margin (Klessmann et al., 2013). In particular, costs associated with procedures of permits acquisition and grid connection constitute a significant part of project development costs. These costs are usually inflated by complex administrative permitting procedures, excessive power quality demand and unfavorable allocation of grid costs.

- Lengthy administrative permitting procedures

Lengthy administrative permitting procedures can significantly increase the project lead time, required efforts and human resources, resulting in increased development costs (Klessmann et al., 2013). They are reported as the primary concern affecting investment decision-making for European solar PV project developers (Luthi and Wustenhagen, 2011; Klessmann et al., 2013). Lengthy permitting procedures are often prolonged by bureaucracy, non-streamlined procedures, lack of transparency or a clear timeline, the involvement of a large number of authorities and a lack of coordination between involved authorities (Del Rio, 2011; Waissbein, 2013; Henrich, 2014; Verhaegen et al., 2016). This is especially relevant to offshore wind (Gatzert and Kosub, 2016).

- Excessive power quality demand

As non-synchronous generators, VRE generators are connected to the grid via power electronics instead of electro-mechanical links (IEA, 2014b). Unlike fossil-fired synchronous generators, they alone lack capabilities for power quality control, such as system inertia, reactive power and voltage support, transient stability and fault ride-through capability (IEA-RETD, 2015; Van Hulle et al., 2014). To maintain grid stability, the grid code may demand VRE to install additional equipment for power quality control before the issuance of grid connection permits (Basit et al., 2012). If such demand becomes excessive, it may incur high costs for the project.

- Unfavorable allocation of grid costs

Due to relatively remote locations, VRE projects typically incur higher costs associated with grid connection and the reinforcement of the existing grid (Auer, 2011). Thus, unfavorable allocation of grid costs can increase development costs. In general, four prototypical allocation approaches can be distinguished, i.e. deep approach, hybrid approach, shallow approach and super-shallow approach, depending on the extent to which grid costs have to be borne by the developer (Auer, 2011; Swider et al., 2008). In the deep approach, the developer pays for all costs; while only grid connection costs are paid in the shallow approach. In the super-shallow approach, all costs are socialized. Since it is difficult to disentangle the marginal impact of a new VRE project on grid reinforcement requirement, deep and hybrid approaches may unfairly increase the financial burden for the developer (Swider et al., 2008 and Zane et al., 2012). Even if a shallow approach is adopted, grid connection alone can still incur significant costs, especially for offshore wind projects far away from shore (Swider et al., 2008).

3.3.2 Lack of social acceptance

The lack of social acceptance ranges from spontaneous protests, professional campaigns and even legal suits (Ecorys, 2008). It often causes delays in project development (especially the permitting step) and the escalation of development costs, which discourages VRE investments (Del Rio, 2011; Enevoldsen and Sovacool, 2016). A high risk perception of social acceptance may also lead to the early rejection of investments at the preliminary risk scanning stage, or a high discount rate in the economic appraisal process (Angelopoulos et al., 2016). Social acceptance towards VRE investments can be distinguished into two dimensions: generic public acceptance at consumer level and local acceptance at community level (Del Rio, 2011).

- Lack of public acceptance

Because of its environmental benefits, social acceptance today for VRE is generally high in major western economies and China (Liu et al., 2013; Knebel et al., 2016; Bertsch et al., 2016). Such acceptance is positively correlated with people's knowledge of VRE, and with education and income levels. This is reflected in the surveyed willingness-to-pay (Liu et al., 2013; Moula et al., 2013). However, ***either too high or substantial increase of support costs*** for VRE can negatively impact public acceptance (Del Rio et al., 2015). This is particularly the case if an additional surcharge in the electricity bill (instead of public budgets or tax-financed funds) is used to finance support costs, e.g. in most European countries (Del Rio et al., 2015). It directly increases the perceived financial burdens of residential end-users and can be socially regressive (Diekmann et al., 2016; Grubb et al., 2016). Due to the ***merit-order effect***, the surcharge level tends to increase with increased VRE penetration. In Germany it increased from 0.011 Euro/kWh to 0.053 Euro/kWh between 2008 and 2012, which has already been declared as too high by more than 51% of Germans (Möhlenhoff, 2014). The high and rapid increase of the surcharge is also explained by the exemption of energy-intensive industry and a large proportion of commercial users (Möhlenhoff, 2014). This form of ***distributive unfairness*** may further endanger public acceptance.

- Lack of local acceptance

Deployment of VRE projects cannot avoid negative local outcomes. Visual impact on landscape, noise and depreciated property value are associated with wind projects, while solar projects can cause heat island effect (mainly in semi-arid lands) and natural habitat losses (Walter and Gutscher, 2010; Barron-Gafford et al., 2016; Carlisle et al., 2016). These impacts tend to increase with project size and often lead to strong opposition by local stakeholders. For instance, local protests forced the withdrawal of the Palen CSP project in California, even though it had been priory approved by state regulators (Roth, 2014). This lack of local acceptance is often cited as "not in my backyard" (NIMBY) syndrome, although this may oversimplify the actual motives of locals (Wustenhagen et al., 2007; Carlisle et al., 2016). Better explanations include ***perceived impacts*** and ***perceived unfairness*** by locals (Wustenhagen et al., 2007; Walter and Gutscher, 2010; Jami and Walsh, 2014; Enevoldsen and Sovacool, 2016). Perceived local impacts of VRE projects can be amplified by ***sub-optimal spatial planning*** and ***misinformation*** (Lantz and Flowers, 2010). Communication with local stakeholders including the provision of credible information and figures corrects misinformation, but its effectiveness can be reduced due to ***mistrust*** of locals towards the (external) project developer (Lantz and Flowers, 2010). Highly complex, non-transparent or inaccurate information, frivolous attitudes towards locals' fears and overlooking long-term relationships with the community all undermine such trust (Walter and Gutscher, 2010). Perceived unfairness includes unfairness associated with the distribution of negative and positive outcomes (i.e. distributive unfairness) and unfairness related to the treatment of relevant stakeholders in the decision-making procedure (i.e. procedural unfairness) (Wustenhagen et al., 2007). Procedural unfairness, distributive unfairness and mistrust often reinforce each other. Factors contributing to distributive unfairness include the use of universalistic resources (e.g. money) to compensate for losses of particularistic resources (e.g. landscape impact) due to VRE deployment, limited distribution of project profits to stakeholders or distribution to a small number of stakeholders, and the exclusion from financial participation of stakeholders (Walter and Gutscher, 2010). Procedural unfairness is affected by limited participation opportunities (e.g. information, consultation, cooperation) and untimely involvement of locals in project development (Walter and Gutscher, 2010; Jami and Walsh, 2014; Langer et al., 2017).

3.4 Barriers at capital access stage

At this stage, the project developer has to access sufficient and affordable capital to finance the investment before the approval of the FID. Financing can be either on-balance sheet corporate financing, or (limited or non-resource) project financing secured against the future project cash flows. Project financing has been increasingly used in the renewable energy sector, and it accounted for 52% of total renewable energy investment in 2015 (OECD, 2016). Due to limited retained earnings reserved for re-investment[12], both corporate financing and project financing require external capitals in the form of debt and equity[13] (IEA, 2014a; De Jager et al., 2011). A high WACC can be caused by ***high risk perception of capital providers*** towards VRE, reducing the project's economic appeal and its affordability to access capital (Campiglio, 2016). Barriers at this stage mainly include the lack of equity and the limited access to bank lending.

3.4.1 Lack of equity

The lack of equity for renewable energy investments was previously only a problem in non-OECD countries (WB and CIF, 2013). In OECD countries, the post-recession macro-economic uncertainty has caused conventional equity investors to favor investment in government bonds with high credit ratings (EC, 2013). Investors in VRE projects often include small and medium-sized utilities (e.g. in Germany) (Jacobs, 2012), but their ability to access equity financing is relatively limited (EC, 2013). In Europe, senior executives in the renewable energy sector have expressed concerns over whether sufficient equity is available to finance the offshore wind prescribed by the EU's 2020 national action plans (Freshfields Bruckhaus Deringer, 2013). Due to the lack of equity, VRE projects have to rely on a large amount of debt to leverage investments. Although such leverage reduces the WACC (cost of debt is generally lower than cost of equity), still a minimum equity ratio in total capital is required by debt holders (because of the risk concerns of debt holders and the senior nature of debt), which is typically 15% in OECD countries and 40% in non-OECD countries (De Jager et al., 2011; IRENA, 2012).

3.4.2 Limited access to bank lending

Bank lending is the leading external source in financing renewable energy investments. Many national and international development banks have established specific programs targeting renewable energy financing with favorable lending rates. However, loans provided by development banks are limited, because they cannot autonomously create credit (i.e. money) and they have to rely on raising capital from secondary markets (Campiglio, 2016). Commercial

[12] Retained earnings account for 2/3 and1/4 of energy sector corporate financing in OECD and non-OECD countries, and they account for only 2.9% total asset financing for renewable energy investment (excluding large hydro) in 2015 (IEA, 2014a; UNEP and BNEF, 2016).

[13] A few financial vehicles have emerged in recent years, such as corporate/project green bonds, institutional investors, crowd funding and YieldCos, but they are currently marginal and under-developed, especially in developing countries (IEA, 2014a; UNEP and BNEF, 2014).

banks create credit to provide loans, but they can be biased against VRE investments due to the perception of unattractive risk-return profiles and relatively short track records (Narbel, 2013; Umamaheswaran and Rajiv, 2015; Campiglio, 2016). Moreover, VRE investments, featuring typically smaller nameplate capacity than fossil-fired electricity generation, tend to face disproportionately ***higher due diligence costs*** to obtain loans from commercial banks, due to the significance of economies of scale (WB and CIF, 2013; IPCC, 2011). This may exclude small and medium projects to access bank loans (WB and CIF, 2013; Hamilton, 2010). Last but not least, access to bank lending is affected by ***side-effects of monetary policy***. To date, many central banks (e.g. Eurozone, Japan) have introduced a negative interest rate policies to address excess liquidity and stimulate economic growth (Demiralp et al., 2017; Hannoun, 2015). This seems to increase the incentives for lending and be beneficial for VRE investments. However, empirical evidence shows that it has actually increased the lending rate in economically underperforming countries, especially in vulnerable countries (e.g. Italy, Spain, Portugal) which experienced severe stress during the recession (Demiralp et al., 2015). This is because banks in these countries have a limited ability to pass on profit losses resulting from negative rates to their depositors, and they tend to charge a higher lending rate to compensate for the reduced profits (Demiralp et al., 2015; Stiglitz, 2016). Post-recession macro-prudential regulations, such as Basel III at the global level and Solvency II at EU level, can also tighten the terms and conditions for financing renewable energy, because they focus on banks' short-term liquidity, solvency and stability (Narbel, 2013; IEA, 2014a; Campiglio, 2016). They are expected to significantly reduce both the availability and period of bank lending (Narbel, 2013). Eckhardt (2012) has estimated that the maximum bank lending period in the future is likely to be below seven years (Narbel, 2013). This is especially harmful for capital-intensive VRE investments that require long-term financing (typically 12-15 year) to cost-effectively spread the upfront costs over their operating lifetime (IRENA, 2012).

4. Synthesis and policy implications

This paper develops an integrated framework that analyzes barriers to VRE investments through a literature review-based analysis. The framework covers most barriers to VRE investments identified in the existing body of literature. Figure 5 presents an overview of this framework, where each box represents a specific barrier elaborated on previously, and the arrow establishes the causal-relationship between two barriers. This framework connects barriers to different stages of the investment decision-making process which is closely related to the project life of VRE assets. Thus it expands the knowledge base on the key mechanisms through which different barriers hinder the realization of VRE investments and enables relevant stakeholders to better diagnose these barriers. Policy implications can also be drawn from the consultation of such a framework. They can help policy-makers and regulators to design effective instruments to address the barriers and safeguard necessary VRE investments consistent with the 2 °C climate target.

Figure 5. Overview of the integrated framework for barriers to VRE investment

The framework confirms the importance of risk reduction for VRE investments, as suggested by a few authors (see e.g. Michelez et al., 2011; Angelopoulos et al., 2016; Angelopoulos et al., 2017). It shows that most barriers can find their impacts, either directly or indirectly, on the economic appeal of VRE investments, which is reflected in the reduced expected NPV or NPV-at-risk value. Barriers in the iterative economic appraisal process chiefly exhibit a negative affect over the sufficiency and/or volatility of the expected revenue, while barriers at other decision-making stages tend to increase the project developer's risk perception and be ultimately fed into the discount rate. To address the impacts of these barriers, policy-makers should design instruments that can improve the risk-return profile of VRE investments. This requires not only the mitigation of actual risks (e.g. social acceptance risks, policy uncertainty risks, revenue volatility risks), but also the addressment of psychological, behavioral and institutional attributors that increase the risk perception. Effective risk reduction necessitates more stable and credible policy instruments that can deliver long-term visibility. They should also be able to target multiple stakeholders involved in VRE investments, including the project developer, capital providers, the general public and locals. Risk reduction can have multiple benefits that contribute to a positive investment decision. In addition to increasing the economic appeal of the project, it increases the chance of progressing the project from investment intention to development action during the preliminary risk scanning stage. Furthermore, It can accelerate the completion of the project development stage and reduce development costs. A reduced risk profile also increases the willingness of capital providers to finance the VRE project at the capital access stage.

Following the integrated framework, two additional main policy implications can be drawn:

Firstly, barriers at different decision-making stages can be distinguished into what we call "**symptomatic**" and "**fundamental**" barriers. The former describes a specific symptom or phenomenon that hinders the decision-making process to move forward, while the latter is the root cause behind this symptom. With the help of arrows in figure 5, they can be easily identified. Symptomatic barriers can be addressed through policy instruments targeting the symptom itself or fundamental barriers that cause such symptom. We argue that addressing fundamental barriers is more effective and has more long-lasting effects when compared to only addressing the symptomatic barrier. For instance, as a symptomatic barrier, revenue insufficiency can be addressed by subsidies from support policy schemes, which can have rapid effects. This solution alone cannot solve the fundamental causes of the symptom, (e.g. unfavorable electricity market conditions, unfavorable policy and the lack of level playing field). We have shown that if not carefully designed, it may even exacerbate the fundamental barriers (e.g. through price distortion effect of production-based support schemes), increase the subsidy level needed, and cause other side-effects (e.g. increased surcharge levels for consumers). Instead, solving fundamental barriers (through establishing a level playing field, directly targeting market failures and adapting the electricity market to increased VRE generation) can eliminate these concerns.

Secondly, when designing instruments to support VRE investments, policy-makers should not overlook negative interactions with other policy instruments or with the well-functioning of the electricity market. Negative interactions not only undermine the effectiveness of a single policy instrument, but also reduce efficiency of the overall policy mix. This research demonstrates that macroeconomic policies can have negative impacts on VRE investments. For instance, austerity measures in fiscal policy can constrain government budgets, reducing the support level for VRE investments. Side-effects of monetary policy (e.g. negative interest rates, macro-prudential regulations) can increase the lending rate and decrease the availability of bank loans for VRE investments. Therefore, the authors argue that a comprehensive policy framework to support VRE investments should not be only limited to the narrow context of climate and energy policy and the electricity market. It should be incorporated into a broader context that also includes monetary and fiscal policies. When redesigning these macroeconomic policies, their potential negative impacts on other policy objectives (e.g. energy transition and VRE investments) should be considered and corresponding measures should be taken to minimize these impacts.

5. Recommendations for further research

This paper provides a comprehensive and up-to-date review-based analysis of barriers to VRE investments, based on the development of an integrated framework that represents different stages of the investment decision-making process. Different barriers identified from the existing body of literature and their causal-relationships are well-integrated into such a framework. However, the developed framework can be improved in a few aspects. This also illuminates directions for further research.

First, this framework connects barriers to VRE investments with the investment decision-making process, based on the underlying rationale that barriers increase the likelihood of the investment decision being rejected. It allows the identification and analysis of different types of barriers from existing literature sources, as well as their attributes and relationships, in a straightforward and qualitative manner. However, application of this framework alone is insufficient to disclose the relative size and significance of each identified barrier in terms of the impact on investment decision-making. To complement this research, the authors suggest further studies to quantitatively assess this aspect. These could be conducted through a case study or a survey-based logistic regression analysis. These studies would also be supportive to verify and refine the developed integrated framework that represents the investment decision-making process.

Second, the framework is developed to represent the investment decision-making process for VRE investments, where facing the three states of unknowns (i.e. risks, uncertainties and ignorance) is inevitable. While ignorance is barely conquerable and should be treated warily at best, the framework in this paper assumes (unquantifiable) uncertainties can be reduced to (quantifiable) risks through assigning a (subjectively) estimated probability. Such a reductionist approach allows the application of probabilistic models (e.g. Monte Carlo simulation) to tackle uncertainties in investment decision-making, especially in the economic appraisal process. Despite its convenience, this approach cannot fully tackle uncertainties in the case of events associated with probabilities that cannot be estimated, and the existence of more than one possible probability distribution. A complementary scenario analysis appears to be capable of addressing this issue and it can include unpredictable system-wide structural change events (e.g. changing the infrastructure of the energy system, changing the rules of the electricity market, changing subsidy schemes) into the decision-making process. Under different scenarios, the relevance of each barrier identified in this paper can differ. Low reliability of the input parameters (e.g. for the economic appraisal) also gives rise to uncertainties in the investment decision-making. The combination of a qualitative pedigree analysis and a quantitative sensitivity analysis can better deal with such uncertainties (van der Sluijs et al., 2005). To take all these into account, the authors propose further model-based studies to develop algorithms which can better allow for uncertainties in the investment decision-making process.

Third, because of zero direct emission, VRE investments are considered more environmentally sustainable than fossil-fired electricity generation projects. Hence, the developed framework in this paper mainly focuses on the risk and economic aspects of investment decision-making from the project developer's perspective. However, from a broader view of sustainability, the environmental and social aspects throughout the entire life cycle (including the supply chain) of the underlying VRE investments are as equally important as the economic aspect. Accomplishing certain steps of the project development stage (e.g. EIA and permits acquisition) usually requires a certain level of social and environmental performance of VRE investments, but it is not sufficient to guarantee a high level of sustainability. Although more stringent sustainability criteria are not mandatary for VRE investments (and thus do not constitute barriers), they are expected to be respected. These criteria can include a low embodied energy/emission; a short energy/emission payback period; limited impact on biodiversity; and the use of locally available supply chain, labour and feedstocks etc. To incorporate sustainability criteria into VRE investments, a multi-criteria decision-making process can be established. An accompanying full life cycle assessment (LCA), which includes Environmental LCA, Social LCA and Life-cycle cost analysis, is needed to support such decision-making. Future studies are recommended to explore this area.

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Reference

ADB (2014), Guidelines for Wind Resource Assessment: Best Practices for Countries Initiating Wind Development, Asian Development Bank (ADB), Manila, Philippines.

Andor, M. and Voss, A. (2016), Optimal renewable-energy promotion: Capacity subsidies vs. generation subsidies, Resource and Energy Economics 45 (2016): 144-158.

Angelopoulos, D., Bruckmann, R., Jirous, F., Konstantinaviciute, Noothout, P., Psarras, J., Tesniere, L. and Breitschopf, B. (2016), Risks and cost of capital for onshore wind energy investments in EU countries, Energy & Environment 27 (2016): 82-104.

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

Auer, H. and Burgholzer, B. (2015), Opportunities, Challenges and Risks for RES-E Deployment in a fully Integrated European Electricity Market, Market4RES.

Auer, J. (2011), Grid Regulation in Competitive Electricity Markets: Methods, Implementation, Experience, and Requirement for the Future, Habilitation Thesis, Energy Economics Group (EEG), Vienna University of Technology, Vienna, Austria.

Baker, H. K. and Nofsinger, J. R. (2010), Behavioral Finance: Investors, Corporations and Markets, John Wiley & Sons, Hoboken, New Jersey.

Baker, P. and Gottstein, M. (2011), Advancing both European market integration and power sector decarbonization: key issues to consider, Briefing Paper by the Regulatory Assistance Project (RAP), Brussels, Belgium.

Barron-Gafford, G. A., Minor, R. L., Allen, N. A., Cronin, A. D., Brooks, A. E. and Pavao-Zuckerman, M. A. (2016), The Photovoltaic Heat Island Effect: Larger solar power plants increase local temperatures, Scientific Report 6 (2016).

Barth, V. and Siebenhuner, B. (2010), Sustainable investment decisions by medium sized power producers, Ökologisches Wirtschaften 2 (2010): 44-50.

Basit, A., Hansen, A. D., Margaris, I, Hansen, J. C. (2012), A Review of Grid Requirements for Wind Farm in Denmark and China, Paper presented at China wind power 2012, Beijing, China.

Bertsch, V., Hall, M., Weinhardt, C. and Fichtner, W. (2016), Public acceptance and preferences related to renewable energy and grid expansion policy: Empirical insights for Germany, Energy 114 (2016): 465-477.

SEMI PV Group (2011), China's Solar Future: A Recommended China PV Policy Roadmap 2.0, SEMI PV Group, Shanghai, China.

BMWi (2015), An electricity market for Germany's energy transition: White Paper by the Federal Ministry for Economic Affairs and Energy, Berlin, Germany.

Branker, K., Pathak, M. and Pearce, J. M. (2011), A Review of Solar Photovoltaic Levelized Cost of Electricity, Renewable and Sustainable Energy Reviews 15 (2011): 4470-4482.

Campiglio, E. (2016), Beyond carbon pricing: The role of banking and monetary policy in financing the transition to a low-carbon economy, Ecological Economics 121 (2016): 220-230.

Carlisle, J. E., Solan, D., Kane, S. L. and Joe, J. (2016), Utility-scale solar and public attitudes towards siting: A critical examination of proximity, Land Use Policy 58 (2016): 491-501.

CEER (2016), Key support elements of RES in Europe: moving towards market integration, Council of European Energy Regulators (CEER), Brussels, Belgium.

Chaves-Avila, J. S., Wurzburg, K., Gomez, T. and Linares, P. (2015), The Green Impact: How Renewable Sources Are Changing EU Electricity Prices, IEEE Power and Energy Magazine 13 (2015): 29:40.

Coulon, M., Khazaei, J. and Powell, W.B. (2015), SMART-SREC: A stochastic model of the New Jersey solar renewable energy certificate market, Journal of Environmental Economics and Management 73 (2015): 13-21.

De Jager, D. and Rathmann, M. (2008), Policy instrument design to reduce financing costs in renewable energy technology projects, by order of IEA-RETD, Ecofys, Utrecht, Netherlands.

De Jager, D., Klessmann, C., Stricker, E., Winkel, T., de Visser, E., Koper, M., Ragwitz, M., Held, A., Resch, G., Busch, S., Panzer, C., Gazzo, A., Roulleau, T., Gousseland, P., Henriet, M. and Bouille, A. (2011), Financing Renewable Energy in the European Energy Market, by order of DG Energy, Utrecht, Netherlands.

De Vries, L. J. and Hakvoort, R. A. (2003), The question of generation adequacy in liberalized electricity markets, Delft University of Technology, Delft, Netherlands.

Del Rio, P. (2011), Analysing future trends of renewable electricity in the EU in a low-carbon context, Renewable and Sustainable Energy Reviews 15 (2011): 2520-2533.

Del Rio, P., Janeiro, L., Klessmann, C. and Genoese, F. (2015), What will be the main challenges for the design of renewable electricity policy in the EU?, A report compiled within the European IEE project towards 2030dialogue.

Deloitte (2014), Establishing the investment case Wind power, Deloitte Statsautoriseret Revisionspartnerselskab, Copenhagen, Denmark.

Demiralp, S., Eisenschmidt, J. and Vlassopoulos, T. (2017), Negative interest rates, excess liquidity and bank business models: Banks' reaction to unconventional monetary policy in the euro area, KOÇ UNIVERSITY-TÜSİAD ECONOMIC RESEARCH FORUM WORKING PAPER SERIES, Sarıyer/Istanbul, Turkey.

Deutsch, M., Gerken A. S., Peter, F., Let's talk about risk: Why we need more than the EU Emissions Trading System to foster investment in wind and solar PV, Discussion Paper, Prognos AG, Berlin, Germany.

Diebold, F. X., Doherty, N. A. and Herring, R. J. (2008), The Known, the Unknown, and the Unknowable in Financial Risk Management: Measurement and Theory Advancing Practice, Princeton University Press, Princeton, United States and Oxford, United Kingdom.

Diekmann, J., Breitschopf, B. and Lehr, U. (2016), Social Impacts of Renewable Energy in Germany – Size, History and Alleviation, Institute of Economic Structures Research (GWS), Osnabrück, Germany.

Donovan, C. W. (2015), Renewable energy finance: powering the future, Imperial College Press, London, United Kingdom.

EC (2013), Green Paper Long-term Financing of the European Economy, COM(2013) 150 final, Brussels, 25.3.2013.

EC (2014), European Commission from the Commission Guidelines on State aid for environmental protection and energy 2014-2020 (2014/C 200/01), Official Journal of the European Union, 28.6. 2014.

Eckhardt, M. T. (2012), Scaling up the financing of renewable energy, Managing Director, Citigroup, USD, 2nd New Energy Forum, October 2012, Guangzhou, China, 2012.

Ecorys (2008), Assessment of non-cost barriers to renewable energy growth in EU Member States – AEON, prepared for DG Energy and Transport, Ecorys, Rotterdam, Netherlands.

Edner, G. and Paulsson, A. (2013), Increased Transparency in Valuation: Extending the DCF Model with Monte Carlo Simulation, Copenhagen Business School, Copenhagen, Denmark.

Effendi, P. and Conrvisanos, J. (2012), Political aspects of innovation: Examining renewable energy in Australia, Renewable Energy 38 (2012): 245-252.

Enevoldsen, P. and Sovacool, B. K. (2016), Examining the social acceptance of wind energy: Practical guidelines for onshore wind project development in France, Renewable and Sustainable Energy Reviews 53 (2016): 178-184.

Fagiani, R. and Hakvoort, R. (2014), The role of regulatory uncertainty in certificate markets: A case study of the Swedish/Norwegian market, Energy Policy 65 (2014): 608-618.

Finon, D. (2013), The transition of the electricity system towards decarbonization: the need for change in the market regime, Climate Policy 13 (2013): 130-145.

Fischer, C. and Preonas, L. (2010), Combining Policies for Renewable Energy: Is the Whole Less than the Sum of Its Parts, International Review of Environmental and Resource Economics 4 (2010): 51-92.

Fontaine, A., Galmiche, F. and Flament, A. (2016), Recommendations for implementation of long term markets (energy and capacity) 2020 - 2050, Market4RES.

Fougner, J. (2011), Cost of capital in a wind generated electricity project: An alternative approach of estimating cost of capital, Department of Economics and Business Administration, Faculty of Economics and Social Science, University of Agder, Kristiansand, Norway.

Freshfields Bruckhaus Deringer (2013), European Offshore Wind 2013: Realizing the opportunity.

Frew, B. A., Milligan, M., Brinkman, G., Bloom, A., Clark, K. and Denholm, P. (2016), Revenue Sufficiency and Reliability in a Zero Marginal Cost Future, National Renewable Energy Laboratory (NREL), Golden, Colorado.

Galgoczi, B. (2015), Europe's energy transformation in the austerity trap, European Trade Union Institute (ETUI), Brussels, Belgium.

Gamel, J., Menrad, K. and Decker (2016), Is it really all about the return on investment? Exploring private wind energy investor's preferences, Energy Research & Social Science 14 (2016): 22-32.

Gatzert, N. and Kosub, T. (2016), Risks and risk management of renewable energy projects: The case of onshore and offshore wind parks, Renewable and Sustainable Energy Reviews 60 (2016): 982–998.

Groot, J., Richstein, J.C. and De Vries, L.J. (2013), Understanding power plant investment decision processes, 13th IAEE European Energy Conference, Dusseldorf, Germany.

Grubb, M., Hughs, N., Smith, A. Z. P. and Drummond, P. (2016), Electricity in Transition: Economic and Policy Dimensions, Research Report Submission to the House of Lords Economic Affairs Committee's Inquiry into The Economics of UK Energy Policy, UCL.

Gruning, C. and Ulf, Moslener (2016), Tackling the barriers to Climate Friendly Investment, 2016 Berlin conference on global environmental change: transformative global climate governance "aprés Paris", Berlin, Germany.

Hamilton, K. (2010), Scaling up Renewable Energy in Developing Countries: finance and investment perspectives, Energy, Environment & Resource Governance Programme Paper 02/10, CHATHAM HOUSE, London, United Kingdom.

Hampl, N. and Wustenhagen, R. (2013), Management of Investor Acceptance in Wind Power Megaprojects: A Conceptual Perspective, Organization, Technology & Management in Construction: an International Journal 4 (2013): 571-583.

Hannoun, H. (2015), Ultra-low or negative interest rates: what they mean for financial stability and growth, Bank for International Settlements, at the Eurofi High-Level Seminar, Riga, Latvia.

Helms, T., Salm, S. and Wustenhagen, R. (2015), Investor-specific cost of capital as explanatory factor for heterogeneity in energy investment decisions – A conceptual model, Sustainable Energy Policy and Strategies for Europe 14th IAEE European Energy Conference, Rome, Italy.

Henrich, C.S. (2014), Market and Policy Outlook for Renewable Energy in Europe and CIS, United Nations Environment Programme (UNDP), New York, United States.

Hirth, L. and Ziegenhagen, I. (2015), Balancing power and variable renewables: Three links, Renewable and Sustainable Energy Reviews 50 (2015): 1035-1051.

Hirth, L., Steckel, J. C. (2016), The role of capital costs in decarbonizing the electricity sector, Environmental Research Letters 11 (2016).

Hirth, L., Ueckerdt, F. and Edenhofer, O. (2015), Integration costs revisited – An economic framework for wind and solar variability, Renewable Energy 74 (2015): 925-939.

Hogan (2017), Follow the missing money: Ensuring reliability at least cost to consumers in the transition to a low-carbon power system, The Electricity Journal 30 (2017): 55-61.

Hogan, W. W. (2013), Electricity scarcity pricing through operating reserves, Economics of Energy & Environmental Policy 2 (2013): 65-86.

Huijts, N. M. A., Molin, E. J. E. and Steg, L. (2012), Psychological factors influencing sustainable energy technology acceptance: A review-based comprehensive framework, Renewable and Sustainable Energy Reviews 16 (2012): 525-531.

IEA (2014a), World Energy Investment Outlook Special Report, International Energy Agency (IEA), Paris, France.

IEA (2014b), The Power of Transformation: Wind, Sun and the Economics of Flexible Power Systems, International Energy Agency (IEA), Paris, France.

IEA (2015), Energy and Climate Change – World Energy Outlook Special Report, International Energy Agency (IEA), Paris, France.

IEA-RETD (2015), Integration of Variable Renewables (RE-INTEGRATION), [A. Conway; Mott MacDonald] IEA Implementing Agreement for Renewable Energy Technology Deployment (IEA-RETD), Utrecht, Netherlands.

IPCC (2011), Annex III Recent Renewable Energy Cost and Performance Parameters, IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, Cambridge University Press,Imgay, Cambridge, United Kingdom and New York, United States.

IRENA (2012), Financial Mechanisms and Investment Frameworks for Renewables in Developing Countries, Internal Renewable Energy Agency (IRENA), December, 2012.

Jacob, D., Couture, T. D., Zinaman, O. and Cochran, J. (2016), RE-TRANSITION: Transitioning to Policy Frameworks for Cost-Competitive Renewables Final Report, IEA-RETD, March 2016.

Jacobs, D. (2012), Renewable Energy Policy Convergence in the EU: The Evolution of Feed-in Tariffs in Germany, Spain and France, Routledge Taylor& Francis Group, London, United Kingdom and New York, United States.

Jagannathan, R., Matsa, D. A., Meier, I. and Tarhan, V. (2016), Why do firms use high discount rates, Journal of Financial Economics 120 (2016): 445-463.

Jami, A. A. N. and Walsh, P. R. (2014), The role of public participation in identifying stakeholder synergies in wind power project development: The case study of Ontario, Canada, Renewable Energy 68 (2014): 194-202.

Janeiro, L., Klessmann, C., Wigand, F. and Grave, K. (2016), Phasing out economic support to mature renewables?: Drivers, barriers and policy options, A report complied within the European IEE project towards2030- dialogue.

Jotzo, F. and Mazouz, S. (2015), Brown coal exit: A market mechanism for regulated closure of highly emissions intensive power stations, Economic Analysis and Policy 48 (2015): 71-81.

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

Kitzing, L., Morthorst, P. E., Mitchell, C. (2014), Risk Implications of Energy Policy Instruments, PhD Thesis, Department Management Engineering, Technical University of Denmark, Roskilde, Denmark.

Klessmann, C. Rathmann, M., de Jager, D., Gazzo, A., Resch, G., Busch, S. and Ragwitz, M. (2013), Policy options for reducing the costs of reaching the European renewables target, Renewable Energy 57 (2013): 390-403.

Knebel, A., Hartman, J. and Kajimura, R. (2016), Opinions on Renewables – A Look at Polls in Industrialised Countries, Renews Kompakt, Berlin, Germany.

Koch, N., Fuss, S., Grosjean, G. and Edenhofer, O. (2014), Causes of the EU ETS price drop: Recession, XDM, renewable policies or a bit of everything? – New evidence, Energy Policy 73 (2014): 676-685.

Langer, K., Decker, T. and Menrad, K. (2017), Public participation in wind energy projects located in Germany: Which form of participation is the key to acceptance?, Renewable Energy 112 (2017): 63-73.

Lantz, E. and Flowers, L. (2010), IEA Wind Task 28 Social Acceptance of Wind Energy Projects "Winning Hearts and Minds" State-Of-The-Art-Report Country report of: United States, IEA Wind, Paris, France.

Lehmann, P., Creutzig, F., Ehlers, M-H., Friedrichsen, N., Heuson, C., Hirth, L. and Pietzcker, R. (2012), Carbon Lock-Out: Advancing Renewable Energy Policy in Europe, Energies 5 (2012): 323-354.

Liu, W. L., Wang, C., Mol, A. P. J. (2013), Rural Public Acceptance of Renewable Energy Deployment: The Case of Shandong in China, Applied Energy 102 (2013): 1187-1196.

Lundmark, R. and Pettersson, F. (2012), The Economics of Power Generation Technology Choice and Investment Timing in the presence of Policy Uncertainty, Low Carbon Economy 3 (2012): 1-10.

Luthi, S. and Prassler, T. (2011), Analyzing policy support instruments and regulatory risk factors for wind energy deployment – A developers' perspective, Energy Policy 39 (2011): 4876-4892.

Luthi, S. and Wustenhagen, R. (2012), The price and policy risk empirical insights from choice experiments with European photovoltaic project developers, Energy Economics 34 (2012): 1001-1011.

Masini, A. and Menichetti, E. (2013), Investment decisions in the renewable energy sector: An analysis of non-financial drivers, Technologies Forecasting and Social Change 80 (2013): 510-524.

Michelez, J., Rossi, N., Blazquez, R., Martin, J.M., Christensen, D., Peineke, C., Graf, K., Lyon, D. and Stevens, G. (2011), Risk Quantification and Risk Management in Renewable Energy Projects, IEA-RETD, Utrecht, Netherlands.

Moula, M. M., Maula, J., Hamdy, M., Jung, N. and Lahdelma, R. (2013), Researching social acceptability of renewable energy technologies in Finland, International Journal of Sustainable Built Environment 2 (2013): 89-98.

Möhlenhoff, J. (2013), Cost to Consumers: A fairer cost allocation mechanism of the feed-in tariff is needed, Renews Kompakt, Renewable Energies Agency, Berlin, Germany.

Munoz, J. I. and Bunn, D. W. (2014), Investment risk and return under renewable decarbonization of power market, Climate Policy, 13 (2013): 87-105.

Narbel, P.A. (2013), The likely impact of Basel III on a bank's appetite for renewable energy financing, , Department of Business and Management Science, Norwegian School of Economics, Bergen, Norway.

Neuhoff, K. (2005), Large-Scale Deployment of Renewables for Electricity Generation, Oxford Review of Economic Policy 21 (2015): 88-110.

Nelson, D., Huxham, M., Muench, S. and O' Connell, B. (2016), Policy and Investment in German renewable energy, Climate Policy Initiative.

OECD (2016), OECD Business and Finance Outlook 2016, Organisation for Economic Co-operation and Development (OECD), 2016.

Oliveira, T. (2015), Support Schemes and the Integration Costs of Renewable Generation, Faculdade de Economia (FEP), Universidade do Porto, Porto, Portugal.

Ondraczek, J., Komendantova, N. and Patt, A. (2015), WACC the dog: The effect of financing costs on the levelized cost of solar PV power, Renewable Energy 75 (2015): 888-898.

Outka, U. (2012), Environmental Law and Fossil Fuels: barriers to Renewable Energy, Vanderbilt Law Review 65 (2012): 1679-1721.

Oxera (2011), Discount rates for low-carbon and renewable generation technologies, Prepared for the Committee on Climate Change, Oxera, Oxford, United Kingdom and Brussels, Belgium.

Park, C. S. (2015), Contemporary Engineering Economics (6th Edition), Pearson Education Limited, London, United Kingdom.

Pistorius (2015), The Rhetoric of Investment Theory – The Story of Statistics and Predictability, PhD Thesis, Erasmus Universiteit Rotterdam, Rotterdam, Netherlands.

REN21 (2015), Renewables 2015 Global Status Report, Annual Reporting on Renewables: Ten years of excellence, Renewable Energy Policy Network for the 21st Century (REN21), Paris, France.

Ricciardi, V. (2008), The Psychology of Risk: The Behavioral Finance Perspective, Fabozzi, Frank. J. editor, The Handbook of Finance Volume 2: Investment Management and Financial Management, John Wiley & Sons, New Jersey, United States

Richardson, D. (2008), The tax treatment of capital investments in renewable energy, The Australia Institute.

Richstein, J. C., Chappin, E. J. L. and de Vries, L. J. (2015), Adjusting the CO2 cap to subsidised RES generation: Can CO2 prices be decoupled from renewable policy?, Applied Energy 156 (2015): 693-702.

Roth, S. (2014), Palen Solar project Dropped by developers, The Desert Sun, November 24, 2014, http://www.desertsun.com/story/tech/science/energy/2014/09/26/palen-solar-plant-developers/16294531/, accessed on November 22rd 2016.

Scharff, R. (2015), Design of Electricity Markets for Efficient Balancing of Wind Power Generation, PhD Thesis, KTH Royal Institute of Technology, Stockholm, Sweden.

Schwanitz, V. J. and Wierling, A. (2016), Offshore wind investments - Realism about cost development is necessary, Energy 106 (2016): 170-181.

Sijm, J. P. M. (2014), Cost and revenue related impacts of integrating electricity from variable renewable energy into the power system – A review of recent literature, Energy research Centre of the Netherlands (ECN), Petten, Netherlands.

Smink, M., Hekkert, M. P. and Negro, S. O. (2015), Keeping sustainable innovation on a leash? Exploring incumbents' institutional strategies, Business Strategy and the Environment 24 (2015): 86-101.

Sovacool, B., Enevoldsen, P., Koch, C. and Barthelmie, R. J. (2017), Cost performance and risk in the construction of offshore and onshore wind farms, Wind Energy 20 (2017): 891-908.

Springer, R. (2013), A Framework for Project Development in the Renewable Energy Sector, National Renewable Energy Laboratory (NREL), Golden, Colorado.

Stern, N. (2008), The Economics of Climate Change, American Economic Review: Papers & Proceedings 98 (2008): 1-37.

Stiglitz, J. (2016), The problem with negative interest rates, The Guardian, Monday 18 April 2016, https://www.theguardian.com/business/2016/apr/18/the-problem-with-negative-interest-rates, accessed on February 15th, 2017.

Stirling, A. (1994), Diversity and Ignorance in Electricity Supply Investment: Addressing the Solution Rather Than the Problem, Energy Policy 22 (1994): 195-216.

Swider, D. J., Beurskens, L., Davidson, S., Twidell, J., Pyrko, J., Pruggler, W., Auer, H., Vertin, K. and Skema, R. (2008), Conditions and costs for renewables electricity grid connection: Examples in Europe, Renewable Energy 33 (2008): 1832-1842.

Tetra Tech (2011), Supporting Wind Power Take-Off In THE SARI/ENERGY Region, Energy Security Report, prepared for United States Agency for International Development, New Delhi, India.

Umamaheswaran, S. and Rajib, S. (2015), Financing large scale wind and solar projects – A review of emerging experiences in the India context, Renewable and Sustainable Energy Reviews 48 (2015): 166-177.

UNEP and BNEF (2014), Global Trends in Renewable Energy Investment 2016, United Nations Environment Programme (UNEP) and Bloomberg New Energy Finance (BNEF), Frankfurt am Main.

UNEP and BNEF (2016), Global Trends in Renewable Energy Investment 2016, United Nations Environment Programme (UNEP) and Bloomberg New Energy Finance (BNEF), Frankfurt am Main.

UNFCCC (2015), Adoption of the Paris Agreement, United Nations Framework Convention on Climate Change (UNFCCC), 2015.

Valentine, S. V. (2011), Emerging symbiosis: Renewable energy and energy security, Renewable and Sustainable Energy Reviews 15 (2011): 4572-4578.

Van der Elst, C. and Bosch, P. (2012), An Outlook for Renewable Energy in the Netherlands, Rabobank Industry Note #320, Rabobank International, Utrecht, Netherlands.

Vandezande, L., Meeus, L., Belmans, R., Saguan, M. and Glachant, J-M., Well-functioning balancing markets: A prerequisite for wind power integration, Energy Policy 38 (2010): 3146-3154.

Van Hulle, F., Pineda, I. and Wilczek, P. (2014), Economic grid support services by wind and solar PV – a review of system needs, technology options, economic benefits and suitable market mechanisms, Final publication of the REserviceS project, September 2014.

Van Hulle, F. (2015), Ancillary services from offshore windfarms in the Netherlands, TKI Offshore Wind, Utrecht, Netherlands.

Van der Sluijs, J., Craye, M., Funtowicz, S., Kloprogge, P., Ravetz, J. and Risbey, J. (2005), Combining Quantitative and Qualitative Measures of Uncertainty in Model-Based Environmental Assessment: The NUSAP System, Risk Analysis 25 (2005): 481-492.

Van Winsen, F., Wauters, E., F., Lauwers, L., De Mey, Y., Van Passel, S. and Vancauteren, M. (2011), Combining risk perception and risk attitude: A comprehensive individual risk behaviour model, The European Association of Agricultural Economists (EAAE) 2011 Congress, Zurich, Switzerland.

Verhaegen, R., Joseph, P., Pinjani, A., Brooks, L., Baatar, B. and Flament, A. (2016), Final Report Documenting the Cost of Regulatory Delays (RE-DELAYS), IEA-RETD, Utrecht, Netherlands.

Voormolen, J. Junginger, H. and van Sark, W. (2016), Unravelling historical cost developments of offshore wind energy in Europe, Energy Policy 88 (2016): 435-444.

Waissbein, O., Glemarec, Y., Bayraktar, H. and Schmidt, T. S. (2013), Derisking Renewable Energy investment: A Framework to Support Policymakers in Selecting Public Instruments to Promote Renewable Energy in Developing Countries, United Nations Environment Programme (UNDP), New York, United States.

Walter, G. and Gutscher, H. (2010), Public Acceptance of Wind Energy and Bioenergy Projects in the Framework of Distributive and Procedural Justice Theories: Insights from Germany, Austria and Switzerland, Universitat Zurich and the Advisory House AG, Zurich, Switzerland.

WB and CIF (2013), Financial Renewable Energy Options for Developing Financing Instruments using Public Funds, The World Bank (WB) and Climate Investment Funds (CIF).

Weber, E. U. and Hsee, C. (1998), Cross-Cultural Differences in Risk Perception, But Cross-Cultural Similarities in Attitudes Towards Perceived Risk, Management Science 44 (1998): 1205-1214.

Wickham, P. (2006), Strategic Entrepreneurship 4th edition, Pearson Education Limited, Essex, United Kingdom.

Wustenhagen, R. and Menichetti, E. (2012), Strategic choice for renewable energy investment: Conceptual framework and opportunities for future research, Energy Policy 40 (2012): 1-10.

Wustenhagen, R., Wolsink, M. and Burer, M. J. (2007), Social acceptance of renewable energy innovation: An introduction to the concept, Energy Policy 35 (2007): 2683-2691.

Ye, S. D. and Tiong, R. L .K. (2000), NPV-at-Risk Method in Infrastructure Project Investment Evaluation, Journal of Construction Engineering and Management 126 (2000): 227-233.

Zane, E. B., Bruckmann, R., Bauknecht, D., Jiroux, F., Piria, R., Trennepohl, Bracker, J., Frank, R. and Herling, J. (2012), Integration of electricity from renewables to the electricity grid and to the electricity market - RES-integration, Final Report for DG Energy, Berlin, Germany.

Zeckhauser, R. (2014), New Frontiers Beyond Risk and Uncertainty: Ignorance, Group Decision, and Unanticipated Themes, Preface in Handbook of the Economics of Risk and Uncertainty, Elsevier, Oxford, United Kingdom and Amsterdam, Netherlands.

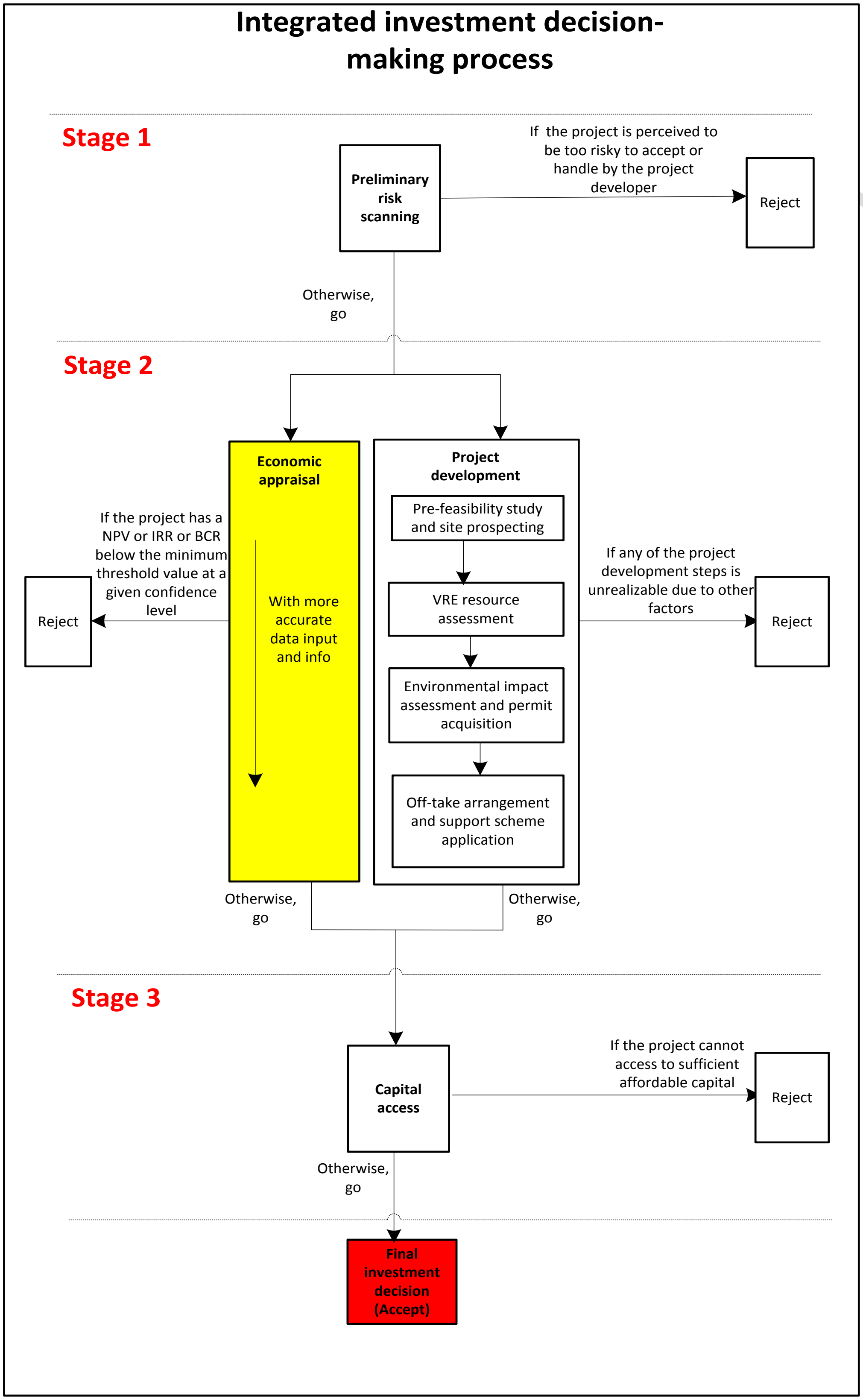

Figure 1. Integrated framework for VRE investment decision-making process

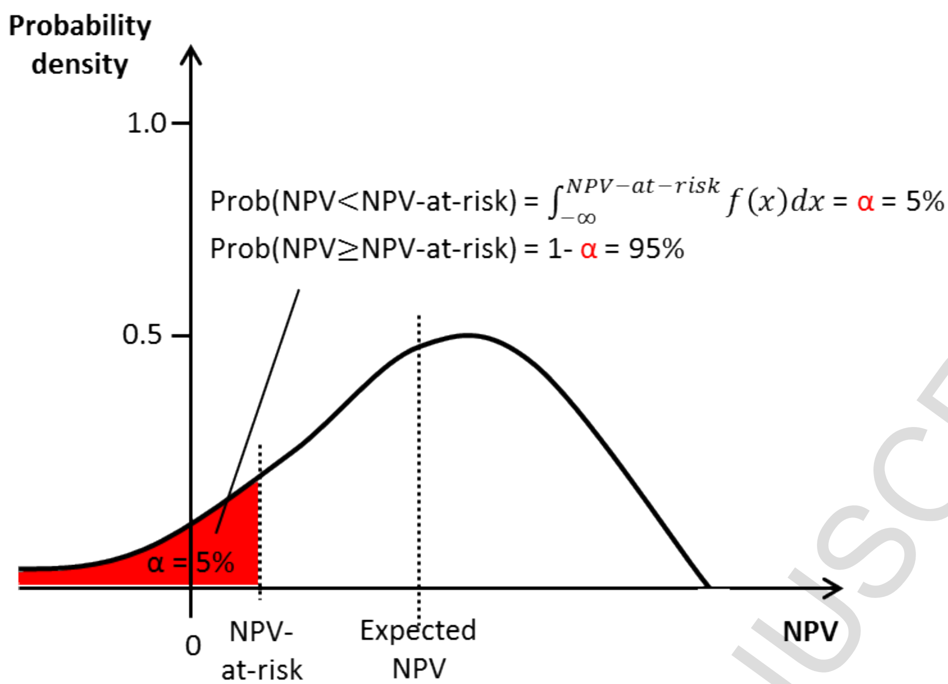

Figure 2. Probability density function of NPV and NPV-at-risk at 5 percentile

Source: adapted from Ye and Tiong (2000)

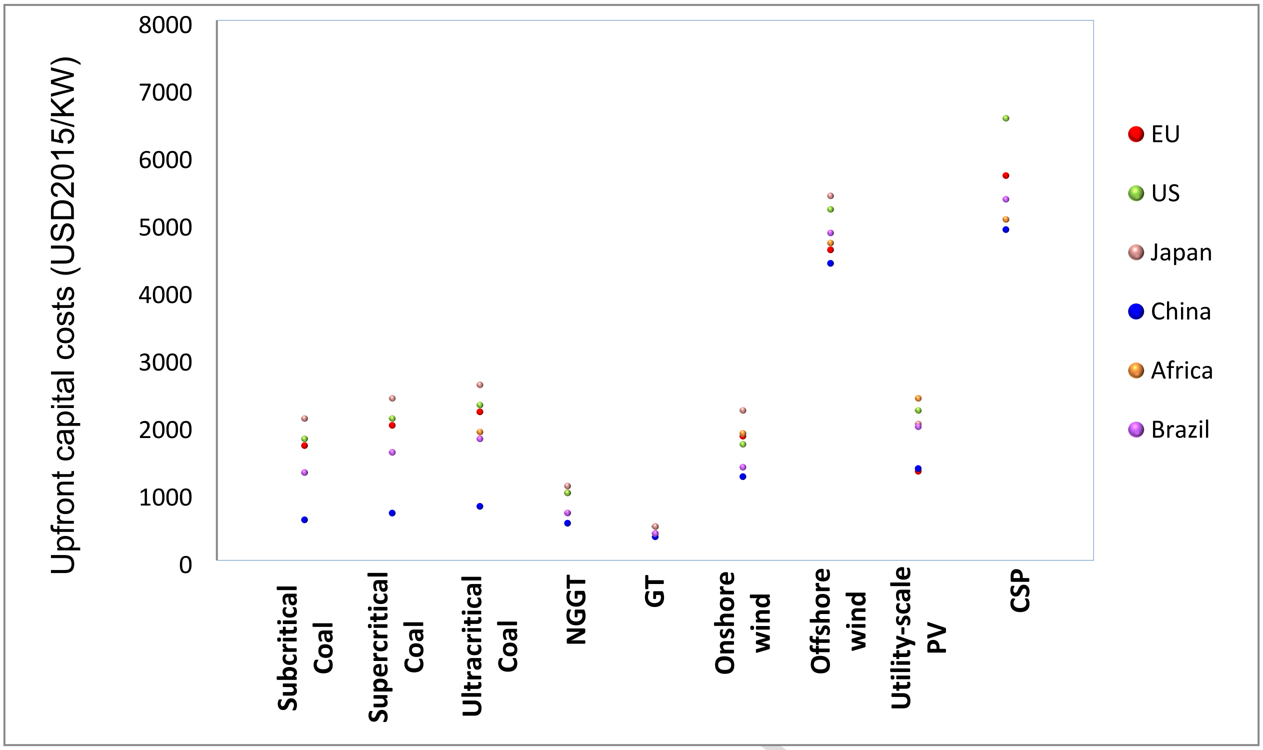

Figure 3. Unit upfront capital costs for investments in different fossil-fired electricity and VRE generation technologies

Source: data derived from IEA (2016)

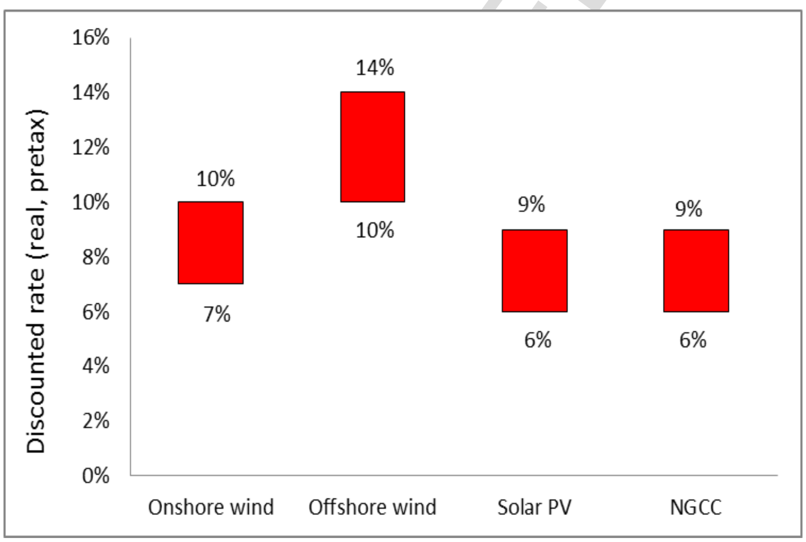

Figure 4: Discount rate ranges for investments in different VRE technologies and NGCC

Source: data derived from Oxera (2011)

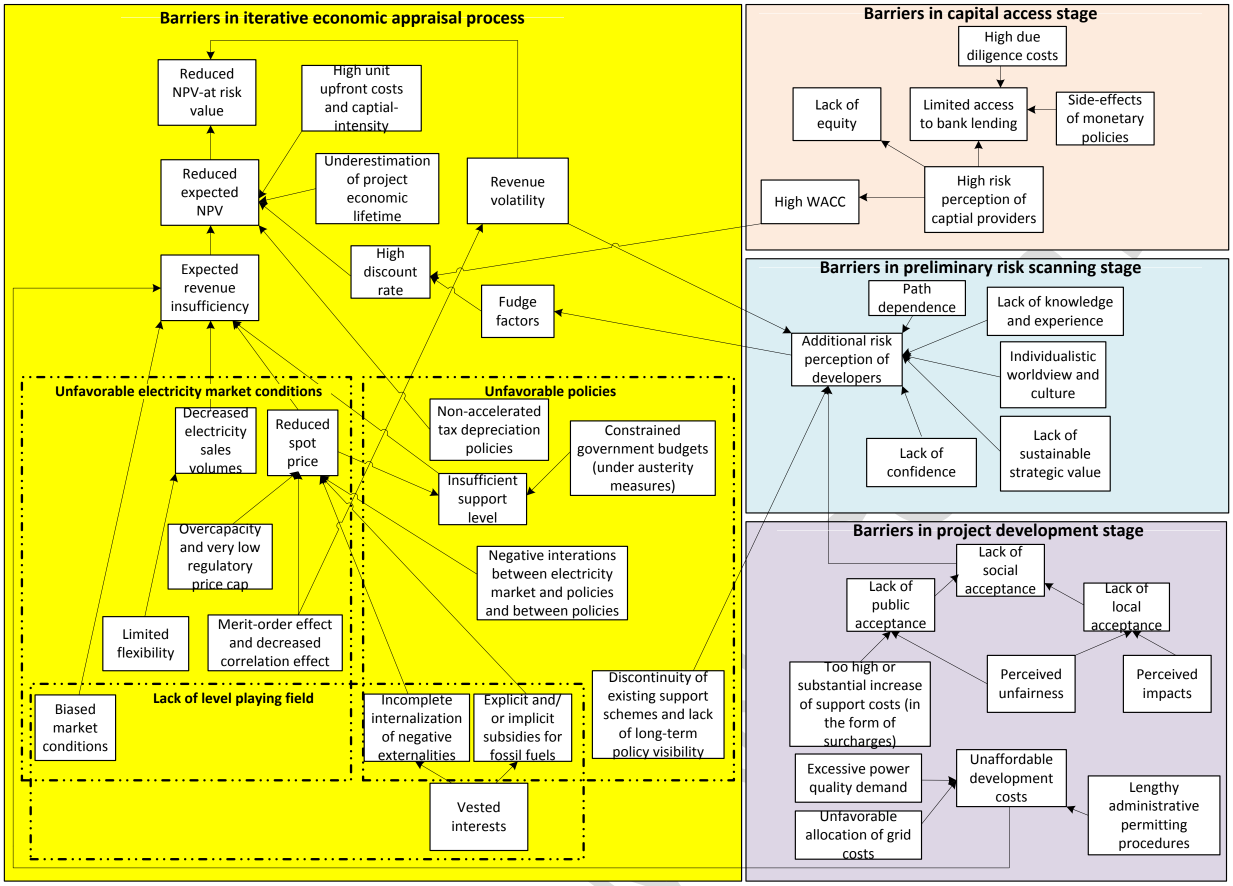

Figure 5. Overview of the integrated framework for barriers to VRE investments

Highlights

- An integrated framework based on VRE investment decision-making process was developed
- Barriers to VRE investments at different decision-making stages were analyzed
- "Symptomatic" and "fundamental" barriers were distinguished
- Side-effects of macroeconomic policy on VRE investments were demonstrated

Table 1. Summary of reviewed literature sources

Academic literature sources	Peer-reviewed journal papers	60
	Textbooks, professional books, PhD theses, conference/working/discussion papers published by academic organizations	29
Non-academic literature sources	Government documents (e.g. European Commission, OECD) and reports published by organizations affiliated to the government (e.g. IEA, IEA-Renewable Energy Technology Development, World Bank)	22
	Government-funded project reports	10
	Consultancy/think-tank/association reports and column articles (e.g. Bloomberg New Energy Finance)	19
Total		140