DETERMINANTS FOR THE MARKET DIFFUSION OF RENEWABLE ENERGY TECHNOLOGIES

An analysis of the framework conditions for non-residential photovoltaic and onshore wind energy deployment in Germany, Spain and the UK

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

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ABSTRACT

The deployment of renewable energy (RE) technologies for electricity generation is a central element of the European energy and climate strategy and was laid down in binding targets on EU-level. The actual RE technology diffusion is, however, shaped by the framework conditions and support measures implemented in the individual EU Member States.

This dissertation aims at contributing to a more integrated view of the influencing factors (determinants) for the deployment of RE technologies. To this end, a conceptual framework is drawn up to assess the boundary conditions for RE diffusion from the RE developer's perspective. The framework is operationalised using a composite indicator (CI) approach and applied in a diffusion model to allow the anticipation of possible future technology deployment. The thesis concentrates on two mainstream RE technologies, namely onshore wind and non-residential PV, and focuses on European countries.

Within the analysis, particular emphasis is placed on providing a holistic assessment of the impact of economic and non-economic determinants on the diffusion of RE technologies at national level. The assessment aims at understanding RE developers' preferences and rationalities regarding the overall framework conditions for RE deployment in order to identify the drivers for and barriers to technological change and to facilitate efficient policy design and regulatory transformation.

The most relevant diffusion determinants from the viewpoint of RE project developers are identified through literature research and moderated expert workshops. The relative relevance of the determinants in the diffusion process is then assessed based on an EU-wide questionnaire that resulted in the collection of >200 datasets. Building on this broad empirical basis, a composite indicator (CI) is developed for the diffusion of non-residential PV and wind onshore. The CI provides a transparent framework for the quantification of the diffusion determinants and allows an evaluation and benchmarking of national RE frameworks.

In a further step, the CI is integrated in a diffusion model which enables projections of possible future market developments under different configurations of the national RE framework. This modelling approach applies and further develops established logistic models of technology diffusion. The overall approach is validated by applying it to three case study countries: Germany, Spain and the United Kingdom. Data collection in these case study countries involved, among others, semi-structured interviews with 31 RE experts. The different regulatory framework conditions in the three countries lead to

different CI results and projected technology diffusion. The results verify the robustness of the approach and the applicability of the concept to different national contexts.

The findings of this thesis contribute to the methodological and empirical basis for understanding and modelling technology diffusion processes in general and RE technology diffusion in particular. The approach developed in this thesis further improves the scientific basis for the evaluation of RE support policies and can contribute to RE targets being achieved in an efficient and sustainable way.

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ACRONYMS

ACER Agency for the Cooperation of Energy Regulators

bn Billion

CEER Council of European Energy Regulators

CFD Contract for Difference

CI Composite Indicator

CSP Concentrated Solar Power

DNO Distribution System Operator

EC European Commission

EU European Union

FIT Feed-in Tariff

FIP Feed-in Premium

GW Gigawatt

IPP Independent Power Producer

IQR Inter Quartile Range

ktoe Kilo tons of oil equivalents

LCOE Levelized Cost of Electricity

MENA Middle East and North Africa

Mio. Million

MW Megawatt

NREAP National Renewable Energy Action Plan

OECD Organisation for Economic Cooperation and Development

PJ Petajoule

PV Photovoltaic

PPA Power Purchase Agreement

RE Renewable Energy

RES Renewable Energy Sources

RES-E Electricity from Renewable Energy Sources

RET Renewable Energy Technology

RO Renewables Obligation

ROC Renewable Obligation Certificate

TSO Transmission System Operator

TWh Terawatt hour

TEU Treaty on the European Union

TFEU Treaty on the Functioning of the European Union

TGC Tradable Green Certificate

UK United Kingdom

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INTRODUCTION AND CONTEXT

This chapter briefly introduces the policy background against which the development of renewable energy (RE) in the European Member States takes place and, on this basis, establishes the motivation, research questions and methodological requirements of this thesis. Thereby, section 1.1 provides a short outline of how RE deployment is embedded in the context of the European RE strategy and targets while section 1.2 presents the most common economic support schemes that are applied to promote RE development on national level. Apart from economic support, also the relevance of framework factors which are not directly related to the economic support of RE is widely acknowledged. This is set out in section 1.3. Against this background, the central research questions of this thesis relate to the role of economic and non-economic framework factors for the diffusion of RE technologies in the EU. The problem definition, research questions and methodological requirements are described in sections 1.4, 1.5 and 1.6. Section 1.7 provides an outline of the structure of the thesis.

1.1 THE EUROPEAN RENEWABLE ENERGY STRATEGY

The energy policy of the European Union (EU) is centred around the objectives to ensure security of energy supply and to realize an integrated, competitive European economy and an ecologically sustainable energy sector. Thereby, apart from the promotion of electricity network interconnections especially energy efficiency and the deployment of RE technologies play a vital role (European Commission, 2008, Art. 194 TEU). The cornerstones of the European RE strategy are defined by the 2009 European Directive on the Promotion of the Use of Energy from Renewable Sources (Directive 2009/28/EC) (European Commission, 2009a). It defines a binding target share of 20% RE in final energy consumption and a share of 10% biofuels in the transport sector on a European level by 2020 (see figure 1). On this basis, each European Member State is obliged to translate the EU-level targets into binding targets on national level by preparing a 'National Renewable Energy Action Plan' (NREAP) (European Commission, 2010). The NREAPs specify a binding target for the national gross final energy consumption from renewable energy sources (RES) and indicate objectives for the RES shares per sector (electricity, heating and transport), the envisaged technology mix and planned deployment trajectories until 2020. They further describe the support measures and policies implemented to reach the stated objectives. Furthermore, each Member State is obliged to present a report on the progress towards the attainment of it's NREAP targets to the European Commission every two years starting in 2011 (European Commission, 2013c).

For the period 2020-2030, the EU Member States have agreed on an EU-wide target share of at least 27% RE in final energy consumption, a 27% improved energy efficiency and a reduction of greenhouse gas emissions by 40% (compared to 1990 levels) (European Commission, 2014d). However, no binding targets on Member State level have been defined for the period after 2020. Until 2050 the EU is committed to reduce greenhouse gas emissions by 80-95% relative to 1990 levels (European Commission, 2012c). It is acknowledged that renewable energy sources (RES) will have a major share in this extensive decarbonisation of the European energy sector with an EU-wide RES share of at least 55% in gross final energy consumption by 2050 (European Commission, 2012c). In the electricity sector RES will have a major contribution to reaching this target. Figure 1 displays the actual and envisaged shares of RES in the overall energy consumption (RES overall) and in the electricity sector (RES-E) of the EU-28.

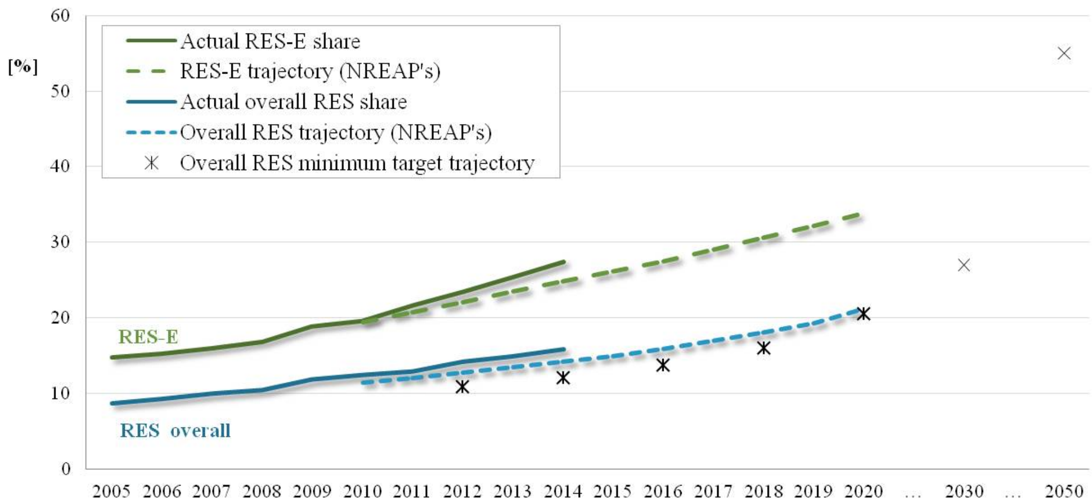

Figure 1: Historical and envisaged share of RES in the final energy consumption (RES overall) and in the electricity sector (RES-E) of the EU Member States (EU-28) until 2050. Sources: Own illustration. Actual RES shares based on EUROSTAT (2014), 2020 targets according to European Commission (2009a), 2030 target according to European Commission (2014d) and 2050 objective in line with European Commission (2012c).

The measures and support policies by means of which the individual EU Member States achieve the RE targets fall within their national responsibility and legal competence. The most common economic support instruments used across the EU are briefly introduced in the subsequent section 1.2. Although the EU Member States are generally autonomous in choosing the instruments for RE support, the European Commission has provided best practice guidelines on the design of RE support schemes (European Commission, 2013b). This guidance document particularly highlights the importance of common approaches in support scheme design (e.g. for determining costs and setting support levels), the establishment of competitive allocation processes for RE support and the reduction of grid- and market related barriers.

This is also emphasized in the EU Commission's 'Guidelines on State aid for environmental protection and energy 2014-2020' (European Commission, 2014c) which define terms and conditions to be met when providing economic support for RE in order to safeguard undistorted competition in the EU internal market. The key requirements put forward by these guidelines are that existing RE support schemes are to be replaced by market-based instruments including competitive elements as well as a gradual opening of national support schemes to other Member States.

In this context, also the endeavours of the EU Commission regarding the completion of the European internal gas and electricity markets (with the corresponding legislative packages of 1996, 2003 and 2009) have laid important groundwork for the liberalization and step-wise harmonization of the regulatory frameworks in the EU Member States. The legislation emphasizes especially the relevance of an EU-wide full ownership unbundling and a high level of transparency in the electricity sector, fair and harmonized conditions for network access as well as greater cooperation between regulatory authorities and transmission system operators (TSO) and the protection of consumer rights (European Commission, 2014f). Nevertheless, the goal of reaching a fully integrated European energy market with harmonised regulatory framework conditions is not yet realised and there are still substantial differences between the EU Member States regarding the level of implementation of best practices in RE policies and market regulation (see e.g. ACER/CEER (2014, 2015), CEER (2013, 2015) and European Commission (2012a, 2013a,b, 2014b)).

1.2 Economic support instruments for renewable energy

All EU Member States have implemented economic support instruments to facilitate the attainment of their RES-E targets. This section intends to provide a concise overview over the most common economic support schemes for RES-E and their application across the EU and to outline the recent trends in RES-E policies.

Promotion schemes for RES-E can be classified in various different ways[1]. A common distinction, however, differentiates between generation-based and investment-based support. Thereby, generation-based support implies that economic incentives for RES-E are provided per unit of generated electricity (i.e. per MWh) over a defined time period, whereas investment-based support lowers the initial investment in the RES-E generation facility, for example, through loan programs or investment tax allowances. An alternative differentiation of support instruments distinguishes between price-driven and quantity-driven mechanisms, whereby price-driven means that the price level for RES-E

1 A detailed discussion of possible classification approaches is provided, for example, by Steinhilber (2015).

is modified through political intervention, whereas in a quantity-based scheme a desired volume or target share of RES-E is fixed while the price is determined based on supply and demand on the market.

The most common **generation-based support** schemes used across the EU are feed-in tariffs (FIT) and feed-in premiums (FIP), which are both price-driven instruments, and quota obligations which are quantity-driven. Often the generation-focused incentives are combined with additional investment-based support (European Commission, 2013b).

A FIT is an instrument that provides a guaranteed price per unit of electricity (i.e. per kwh) which is paid to eligible RES-E producers. Usually, a FIT also implies a warranty that the produced electricity is actually purchased by a utility or system operator. Therefore, the RES-E generator has a guaranteed income over the designated support period. In a FIP system, a defined premium is paid as a supplement to the income that RES-E producers receive from selling their electricity on the market. However, finding a buyer for the electricity is subject to the responsibility of the generator. The price-driven support through FIT, and increasingly also through FIP schemes, is the most commonly applied economic support for RES-E across the EU. Some examples of EU Member States that apply FIT systems are France, Portugal, Greece, Austria, Hungary, Bulgaria, Estonia or Ireland. Feed in premium schemes as main support instrument are currently implemented in Denmark, Finland, the Netherlands, the Czech Republic and Estonia. Several EU countries also apply combinations of FIT and and FIP schemes (e.g. Germany and Italy) or FIT and quota schemes (UK and Belgium).

Under a quota scheme, the government stimulates the demand for RES-E by imposing an obligation, usually to the electricity suppliers, to provide a defined target share of RES-E in their generation portfolio. To measure the target attainment, 'Tradeable Green Certificates' (TGC) are issued per unit of RES-E generated. The certificates can be traded at a certificate market while the electricity itself is sold independently at the electricity market. The overall revenue for the RES-E generator is the sum of the electricity price and the TGC price. The certificate price depends on the supply and demand of TGCs on the market. Thus, the definition of the target quantity of RES-E in a quota scheme is critical to ensure that the competition at the certificate market allows for attractive incentives for existing and new RES-E generators. If the quota target is set too low, this could lead to an oversupply of certificates which would cause a deterioration in TGC prices while an overly ambitious quota could lead to a target shortfall.

Therefore, for quantity-driven instruments like quota schemes, it is particularly important to be able to anticipate a realistic future market growth for RES-E technologies to allow for definition of adequate quota targets. To safeguard that the defined target quantities in a quota scheme are actually reached, monitoring and penalty systems need to be implemented. Examples of EU countries that have currently implemented quota schemes are Sweden, Poland and Romania. A combination of quota and FIT schemes is applied in the UK and Belgium.

Investment-based support is often granted in form of investment tax reductions or tax exemptions, investment subsidies or through low interest loans for the initial capital expenditure for the RES-E facility. Mostly the support is given per installed unit of generating capacity (Haas et al., 2011). Investment incentives are often used to provide complementary support for certain RE technologies or for specific stakeholder groups (e.g. small-scale investors). Most EU Member States have integrated some elements of investment-based support as an additional instrument in their national RES-E promotion schemes (European Commission, 2013b).

All of the above described basic types of generation- and investment-based economic support instruments for RES-E can be customized and designed in further detail in order to meet individual, national requirements. Further differentiation is possible, for example, regarding: the level of support for different RES technologies (e.g. depending on the available natural resources and envisaged technology portfolio); the location and size of RE projects (e.g. taking account of resource quality at different locations or the proportionality of generation costs and project sizes); different investor types (e.g. providing specific support for small-scale developers or certain economic sectors); the duration of the support or possible mechanisms for a gradual reduction of the support level (degression) over time. A detailed description of possible design elements is, for example, provided by Pablo Rio et al. (2012).

In order to add a competitive element to promotion schemes, both, generation-based and investment-based support instruments, can be combined with **tendering schemes** for the allocation of the subsidy. Tendering schemes are quantity-driven instruments meaning that subject of the invitation to tender usually is a designated quantity (i.e. installed capacity or electricity generation) of a certain RES-E technology. The submitted project offers are then evaluated according to defined selection criteria in order to identify those bids with the best cost-performance ratio. The selected projects can either be awarded a form of generation-based support (e.g. via a FIT, FIP or quota scheme) or an investment-based incentive (e.g. an investment grant). Monitoring and penalty mechanisms are typically required in a tendering scheme to ensure that the projects awarded in the tender are actually built and the desired RES-E capacity is reached. Analogue to quota schemes also for tendering schemes it is crucial to have a realistic understanding of the possible future market growth of the concerned RE technologies. Only if the tendered volumes appropriately reflect the potential future RE market development under the given framework conditions, an adequate degree of competition among RE project developers will lead to actual cost-reductions for RE projects (CEER, 2016, p. 18).

Across the EU Member States there is a growing tendency of combining generation-based support instruments with tendering schemes to enhance competition among the market participants and thereby reduce support costs. Tendering schemes have been introduced, for example, in Denmark, France, Germany, Italy, Portugal, Slovenia, the Netherlands and recently also in the UK (see e.g. (European Commission, 2013b, Table 3)).

This development is also strongly driven by the European Commission which demands in it's 'Guidelines on State Aid for Environmental Protection and Energy 2014-2020' (European Commission, 2014c) that competitive bidding processes, i.e. technology-specific tenders, should be introduced by 2017 in all EU Member States to stimulate competition and to ensure that RE support costs are minimized (European Commission, 2014c, paragraphs 109, 110 and 126). According to the European Commission (2014c), after January 2017, all national financial aid to RES-E generation must be granted through competitive bidding processes based on clear, transparent and non-discriminatory criteria. It is further expected that between 2015 and 2016 at least 5% of the added RE capacity in the EU Member States should be allocated through competitive bidding processes (European Commission, 2014c, paragraph 126).

Additionally, the guidelines require that RE support maximizes the integration of RE into the electricity markets (European Commission, 2014c, paragraph 123). Thus, from January 2016 on, all new RE support schemes should oblige RE generators to sell their electricity directly on the market. Subsidies for RE can thus only be granted in form of market premiums or green certificates supplementing the regular market price (European Commission, 2014c, paragraph 124a). Finally, the European Commission demands that national RE support schemes should, in principle, be open to RES-E generated in other EU Member States in order to minimize overall costs and reduce possible distorting effects of national RE subsidies (European Commission, 2014c, paragraph 122).

Overall, the above described trends in the EU Member States and the efforts of the European Commission to realise the internal energy market imply a growing importance of the competitive conditions for RES-E generators on national and on European level. In this context, a close monitoring of the framework conditions for RE development is important for both, following the progress towards the completion of the EU internal energy market and for safeguarding the proper functioning of competitive, market-based RE support schemes.

1.3 NON-ECONOMIC FACTORS FOR RENEWABLE ENERGY DEPLOYMENT

Besides the provision of economic incentives through RES-E subsidy schemes, the establishment of non-discriminatory and innovation-friendly market conditions allowing for genuine competition of RE technologies with conventional generation technologies are highly important. This circumstance has also been acknowledged by the European Commission, for example in the 'Guidance for the Design of Renewables Support Schemes' (European Commission, 2013b) which, apart from the design of RES-E subsidy schemes, explicitly addresses issues related to the grid connection, market integration and administrative procedures for RE projects. Such aspects, although they are not necessarily directly reflected in the economic evaluation of a RE project, can still play an important role when it comes to RE investment decisions. This is supported by numerous studies which point out the importance of such *non-economic factors* for the market diffusion of RE technologies (see e.g. Alagappan, Orans and Woo (2011), Eleftheriadis and Anagnostopoulou (2015), Friebe, Von Flotow and Täube (2014), Lüthi and Wüstenhagen (2012), Margolis and Zuboy (2006), Masini and Menichetti (2013), Painuly (2001) and Richards, Noble and Belcher (2012) and also a growing number of European research projects addresses the topic of bureaucratic, regulatory or other non-economic barriers to RE deployment (e.g. 'AEON-study - Assessment of non-cost barriers to renewable energy growth in EU Member States' (ECORYS, 2010), 'PV-Legal' and 'PV-Grid' (PV Grid, 2014; PV Legal, 2012) or 'Keep-on-Track' (Keep-on-Track!, 2014)). Just to mention a few examples of non-economic factors whose importance for RE deployment is stressed in the literature:

- Reliability of the national (RES-E) policy framework (see e.g. Chowdhury et al. (2014), Friebe, Von Flotow and Täube (2014), González and Lacal-Arántegui (2016), Holburn, Lui and Morand (2010) and Mani (2012);
- Access conditions and diversification of electricity markets (see e.g. Alagappan, Orans and Woo (2011), Held, Ragwitz, Merkel et al. (2010), Margolis and Zuboy (2006), Najdawi et al. (2013) and Painuly (2001));
- Availability of electricity grid capacity and grid access conditions (see e.g. B. Barth, Concas, Binda Zane et al. (2014), Friebe, Von Flotow and Täube (2014), González and Lacal-Arántegui (2016), Holburn, Lui and Morand (2010), Najdawi et al. (2013) and Swider et al. (2008));
- Bureaucratic burdens related to RE project authorisation (see e.g. B. Barth, Concas, Binda Zane et al. (2014), Cena et al. (2010), ECORYS (2010), Holburn, Lui and Morand (2010) and Iglesias, Río and Dopico (2011));
- Social acceptance for RE (see e.g. ECORYS (2010), Margolis and Zuboy (2006) and Najdawi et al. (2013)).

Further factors and a more detailed discussion of the existing literature on non-economic drivers and barriers to RE deployment are presented in chapter 4 section 4.2.1.

The above mentioned empirical evidence makes clear that, in order to gain a comprehensive understanding of RE diffusion processes and to be able to optimize the framework conditions for RE deployment, economic and non-economic barriers have to be equally addressed.

The previous sections have pointed out that the EU has set ambitious targets for the deployment of RE and that RES-E plays a major role in view of the European goals for climate protection, ensuring security of energy supply and realizing an ecologically sustainable and integrated European energy sector (cf. section 1.1). The deployment of RE in the EU is primarily framed by the 2009 RE Directive and is driven by different national schemes providing economic support for RES-E generation, whereby the European Commission pursues a shift towards competitive, market-based subsidy schemes (cf. section 1.2). However, also the relevance of other framework factors, which are not directly related to RES-E subsidies, is widely acknowledged by researchers and policy makers and numerous studies have pointed out that these factors can have a decisive impact on RE diffusion (cf. section 1.3).

Against the background of the efforts of the European Commission to realise an integrated EU energy market and to establish competitive, market-based RE support schemes, a holistic understanding and monitoring of the framework conditions for RE development gains importance. Especially in order to safeguard a fair competition in tendering schemes for RES-E subsidies it is crucial to identify potential non-economic barriers which might distort the competitive price determination. But also for quantity based RE support instruments (i.e. tender or quota schemes) in general it is crucial to be able to realistically anticipate future market sizes of RE technologies to enable an adequate policy design (e.g. for the design of auctions or the definition of quota targets). A central requirement in this regard is a more comprehensive understanding of the relevance of economic and non-economic determinants and how they impact the technology diffusion process. So far, no consistent framework exists to assess these factors and their impact on RE diffusion. Non-economic barriers are usually neglected or strongly simplified in energy economic modelling and thus not sufficiently reflected in energy scenarios.

Eventually, the diffusion process depends on the decisions of individual actors, namely RE project developers and investors, and their preferences and perceptions of the given framework conditions. Therefore, a better understanding of their valuations and assessment criteria is crucial to be able to comprehend and predict diffusion processes; to identify key blocking and enabling factors for the diffusion of RE technologies and to suggest policies which pinpoint the most important factors and which can enable technology diffusion in a cost- and time-efficient way.

The key objective of this thesis is to contribute to a more integrated understanding of RE technology diffusion processes and, in particular, to improve the scientific knowledge base on the impact of non-economic parameters on RE deployment. Thereby, the results also aim to close the gap between economic modelling concepts for the diffusion of RE technologies and qualitative approaches analysing the preferences and decision-making processes of RE project developers and investors. The findings are intended to facilitate the evaluation of policies and support frameworks for RE by providing tools for assessing the conditions for RE deployment and for estimating possible future RE diffusion. This way, the identification of policy measures that enable technology deployment in a cost- and time-efficient way shall be supported.

More precisely, the major objectives of this thesis can be summarized as follows:

- Systematize the most relevant determinants for RE diffusion from the RE developers' or investors' perspective (i.e. develop a general conceptual framework);
- Operationalize these determinants in the form of a composite indicator (CI) for the evaluation of the country-specific framework conditions for RE diffusion;
- Combine the findings in a diffusion model to allow for quantitative projections of the expected future RE market growth under different framework conditions (i.e. allow for assessment of policy scenarios).

To be able to take account of technology-specific characteristics and requirements, the scope of this thesis is limited to two RE technologies, namely onshore wind and non-residential PV installations. The approach is applied to three European case study countries, namely Germany, Spain and the UK.

Corresponding to the above objectives, the central research questions of this thesis can be formulated as follows:

1. Which are the major determinants framing the diffusion of wind energy onshore and non-residential PV and how can they be conceptualized?
2. What is the relevance of these determinants from RE developer's / investor's perspective?
3. How can the determinants be characterized in a quantitative manner and utilized for benchmarking purposes (i.e. an indicator)?
4. How do the determinants reflect in the resulting RE technology diffusion?

A secondary research question is how policies and support measures should be designed in order to adequately address the identified determinants.

As outlined in section 1.5, this thesis aims at a more holistic understanding of the relevance of economic and non-economic framework factors for the deployment of RE technologies and to incorporate them in diffusion modelling tools. Thereby, the focus is on two of the most established RE technologies in the EU, namely wind energy onshore and solar photovoltaic (PV). Regarding PV, the emphasis is on non-residential installations (here installations with a capacity >10 kWp) as these make the major share of installed PV capacity in most EU countries. Also the framework conditions and decision criteria for investments in residential and non-residential PV installations presumably differ, thus a combined assessment of the two technology segments would not be meaningful.

Based on the stated objectives described in section 1.5, the following requirements apply to the research methodology:

- It should consistently capture the relevant decision makers' (i.e. RE project developers' or -investors') perspective;
- It should be transparent, traceable and unbiased to ensure applicability for policy evaluation purposes;
- It should allow for a maximum of transferability (i.e. with respect to different country situations) in order to allow for a broad applicability and comparability of results (i.e. for benchmarking purposes).

In order to meet the above requirements, a combination of qualitative and quantitative research methods is required for the overall research design which are briefly discussed in the following paragraphs. A detailed description of the applied methodology is provided in chapter 3.

Alongside a thorough review of existing literature on the drivers and barriers for RE diffusion the approach draws upon a comprehensive stakeholder consultation process to gain first-hand insights into the relevant stakeholders' (i.e. RE developers and investors) perspectives. Especially as the results aim to serve as tools for policy assessment it must be safeguarded that the analysis is based on a broad empirical basis, avoids arbitrary judgements and considers the relevant stakeholders' viewpoints. To address this issue, different methods are combined, namely moderated group discussions with energy sector experts, a questionnaire-based survey addressing a large number of RE stakeholders across the EU and in-depth interviews with selected RE experts (cf. chapter 3, sections 3.2, 3.3 and 3.5).

To guarantee the transparency and traceability of the approach it should build on proven methods and best practices both for the construction of composite indicators (e.g. the common guidelines for constructing composite indicators provided by OECD (2008)) and for the development of diffusion models in line with general diffusion theory (e.g.

Geroski (2000), Grübler, Nebojsa Nakićenović and Victor (1999) and Rogers (1995)). This is ensured through a thorough review of the relevant streams of literature (cf. chapter 2 and chapter 3, sections 3.2, 3.3 and 3.4).

In order to allow for a broad applicability of the findings (e.g. for country benchmarking), the developed methodology should be designed in a way that allows application to a wide spectrum of country situations (e.g. to more advanced and less developed RE markets). This affects considerations regarding the selection of indicators and scales (i.e. including characteristics that may not apply to EU countries but might be relevant in some non-EU countries). To validate the applicability and transferability of the developed approach it is applied to different country contexts and tested for its robustness under various framework conditions. Thus, case study countries are selected in order to illustrate differences between the role of influential factors for RE diffusion while, at the same time, taking account of the ease of obtaining access to data, i.e. existence of contacts and data availability (cf. chapter 3 section 3.5)).

The present thesis was developed as a research associate at the *Fraunhofer Institute for Systems and Innovation Research* in Karlsruhe (Germany) and as distance-learning PhD student at the University of Exeter between May 2014 and November 2016. A major part of the research was carried out in the frame of the European research project 'DIA-CORE'[2] which focused on a 'Policy dialogue on the assessment and convergence of RES policy in the EU Member States' (DIA-CORE, 2013) and the 're-frame' project[3] which aimed at assessing the drivers and barriers for RE deployment in the EU. In this context, the design and practical implementation of the research were partly influenced by the requirements of these projects.

1.7 OUTLINE OF THE THESIS

Corresponding to the above described research questions and methodological steps, this thesis is structured as follows:

The present introductory chapter (chapter 1) described the general background of the research topic and the context in which the development of RE in the European Member States takes place. It further introduced the research questions and objectives as well as the general methodological requirements of this thesis.

Chapter 2 sets out the theoretical foundation of the most established concepts for technology diffusion (section 2.1) and explains how different streams of research examine and incorporate technology adoption processes (section 2.2). On this basis, the research gap and the selected approach for this thesis are deduced (section 2.3).

2 'DIA-CORE' project website: www.diacore.eu (last accessed 18.7.2016).
3 're-frame' project website: www.re-frame.eu (last accessed 18.7.2016).

In chapter 3 the methodology applied for this research project is explained. The chapter commences with an overview over the major methodological steps of the research process and the requirements by which the research design is motivated (section 3.1). Sections 3.2, 3.3, 3.5 and 3.4 then describe the methods applied for each of the steps in detail. Section 3.6 concludes and summarizes the chapter.

Chapter 4 presents the conceptual and analytical framework for RE diffusion that was developed in the frame of this thesis. The results are presented in line with the methodological steps as explained in section 3: identifying the major determinants in the RE diffusion process (section 4.2), assessing their relative relevance (section 4.3) and translating them into a composite diffusion indicator (section 4.4) and a diffusion forecast model (section 4.5). In section 4.6 the chapter results are summarized and discussed.

In chapter 5 the analytical framework presented in chapter 4 is applied to three case study countries to verify the approach and its applicability to different country situations. To this end, policy scenarios are are introduced (section 5.2) which are applied for modelling possible future diffusion pathways. Then, sections 5.3, 5.4 and 5.5 present the findings for the assessment of the RE frameworks in Germany, Spain and the UK. Each country case study includes an overview over the legal and regulatory framework for RE as regarded for the diffusion indicator. The resulting composite diffusion indicator scores are then used for diffusion forecasts based on the policy scenarios. Section 5.6 provides a summary and discussion of the chapter results.

Chapter 6 summarizes the main results of the the research project and provides a critical assessment of its limitations and its contributions. Thereby, section 6.1 briefly reviews the motivation and research objectives of the thesis and section 6.2 summarizes its major findings. Section 6.3 then discusses the relevance of the outcomes with regard to the energy policy context. Finally, section 6.4 highlights the contributions of the presented work (subsection 6.4.1) and points out its limitations and possible directions for future research activities (subsection 6.4.2).

2

APPROACHES TO ANALYSING TECHNOLOGY DIFFUSION PROCESSES

This chapter begins with an introduction to the theoretical foundation of the most established concepts for technology diffusion (section 2.1). Then, section 2.2 outlines how different streams of research examine and incorporate technology adoption processes. On this basis, the research gap on the interface between diffusion theory and modelling of market development is pointed out in section 2.3.

2.1 DIFFUSION THEORY AND MODELS FOR TECHNOLOGY ADOPTION

The diffusion of innovations describes their gradual uptake by a population of potential adopters over time. Rogers (1995) defines it as *"the process by which an innovation is communicated through certain channels over time among the members of a social system"* (Rogers, 1995, p. 5). Thereby, innovation is defined as *"an idea, practice or object that is perceived as new by an individual or other unit of adoption"*. However, newness does not necessarily refer to the time of invention of the technology or idea but *"may be expressed in terms of knowledge, persuasion, or a decision to adopt"* (Rogers, 1995, p. 11). Accordingly, the diffusion of a technology is a consequence of a multitude of adoption decisions among a population of actors.

According to Rogers (1995), research on the diffusion of innovations dates back to the end of the 19^{th} century when Gabriel Tarde (1843-1904), a French lawyer and judge, began to analyse trends in society based on the legal cases he was confronted with. Tarde observed patterns in the adoption of innovations, namely an uptake by only a small number of individuals in an initial stage followed by a period of broad adoption and finally a slowdown of the process until a saturation point was reached. The resulting adoption rate forms an s-shaped curve (see figure 2). Tarde attributed this common pattern mainly to the fact that individuals tend to imitate the behaviour of others.

Further studies from the area of sociology, but also from other disciplines, such as marketing, education, medicine or economics, have continued observations in the field of diffusion research. Early examples comprise, among others, evidence from rural sociologists studying the diffusion of agricultural practices among farmers in the United States of America. For example, Griliches (1960) investigated the diffusion of hybrid corn and other technical innovations among US American farmers and found that the adoption

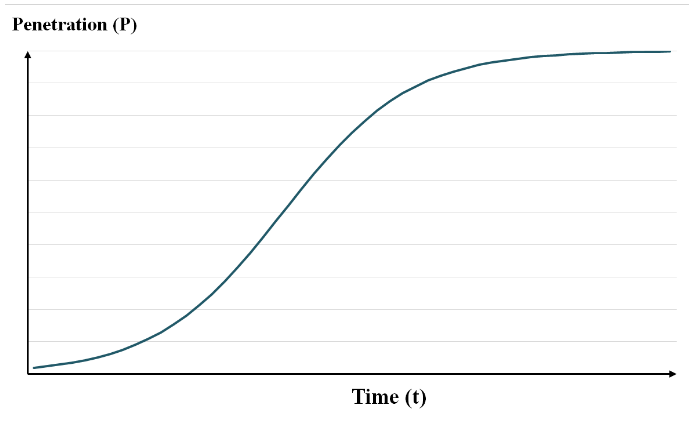

Figure 2: Stylized, s-shaped diffusion curve representing the market penetration (P) of a technology over time (t).
Source: Own illustration.

rate always followed an s-shaped pattern. Mansfield (1961) analysed the diffusion of 12 types of innovations among firms from different economic sectors. His results also found the typical s-shape of the adoption curves. The s-curve pattern in the diffusion of innovations has since been confirmed by a multitude of empirical observations (see, e.g. Geroski, 2000; Grübler, Nebojsa Nakićenović and Victor, 1999; Kemp and Volpi, 2008; Rao and Kishore, 2010; Rogers, 1995) and is thus accepted as the common pattern of adoption processes.

Explanations for the observed s-curve patterns, as brought forward by Tarde or Rogers, emphasize the role of interactive behaviour, such as communication and imitation, for the adoption process. However, these explanatory approaches clearly contrast neo-classical economic theories. Neo-classical approaches are based on the assumptions that individuals at all times maximize usefulness (utility) and/or profits in their choice decisions; that their decisions are based on fully rational and independent preferences; and that all individuals have access to all relevant information (Barber, 1967, pp. 163 et seq.). These assumptions would imply that innovations, as soon as they provide a gain of utility or profit for society, would be adopted instantaneously. However, in reality it can be observed that the adoption of innovations is a slow and gradual process which sometimes takes decades (Mansfield, 1961).

Different concepts exist for explaining diffusion patterns and for identifying the relevant processes governing adoption processes. Generally, external and internal factors influence the adoption decisions of individuals and can be represented in different diffusion models (Mahajan and Peterson, 1985). As a basic classification, Wejnert (2002) distinguishes between three major dimensions governing technology diffusion: the characteristics of the innovation, the characteristics of the potential adopter and the environmental context (see figure 3).

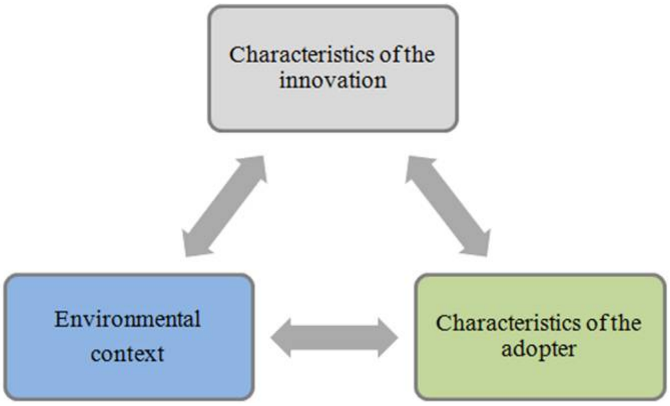

Figure 3: Basic classification of variables influencing the diffusion of innovations.
Source: Own illustration based on Wejnert (2002).

According to Wejnert's classification, the characteristics of the innovation relate particularly to the costs and benefits and the personal and societal consequences of a potential adoption decision. The environmental context refers to geographical settings, societal structure and political conditions, whereas the adopter can be characterized, e.g. through his societal status, socio-economic background, position in social networks and further, personal or cultural characteristics. The above concept thus implies that potential adopters - based on their individual rationalities and abilities - evaluate the advantages and disadvantages of different technologies in the light of the overall contextual background. Wejnert (2002) further emphasizes the relevance of the interactive impact of the diffusion variables and highlights that the interplay of the three dimensions governs the final outcome of the adoption decision.

With regard to the commonly observed, s-shaped diffusion pattern, several explanatory models have been developed which, to different degrees, incorporate the above mentioned dimensions of the adoption process.

A very common concept is the epidemic model which assumes that mainly a lack of information about innovations slows down diffusion processes. Here, the gradual spread of information among the societal members leads to the s-curve, as the adoption process gains momentum with a growing number of adopters interacting with the remaining non-adopters. Thereby, the innovation spreads like an epidemic until the saturation point is reached (Geroski, 2000). However, the epidemic model abstracts from the characteristics of the adopter population and neglects all factors other than communication among the potential adopters. The model is thus most appropriate if mainly external, societal factors affect a diffusion process (Geroski, 2000).

An alternative explanation, the probit model, is focused more on the individual decision making process and assumes that firms have different strategies and abilities which drive them to adopt innovations at different times. This approach takes account of the characteristics of various adopter groups but, for this purpose, requires a detailed knowledge about the relevant factors and thresholds defining the specific time when each group adopts an innovation. Different firms might, for example, vary in terms of profit expectations, their level of risk aversion or their general investment strategy. According to the probit model, the distribution of adopter groups and their individual adoption thresholds finally define the shape of the resulting diffusion curve (Geroski, 2000).

Another approach that takes account of both, exogenous factors and characteristics of the adopter population, but in a more stylized way, is the categorization of general adopter groups by Rogers (1995). He classifies five adopter types, namely innovators, early adopters, the early majority, the late majority, and laggards (see figure 4). The classification of the adopter types refers to their innovativeness, namely their willingness and ability to adopt innovations at a certain time. The classification is based on the adoption time by means of the standard deviation (sd) from the average adoption time (x).

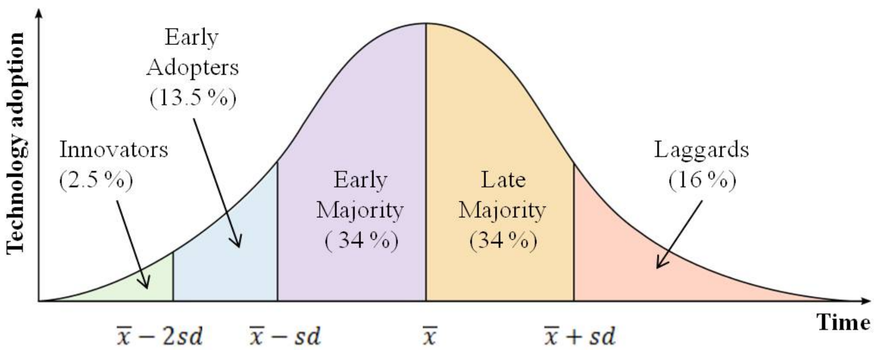

Figure 4: Classification of adopter types based on their level of innovativeness.
Source: Own illustration based on Rogers (1995).

According to Rogers (1995) the five adopter types are characterized as follows:

1. Innovators are characterized as the most venturesome and risk-affine actors with a strong interest in new ideas and well developed communication networks. They also possess the financial capabilities to deal with a high level of uncertainty about innovations and to tolerate potential misinvestments. Innovators only constitute a rather small percentage (2.5%) of the overall potential adopters.

2. Early adopters are less venturous than innovators and they take their decisions based on careful considerations of advantages and disadvantages of an innovation. They are considered as important change agents in diffusion processes, as they are respected and well-connected members of the social system and might thus act as role models for potential further adopters.

3. The early majority is characterized by a strong willingness to adopt innovations but is unwilling to lead the adoption processes. Therefore, it adopts innovations just before the average member of the social system does. It accounts for 34% of the social-system's population.

4. The late majority is cautious and sceptical about innovations and does not adopt unless the risks associated with the innovation are well assessable. As this group possesses relatively scarce resources, the adoption process is rather driven by external pressure than by intrinsic motivations. It accounts for 34% of the members of the social system.

5. The laggards are the last group to adopt innovations and represent the most cautious actors. They are characterized by a low willingness and limited possibilities (i.e. resources) to adopt new ideas. Laggards are traditionalists and do not adopt an idea if any risk of failure is attached to it.

Applying the above described stylized adopter categories to the diffusion of an innovation in a social system again leads to the typical, s-shaped diffusion curve (cf. figure 2). Depending on the benefits, risks and resource requirements related to different types of innovations and in line with the characteristics of the above adopter groups, the steepness of the resulting diffusion curve (i.e. the speed of the technology roll-out) may vary. For example, assuming an innovation that entails low risks and strong benefits or for which particularly favourable framework conditions exist, the adoption threshold for most of the adopter types would be low. In this case, the average adoption time (i.e. the inflection point of the s-curve) is reached earlier and the overall diffusion process is faster compared to innovations whose adoption is more critical for part of the adopter groups.

Further, more complex approaches and models for the explanation of diffusion patterns exist which build, for example, on competition between different innovations and with existing technologies or on information cascades and path dependencies in adoption processes (see e.g. Dreher (1997), Geroski (2000), Mahajan and Peterson (1985) and Rao and Kishore (2010)).

In the context of this thesis, the most important insights from the above are that the gradual diffusion of (technological) innovations is the consequence of a multitude of cumulative adoption decisions of members of a social system. The aggregate of these decisions then translates into a characteristic adoption rate over time (Rogers, 1995). Against this background, it is crucial to understand what drives or prevents potential adopters to implement an innovation and to comprehend their decision criteria. Major parameters in the decision process are the intrinsic properties of the innovation itself, characteristics of the adopter and external factors in the respective market (Wejnert, 2002). Of particular interest in the frame of the present work is the interplay of the valuations and preferences of potential adopters (i.e. RE developers or investors) and the overall context they operate in, namely the economic and non-economic framework conditions for the deployment of RE technologies.
Further, the empirical evidence discussed in this section shows that an s-shaped diffusion curve is a commonly observed pattern for the diffusion of various technical innovations into markets (see e.g. Geroski, 2000; Griliches, 1960; Grübler, Nebojsa Nakićenović and

Victor, 1999; Kemp and Volpi, 2008; Mansfield, 1961; Rao and Kishore, 2010; Rogers, 1995). Therefore, the s-curve is an accepted stylisation of technology diffusion processes and is broadly applied for diffusion modelling (Geroski, 2000; Mahajan and Peterson, 1985; Rao and Kishore, 2010).

2.2 Diffusion of renewable energy technologies in different scientific disciplines

2.2.1 *Energy-economic modelling*

Energy-economic models are tools for ex-ante or ex-post investigation of developments in energy systems. They can be applied for several purposes, for example, to derive scenarios for the future evolution of electricity systems assuming different technical and economic framework conditions or to reproduce and understand historical observations. Energy sector models can be utilized as tools for decision support by both, investors in energy infrastructure who want to gain insights whether an investment will be profitable under given framework conditions, and by policy makers who want to compare possible outcomes of different political measures. Against the background of global climate change, energy-economic models have gained particular importance as instruments for evaluating the impacts of different policy pathways on RE diffusion and global decarbonisation targets (Koch, Harnisch and Blok, 2003).

Typically, energy-economic modelling covers rather a medium- to long-term perspective and is applied in order to compare the outcomes of long-term development pathways. Thereby, the geographical scale can vary from a regional to a global level. Major input parameters for the modelling usually comprise detailed data on available RE resources and assumptions for techno-economic parameters such as the development of technology- and fuel costs, availability and cost of transmission grids, different market mechanisms and emission cost or CO_2 prices, respectively.

There are several types of energy-economic models which vary in their approach, their focus and the level of detail of the analysis. Generally, it can be distinguished between top-down and bottom-up modelling approaches. Top-down models usually consider techno-economic parameters on an aggregated level and with a high degree of abstraction (e.g. supply curves instead of individual supply units), whereas bottom-up approaches feature a more detailed representation of individual characteristics of the energy system and its components (e.g. technologies and actors). Therefore, top-down models allow for investigations on a larger scale, for example, for assessing how energy systems interact with other sectors of the economy. In turn, bottom-up models are able to represent the technical characteristics of the energy system with a higher degree of detail. Also hybrid-approaches between the two types exist (see figure 5). Another classification of electricity models can be based on their emphasis on either a detailed representation of markets, i.e. market rules and strategies of different participants, or on the electricity system as such, with a focus on technical aspects and/or longer time perspectives (Pfluger, 2013). A clear distinction between different model types is, however, not always possible as approaches can be combined and merge into each other. The details of the different model types will not be discussed here. An overview over different modelling approaches and model types is provided, for example, by Koch, Harnisch and Blok (2003), Worrell, Ramesohl and Boyd (2004), Ventosa et al. (2005) and Pfluger (2013).

With the objective of analysing RE diffusion processes in a comprehensive manner, bottom-up models are generally of higher relevance compared to top-down models as they allow for representation of detailed characteristics of technologies and individual actors in the energy system. Therefore, they are able to provide a more realistic picture of diffusion processes. Three major groups of bottom-up models can be distinguished: optimization models, equilibrium models and simulation models (Ventosa et al., 2005).

Optimization models apply optimization algorithms to identify optimal, i.e. mostly least-cost, solutions for the energy system over the regarded time horizon and under consideration of previously defined constraints. These constraints might refer, for example, to the availability of technologies, emission limits, restricted grid capacities or other techno-economic factors. The modelling allows a very detailed representation of technical characteristics. Usually, optimization models assume perfect foresight and completely rational decision making of all actors in the energy system (Koch, Harnisch and Blok, 2003). Consequently, the diffusion of RE technologies in these models represents an ideal, least-cost development and does not account for market imperfections.

Equilibrium models represent the market behaviour and strategies of different actors competing in the energy market while balancing supply and demand of energy. The balance between supply and demand is based on iterative algorithms identifying the optimum solution for all concerned players in the energy market and can be based on different mathematical approaches (see, e.g. Ventosa et al., 2005). The underlying concept of this approach is the neo-classical theory (Koch, Harnisch and Blok, 2003). Therefore, the progression of technology diffusion in these models represents the pure balance between supply and demand.

Simulation models are applied when modelling problems get too complex to be solved by equilibrium models (Ventosa et al., 2005). They build on sets of operational decision rules for actors in the energy system and thus allow for representation of a large variety of interrelations between the energy system's components. Additional factors, such as non-monetary effects of policy measures, strategic behaviour and learning of actors, as well as market imperfections and barriers to technology adoption, can be implemented and reflected in the resulting diffusion patterns. Thus, simulation models are most flexible regarding the comparison of scenario outcomes under variation of a large number of parameters (Ventosa et al., 2005) and thereby most suitable for obtaining a realistic representation of RE diffusion processes (Koch, Harnisch and Blok, 2003). A vast number of simulation models with different applications exists. An overview is presented, for example, by Worrell, Ramesohl and Boyd (2004).

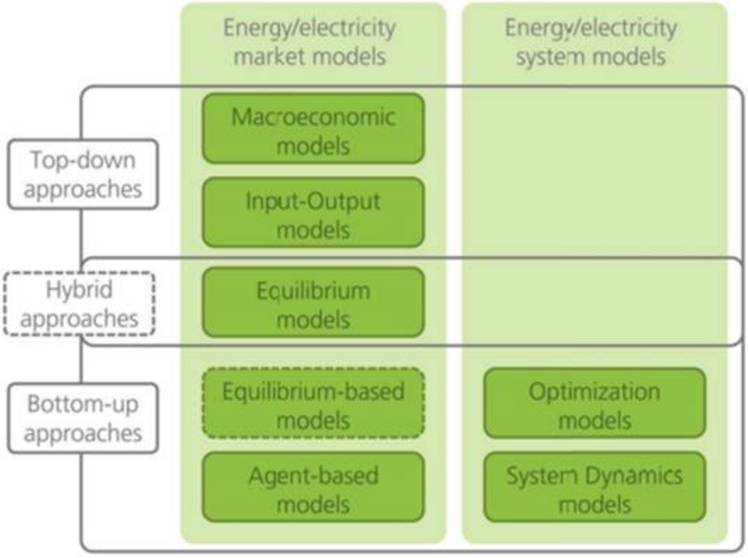

Figure 5: Classification of energy sector modelling approaches.
Source: Included with the kind permission of Pfluger (2013, p. 25)

2.2.1.1 *Non-economic factors in energy-economic models*

As pointed out above, especially simulation models are suitable for integrating large and heterogeneous sets of parameters in RE diffusion scenarios. However, especially the representation of non-economic factors in RE diffusion processes is still difficult to implement due to a lack of empirical data for quantification of these aspects. Worrell, Ramesohl and Boyd (2004) review energy economic modelling approaches with regard to their ability to adequately represent the effects of policy instruments on the diffusion of innovations in the field of energy efficiency (EE). Although their review focuses on EE rather than on RE technologies, their results highlight that there is a general gap in energy models regarding the realistic representation of policy instruments and especially non-monetary policies (Worrell, Ramesohl and Boyd (2004)). In order to improve the relevance of energy models for policy evaluation, the authors point out that: *"New modelling approaches for the decision-making framework (or behavioural representation) and process are needed that can be used in the economic-engineering models. These approaches need to include barrier representation [...], decision-making behaviour, as well as the effect of policies. The impact of non monetary policies and policies aiming to reduce barriers are especially important."* (Worrell, Ramesohl and Boyd, 2004, p. 375). Barreto and Kemp (2008) in their review of the implementation of technology diffusion in energy models support this statement and

emphasize the need for integrating a broader range of parameters, such as regulatory instruments and policy tools, in energy models in order to provide policy makers with more adequate tools for policy assessment.
One possibility to represent non-economic parameters in energy models is the implementation of a diffusion curve which displays the penetration rate (cumulative adoption) for a certain technology over time (cf. section 2.1). The penetration rate can be given in Megawatt per year (MW/a) or as a percentage of the total available potential (%). As described in section 2.1, the diffusion of technologies into a new market usually follows an s-curve pattern. In order to take account of non-economic barriers for technology diffusion, one possible approach is to adapt an optimal diffusion curve of a certain technology according to the predominant non-economic influence factors. Thereby, parameters influencing the diffusion curve can have different effects on the diffusion rate (see figure 6):

- Blocking factor: resulting in no further diffusion of the technology
- Decelerating factor: resulting in a lower diffusion rate
- Accelerating factors: resulting in a higher diffusion rate

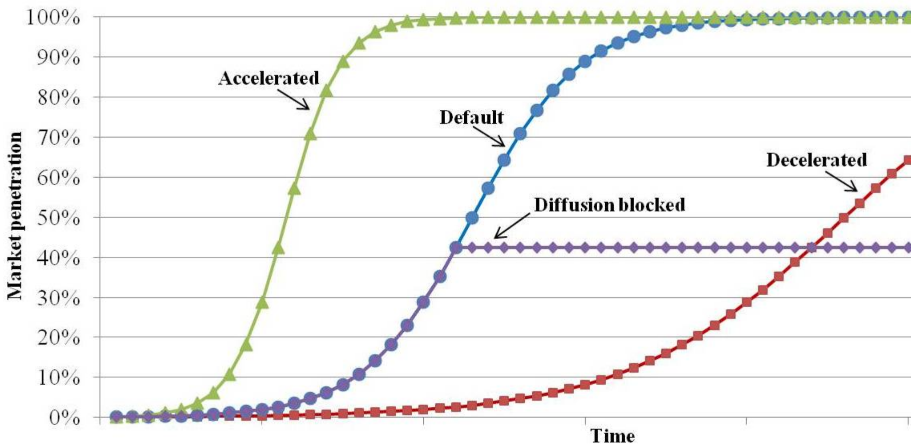

Figure 6: Schematic s-shaped diffusion curves indicating the impact of blocking, decelerating and accelerating factors on RE diffusion.
Source: Own illustration.

2.2.2 *Short-term market forecasts*

In order to provide practical estimations of expected market sizes for RE technologies in the short term, several consultants and technology representatives publish regular market forecasts, for the development of wind and solar technologies. In contrast to quantitative economic modelling, these assessments are usually of qualitative nature and based on observations of past and present market developments combined with the judgements of individual country experts. However, the forecasts explicitly integrate the impact of non-economic factors (such as policy measures, regulatory uncertainty and policy instability) on the expected future diffusion. This makes these market forecasts interesting as reference or guidance for possible trends in market development. However, the methodologies for their derivation are mostly not transparent and traceable but based on the views of individual stakeholders or lobbies which makes them prone to bias and not suitable for policy assessment. Some examples of prominent short-term market forecasts are as follows:

- The International Energy Agency (IEA) publishes yearly reports on the expected medium term development of a broad range of RE technologies in all OECD and some non-OECD countries (IEA, 2012, 2013). The forecast covers a period of five years and is based on past and present market observations and the judgements of local country experts.
- The European Photovoltaic Industry Association (formerly EPIA, now 'Solar Power Europe') publishes regular market outlooks for the global development of grid-connected PV (EPIA, 2014). The outlook covers a period of five years and regards two different scenarios: the 'Business-as-Usual' scenario assumes a steady continuation of the historical diffusion and the 'Policy-Driven' scenario assumes a stronger deployment due to additional policy measures. The methodology is based on analysis of past diffusion trends and consultation of local stakeholders.
- Every two years the Global Wind Energy Council (GWEC) publishes global wind energy reports including four-year market forecasts for wind energy development worldwide (GWEC, 2008, 2010, 2012). The forecasts cover onshore and offshore wind and are based on global policy scenarios and historical deployment trends.

2.2.3 *Composite indicators for country benchmarking*

Analogue to the short-term market forecasts described in section 2.2.2, several institutions have developed composite indicators for evaluating and benchmarking the attractiveness or readiness of markets for RE development. Composite indicators assess individual factors and combine them to an aggregate value in order to allow for a comprehensive representation of relevant framework conditions (OECD, 2008). The aggregate values can be used for comparative purposes (e.g. ranking of countries) or, if time series are collected, for observation of temporal changes (OECD, 2008). The composite indicator approach is relevant for the present research project as it also aims at systematizing the assessment of barriers and drivers for RE development on country level and it allows for comparing them in an international and inter-temporal context. Prominent examples for composite indicators in the field of RE are listed in table 1. Further indicators with different purposes, technological and geographical foci exist. Overviews are provided, for example, by IRENA (2014) or the World Bank (2014).

Table 1: Overview over existing indicators for RE deployment

Indicator	Publisher	Description
Readiness for Investment in Sustainable Energy (RISE)	The World Bank	Measures the country performance regarding 28 individual indicators grouped into the four topics: energy access, energy efficiency, renewable energy and cross-cutting aspects. All indicators score on a scale from 0-100 and are weighted equally when being aggregated to the final indicator. In a first stage the indicator was applied to 17 countries but a global coverage is envisaged. (World Bank, 2014)
Arab Future Energy Index (AFEX)	Regional Centre for Energy Efficiency and Renewable Energy (RCREEE)	Benchmarking of 18 Arab countries regarding their framework for private sector investments in RE technologies (RCREEE, 2013). Scores are allocated in four categories: market structure (openness of market for RE), policy framework (political commitment and support for RE), institutional capacity and finance and investment framework. In total, 25 indicators are assessed, each on a scale from 0-100. Data sources comprise quantitative and qualitative sources. The scores are normalized and aggregated with different weights. Weights are not published and based on expert judgement. The first publication was in 2013, further updates are announced. (RCREEE, 2014)
Climate Scope Index	'Bloomberg New Energy Finance' (BNEF) and 'The Multilateral Investment Fund' (MIF)	Ranking of 26 Latin American and Caribbean countries according to their ability to attract clean energy investments in the past, present and future. The indicator is composed of the four major categories: enabling framework, clean energy investment and climate financing, low carbon business and clean energy value chains and greenhouse gas management activities. The four categories comprise 39 individual indicators (each ranging on a scale 0-5) which are weighted before they are aggregated to the final score. The indicators rely on quantitative and qualitative sources which are denoted transparently. The weightings are based on expert judgements. The first edition of the indicator was published in 2012 and updated in 2013. Further updates are announced. (BNEF, 2013)
RE Country Attractiveness Index (RECAI)	Ernst and Young (EY)	Since 2003, EY publishes quarterly rankings of the RE investment climate in over 40 countries worldwide. The assessment focuses on three categories: macro-level trends, energy market aspects and technology specific aspects. The assessment distinguishes between wind and solar technologies. The three categories comprise 16 different indicators which are weighted before aggregation. Neither the underlying data sources, nor the weightings applied for the ranking are disclosed publicly. (Ernst & Young, 2014)

Table 1: Overview over existing indicators for RE deployment

Indicator	Publisher	Description
Renewable Energy Market Competence Index	Developed by Elrefaei, Bida, Hallouda et al. (2013)	The index was developed as a benchmarking tool for Middle Eastern and North African (MENA) countries comparing their attractiveness for RE against other countries worldwide. It is a predecessor of the 'AFEX' and is composed of 18 indicators in four fields: political and economic framework, energy sector, financial and environmental framework and technology specific aspects. The indicators are aggregated and weighted based on judgement of the authors. The full methodology is explained by Elrefaei, Bida, Hallouda et al. (2013). In Elrefaei, Bida, Elsobky et al. (2013) it has been applied to Concentrated Solar Power (CSP) comparing a selection of eight North African countries with ten benchmarking countries worldwide.
Electricity Market Preparedness Indicator	Developed by Held, Ragwitz, Merkel et al. (2010) in the frame of the 'RE-Shaping' project[1]	The index measures the ability of electricity markets to integrate RES-E. The focus lies on the design and -structure of the electricity market in terms of its preparedness to accommodate RES-E by measuring: the level of unbundling in electricity transmission, the market concentration in generation and retail sectors, the share of electricity traded at spot markets and gate closure times at electricity exchanges. All sub-indicators receive the same weights. The analysis focuses on EU countries and is not technology-specific, although it emphasizes the requirements of fluctuating RES (i.e. wind and solar). (Held, Ragwitz, Merkel et al., 2010).
RE Readiness Score	Developed by Mondal et al. (2013) in the frame of the 'Gulf Cooperation Council Clean Energy Network'	The indicator benchmarks the Gulf States in terms of their general readiness to deploy RE. Three broad categories (infrastructure, institutions, human capital) are regarded which are each composed of several sub-categories. Data collection is partly done via stakeholder consultation (questionnaire based) and partly relies on existing indicators (e.g. the 'Global Competitiveness Report' of the World Economic Forum WEF (2014)). Categories and sub-categories of the indicator score on a scale from 0-7 and are weighted equally. So far, only one edition of the indicator was published (covering 2011- 2012). (Mondal et al., 2013).

Already from the non-exhaustive list presented in table 1 it can be observed that, similar as for the market forecasts (cf. section 2.2.2), also the indicators often lack a transparent description of their methodology, especially regarding the relative weighting of the individual indicators, and of the underlying data sources. This arbitrariness of normalization, weighting and aggregation methods reduces the transparency of the results and makes them prone to bias, which reduces their value as policy tools. Freudenberg (2003) sees a major shortcoming of composite indicators in the subjective selection of weights. It has also been criticised that most indicators strongly focus on market sizes and the level of government subsidies but fail to represent regulatory risks in a satisfactory manner

1 Weblink: www.reshaping-res-policy.eu (last accessed: 5.2.2015).

(Holburn, 2012). As a reaction to the lack of consistent methodologies and the growing number of composite indicators worldwide, the 'Organisation for Economic Cooperation and Development' (OECD) has published guidelines on the construction of composite indicators in form of the 'OECD Handbook on Constructing Composite Indicators' (OECD, 2008). This guideline is a prominent reference and describes best practice methodologies for selection of variables and data treatment.

2.2.4 *Country case studies*

Several studies and research projects have investigated the impact of individual drivers and barriers (including non-economic and regulatory factors) on the adoption of RE technologies on national level. Such country case studies provide important insights into the prevalence of different barriers in individual countries and into how particular determinants affect RE diffusion processes. Therefore, country case studies constitute an important source of information in the overall context of identifying the general determinants for the diffusion of RE technologies. Nevertheless, since such case studies mostly focus on very specific thematic issues and do not follow a uniform methodology, they are not fully comparable and can not necessarily serve for cross-country comparison. Also they typically only provide a one-time, historical and/or status quo assessment and do not imply regular updates or follow up investigations. A few examples of case studies are discussed in the following.

Toke, Breukers and Wolsink (2008) investigate differences in wind energy diffusion based on comparative case studies for Denmark, Spain, Germany, Scotland the Netherlands and Wales/England. Their study lays a particular focus on the role of planning systems, financial support mechanisms, landscape preservation and project ownership patterns. They find that particularly the stable support schemes in Denmark, Germany and Spain had driven wind development, whereas a lack of consistency in support has slowed down the diffusion in the Netherlands, England and Scotland. Local opposition and strict landscape protection rules were identified as barriers for wind energy diffusion especially in Wales and Scotland. In contrast, local project ownership, as prevalent in Denmark, Germany and the Netherlands, favoured wind diffusion in these countries. The planning environment was evaluated as fairly positive in all cases.

Another multiple case study covering The Netherlands, England and Germany (North Rhine Westphalia) carried out by Sylvia Breukers and Maarten Wolsink (2007), evaluates the impact of public acceptance and the local planning environment on wind power implementation. Their study emphasizes the important role of local institutional capacity building and the local planning context, in combination with a stable and reliable support scheme, as major drivers for wind energy implementation.

A general assessment of drivers and barriers for PV and wind energy in Spain has been conducted by Rio and Unruh (2007). They point out that for wind energy particularly issues related to grid connection constitute a major barrier, whereas for PV primarily the high investment cost slowed down the diffusion process. Long administrative lead times were found to affect both technologies.

Iglesias, Río and Dopico (2011) investigate the role of regional differences in authorisation procedures for wind energy projects in Spain. They find that especially a lack of coordination between administrative bodies and the inhomogeneity of administrative procedures on regional level lead to inefficient siting decisions and thus hamper the overall development of wind energy in Spain. Khan (2003) finds similar results based on his case studies on wind energy development in three municipalities in Sweden. He points out that a lack of planning capacities at municipal level can hamper wind diffusion as it influences siting decisions and public participation in planning processes. Nonetheless, he also emphasizes that a certain level of coordination between the administrative procedures in individual municipalities is required to ensure that wind energy diffusion is realized efficiently and democratically.

Ohl and Eichhorn (2009) investigate the conditions for wind energy deployment in West Saxony, Germany and emphasize that spatial planning (i.e. designation of areas for wind development) should be better coordinated with support scheme design. They highlight that eligibility criteria for RE support under the German EEG (i.e. reference yields) cannot be met in all of the specified areas and spatial planning could thus become a major barrier for wind development. Holburn (2012) conducts comparative case studies for Ontario (Canada) and Texas (USA) in which he elaborates on the importance of regulatory risks for RE investment decisions. He finds that particularly the autonomy of regulatory institutions and the processes and institutional settings for energy policy formulation constitute major factors which influence the decisions of RE investors.

Based on nine European case studies, Boie, Fernandes et al. (2014) show that barriers for RE integration and infrastructure development greatly vary across the EU. Several barriers, such as long administrative lead times and public opposition against RE and transmission projects, were reported for all case study countries whereas other barriers appeared to be more relevant in individual regions. For example, a lack of national financing opportunities was mentioned as being notably relevant in Eastern European countries, whereas environmental concerns were evaluated as particularly critical in densely populated areas (e.g. Northern Europe) and vulnerable landscapes, such as the Austrian Alps or the Islands of Scotland (Outer Hebrides).

Also a growing number of European and global research projects monitors RE deployment and investigates the impact of regulatory and non-economic factors on RE penetration. Such research projects, which typically feature a broader geographical coverage than country level investigations, provide meaningful insights into the occurrence of barriers in a cross-country comparison as they usually follow a uniform methodology. Especially long-term projects which provide regular updates on assessments can serve as useful information source and cross-check for country comparisons. Some prominent examples for EU research projects are summarized in table 2.

Table 2: Overview over research projects on non-economic barriers for the diffusion of RE

Project title	Coverage	Methodology	Major findings
'Keep on Track!'[2]	11 EU countries, since 2014 EU-28, all RET	Monitoring of the progress of EU Member States in attaining their RE targets for renewable electricity (RES-E), heating (RES-H) and transport (RES-T). Assessment of barriers for RE diffusion via qualitative surveys on national level (consultation of local industry stakeholders via questionnaires and online database). Yearly updates on the status of deviations and barriers on MS level (2013, 2014, 2015).	In 2014, 772 individual barriers were reported across all MS and sectors, most of which referred to RES-E. Najdawi et al. (2013) and Spitzley et al. (2014)
'PV legal' and 'PV grid'[3]	'PV Legal': 12 EU countries, 'PV Grid': 15 EU countries, only PV	Assessment of bureaucratic and grid access barriers for different PV applications through local stakeholder consultation. 'PV Grid' (2012-2014) is the successor project of 'PV Legal' (2009-2012). Results are presented in an online database for benchmarking the administrative framework for PV development across the EU.	Administrative and regulatory conditions for PV development vary greatly across the EU (PV Grid, 2014). Apart from regulatory, also several technical barriers decelerate PV deployment in the EU (B. Barth, Concas, Rafael Cossent et al., 2013).
'WindBarriers' (Cena et al., 2010)	EU-27, wind onshore and offshore	Assessment of administrative and grid access barriers for development of wind projects, through stakeholder consultation and analysis of projects implemented 2007-2008. Main parameters investigated: lead time for obtaining building permits and grid connection, number of authorities and third parties involved in the permitting process and administrative cost.	Major obstacles are identified as the complexity of administrative procedures (number of authorities) and a lack of information about available grid capacities. (Cena et al., 2010)

2 Weblink: www.keepontrack.eu (last accessed: 16.4.2016).
3 Weblink: www.pvlegal.eu, www.pvgrid.eu (last accessed: 16.4.2016)

Table 2: Overview over research projects on non-economic barriers for the diffusion of RE

Project title	Coverage	Methodology	Major findings
'AEON - Non-cost barriers' (ECORYS, 2010)	EU-27, all RET	Assessment of non-economic barriers to RE integration based on consultation of national stakeholders. Results are summarized in country reports and a summary report.	Across all investigated countries, three major barrier types were identified: 1) Administrative issues (delays, lack of co-ordination, high cost, insufficient spatial planning); 2) Grid connection issues (long lead times, insufficient information on grid capacity); 3) Lack of public acceptance for RE projects (ECORYS, 2010). The prevalence of the barriers varies from country to country.

2.2.5 *Other streams of research*

Further research fields are concerned with the diffusion of RE in energy systems or with investment decisions for RE projects, respectively. Since these approaches are not directly relevant for the present research they will not be discussed in detail. For example, statistical and econometric approaches analyse the diffusion of technologies from a top-down perspective by searching for interrelations in historical datasets of technology deployment and other framework factors. However, econometric approaches are only applicable when large samples are analysed and when abundant historical data for all relevant determinants are available. Otherwise, no reliable statements about cross-relations can be deduced. Therefore, this approach is less suitable if qualitative framework factors, such as e.g. regulatory stability, are to be analysed for which usually no long, quantitative time series exist. As an example, Pfeiffer and Mulder (2013) analyse the diffusion of RE in developing countries based on regression analysis. However, regarding policy and regulatory instruments they apply strongly aggregated dummy variables and the results are not fully plausible.

In contrast, psychological and behavioural approaches, as applied in behavioural finance, strongly focus on the perspective and rationality of individuals or firms and are thus typically case-specific. They assess, for example, how a-priori beliefs, peer-pressure, past experience or educational background of decision makers influence their investment decisions or how company-specific strategies and decision making processes affect RE investments. For example, Cannemi et al. (2014) and Aragonés-Beltrán et al. (2014) investigate company-specific decision processes for investments in biomass power plants and solar thermal power plants, respectively. From their analyses, they deduce analytical network models to support inner-firm decision making processes. Masini and Menichetti (2012) and Lüthi and Wüstenhagen (2012) apply behavioural finance approaches to analyse selected behavioural factors in RE investment decisions. Lüthi and Wüstenhagen (2012) conduct choice experiments with 63 European PV developers to investigate their preferences regarding RE support design and regulatory frameworks. Their analysis covered five attributes, namely the level and duration of the RE tariff, the existence of a cap for RE support, the duration of administrative procedures and policy instability. Their findings confirm the relevance of non-economic barriers and thereby highlight the role of the duration of administrative procedures and the support level. However, as the assessment covers only five policy attributes, the relative relevance of other factors cannot be deduced from the results.

A further stream of academic literature deals with the diffusion and adaptation of innovations, such as new energy technologies, with a holistic view on the overall system within which innovations spread (i.e. innovation system analysis). This type of analysis is not limited to the perspective of an individual or a group of individuals, respectively, but regards various dimensions that shape the overall regime for technical change and the environment for the replacement of established technologies by new, innovative technologies. This may include, for example, social, political, legal, technical, institutional, organisational or cultural factors and the interplay among them (see e.g. Alkemade, Kleinschmidt and M. Hekkert (2007), Edquist (2006), Gallagher et al. (2012), Lundvall (1992) and Markard, Raven and Truffer (2012)). In this context, technological transition processes can be understood as the movements of technologies from the level of niche innovations to that of established technologies which eventually become aligned with and anchored in the general norms of the respective system (see e.g. Geels (2011) and Markard, Raven and Truffer (2012)). This systemic approach which understands technological change as a dynamic, multi-dimensional process is also widely deployed in analyses of energy systems. In particular it is applied to examine the development of RE technologies in established energy systems in order to identify potential barriers and system failures which hinder a transformation to a more sustainable energy system (see e.g. Bergek and Staffan Jacobsson (2003), Dewald and Truffer (2011), Foxon et al. (2005), Gallagher et al. (2012), S. Jacobsson (2004), Staffan Jacobsson and Bergek (2011), Staffan Jacobsson and Johnson (2000), Markard and Petersen (2009), Markard, Raven and Truffer (2012), Negro (2008), Negro, M. P. Hekkert and Smits (2007) and Truffer et al. (2012)). However, the present thesis focuses on the perspective of RE developers and investors. Therefore, this stream of literature, although highly relevant from a system's perspective, plays a secondary role for the approach chosen in this thesis. Still the contributions of this work should also be seen in the broader context of innovation system analysis as they add an important vantage point to the general understanding of technical innovation systems (cf. section 6.4.1).

2.3 SUMMARY AND CONCLUSION

The previous sections have shown that several streams of literature investigate the diffusion of RE technologies from different perspectives and under application of various methodologies. Thereby, the spectrum of objectives, the level of detail and the scale of the analyses varies strongly (see summary in table 3).

Long-term energy scenarios in energy-economic modelling build on detailed technology and resource information but usually fail to integrate non-economic factors into the analysis (Barreto and Kemp, 2008; Worrell, Ramesohl and Boyd, 2004). Simulation models generally allow for integration of non-economic framework factors but largely lack an empirical basis for their representation. Market forecasts, based on estimations and judgements of country experts, might serve as useful estimations of possible short-term developments but bear the risk of being biased and often lack a transparent methodology. Country case studies deliver detailed insights into drivers and barriers for RE deployment on national level but usually remain on a qualitative level which makes it difficult to compare results in the international context. Composite indicators, on the contrary, constitute useful benchmarking tools for comparing different countries' framework conditions. However, often the structure of the indicators, the balance between their individual components and the selection and treatment of underlying data sources are defined based on opaque methodologies or expert judgements, which again involves the risk that results are subject to bias (cf. Böhringer and Jochem (2007), Freudenberg (2003) and Sharpe (2004)). Statistical and econometric analyses imply extensive data requirements as they depend on long-term, quantitative historical datasets. Approaches focusing on the individual decision maker and his personal background feature a high level of detail but can rarely cover a broad spectrum of parameters. Mostly they are case-specific and lack transferability to other cases.

In this context, the present thesis aims at closing a gap between macro-level economic modelling approaches and detailed, micro-level case study analyses which capture the views of individual actors. To this end, it aims to systematize the major framework factors for RE diffusion from the relevant decision makers' perspective and to make them quantifiable for application in energy economic simulation models (cf. section 1.5).

The methodology that corresponds most closely to these targets is the composite indicator approach as it serves to structure a broad range of influential factors for a certain development and aggregates them for comparisons on international level. However, a major methodological shortcoming of most composite indicators is the lack of empirical substantiation for the selection, weighting and aggregation of their individual components (cf. Böhringer and Jochem (2007), Freudenberg (2003) and Sharpe (2004)). Sharpe (2004, p. 5) summarizes the criticism regarding aggregated indicators as follows: *"Their key objection to aggregation is what they see as the arbitrary nature of the weighting process* *by which the variables are combined."* This statement emphasizes the importance of a robust framework for weighting of the variables in order to truly capture the stakeholders' perspective in an unbiased manner.

Table 3: Overview over characteristics of selected approaches to analyse RE diffusion

Objectives	Methodology & Focus	Temporal & spatial scale
Energy economic modelling		
Provision of long-term, technology deployment scenarios, forecasts under different framework assumptions, partly assessment of policy implications	Techno-economic optimization or simulation based on RE resource data and assumptions for technology cost developments and other parameters, focus on techno-economic parameters, mostly non-economic parameters are neglected	Mostly long term scenarios on macro to meso-level (national, trans-regional or global)
Short-term RE technology market forecasts		
Predictions of expected market sizes and short- to medium term investment opportunities	Qualitative assessments, expert judgements based on market observations, including economic and non-economic parameters	Short- to medium term forecasts (mainly short term) on macro to meso-level (National, regional or global)
Composite indicators for RE deployment		
Assessment and benchmarking of country conditions, systematization of framework factors	Qualitative (expert judgements) and quantitative components including economic and non-economic parameters	Mostly status quo assessment on meso-level (mostly national)
RE diffusion case studies		
Gaining a better understanding of technology diffusion processes on country level	Qualitative assessments based on different methodologies regarding economic and non-economic parameters	Status quo assessment and ex-post analyses on meso to micro-level (mostly national or regional)
Statistical and econometric analyses		
Understand interrelations between diffusion parameters based on correlations in historical data, allow for short-term forecasts	Quantitative approach based on historical data (quantitative parameters)	Ex-post analyses used for short to medium term projections on macro to meso-level (mostly national)
Psychological / behavioural analyses		
Develop a better understanding of individual decision making processes	Qualitative and semi-quantitative approaches considering economic and non-economic parameters	Status quo assessment, also utilizable for projections, focused on micro-level (individual's or firms perspective)
Innovation system analyses		
Understand processes of innovation and systemic drivers and barriers of system transformation	Qualitative analyses considering a broad range of parameters (e.g. social, political, legal, technical, institutional, etc.)	Mainly ex-post and status quo assessments, analyses on various scales (local, national, regional, etc.)

3 METHODOLOGY

This chapter describes the methodology applied for completing this research. It starts with an overview and a brief introduction to the major requirements on which the research design is based (section 3.1) and continues with a description of the different methods for data collection and data analysis. Section 3.2 describes how the main determinants for the RE diffusion process were identified, section 3.3 introduces the approach for assessing the relative relevance of the determinants in the diffusion process, section 3.5 explains how the approach was applied to country case studies and section 3.4 outlines the approach to deriving the final diffusion model. Finally, section 3.6 concludes and summarizes the chapter.

3.1 OVERVIEW

As outlined previously in chapter 1 (sections 1.5 and 1.6) the central objectives of this thesis are to develop a transparent and objective analytical tool for the assessment of RE diffusion frameworks (i.e. a diffusion indicator) and to represent the major drivers and barriers for RE diffusion in a model suitable to project RE diffusion. The results aim to facilitate policy making and, in particular, to support a more efficient policy design.
In this context, the central research questions can be summarized as follows:

1. What are the major determinants framing RE diffusion processes?
2. How can the determinants be operationalized (i.e. represented and assessed quantitatively) in form of an indicator?
3. What is the relative relevance of the determinants from the decision maker's (i.e. project developer's / investor's) perspective?
4. How do the determinants reflect in the resulting RE diffusion?

The research objectives entail a number of requirements which need to be considered with respect to the research design.

- Firstly, the observable diffusion of RE technologies, in the context of this research, is understood as the cumulated effect of the decisions of individuals, namely RE developers or RE investors, on whether to realize a RE project or not. Therefore, one major prerequisite for attainment of the stated research objectives is a profound understanding of the role of different framework factors (determinants) that influence the decisions of the relevant stakeholders. Hence, it is crucial that the analysis is consistent in taking the decision makers' perspective (in contrast to e.g. a system's perspective) to ensure coherence of the analytical framework.

- Secondly, the relevant determinants must be quantified and assessed in a transparent and objective manner and grounded on a reliable, empirical basis. This is crucial to ensure transparency of the approach and to avoid biases when applying the results for policy assessments.
- Thirdly, the developed analytical framework aims for a maximum of transferability to safeguard a broad applicability of the approach, for example for the purpose of country benchmarking. This requires a research design that covers all major decision factors while at the same time being general enough to ensure applicability to various country contexts (e.g. different market maturity levels).

To address the above research questions and methodological requirements, the research design includes several qualitative and quantitative elements. In summary, the applied methods comprise the following:

- A systematic review of relevant literature sources and own past interview findings to get a comprehensive overview of possible determinants for RE diffusion as identified by previous research.
- Moderated expert workshops (i.e. group discussions) to narrow down the compilation of possible determinants and to develop the final conceptual framework for the diffusion indicator and diffusion model.
- An EU-wide, questionnaire-based consultation of RE-stakeholders to assess the relative relevance of the diffusion determinants.
- Conduction of three contrasting country case studies (in Germany, Spain and the United Kingdom) involving 31 in-depth, semi-structured expert interviews and data collection from various secondary data sources to apply and validate the developed concept.
- A model-based analysis of the RE-diffusion patterns in the three case study countries under application of existing modelling approaches for technology diffusion and building on the theoretical framework of general diffusion theory (see e.g. Geroski (2000), Grübler, Nebojsa Nakićenović and Victor (1999) and Rogers (1995)).

The research was organized in four partly overlapping phases. Data collection for the selection of the diffusion determinants and the development of the conceptual model (step 1) mainly took place between May and December 2013, the assessment of the relative relevance of the determinants (step 2) was completed between December 2013 and June 2015 and the interviews in the case study countries (for step 4) were conducted between

January 2014 and June 2015. The development of the diffusion model (step 3) began in parallel to step 2 but was continued throughout the data collection phase to adapt the model where necessary. Data evaluation and application of the diffusion model to the country case studies (step 4) took place between June 2015 and February 2016. The main part of the literature research was carried out before the collection of primary data started but the review was continuously updated with new publications during the entire research process.

An overview over the major methodological steps, utilized data sources and outputs of each step is also provided in figure 7. The individual steps are explained in more detail in the following sections.

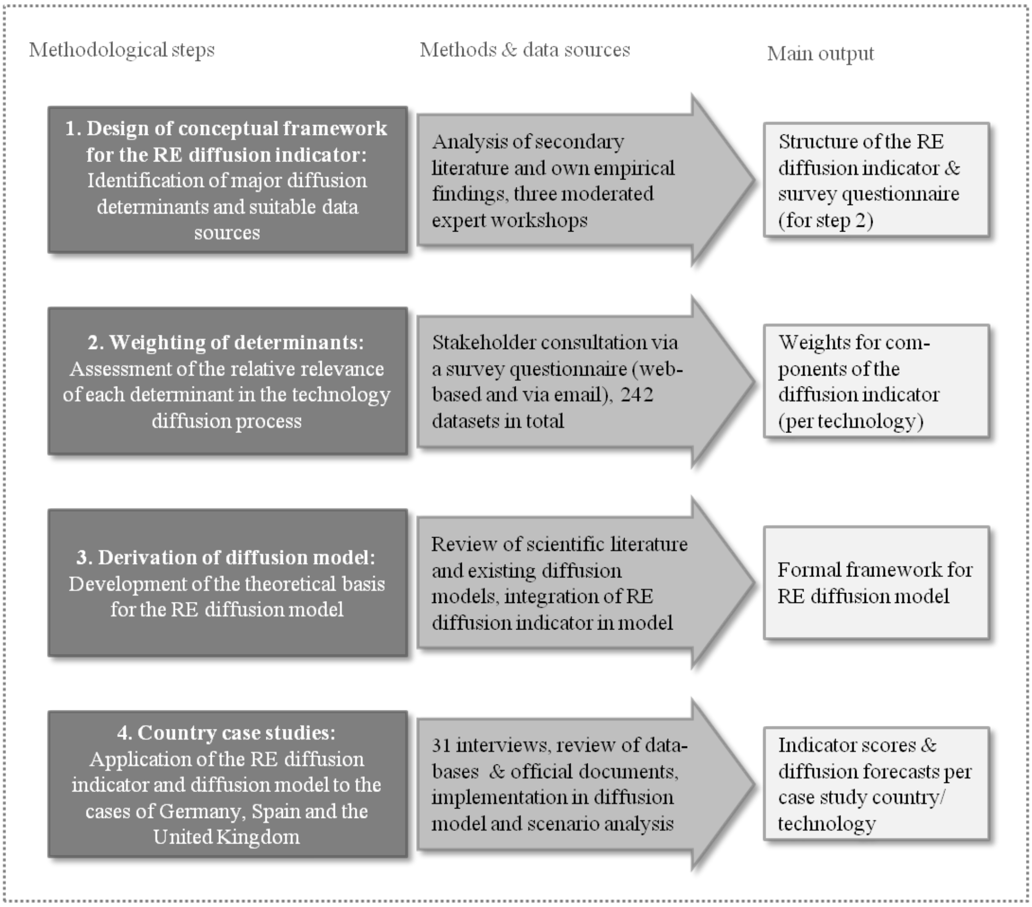

Figure 7: Overview over major analytical steps, data sources and methods used for the thesis. Source: Own illustration.

3.2 Identifying the major determinants for renewable energy diffusion

The methodology for identifying the major framework factors for RE diffusion, which define the structure of the diffusion indicator, is based on a qualitative assessment that draws upon a systematic review of existing research on RE diffusion (secondary literature and own empirical findings) complemented by consultations of RE experts. The main output of this step is a conceptual model for the diffusion indicator which is directly translated into a survey questionnaire. The questionnaire is required to allow for the standardized collection of data on the relative relevance of the diffusion determinants carried out in the subsequent step (see section 3.3).

3.2.1 *Review of secondary data*

Literature research As a first step, a systematic review of existing literature was carried out to identify framework factors previously reported as being important for RE diffusion. Relevant publications in this regard comprise articles published in scientific journals as well as relevant grey literature, such as reports of research projects, official policy documents or guidance reports with a corresponding thematic focus. The literature review included multidisciplinary scientific publication databases such as 'SpringerLink', 'Scopus' and 'Science Direct' using the following search terms: diffusion; diffusion analysis; renewable energy; renewable energy technologies; technology adoption; drivers and barriers, composite indicator. Additionally, in order to identify relevant grey literature, a general internet search (i.e. using common search machines) was performed using the same search terms as described above. The most relevant streams of scientific literature that were regarded in the literature review are presented in section 2.2. The outcome of the literature review was a comprehensive list of possible diffusion parameters. These were further grouped into thematic categories, such as economic, regulatory, technical, social or market issues.

Review of own empirical findings from past research Further, the reviewed material included empirical findings from my own previous research, namely the results of semi-structured interviews and workshops with 70 energy sector and policy experts which were conducted between July and September 2012 and have previously been described in Boie, Ragwitz and Steinhilber (2014)[1]. The interviewees comprised energy sector- and policy experts (representatives of utilities, RE agencies, regulatory agencies and the energy research sector) in EU countries (Germany, Austria, Spain and the Nether-

1 The findings were part of an analysis conducted in the frame of the project *'Assessment of possible future RES-E support schemes in the EU-MENA region – Case studies for Egypt, Morocco and Algeria'* which was conducted on behalf of the 'Desertec Industrial Initiative' (Dii) in 2012/2013.

lands) and in North Africa (Algeria, Morocco and Egypt). The interviews were based on a questionnaire with a closed part asking for preferences regarding different RE policy design options and an open discussion about barriers and drivers for RE deployment in the respective national context. From the results of the open discussion, the drivers and barriers referred to by the stakeholders were compiled and evaluated with respect to the frequency with which each factor was mentioned. Even though the present thesis focuses on EU countries, the results of this analysis were additionally taken into account for the compilation of possible framework factors for RE diffusion. This was done, on the one hand, to broaden the overall empirical basis of the research and, on the other hand, to aim for a maximum transferability of the conceptual model to different country contexts (cf. sections 1.6 and 3.1). Significantly different results for non-EU countries would provide an important indication on the applicability of the approach to other world regions and additional determinants could be included in the indicator to address this.

3.2.2 *Moderated expert workshops*

To refine and eventually select the most relevant diffusion determinants and to design the questionnaire for the subsequent assessment of their relevance, a series of three moderated expert workshops (i.e. focus group discussions) was conducted. Focus group discussions can be defined as debates about predefined topics among a small group of selected individuals in which a researcher actively encourages group interaction, for example, by moderating the discussion and by providing stimulus material (Barbour, 2007; Wolff, Knodel and Sittitrai, 1993).

METHODOLOGICAL CONSIDERATIONS One important advantage of group discussions in general is that they allow for a more efficient collection of information, i.e. larger amounts of information can be transmitted in a shorter period of time, compared to individual interviews with the same number of individuals (Nassar-McMillan and Borders, 2002; O'Brien, 1993). Also, the dynamics of group discussions may have a catalyst effect and thereby foster creativity and the development of a broad range of ideas and more comprehensive results than one-on-one interviews or rigid survey questionnaires (Nassar-McMillan and Borders, 2002; O'Brien, 1993; Wolff, Knodel and Sittitrai, 1993). Disadvantages of group discussions particularly relate to potential interdependencies or group-reinforced biases in the participants' opinions (Krueger et al., 2012; Nassar-McMillan and Borders, 2002) and to the possible dominance of individual participants over the rest of the group (Krueger et al., 2012). However, this can be avoided by a thorough selection of the group participants and careful moderation of the discussion (Wolff, Knodel and Sittitrai, 1993).

Due to their high degree of flexibility and efficiency, focus group discussions are a common methodological instrument used especially in the exploratory phase of research projects (Barbour, 2007). They are often used to develop, refine or adjust survey instruments for a specific research context (Barbour, 2007; Nassar-McMillan and Borders, 2002; O'Brien, 1993; Wolff, Knodel and Sittitrai, 1993). Especially multidisciplinary focus groups can be beneficial to the development of surveys, i.e. to adjust the wording of survey questions or to select items to be included in a questionnaire (Barbour, 2007, p. 17). Here, particularly the heterogeneity of the participants adds value to the discussion and ensures that no important aspects are overlooked (Barbour, 2007, p. 17).

For the present research project, expert group discussions were chosen for defining the concept of the survey questionnaire due to several reasons. Firstly, given the the large number of possible diffusion determinants and the need for intense discussions about each of them, a group discussion was considered as more efficient than a series of one-on-one interviews with individual experts. Also, the flexible and interactive discussion process during the workshops was considered as more beneficial than bilateral discussions or interviews as the various experts in a group discussion are able to reflect different perspectives of the problem and to integrate their expertise while working towards a consolidated result (i.e. benefits of group interaction). Additionally, analysing the dynamics of group discussion allows for the collection of implicit information on the contextual relevance of the different discussion points which is usually not possible using more rigid survey methods such as questionnaires (Wolff, Knodel and Sittitrai, 1993). Further, observing the expressions and phraseology used by the participants of the group discussions facilitates the selection of words and phrases to be used in the questionnaire in order to make it clear and understandable for the targeted respondents (O'Brien, 1993). A similar approach based on an initial literature research and a series of focus group discussions for the design of a questionnaire was taken, for example, by Nassar-McMillan and Borders (2002) and has proven to be adequate by several further studies (see e.g. Barbour (2007), O'Brien (1993) and Wolff, Knodel and Sittitrai (1993)).

PRACTICAL IMPLEMENTATION The group discussions took place between July 2013 and January 2014: On July 11^{th} 2013 in Berlin (8 participants), on August 15^{th} 2013 in Berlin (5 participants) and on January 30^{th} 2014 in Vienna (16 participants). The discussions each took between 1.5 and 2.5 hours. The group participants comprised European RE experts with different work foci (e.g. electricity market design, RE policies, grid regulation or energy economic modelling) who were part of the project team of the 'DIA-CORE' project in the frame of which this part of the research was conducted (cf. project description in section 1.6). Even though the group participants did not comprise RE developers, it was assumed that the group of experienced scientists with different thematic backgrounds would be able to adequately reflect the perspectives of the target group.

In the course of the meetings, slides were presented to the participants as stimulus material for the discussion. The slides showed compilations of possible parameters influencing RE diffusion as well as draft categories for structuring them as derived from the foregone literature review (e.g. economic, market, grid or social issues). However, it was made clear to the participants that the structure could be changed and that determinants could be added and removed any time. The participants were then asked to identify the most relevant factors influencing RE diffusion during a moderated group discussion. Thereby, the key decision criterion was that each determinant should be of direct relevance from the decision makers' (i.e. RE-project developer or RE investor) perspective.

The results of the discussion were fixed by directly adjusting the presentation slides and by taking additional notes. Due to the high number of potential diffusion determinants it was not possible to finalize the discussion and to come to a consensus in the frame of a single workshop. Thus the discussion was continued during the subsequent workshops. To this end, in the beginning of the second and third workshop, the result of the previous discussions were again presented to the participants as stimulus material and they were asked to reflect upon it. This step-wise iteration and refinement constituted a major input for the final selection and categorization of the diffusion determinants. Exemplary slides as used for the group discussions are included in appendix A.1.

To allow for a quantification of the diffusion determinants when applying the concept to an actual case study, each of them needs to be represented by suitable indicators. The indicators have to be chosen in a way that ensures an adequate and transparent representation of each determinant while at the same time considering data availability and feasibility of data collection. Optimally, indicators should be based on reliable, publicly available data bases, which have regular updates and a transnational coverage. If such data sources do not exist, other sources, such as official government reports or legal documents, research reports or interviews with country experts are possible. Also suitable indicators and possible data sources for each diffusion determinant were discussed within the framework of the expert workshops as soon as the general structure of the determinants was settled.

A description of the above approach is also provided in Boie, Ragwitz and Held (2015). The results of this working step are presented in sections 4.2 and 4.4.

3.2.3 *Verification through follow-up interviews*

As mentioned before, the selection and grouping of the diffusion determinants was used for the design of the conceptual model for the diffusion indicator and translated into the design of the survey questionnaire needed for the subsequent step (cf. section 3.3.1 below). To ensure that the design of the conceptional model and the questionnaire adequately reflects the perspective of the relevant stakeholders (i.e. RE developers and investors) is was verified within the frame of interviews with RE project developers and other RE sector representatives. These interviews were part of the case study analysis and comprised 31 semi-structured phone interviews based on a comprehensive interview guideline (further details on the interviews are provided in section 3.5). The interviews took place between January 2014 and June 2015. Prior to the interviews, the interviewees had received the survey questionnaire showing the diffusion determinants (further details on the weighting are provided in section 3.3). At the beginning of each interview the interviewees were asked for their opinion on the selection of determinants and whether they think that there are important aspects missing (cf. question 1.2 in interview guideline, see annex A.3). The respective answers were used to critically reflect upon the selection of determinants and to consider adaptations of the questionnaire for potential future data collection beyond the present research project.

3.3 Assessing the determinants' relative relevance (weighting)

3.3.1 *Questionnaire-based survey*

In this step, the previously selected diffusion determinants are evaluated in terms of their relevance for the RE technology diffusion process. The assessment is based on an extensive consultation of relevant stakeholders (i.e. RE developers and other RE experts) by means of a survey questionnaire. The main output of this step are data on the relative relevance of the determinants for RE diffusion which are then used to weigh the components of the diffusion indicator.

Underlying assumptions and requirements The basic underlying assumption for this working step is that not all of the identified parameters influencing RE diffusion (i.e. determinants) are equally relevant. Some factors may be able to cause a complete blockage of RE development while others might be of comparatively low relevance for the investment decision for a RE project.

The importance of the determinants may further vary depending on the RE technology concerned (e.g. due to varying market maturity levels or technical parameters of different RE technologies). In case that, for example, wind energy and PV developers have different priorities in their decision making process, this would have to be taken into account when evaluating the framework conditions for the two technologies. Consequently, if such differences in the relative relevance of the determinants exist, they are to be considered when applying the RE diffusion indicator as they define with which weight the scores for each determinant enter the calculation of the overall indicator score.

As an analogy, one could envisage the RE diffusion process as a flow of power through a circuit (see figure 8). The current for the case of minimum resistance (analogue to the maximal possible pipeline of economically viable RE projects) is diminished by different resistors which represent the major determinants for the technology diffusion process. The level of resistance of each resistor represents the relevance of the respective parameter. The actual current resulting from the effects of the resistors reflects the reduced number of realized projects under the given conditions. If a resistor blocks the flow completely, no technology diffusion occurs. If all determinants are in optimal conditions, all potential projects can be realized [2]. The goal of this step is to define the level of each of the resistors or to assess the relevance of the underlying parameters of the diffusion process, respectively.

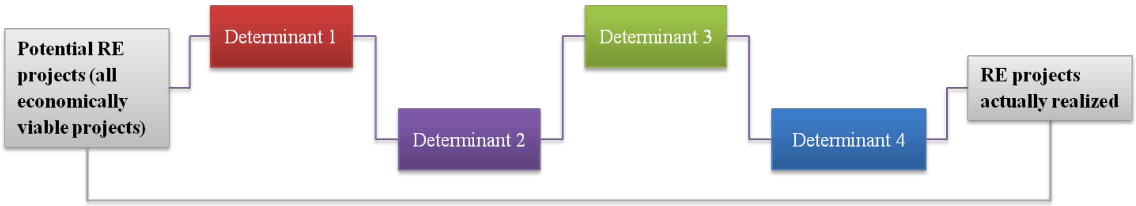

Figure 8: Schematic illustration of the RE-technology diffusion process represented as a power circuit. The main determinants act as resistors which define the actual project implementation. Source: Own illustration.

In this context and in line with the objectives of this thesis to capture the decision makers' (i.e. RE developers and investors) perspective on RE diffusion and to provide a reliable, empirical basis for RE policy evaluation (cf. section 1.5), the present assessment requires a transparent approach which considers the viewpoint of the relevant players.

It is acknowledged that integrating the relevant target groups' perspectives and avoiding arbitrary judgements is a crucial step to substantiate the construction of composite indicators (OECD, 2008; Sharpe, 2004) and the development of (environmental) modelling tools (Krueger et al., 2012). However, there is a need for formalized and transparent ways to include stakeholder expertise in the process of constructing and parametrizing conceptual models (Krueger et al., 2012).
Accordingly, the central method chosen to assess the relevance of the individual diffusion determinants is a questionnaire-based survey which allows to consult a large number of relevant stakeholders to gather a broad basis of standardized empirical evidence.

QUESTIONNAIRE DESIGN As mentioned above, the questionnaire survey aims to assess the relative relevance of the individual determinants with regard to the realization of RE projects. The results are applied to define the weights of the composite indicator (CI) components which implies specific requirements regarding the questionnaire

2 A similar analogy has been used by Neuhoff (2009) who compared four major fields in RE policy (i.e. planning, grid, supply chains and project finance) to levers that may either enable or disable RE deployment.

design. Firstly, to allow for a translation of the relative relevance into weights, the relevance should be rated on a quantitative (i.e. numerical) scale. Here it is important that the data is collected in a standardized format and that the maximum possible number of datasets is collected to allow for comprehensive analyses and robust results. A further requirement for the design of the questionnaire is that it should be as concise and intuitive as possible to encourage participation and to maximize the response rate of the survey. Only a large number of uniformly formatted datasets allows for analyses of potential technology-specific differences or other systematic patterns.

In line with the above requirements a questionnaire form was developed which allows for a rating of the determinants' relevance on a numerical scale.

Various methods exist for rating and ranking the relevance of survey items. Several possible methodologies for weight elicitation are presented and compared by Bottomley and Doyle (2001), Pöyhönen and Hämäläinen (2001) and Alfares and Duffuaa (2009).
For example, in the *'Max100'* method respondents are asked to assign 100 points to the most important item of a list and allocate less points (between 0 and 99) to the other aspects, accounting for their relative importance compared to the most important item (Bottomley and Doyle, 2001; Pöyhönen and Hämäläinen, 2001). In the *'Min10'* approach, in contrast, the least important item is rated with 10 points and the others are rated accordingly on a scale from 11 to 100 (Bottomley and Doyle, 2001; Pöyhönen and Hämäläinen, 2001).

However, assuming a larger number of items (as in the present case) these approaches have a limited feasibility as it becomes increasingly difficult for the respondents to graduate the ratings for several items on such wide scales (Pöyhönen and Hämäläinen, 2001).
Also the allocation of a defined budget (e.g. 100 points) among a group of items to account for their relative relevance is not a suitable method for groups of items greater than 12 because the allocation process becomes cognitively too demanding for the respondent (OECD, 2008, p. 32).

A simplified and more intuitive option is to ask respondents to simply sort items on an ordinal scale according to their relevance (Alfares and Duffuaa, 2009). However, a simple hierarchy does not allow for representation of equally important aspects which might be the case for some of the determinants in the present case. Also, this approach would not allow for directly specifying the relevance, i.e. the actual distance between the items on the ordinal scale.

The selected approach for the weighting questionnaire is therefore based on a Likert-type, numerical rating scale. A Likert scale is defined as a psychometric scale measuring the level of agreement of an individual to a statement. In its original form, the Likert scale consists of five equidistant points and provides verbal descriptions (anchors) for all points ranging from 'strongly disagree' to 'strongly agree' (Likert, 1932). Over time, numerous adaptations of the original Likert scale have been made, for example, to measure the perceived usefulness or relevance of survey items (Harpe, 2015). Rating scales which deviate from the original design as developed by Likert can be categorized as Likert-type rating scales (Uebersax, 2006).

For the present application, an 11-point rating scale, ranging from zero to ten, was chosen. This implies that the respondent is asked to allocate a value between 0 and 10 to each item accounting for its relevance regarding the realization of RE projects. The 11-point rating scale was selected as it offers a high degree of granularity for the later weighting of the indicator components (in contrast to five-point scales) while still being intuitive and well manageable for the respondents (in contrast to e.g. 100-point scales). A further benefit of the chosen rating scale is that it allows for assignment of equal weights to different items (in contrast to e.g. the *Max100*, *Min10* or simple ranking methods), which can be an important piece of information in the context of the present research questions.

An uneven number of items, i.e. the inclusion of an intermediate value, was chosen to allow the respondents to express a potential indifference regarding the determinants' relevance. Anchors were indicated only for the endpoints and the mid value of the scale (10 = extremely relevant, 5 = moderately relevant/indifferent, 0 = not relevant at all) to maximize the simplicity and clarity of the questionnaire. The utilized category descriptors were based on existing definitions in the literature to safeguard that, based on the wording, the perceived distance between the items of the scale is actually equal (Friedman and Amoo, 1999; Likert, 1932).

The general format of the questionnaire is based on the structure of the conceptional model for the CI as defined in the previous step (cf. section 3.2 above). This means that the survey items (i.e. the determinants) directly correspond to the wording and structure of the CI. The determinants are presented in a clear, hierarchical structure arranged into four thematic blocks, namely political and economic framework, market structure, grid regulation and infrastructure and administrative processes (cf. description of results in section 4.2.3). The grouping of the items in a hierarchical structure is supposed to facilitate the weighting procedure for the respondent and to be suggestive of a manageable and easy procedure in contrast to providing a long list of unstructured items.

An excerpt of the weighting questionnaire is shown in figure 9. The complete form is presented in annex A.2.

Further, the questionnaire contains a brief introduction to the research context, concise instructions for the weighting procedure as well as a glossary with short definitions of each determinant in order to avoid misunderstandings. In particular, the respondents are explicitly requested to abstract from the actual manifestation of the items in their operating context and to specify the general relevance of the parameters in their decision making process. This is important to avoid a country-bias in the weighting results which are supposed to represent a general assessment framework rather than a country-specific context.

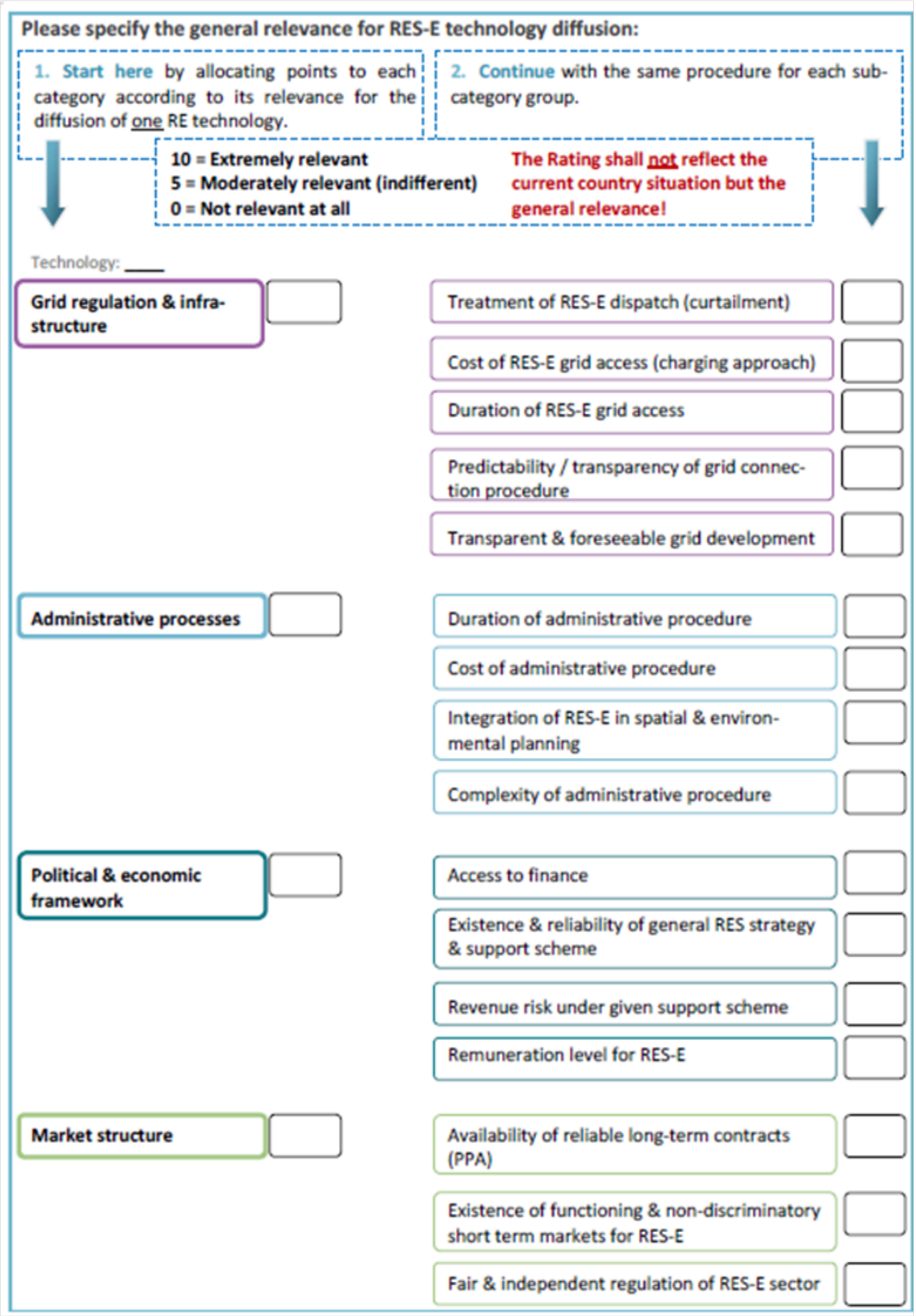

Figure 9: Excerpt of the weighting questionnaire for assessing the relative relevance of the diffusion determinants.

The form also contains a section in which the respondent is asked to specify his technological and geographical focus as well as his institutional affiliation. This information is relevant for a later analysis of potential technology- or actor-specific differences in the results. The respondents were not requested to provide their contact information but could do so voluntarily. Also, they were assured that all data provided would be processed anonymously and that no contact data would ever be published or passed on to third parties. Additionally, the questionnaire offers the possibility to leave additional comments or suggestions in an open entry field.

The usability of the questionnaire was tested with a small group of eight researchers at Fraunhofer ISI. Minor comments regarding the instructions and the wording of the questionnaire were integrated into the final version. According to the general feedback, no major adjustments were required. Finally, the form was translated into English, Spanish and French to facilitate completion by various nationalities.

DISTRIBUTION OF THE QUESTIONNAIRE The questionnaire was distributed via email in form of a protected text document with dedicated entry fields for the weights. The document is presented in appendix A.2. Additionally, in order to maximize the coverage of the survey, an online version of the questionnaire was created. It was embedded in the European research project *'re-frame'* (Eclareon, 2015) which aims for a broad assessment of barriers for RE deployment across the EU Member States through an extensive online survey (cf. section 1.6). The online version of the weighting questionnaire was integrated in the *'re-frame'* survey so that the weighting exercise had to be completed prior to the survey. The major benefit of integrating the weighting questionnaire with the *'re-frame'* project related to the size of the target audience. As the project' *re-frame'* involved several RE industry associations across Europe which had an intrinsic motivation to participate in the survey and who mobilized their members to do likewise, it was possible to reach a much larger audience than through the emailing campaign only. On the other hand, the online survey also entailed a reduced control of the respondent composition as the online platform was openly accessible and the participation in the survey was not restricted. The implications of this circumstance for the data quality are further discussed in section 3.3.2.

The online questionnaire was structured in line with the questionnaire developed for the mailing campaign and provided the same instructions and background information, e.g. on the definition of the determinants and the confidentiality of the provided information. The weighting of the determinants was done by adjusting slide bars on a scale between 0 and 10. The technical implementation of the online questionnaire was realized by a computer scientist in the context of the *'re-frame'* project. A screen shot of the online interface is presented in figure 10.

The major target groups for the questionnaire comprise:

- Wind energy and PV project developers;
- RE investors or financing institutions;
- RE associations;

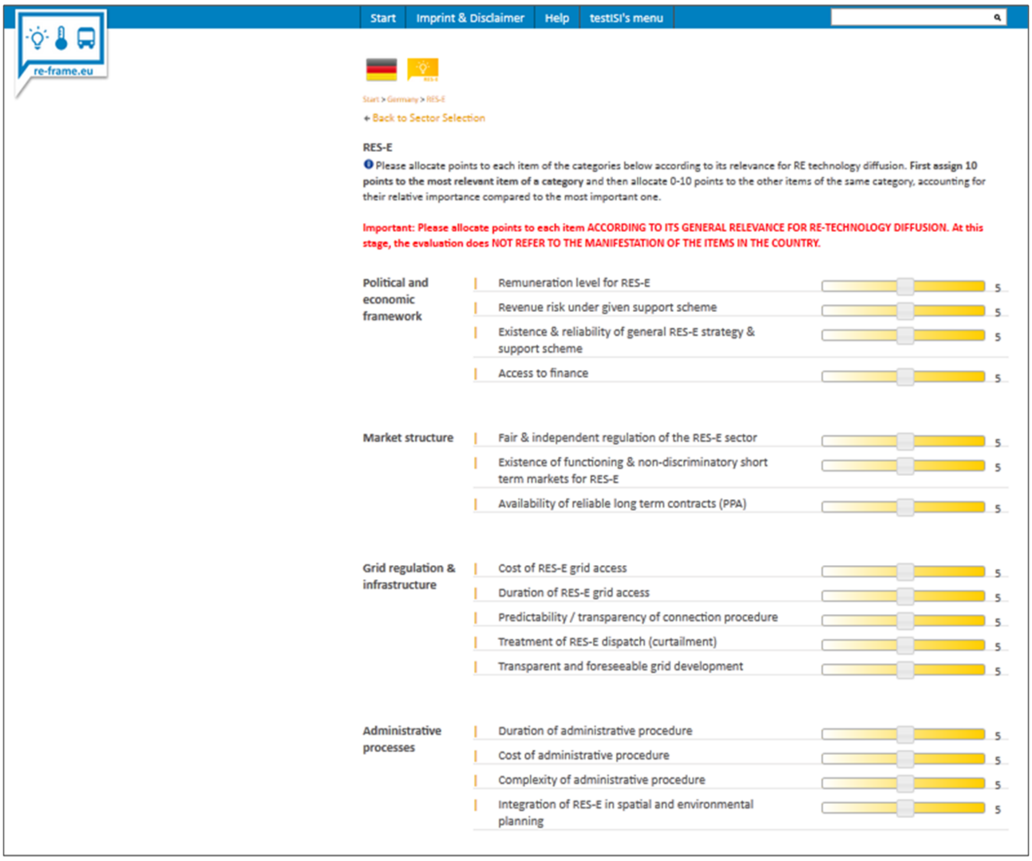

Figure 10: Screen-shot of the online interface for the assessment of the relative relevance of the diffusion determinants: Slide bars can be adjusted to represent the relevance of the individual items.

- Regulatory authorities in the electricity sector;
- Energy policy stakeholders;
- Stakeholders from the energy policy research sector or other policy and market experts (e.g. consultancies).

As the approach aims to consistently cover the decision makers' perspective, the first two of the above groups are the major target groups for the survey since they are the main actors when it comes to decisions on the realization of RE projects. However, inclusion of stakeholders from other sectors, such as the policy, regulation and research sector, allows for identifying potential deviations of their assessments from those of the primary decision makers. Such discrepancies are a relevant piece of information for the policy discourse. A significant number of consultations with experts from the above target groups is needed to allow for drawing robust conclusions on the relevance of the determinants. Especially for the evaluation of potential technology- and actor specific differences a large database is required to be able to draw robust conclusions. Therefore, this part of the assessment does not focus on individual case study countries but covers the European level (even including some non-European contributions).

Emails with a short cover letter and the questionnaire attached were deliberately sent to a large number of relevant players across Europe. The recipients covered the above mentioned target groups but had a strong focus on RE project developers and investors. Email addresses were acquired based on existing address databases at Fraunhofer ISI where comprehensive mailing lists are available through past and current international research projects (comprising e.g. cooperation partners, recipients of earlier surveys, invitees to workshops or conferences etc.). Additional addresses were procured through web research for relevant companies. The mailing campaign took place between January 2014 and June 2015. The period was comparatively lengthy as response times of the recipients were long and several reminders had to be sent to them. Also access was gained to additional contact data over time which was then included in the survey[3].

The respondents to the online questionnaire were recruited mainly indirectly through contacts to European RE associations who encouraged their members to participate in the survey in the context of the '*re-frame*' project. Consequently, the recipients largely belong to the RE industry (RE developers and manufacturers) but also to other groups affiliated to RE associations. The online interface was open for contributions from end of November 2013 until end of April 2014. It had no access restrictions and was thus openly accessible to all contributors who took note of the survey. The survey was advertised through the activities related to the '*re-frame*' project and the 'DIA-CORE' project (cf. section 1.6) on the project websites, during workshops and conferences. A detailed description of the overall composition of the participants of the survey is provided in the subsequent section.

3.3.2 *Properties and processing of the data sample*

The responses to the mailing campaign and the online survey resulted in the collection of a total of 242 datasets of which 102 originated from the mailing campaign and 140 from the online interface. Data from the online interface was obtained in an SQL-database format. The completed questionnaires were received as text files. All datasets were compiled in an *MS-Excel* file for further analysis.

The raw data were processed for the subsequent analyses. In an initial step, in order to ensure adequate data quality, datasets with either incomplete or implausible information were excluded from the subsequent analytical steps. Datasets were discarded if >50% of the requested values were missing as these datasets are considered as being too fragmented. If only individual numbers (<50% of the requested values) were missing, the respective dataset was retained. The data gaps are neither complemented nor counted as

3 The interviews in the case study countries (see 3.5.1) ran partly in parallel to the mailing campaign as follow-up interviews were agreed upon with the respondents as soon as possible after receipt of the completed questionnaire.

zero as this would lead to a distortion of the results. The same applies to questionnaires in which individual values had been filled-in by hand and were not clearly readable.

Furthermore, datasets were discarded if >50% of the requested values are identical. This is justified by the assumption that, in these cases, the numbers do not provide meaningful information because they have been set arbitrarily. This could happen, for example, if a respondent moves all slide bars in the online survey to five or to zero just to complete this mandatory step as soon as possible. Since such implausible datasets would reduce the significance of the overall results, they are not considered for the succeeding analysis. The above described criteria lead to exclusion of 32 datasets, all originating from the online survey[4]. For the remaining 210 datasets, minimum, maximum, mean and average values of the weights for each determinant, were calculated using *MS-Excel*. The outcome of this step provides a first overview of the characteristics of the overall dataset. The results are presented in section 4.3.

Further, in order to look into the weighting results in more detail and to reveal potential differences in the relevance of the diffusion determinants depending on the RE technology and the stakeholder type, the result were broken down into several segments. To be able to do so, the online survey as well as the mail version of the questionnaire (cf. annex A.2), requested the respondents to indicate their major **technological focus**. Although respondents were requested to chose the most appropriate answer and to avoid multiple answers, many datasets refer to more than one RE technology. Consequently, there are overlaps between the technology-specific data sub-sets which reduce the distinction between the results. In order to be able to clearly separate the weighting results for wind onshore and PV large-scale (without overlaps), two additional categories are introduced which contain datasets that refer only to wind onshore (category 'wind focus') or PV large-scale (category 'PV focus'), respectively. Figure 12 provides an overview over the technological coverage of the data sample and figure 11 illustrates the overlaps between the data sub-sets.

Also, the respondents to both, the mail version of the questionnaire and the online survey, were requested to specify their **institutional background** whereby multiple answers were possible (cf. annex A.2). Inherently, there are some overlaps between the stakeholder groups, for example, if utilities are also active as RE developers. An overview over the institutional coverage of the dataset provided in figure 13.

Finally, each dataset was assigned to a **primary country for analysis** which refers to the state in which the respondent is based or mostly active, respectively. For the online survey this entry was mandatory and no multiple answers were possible, whereas in the questionnaire this was an open input field. In case that a respondent to the questionnaire

4 The occurrence of lower quality datasets in the data originating from the online interface is likely due to the fact that the online interface also hosted an additional survey of the 're-frame' project (cf. section 3.3). It can be assumed that part of the respondents did not deliberately participate in the weighting exercise but completed the questionnaire only in order to proceed with the 're-frame' survey. In this case it is conceivable that the respondents just provided random answers to save time.

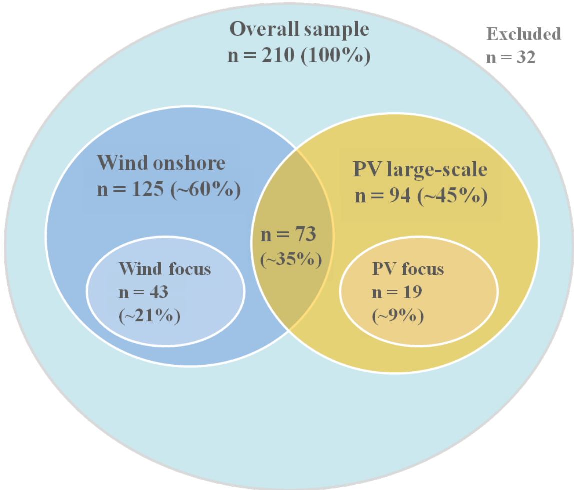

Figure 11: Overview over the weighting data sample with sub-samples for wind onshore and PV large-scale and their share in the overall sample

did not indicate a country, the dataset was assigned to the location of the headquarters of his/her company (if known). The same applies to questionnaires in which the respondent has indicated several countries. In exceptional cases, if no other information about the location was known, the allocation was based on the ending of the email address of the respondent. This way, all datasets were assigned to one primary country[5]. The resulting overview over the geographical coverage of the data sample is presented in table 4. The results of the above described segmentation of the weighting results (per technology, stakeholder type and country) are presented in section 4.3.2. The data sample, although not fully representative for the entirety of European wind and PV developers, can be considered as highly relevant with regard to the research questions (cf. section 1.5) as it covers a large number of RE experts with a high percentage of RE developers (cf. figure 13) and experts for both wind onshore and PV (cf. figure 12).

Table 4: Geographical coverage of the weighting data sample

Country	Datasets	Country	Datasets
Austria	3	Latvia	10
Belgium	23	Lithuania	16
Bulgaria	4	Morocco	1
Croatia	1	Netherlands	2
Czech Republic	2	Norway	1
Estonia	1	Poland	2
Finland	2	Portugal	9
France	21	Slovenia	2
Germany	31	Spain	23
Greece	10	Sweden	11
Hungary	1	Switzerland	1
Ireland	3	Turkey	2
Italy	12	United Kingdom	16

5 As the weighting results are supposed to be country-independent, this parameter is not a major criterion for the evaluation but mainly relevant for verification purposes.

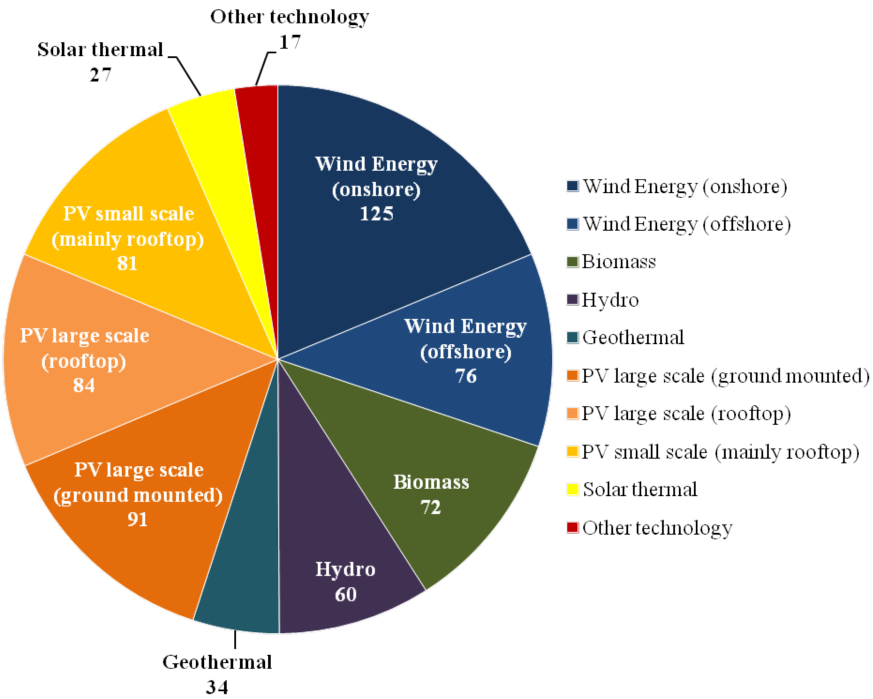

Figure 12: Data sample for weighting of determinants: Technology coverage. Multiple answers were possible.

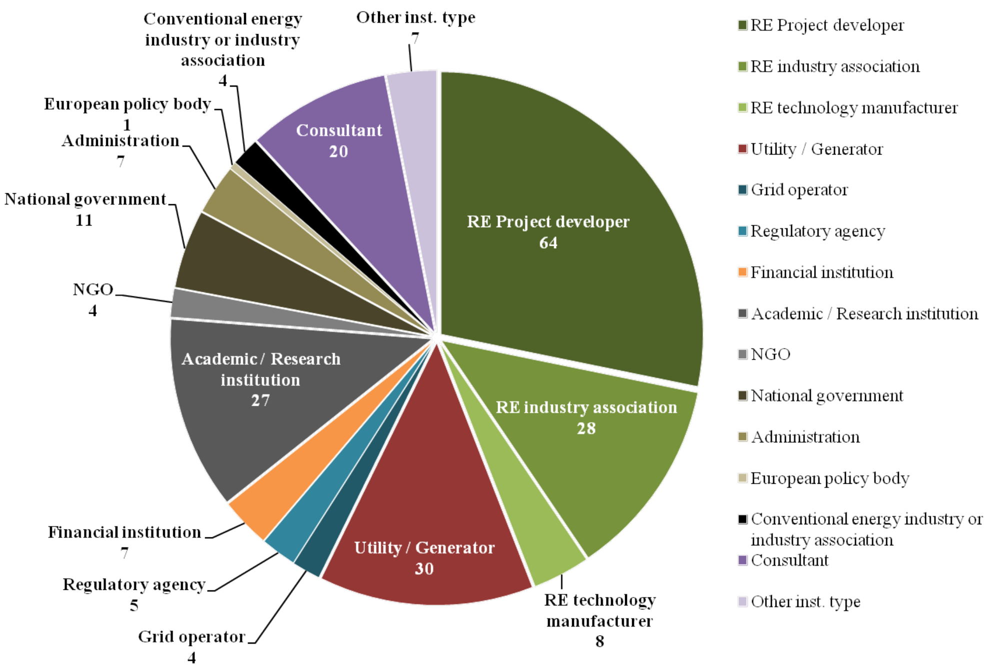

Figure 13: Data sample for weighting of determinants: Institution coverage. Multiple answers were possible.

3.3.3 *Statistical analysis of survey results*

To provide a full picture of the characteristics of the weighting data, the datasets for each determinant were analysed with regard to their basic statistical parameters (minimum, maximum, mean, median, standard error, standard deviation, etc.) using the data analysis tools provided in *MS-Excel*. Initially, the analysis was performed for the overall dataset, subsequently it was carried out for each technology segment of the data sample separately to be able to identify systematic differences between the data sub-sets. For presentation of the results, box-plot diagrams are prepared which display the most important information, namely minimum, maximum, median and quartiles, for each determinant and dataset (see sections 4.3.1 and 4.3.2). A complete overview over these descriptive statistics is also included in appendix A.4 in table 21.

Further, the results of the segmentation analysis, more precisely the differences in the weights per technology, were investigated with regard to their statistical significance. This step is important to show whether observed differences between the individual segments of the data sample are conclusive or whether additional data would be needed to draw more robust conclusions on the technology-specific weights. A standard method in this regard is the *t-test* which reveals whether there are statistically significant differences between the observed values of two independent data sets (Bortz, 1999, p. 137 ff.). With the *t-test*, the weights for each determinant can be compared between the data segments for wind and for PV.

As a precondition for conducting the t-test it must be determined whether the variances of the datasets to be compared are homogeneous or heterogeneous as different variants of the *t-test* apply depending on this criterion (Bortz, 1999, p. 138). To this end, another standard test, the *F-test* was applied to the data sets first. The *F-test* reveals the difference between the variances of two independent datasets (i.e. tests the null hypothesis that the variances are equal) (Bortz, 1999, p. 145ff.). Depending on the outcome of the *F-test*, the respective variant of the *t-test* was applied to each data subset. For both statistical tests, the commonly used significance level of $\alpha = 0.05$ ($p \leqslant 5\%$) was assumed. All tests were conducted using the data analysis function in *MS-Excel*. The results of the statistical analysis are presented in section 4.3.3.

3.3.4 *Verification through follow-up interviews*

Follow-up interviews were used to reflect upon the survey results and to gain a deeper understanding of the argumentation behind individual scores attributed by the respondents. The interviews were conducted within the scope of the case study analysis (see section 3.5) and were thus limited to stakeholders in Germany, Spain and the United

Kingdom. For reasons of feasibility it was not possible to conduct interviews with all questionnaire respondents. Also the availability and willingness of the stakeholders to participate in an interview limited the number of potential interviewees. Between January 2014 and June 2015 31 phone interviews were conducted based on a comprehensive interview guideline (see appendix A.3). In order to identify potential methodological issues related to the questionnaire, the interviewees were initially asked whether the procedure was well understandable and if the respective explanations on the questionnaire were clear to them. Further, the interviews allowed for discussion and contextualization of the weighting results which supported the understanding of the diffusion parameters.

3.4 DERIVATION OF THE RENEWABLE ENERGY DIFFUSION MODEL

The RE diffusion model is developed to be able to comprehend patterns of RE technology uptake and to enable projections of possible future RE diffusion trends. To this end, existing approaches for modelling technology diffusion are reviewed and an enhanced modelling framework is developed which allows for integrating the RE diffusion indicator. The major output of this step is the formal description of the RE diffusion model.

UNDERLYING ASSUMPTIONS AND REQUIREMENTS The basic underlying assumption for the RE diffusion model is that the determinants identified in the initial step of this research project (see section 3.2) are the major factors that shape RE technology diffusion. Therefore, the diffusion model should be able to integrate and reflect the influence of the determinants on the technology diffusion process. Further, the model should be transparent and well manageable also using standard software and basic computing resources to ensure a maximum transparency and to facilitate later application of the approach.

SELECTION OF THE GENERAL MODELLING APPROACH To set up the basic framework of the RE diffusion model, in a first step, existing and established approaches of diffusion models were reviewed and examined with regard to their applicability to the present research questions. Important references in this regard comprise Mahajan and Peterson (1985) who provide a detailed overview over various models for innovation diffusion and Rogers (1995) who authored the standard work on 'The Diffusion of Innovations'. More recent studies are provided, for example, by Meade and Islam (2006) who examine various diffusion modelling approaches or by Geroski (2000) who analyses logistic technology diffusion patterns. Special reference to the diffusion of energy technologies is made by Kemp and Volpi (2008), Barreto and Kemp (2008) and Rao and Kishore (2010) who all provide critical reviews of various diffusion models. Karakaya, Hidalgo and Nuur (2014) contribute to literature with an analysis of research on the diffusion of eco-innovations in different scientific disciplines. Another important contribution is made by Peter Lund (2006) and P. Lund (2010) who investigates and forecasts market penetration patterns of energy technologies by fitting them to an epidemic diffusion model.

In literature there is a broad consensus and extensive empirical evidence is presented regarding the common course of technology diffusion processes. Thereby, the most frequently observed pattern is the sigmoid curve, or s-curve, respectively. The s-curve illustrates the cumulative adoption of a technology (or any innovation) into a market over time. It implies a low number of adoptions in the beginning, a high adoption rate in the medium term and a saturation of the market, resulting in decreasing numbers of adoptions in the long-term (Rogers, 1995).

Corresponding observations of s-shaped diffusion curves have been described for a variety of technologies, for example, by Geroski (2000), Griliches (1960), Grübler, Nebojsa Nakićenović and Victor (1999), Kemp and Volpi (2008), Mansfield (1961), Meade and Islam (2006), Rao and Kishore (2010) and Rogers (1995) or Pulkki-Brännström and Stoneman (2013). An s-curve can be represented mathematically by a logistic function as presented in equation 1.

$$P(t) = \frac{a}{1 + \exp^{-c\cdot(t-t_0)}} \tag{1}$$

Where:

P(t) = Technology penetration over time

a = Saturation level of the s-curve

c = Parameter defining the growth rate (steepness) of the s-curve

t_0 = *Shift on the time axis*

Different interpretations have been put forward to explain the recurring s-curve pattern and to reflect it in the formal framework of diffusion models. Often these theories refer to interactions between the potential adopters, such as the spread of knowledge, social pressure or increasing acceptance for the respective innovation in society (Mahajan and Peterson, 1985, p. 17 ff.)[6]. A prominent s-curve diffusion model is the *Bass model* (Bass, 1969) which explains the adoption of innovations based on innovative and imitative behaviour of potential consumers. This model type has been frequently applied and adjusted to a multitude of use cases. Mansfield (1961), for instance, investigated the adoption of technical innovations in several industrial sectors and Dodds (1973) developed a long-term forecast of cable TV adoption based on the *Bass model*.

6 These assumptions form the basis of so called*internal influence models*. These models assume that the diffusion rate is a function of interpersonal contacts within a adopter population as opposed to *external influence models* which build on the hypothesis that exogenous variables (such as the influence of mass media, advertisement or governments agencies) drive the diffusion process (Mahajan and Peterson, 1985, p. 15 ff.).

Another common model is the *Gompertz model* which describes an asymmetric sigmoid curve (Gompertz, 1825). It is frequently used in medicine, among other things, for modelling cell growth but is also applied in other scientific disciplines, e.g. by Harrison and Pearce (1972) to predict the production of several chemicals in the USA or by Islam, Fiebig and Meade (2002) who forecasted the diffusion of telecommunication technologies in European countries.
A further explanatory approach for the sigmoid curve is based on the heterogeneity of the adopter population. Rogers (1995) suggests that differences among the potential adopters, namely regarding their innovativeness, lead to variations in the preferred adoption time of an innovation. He distinguishes four adopters types with different adoption thresholds which are normally distributed across the adopter population, thus leading to the s-shaped adoption pattern over time (Rogers, 1995, p. 261 ff.) (cf. section 2.1 for a detailed discussion).
Further s-curve models have been developed for applications in various scientific disciplines and for numerous use cases. Mainly these models constitute modifications of the basic logistic model (cf. equation 1) which has been adapted in order to increase the flexibility of the model to integrate additional variables (Meade and Islam, 2006). Examples comprise the *log reciprocal* or *cumulative normal/lognormal* models, the *Floyd model* or the *Sharif-Kabir model*, to mention but a few. For more detailed descriptions of common diffusion models and their formal representation please refer to Mahajan and Peterson (1985) or Meade and Islam (2006).

According to Meade and Islam (2006) it is a common practice in diffusion research to build on existing, basic diffusion models and to adjust them in order to integrate additional variables. Thereby, using an s-curve model to derive technology deployment forecasts is the most common step (Meade and Islam, 2001). Meade and Islam (2001) further highlight that simpler diffusion models tend to lead to better results than more complex ones which is supported by the findings of Green and Armstrong (2015) who found in a comprehensive meta-study of forecasting models that growing model complexity significantly increased forecasting errors.

Consequently, for the present application and in consideration of the stated research objectives (cf. section 1.5), a basic logistic model is chosen as foundation for the RE diffusion model. The s-curve approach is considered as suitable for this purpose because a significant body of empirical findings has proven its applicability to technology diffusion processes, also with specific reference to energy technologies (Grübler, Nebojsa Nakićenović and Victor, 1999; Kemp and Volpi, 2008; P. Lund, 2010; Peter Lund, 2006; Marchetti and N. Nakićenović, 1979; Resch, 2005, see e.g.). Further, the formal framework of logistic diffusion models is well established and transparent and allows for flexible adaptation to specific research questions (Meade and Islam, 2006). In the present case, this involves the inclusion of the identified determinants for RE diffusion which are aggregated in the composite diffusion indicator. Regarding the logistic function, a basic variant (cf. equation 1) is preferred over more complex models to ensure maximum transparency and simplicity of the model and to minimize potential forecasting errors (cf. Green and Armstrong (2015)).

derivation of the final diffusion model Building on the basic formal framework of the logistic model, the RE diffusion model is developed further to be able to integrate the RE diffusion indicator and to consider its influence on the speed of the technology diffusion process. Thereby the score of the RE diffusion indicator determines the slope of the sigmoid curve. Similar approaches have previously been applied by Resch (2005) to integrate diffusion constraints for RE technologies in an energy economic simulation model and by Peter Lund (2006) and P. Lund (2010) to forecast diffusion trends of various energy technologies.
A detailed description of the formal framework of the diffusion model and its derivation are presented in detail in chapter 4, section 4.5.

application to country case studies The modelling approach is verified by applying it to the three case study countries. To this end, historical deployment data for wind onshore and PV (retrieved from EUROSTAT (2014)) is combined in the model with the RE diffusion indicator data collected in the course of the country case studies (cf. section 3.5). The results of this step are presented in chapter 5.

scenario analyses and verification of results For the projections of the technology diffusion in the case study countries, a set of policy scenarios is defined which reflects possible future developments in the framework conditions for RE diffusion. Barreto and Kemp (2008) emphasize the need for integrating the impact of policy instruments in technology diffusion models to provide useful insights for policy makers. Therefore, the scenarios comprise a comparative,'*Business as Usual*' (BAU) scenario which reflects the recent conditions without any changes and three scenarios with variations regarding the framework for administrative procedures, grid development and spatial planning, respectively. The scenarios are described in detail in chapter 5 section 5.2.
For each case study country, the possible future diffusion paths of wind energy and PV are calculated for the policy scenarios. The results are compared and discussed with regard to their plausibility and their relevance for the policy making process (see chapter 5 section 5.6).

In order to validate the developed conceptual model of the RE diffusion indicator and the diffusion model and to test their applicability to real-life examples, three contrasting country case studies were conducted. To this end, data for the quantification of the determinants (cf. section 4.2) were collected by means of stakeholder interviews and review of secondary data sources and legal documents. The analysis covered the time frame 2012 to 2014. The collected indicator data was combined with the weights as assessed through the questionnaire survey (cf. section 3.3) to derive the overall CI scores.
The major outputs of this step are the technology-specific RE diffusion indicator scores for the three case study countries which were then applied for projecting possible technology deployment scenarios with the diffusion model.

METHODOLOGICAL CONSIDERATIONS The country case studies are an important component of this thesis to confirm the suitability of the developed theoretical concepts for the RE diffusion indicator and the diffusion model. Although the previous research steps draw upon sound empirical data and involved significant participation of relevant stakeholders, only the actual application of the developed tools to real-life cases will prove their usability for the assessment of RE frameworks.
A multiple case study design was chosen for this step, firstly, to be able to assess the transferability of the developed approach to different country contexts. As the diffusion indicator and diffusion model are meant to serve as tools for the assessment and benchmarking of RE frameworks across (and potentially beyond) the EU Member States, they should be applicable to various country situations (cf. section 1.5).
Secondly, the case studies aim to demonstrate how different determinants may affect RE diffusion by changing the decision makers' overall perception of the framework conditions for RE project development (i.e. the overall CI score). Therefore, the countries were selected such that a variety of different settings, i.e. contrasting cases, are covered (cf. Yin (2009, ch.2)).
Another important criterion for the selection of the case study countries was the availability of quantitative data and the ease of getting access to the relevant stakeholders. Here important criteria concern, for example, the existence of contact data for interviews or potential language barriers (cf. Yin (2009, p. 26)). On the basis of these criteria, three case study countries were selected:

- **Germany** as a country with a stable regulatory environment for RE and RE support being provided mainly through feed in tariffs (FIT) and, since 2012, also through feed in premiums (FIP). The accessibility of relevant stakeholders is good due to contacts existent at Fraunhofer ISI.

- **Spain** with a high level of regulatory instability implying even retroactive changes of RE support in the past. The former FIT/FIP system was abandoned in 2012 leaving the country with no significant support for RE. Basic language skills exist. Contacting stakeholders for interviews was supported by Spanish native speakers at Fraunhofer ISI.
- The **United Kingdom** with RE support being mainly provided through a quota scheme and just recently through competitive tenders (for large-scale RE). Access to potential interviewees was facilitated through existing contacts at the Energy Policy Research Group at the University of Exeter.

In summary, the main purpose of the country case studies is to validate the applicability of the developed tools, i.e. the diffusion indicator and diffusion model, and to demonstrate how these tools can be used for the evaluation of RE frameworks and the assessment of corresponding political measures.

3.5.1 *Stakeholder interviews for primary data collection*

Interviews with RE experts in the three case study countries constituted a major source of information for the quantification of the RE diffusion indicator as first-hand information is required for several of the indicator components.

SELECTING AND CONTACTING STAKEHOLDERS The target groups for the interviews were identical to those mentioned in section 3.3. The focus clearly lies on the primary decision makers, namely RE developers and investors, in order to gain direct insights into the reality of RE project development in the respective country. As mentioned above (cf. section 3.3), addressees of the mailing campaign for the questionnaire survey were, at the same time, asked for their willingness to participate in a follow-up interview. Additionally, relevant stakeholders were identified via web research and approached via email and by phone. It was the objective to realize interviews with at least ten experts (covering both, wind energy and PV developers) from each case study country in order to obtain a differentiated impression of the situation of the RE framework in each country.
Eventually, thirty-one persons agreed on participating in phone interviews. An overview over the interviewed stakeholders is provided in Table 5.

Table 5: Overview of interviewed stakeholders in the three case study countries

Interview	Institution type	Company scale	Technology focus
Germany			
1	Investor/ Financing institution	large	All RET
2	Academic research / consultant	-	All RET
3	RE developer & utility	medium	Wind onshore
4	RE developer	medium	Wind onshore
5	RE developer	large	Wind (on- and offshore)
6	RE developer & utility	large	Wind, PV
7	RE developer & utility	medium	PV, Wind onshore
8	Research institution	-	PV
9	RE developer & manufacturer	large	PV
10	Research/Consultant	-	PV
11	RE developer	medium - large	Wind onshore
Spain			
12	Academic research	-	All RES
13	RE developer & utility	large	Wind onshore
14	RE industry association	-	Solar thermal
15	RE developer & utility	large	Wind onshore
16	Research institute	-	Wind / PV
17	Government	-	Wind / PV
18	RE developer	small - medium	All RET
19	RE developer & utility	large	Wind onshore
20	RE developer	small - medium	Biomass, Solar-thermal
21	RE association	-	All RET
United Kingdom			
22	RE financing & Consultant	-	All RET
23	RE developer	medium - large	Wind onshore
24	Regulatory agency & research	-	PV
25	RE association	-	Solar (PV)
26	RE association	-	Solar (PV)
27	RE developer	large	PV
28	RE developer	large	Wind onshore
29	RE developer & investor	large	PV
30	RE developer	large	Wind onshore
31	RE developer	large	PV (wind)

preparation and implementation of the interviews The stakeholder consultation was conducted in form of semi-structured interviews based on a comprehensive interview guideline which is included in appendix A.3. The guideline follows the same structure as the weighting questionnaire (cf. appendix A.2), with questions arranged according to the four major thematic blocks: Political and economic framework, market structure, grid issues and administrative procedures.

The interview guideline is based on best practices for the conduction of expert interviews (cf. Gläser and Laudel (2010, ch. 4.2 & 4.3)). The questions are phrased as short as possible and formulated in a clear and neutral, non-suggestive way. The list of questions consists of open (context) questions and closed (factual) questions (Gläser and Laudel, 2010, pp.122-130)) and can be adapted modularly to the background of the respective interviewee. If an interviewee is not familiar with a certain thematic area (e.g. grid access conditions), complete sections of the guideline can be skipped easily. The open questions leave room for discussion and aim to gain a better understanding of the background and mechanisms of action of the diffusion determinants while the closed questions are supposed to yield actual information for their quantification.

The questions cover the time frame 2012 to 2014 by asking for the present situation (2014/2015) and the trend over the past three years. An example for questions regarding the complexity of administrative procedures for RE projects is presented in figure 14. The question types are marked with symbols: The open questions are tagged with stars, the closed questions are denoted by arrows. The complete interview guideline is provided in appendix A.3.

The interviews took place between January 2014 and June 2015. Each interview took about one hour on average (minimum 30 minutes, maximum 3 hours). Due to practical reasons (i.e. time and budget constraints), the interviews were conducted via phone. There were two exceptions of interviews being conducted face-to-face. These interviews were carried out in Spanish by a native speaker based in Spain[7]. To this end, the interview guideline was translated into Spanish to safeguard that, based on this comprehensive manual, the interviews could be conducted in the same way as the other interviews. The interviews for the German case study were conducted in German. All other interviews (apart from the two Spanish ones) were conducted in English.

Prior to the interviews, all potential interviewees were informed about the context and objectives of the study. They were also assured that all provided information would be anonymized and that no contact details would ever be published or passed on to third parties. The interviews were recorded upon consent of the interviewees. The interviewees were assured that all recordings and protocols would be stored confidentially and that all files will be deleted after completion of the research.

7 The reason for this was that the interviewees were not fluent in English and preferred a face-to-face interview in Spanish.

A(4) a)	How would you evaluate the current complexity of the administrative procedures for RE projects in your country?	◯ not complex ◯ average/medium ◯ very complex ◯ no opinion
A(4) b)	✪If you experienced problems related to the administrative process for RE projects in the past, which were the reasons (e.g. high number of authorities involved, unclear responsibilities, incompetency, lack of communication among authorities, other issues)?	
A(4) c)	➲How many permits are currently required to complete the administrative process?	permits
A(4) d)	➲What is an acceptable number of permits in your opinion?	permits
A(4) e)	➲How many authorities do you currently have to contact during the process?	authorities
A(4) f)	✪Would online application platforms and/or definition of time limits (maximum durations with automatic approval) facilitate the process?	
A(4) g)	✪Would a one-stop-shop approach be a suitable solution?	
A(4) h)	✪What characterizes the optimal administrative framework for RE project development, from your point of view?	
A(4) i)	➲Compared to today, how was the complexity of administrative procedures 3 years ago?	◯ better ◯ equal ◯ worse ◯ no opinion

Figure 14: Extract from the interview guideline: Sample questions about the complexity of administrative procedures for RE projects

Processing of interview results The interview recordings were transcribed using text editing software and the transcription tool *'DSS-Player Transcription Module'*. For the German interviews, the transcripts were written in German and not translated into English. All interviews conducted in English were also transcribed in English and the two interviews that were conducted in Spanish were converted into English transcripts. During transcription, errors and omissions in the spoken protocols were generally not corrected in order to maintain the original wording of the statements. Only in individual cases, quotes that are presented in the text were edited or complemented to enhance the reading flow. The adjustments are set in square brackets. The analysis of the interview contents and the management of quotes was carried out with the text analysis software '*ATLAS.ti*'. A software-based approach was chosen to facilitate the management of the extensive volume of information extracted from the raw material. The 31 transcripts comprised 667 pages in total. Also, software-based text analysis tools facilitate the compilation of data for various evaluation purposes (Kuckartz, 2010, ch. 1); in this case, quantification of the determinants, verification of the conceptual model and reflection of the weighting results. In contrast to approaches based on the manual compilation of interview quotes (e.g. in paper format on index cards) software-based tools also significantly simplify the review of the context of individual quotes at any time of the research process. With the help of the software, the positioning of individual quotes in the original transcripts can be easily retrieved, if necessary.

CONTENT ANALYSIS The raw material collected in the case study countries is analysed following a simplified concept of qualitative content analysis. In general, qualitative content analysis aims at a systematic, rule driven and theory-based analysis of communication (Mayring (2010, p. 13), Gläser and Laudel (2010, pp. 199-204)). Thereby, the focus of analysis can be on different aspects of the communication process; apart from the actual subject of communication it might be on the socio-cultural or emotional background, beliefs or intentions of the communicators (Mayring, 2010, pp.56-57). A broad spectrum of methods exists to extract these different types of information from communication protocols. Detailed descriptions of these methods are provided e.g. by Mayring (2010, pp. 67) or Kuckartz (2010, ch. 4).

For the present work, however, as only the actual thematic content of the communication is in the focus of interest, a basic approach is chosen by which the text material is structured and reduced in its volume. For this purpose, thematic codes were defined for each determinant to indicate the location of a respective information related to this determinant in the text. Thematic codes provide rules according to which text information is assigned to different categories and extracted from the material (Kuckartz, 2010, ch. 4.2). This approach is particularly suitable for material which has been collected based on a structured guideline (Kuckartz, 2010, p. 91) which is the case for the present research. The a-priori definition of extraction rules (i.e. codes) safeguards the traceability and reproducibility of the analysis which is relevant to ensure that the results comply with basic quality criteria such as objectivity, reliability and validity of the results (cf. Mayring, 2010, ch. 5). Generally, another person should be able to replicate the analysis based on the defined extraction rules.

An example showing the interface of the code manager of the software '*ATLAS.ti*' is presented in figure 15. In the interface, the individual codes (corresponding to the determinants) are listed on the upper right-hand side. They are organized into categories ('code families') to facilitate the handling of the program (shown on the left-hand side).

The extraction rule for a selected item is displayed in the lower right-hand part of the interface. Here, the example shows the determinants for the category 'political and economic framework' and displays the extraction rule for the determinant 'access to finance'.

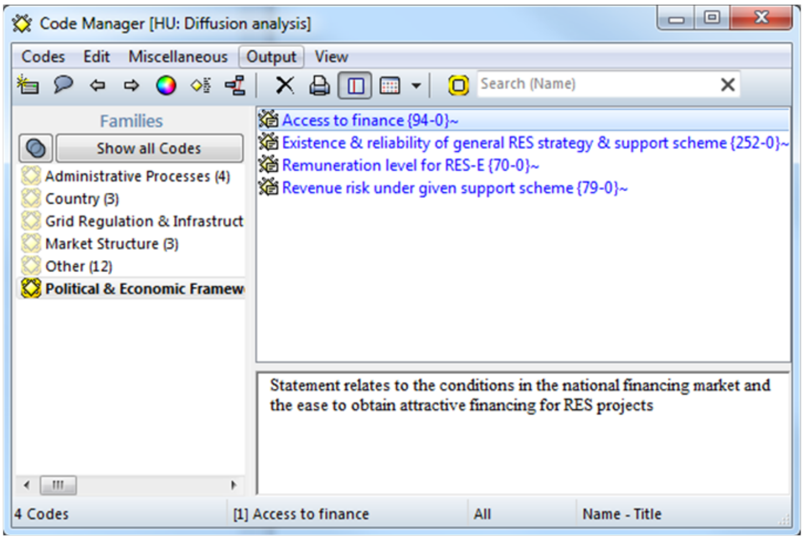

Figure 15: Interface of the code manager of the software '*ATLAS.ti*' which was applied for extracting and managing interview quotes.

The extraction rules were defined relating to each of the determinants as specified in section 4.2 implying that all text sections were marked which relate to the role or manifestation of one of the determinants (cf. figure 15). The resulting quotation database was further managed with the software *ATLAS.ti* which provides analysis tools to retrieve quotes relating to individual codes or code combinations from one or several documents or document groups (e.g. sorted by country). In this way, information relating to each sub-determinant and each country can be extracted from the material as needed by applying document- and code filters. In case that additional determinants or aspects were suggested by the interviewees, which were not covered by the pre-defined category system, these were highlighted as well, allowing to recover this information for the later analysis. Furthermore, comments regarding the structure of the indicator or the methodology of the weighting questionnaire were used to verify and reflect upon the respective results. This feedback loop enhances the groundedness and reliability of the overall results.

Interview quotes are presented particularly in chapters 4 and 5 to substantiate the presented results on the diffusion indicator and to demonstrate the stakeholders' perspective on the RE framework in the case study countries.

3.5.2 *Collection and analysis of secondary data*

Complementary to the interviews, information for the quantification of the diffusion determinants was gathered in each case study country based on secondary data, such as:

- National legal and regulatory documents in official databases;
- National energy strategy documents, such as the National Renewable Energy Action Plans (NREAPs) and the respective bi-annual progress reports for the European Commission (European Commission, 2013c);
- Information published by national regulatory agencies and transnational regulatory associations (e.g. annual reports);
- Information published by national renewable energy associations;
- Reports of relevant research projects;
- Relevant scientific publications.

Analogue to the interviews, secondary data is gathered for the time period 2012 to 2014 in order to represent the manifestation of the RE framework conditions in these years. More details about the data sources used for each of the determinants are discussed with the presentation of the diffusion indicator in section 4.2.3.

3.5.3 *Data processing and compilation of results*

The information derived from the interviews and the secondary data sources is compiled in an *MS-Excel*-spreadsheet. Figure 16 shows an exemplary screen shot of the database. The spreadsheet is organized into 11 columns providing the following information for each data entry:

- The **thematic block (determinant)**: Corresponding to the questionnaire, the determinants are structured into four major thematic blocks, namely the political and economic framework, grid regulation and grid infrastructure, market structure and administrative procedures. This structure facilitates the handling and improves the clarity of the data. Colours have been assigned to each thematic block to further facilitate handling the data.
- The **sub-determinant**: Each decision factor from the questionnaire is included with the same label in the database. There are 16 of these so-called sub-determinants (cf. results in section 4.2).

- The **indicator**: Each of the sub-determinants is quantified by one or several indicators (cf. results in section 4.2). The indicators for each sub-determinant are listed separately in the database.
- The **country**: As the database compiles the data for all three case study countries, this field specifies which country the data point refers to.
- The **technology**: Since data is collected for both, wind onshore and PV, this column differentiates the technology that the information applies to. In case that a data point applies equally to both technologies, the respective data entry is duplicated (and once assigned to wind and once to PV) in order to obtain a full dataset for each technology.
- The **technology segment**: Some of the utilized secondary data sources distinguish between technology segments, for example, different size categories of PV plants. In these cases, the original values for all relevant segments are initially included in the database to ensure data transparency. To obtain the final score, however, the data is aggregated.
- The **year**: Data is collected for the years 2012, 2013 and 2014 and each entry is labelled accordingly. In cases where additional data were available (e.g. from public databases) which could be transferred into the diffusion database with little effort, these were included for potential future use. Reference times for some indicators thus range from 2009 to 2015.
- The **value of the indicator**: Depending on the respective indicator, this field provides information on its manifestation (for the specific reference year, technology and country).
- The **data source**: To ensure transparency and traceability of the results, each indicator is backed with information on the exact source of raw data (e.g. the interview(s), the title and page of a report or publication, the name of public database, etc.).
- The **indicator score**: The score for the diffusion indicator is calculated based on the indicator value by transforming it into a number between zero and one (normalization). The normalization methods vary depending on the indicator. The methods used for each indicator are described in chapter 4 section 4.4.
- The actual **utilization**: An additional column was introduced to specify whether a data point will actually be used for the indicator calculation. Including this column allows to incorporate data entries which are not utilized in their original form but transformed (e.g. two values aggregated) before they are actually utilized for the indicator calculation. Including this information enhances the transparency and traceability of the database, as for each indicator score the underlying value(s) can be traced back to the original data source(s).

	A	B	C	D	E	F	G	H	I	J	K
1	Determinant	Subdeterminant	Indicator	Country	Technology	Segment	Year	Value	Data source	Use for scoring	Score
197	A Political and economic framework	A-IV Access to finance	National credit rating	UK	Wind	all	2014	AAA	S&P Credit rating as of 28-Apr-1978	y	1.00
204	A Political and economic framework	A-IV Access to finance	National credit rating	Spain	Wind	all	2014	BBB	S&P Credit rating as of 23-May-2014	y	0.62
205	A Political and economic framework	A-IV Access to finance	National credit rating	Germany	Wind	all	2013	AAA	S&P Credit rating as of 17-Aug-1983	y	1.00
206	A Political and economic framework	A-IV Access to finance	National credit rating	UK	Wind	all	2013	AAA	S&P Credit rating as of 28-Apr-1978	y	1.00
207	A Political and economic framework	A-IV Access to finance	National credit rating	Spain	Wind	all	2013	BBB	S&P Credit rating as of 23-May-2014	y	0.62
208	A Political and economic framework	A-IV Access to finance	National credit rating	Germany	Wind	all	2012	AAA	S&P Credit rating as of 17-Aug-1983	y	1.00
209	A Political and economic framework	A-IV Access to finance	National credit rating	UK	Wind	all	2012	AAA	S&P Credit rating as of 28-Apr-1978	y	1.00
210	A Political and economic framework	A-IV Access to finance	National credit rating	Spain	Wind	all	2012	BBB-	S&P Credit rating as of 10-Oct-2012	y	0.57
211	A Political and economic framework	A-IV Access to finance	National credit rating	Germany	PV	all	2014	AAA	S&P Credit rating as of 17-Aug-1983	y	1.00
212	A Political and economic framework	A-IV Access to finance	National credit rating	UK	PV	all	2014	AAA	S&P Credit rating as of 28-Apr-1978	y	1.00
213	A Political and economic framework	A-IV Access to finance	National credit rating	Spain	PV	all	2014	BBB	S&P Credit rating as of 23-May-2014	y	0.62
214	A Political and economic framework	A-IV Access to finance	National credit rating	Germany	PV	all	2013	AAA	S&P Credit rating as of 17-Aug-1983	y	1.00
215	A Political and economic framework	A-IV Access to finance	National credit rating	UK	PV	all	2013	AAA	S&P Credit rating as of 28-Apr-1978	y	1.00
216	A Political and economic framework	A-IV Access to finance	National credit rating	Spain	PV	all	2013	BBB	S&P Credit rating as of 23-May-2014	y	0.62
217	A Political and economic framework	A-IV Access to finance	National credit rating	Germany	PV	all	2012	AAA	S&P Credit rating as of 17-Aug-1983	y	1.00
218	A Political and economic framework	A-IV Access to finance	National credit rating	UK	PV	all	2012	AAA	S&P Credit rating as of 28-Apr-1978	y	1.00
219	A Political and economic framework	A-IV Access to finance	National credit rating	Spain	PV	all	2012	BBB-	S&P Credit rating as of 10-Oct-2012	y	0.57
238	A Political and economic framework	A-IV Access to finance	Average interest rates fo	Germany	Wind	all	2014	1.16%	EUROSTAT: Interest rate on long tem gov	y	1.00
239	A Political and economic framework	A-IV Access to finance	Average interest rates fo	UK	Wind	all	2014	2.14%	EUROSTAT: Interest rate on long tem gov	y	0.83
240	A Political and economic framework	A-IV Access to finance	Average interest rates fo	Spain	Wind	all	2014	2.72%	EUROSTAT: Interest rate on long tem gov	y	0.73
241	A Political and economic framework	A-IV Access to finance	Average interest rates fo	Germany	Wind	all	2013	1.57%	EUROSTAT: Interest rate on long tem gov	y	1.00
242	A Political and economic framework	A-IV Access to finance	Average interest rates fo	UK	Wind	all	2013	2.03%	EUROSTAT: Interest rate on long tem gov	y	0.95
243	A Political and economic framework	A-IV Access to finance	Average interest rates fo	Spain	Wind	all	2013	4.56%	EUROSTAT: Interest rate on long tem gov	y	0.65
244	A Political and economic framework	A-IV Access to finance	Average interest rates fo	Germany	Wind	all	2012	1.50%	EUROSTAT: Interest rate on long tem gov	y	1.00
245	A Political and economic framework	A-IV Access to finance	Average interest rates fo	UK	Wind	all	2012	1.74%	EUROSTAT: Interest rate on long tem gov	y	0.98
246	A Political and economic framework	A-IV Access to finance	Average interest rates fo	Spain	Wind	all	2012	5.85%	EUROSTAT: Interest rate on long tem gov	y	0.79
247	A Political and economic framework	A-IV Access to finance	Average interest rates fo	Germany	PV	all	2014	1.16%	EUROSTAT: Interest rate on long tem gov	y	1.00
248	A Political and economic framework	A-IV Access to finance	Average interest rates fo	UK	PV	all	2014	2.14%	EUROSTAT: Interest rate on long tem gov	y	0.83

Figure 16: Screen shot of the RE diffusion indicator database in MS-Excel

3.6 SUMMARY AND REVIEW OF METHODOLOGY

This thesis aims to develop a diffusion indicator for wind energy onshore and non-residential PV as a transparent and objective analytical tool for the assessment of RE frameworks. The indicator forms the basis for the development of a RE diffusion model which can be applied to represent the impact of various framework factors on the development of RE technologies. The results aim to support the assessment of framework conditions for RE diffusion and to facilitate the design of more favourable and efficient policies for RE.

To meet the methodological requirements associated with these objectives (cf. section 3.1), the research design includes qualitative and quantitative elements with a strong focus on involvement of the major decision makers, in particular RE developers and investors. To this end, several elements of stakeholder interaction, namely moderated group discussions, a questionnaire survey and in-depth, semi-structured interviews, are applied, which ensure that the perspectives of the relevant stakeholders are actually captured by the approach.

Regarding the development of the RE diffusion model, the chosen approach builds on the well established framework of the logistic (sigmoid) model and develops it further to be able to accommodate the implications of the RE diffusion indicator. The s-curve approach is a widely accepted and empirically proven approach (Mahajan and Peterson, 1985; Meade and Islam, 2001, 2006), not only for explaining technology diffusion in general but also regarding the diffusion of energy technologies in particular (cf. Grübler, Nebojsa Nakićenović and Victor (1999), Kemp and Volpi (2008), P. Lund (2010), Peter Lund (2006), Marchetti and N. Nakićenović (1979) and Resch (2005)). The use of the basic logistic model, in contrast to more complex models, sets out the conditions for a clear and coherent formal framework which ensures a maximum of transparency and enhances the applicability of the results. The implementation of the model in standard software products (i.e. *MS-Excel*) safeguards a broad and intuitive usability of the diffusion model.

Finally, the research design includes the application of the developed approach (i.e. the diffusion indicator and the diffusion model) within the scope of three country case studies for Germany, Spain and the United Kingdom. The main purpose of the case studies is to validate the developed theoretical concepts on the basis of real cases and to illustrate their applicability to different country contexts. To this end, the case study countries were selected in a way that allows for contrasting results and meaningful comparisons. By investigating and comparing different scenarios for the development of the future policy framework, possible implications for policy makers can be evaluated which enhances the relevance of the research for the policy making context.

4

CONCEPTUAL FRAMEWORK FOR THE DIFFUSION OF RENEWABLE ENERGIES FROM THE DEVELOPER'S PERSPECTIVE

This chapter introduces the conceptual and analytical framework that is developed in this thesis to contribute to a deeper understanding of the diffusion processes of non-residential PV and onshore wind energy, to capture the major determining factors for RE diffusion in an indicator and finally to integrate them in a diffusion model.

The chapter is structured as follows: Section 4.1 briefly summarizes the motivation and objectives of this working step; section 4.2 introduces the conceptual model that forms the basis for the diffusion analysis; section 4.3 describes the relevance each determining factor has for the diffusion process and section 4.4 explains how these findings are used to construct an indicator that can be widely applied as a transparent tool to evaluate RE frameworks[1]. Finally, section 4.5 explains how this diffusion indicator is applied in a diffusion model that is able to provide short-term projections for the deployment of RE technologies[2]. Section 4.6 provides a summary and discussion of the chapter's findings. The underlying methodology is presented in chapter 3.

4.1 OBJECTIVE

As set out in section 1.1, extensive deployment of RE technologies and the replacement of fossil fuels, particularly in the electricity sector, are major components of the European climate change mitigation strategy. For the realization of the European RES-E targets, extensive investments by the private sector will be required (BNEF, 2014).
However, to ensure that these investments will actually be realized within the envisaged time frame it must be safeguarded that the national policy frameworks for RE deployment sufficiently support the desired development. Therefore, it is important to closely monitor the RE diffusion process and, if required, to adjust the framework conditions affecting it. To enable policy makers to initiate such changes timely, tools are required to monitor the framework conditions and to assess the impact that different policy changes might have on the future technology diffusion process.
As the observed diffusion of a RE technology on national level is the cumulated result of

1 Initial results on the conceptual model for the diffusion indicator have previously been published in Boie, Ragwitz and Held (2015).
2 Initial results of the diffusion model and its application to the case of Germany have previously been published in Boie, Ragwitz and Held (2016).

the decisions of individual RE project developers and investors (cf. section 2.1), the basic prerequisite when developing a diffusion monitoring tool is a holistic understanding of the major factors affecting the decision processes of these stakeholders. In this context, the following questions are especially relevant:

- What are the major factors (determinants) that affect the realization of RE projects, i.e. the decisions of RE project developers/investors?
- How relevant is each determinant?
- How are the determinants reflected in the resulting diffusion process?

To answer these questions, this chapter develops a conceptual approach that takes the major determinants of RE diffusion processes and systematizes them in the form of a composite indicator for RE diffusion. The objective is to capture the perspective of the major decision makers in the RE diffusion process, namely project developers or investors. Further, the approach aims at maximum transferability so that it can be applied to different national contexts (e.g. for benchmarking purposes). The analysis focuses on wind onshore and PV, two mature RE technologies which, besides concentrated solar power (CSP), account for the majority of annually added RE capacity worldwide (REN21, 2014). The emphasis for PV is on non-residential projects[3] as the stakeholders and decision-making factors differ significantly between large-scale projects and small-scale applications, e.g. on household level[4].

A diffusion model is then developed on this basis, which can assess the impact of individual framework factors (determinants) on the resulting diffusion process. The model is intended to serve as a policy evaluation tool to appraise the influence of changes in the policy framework on future RE diffusion patterns.

The above objectives imply that, firstly, the major relevant parameters of the diffusion process need to be identified and systematized. Secondly, the relevance of each determinant has to be determined from the decision maker's perspective. Thirdly, suitable data sources need to be selected for the quantitative representation of each determinant in a composite indicator. And, fourthly, the effect of each determinant on the diffusion process has to be ascertained.

3 The term non-residential, in the context of this work, refers to medium- and large-scale installations with a capacity >10 kW. This includes large rooftop and ground-mounted installations but excludes common household applications.

4 Applicability of the approach to other technologies or technology segments besides wind onshore and utility-scale PV is not excluded but would possibly require adaptation of the indicator components and data sources.

4.2.1 *Drivers and barriers for renewable energy diffusion in the literature*

Numerous studies have investigated drivers and barriers for RE deployment with different focuses and by various methodological means. However, three types of sources are considered as most relevant for the present analysis and were thus in the focus of the literature review:

- Case studies investigating drivers and barriers for RE technologies on a national level: This document category comprises publications in scientific journals as well as reports of relevant research projects or meta studies about these sources. Case studies are relevant sources because they provide bottom-up information on important factors influencing RE deployment which helps to identify similarities and general patterns regarding the determinants for RE diffusion.
- Official policy documents, guidance reports and assessments of RE deployment in the EU Member States published by the European Commission: EU policy reports are relevant references as they are reliable, official sources of information on common barriers and best practices for RE deployment on European level.
- Literature on existing composite indicators in the field of renewable energy: Reviewing the structure and the approach of existing composite indicators in the energy sector is important to gain insights into the underlying assumptions regarding the major influencing factors for RE deployment. It further helps to identify potential gaps or inconsistencies in their structure and to avoid them in the present work.

As an initial step of this research project, a comprehensive review of the above publications types was conducted (cf. section 3.2.1). The literature review focused particularly on publications referring to the drivers and barriers for the diffusion of onshore wind energy and non-residential PV but also included publications referring to other RE sources. In the following, selected publications from each of the above mentioned publication types are referenced and findings regarding the determinants for RE diffusion are briefly summarized.

CASE STUDIES A general framework for the analysis of barriers to RE deployment with a focus on developing countries has been proposed by Painuly (2001). Seven categories of barriers are suggested: Market failures (e.g. market access barriers), market distortions (e.g. financial disadvantages or trade barriers for RE), economic & financial barriers (e.g. high technology cost or insufficient access to financing), institutional issues (e.g. insufficient regulatory and institutional set-up), technical barriers (e.g. lack of standards and expertise), social, cultural and behavioural barriers (e.g. lack of consumer awareness) and other barriers (e.g. uncertainty of government policies, lack of infrastructure). Painuly (2001) proposes that in country case studies the suggested categories should be evaluated based on stakeholder consultation to assess the relevance of individual barriers in the country context and to be able to identify suitable policy measures.

A meta-analysis of 19 studies investigating non-technical barriers to PV deployment in the United States was conducted by Margolis and Zuboy (2006). The reviewed publications comprised several studies based on surveys, interviews and focus group discussions with stakeholders from the PV industry, potential technology adopters, the policy sector and public agencies as well as case studies and policy analyses. The barriers mentioned most frequently in the reviewed studies (at least in 10 out of 19 studies) comprised: Lack of supportive policies, lacking consumer awareness, high cost of RE technologies, difficulties for RE entering established energy systems and inadequate financing options.

In a survey conducted by Holburn, Lui and Morand (2010) 29 Canadian wind energy developers ranked 15 factors on a scale from 1 (not important) to 5 (essential) accounting for the level of importance these factors have for their decision to become active in a given wind power market. The factors were grouped into operational aspects (wind conditions, availability of local technology suppliers, construction cost), regulatory policies (incentive level, duration of PPA, availability of transmission capacity, transparency of procedures to obtain PPA) and regulatory governance (policy stability, liability of RE targets, institutional coordination, ease of passing all required approval procedures). The wind conditions were ranked first (with 4.54 points) but regulatory factors received similarly high scores. The second most important factor is the stability of the policy environment (4.38) followed by the availability of transmission infrastructure (4.32), the existence of long-term RE targets (4.14), the transparency of PPA conditions and the ease of obtaining grid connection (both 4.07). Interestingly, the level of government incentives for RE ranks only thirteenth (3.34) and the availability of local technology suppliers ranks last with 1.93 points. The aggregated results for the three groups point out that regulatory governance is most important (3.96), regulated policies are second most important (3.87) and operational factors are least important (3.07).

Lüthi and Prässler (2011) investigate the relevance of regulatory risk factors for EU and US wind energy project developers through choice experiments. Their analysis covers six factors: Duration of administrative procedures; legal security; grid access cost; remuneration level, availability of credit financing and conditions for investment grants. Their results show that project developers revealed strongest preferences for a high legal security and an attractive remuneration level, followed by short administrative processes.

Statistical analysis of 14 RE markets globally conducted by Alagappan, Orans and Woo (2011) investigates the relation between historical RE deployment and the market structure, the support scheme (FIT/no FIT), the mode of transmission planning and the level of grid connection costs. Alagappan, Orans and Woo (2011) find that implementation of a FIT, anticipatory transmission planning and low grid access cost closely correlate with high RE deployment.

Lüthi and Wüstenhagen (2012) revealed through choice experiments with 63 European PV developers that the duration of administrative procedures had the highest relative relevance (25.56%) in an the investment decision for a PV project, closely followed by the FIT level (24.37%). Further factors with a lower relative relevance were the existence of capacity caps for PV support (18.72%), the presence of drastic changes in the past support policy (17.74%) and the guaranteed duration of the FIT (13.61%). They conclude that policy design should therefore focus on reducing policy risks to lower RE support costs.

Mani (2012) studied the framework conditions that impact the uptake of RE and energy efficiency technologies based on five comparative case studies in South Asian countries. Apart from country-specific factors, interviews with local stakeholders revealed ten general, cross-cutting determinants which are particularly critical for RE investments: Clarity & coherence and consistency of clean energy policies, government commitment & credibility of RE strategies, complexity of administrative procedures, institutional capacity of RE agencies, compliance with contractual arrangements (PPAs), coordination among clean energy agencies, access to capital for financing clean energy projects, transparent rules and standards for grid access and availability of high quality spatial information on RE potentials. Further, Mani (2012) develops a basic scoring system, the 'Climate Investment Readiness Index' (CIRI), which intends to *"provide a fair indication of some of the key elements that a country needs to have in place to give a clear signal to private investors"* (Mani, 2012, p. 14). It consists of four cross-cutting indicators (existence of RE policy & laws, RE targets and RE purchase/off-take obligations and availability of tradable instruments for RE) and six technology-specific indicators (tariffs for RE, RE investment related incentives, RE production related incentives, income tax exemptions for RE, RE trade benefits and other tax benefits for RE). All indicator components are weighted equally and the scores range between zero and one, leading to an total maximum score of 10.

Friebe, Von Flotow and Täube (2014) investigate factors that influence wind park developer's investment decisions with a focus on investments in emerging economies. Their research is based on interviews and a workshop as well as a questionnaire-based survey (applying a ranking technique) to assess the relative importance of the factors mentioned in the interviews. Four factors were specified as inevitably necessary for any market development: Availability of wind resources, stability of the political regime, financial viability of the project and access to the grid. Friebe, Von Flotow and Täube (2014) concluded that, if one of these conditions is not provided, no significant market growth can be expected. Regarding the ranking results, the conditions for which investors showed strongest preference included: A long term FIT (fixed for 20 years), guaranteed grid access and priority dispatch, good legal security, low risk of unforeseen policy changes, transparent project approval procedures with a maximum duration of 18 months, availability of attractive financing from development banks and mechanisms for hedging inflation risk (i.e. tariff adjusted to inflation rate).

Chowdhury et al. (2014) investigate the impact of public policy on the diffusion of PV in Germany and Japan from 1990 to 2011. They conclude that mainly the long-term secure and economically attractive support through a FIT was the major driver for PV development in Germany and that the financial support guaranteed by law has created a legitimization which allowed the technology to proceed to the stage of market stabilization. In Japan, although the diffusion process started earlier, the financial support was not as continuous and attractive and thus led to a stagnation of the diffusion after 2005.

Regulatory and non-economic barriers for wind energy and PV deployment have also been studied in several research projects funded by the European Commission. Particularly relevant in this regard is, for example, the project 'Wind Barriers' (Wind Barriers, 2009) which analysed administrative and grid-related obstacles for wind energy projects across all EU Member States (project duration: 2008-2010). It included an evaluation of 200 on- and offshore wind energy projects with regard to the administrative lead time, grid access lead time and complexity of the related procedures. The complexity of administrative procedures, and in particular spatial planning issues, as well as insufficient information on transmission grid capacities were identified as major barriers to wind project development in most countries (Cena et al., 2010). However, the precise manifestation of the analysed factors varied greatly across the European countries (see Cena et al. (2010)).

In the frame of the study 'Assessment of non-cost barriers to renewable energy growth in EU Member States - AEON', ECORYS (2010) conducted an analysis of non-economic barriers to RE deployment in the EU Member States (project duration: 2008-2010). The analysis was based on interviews with local stakeholders and covered all major RE technologies. Results pointed out that barriers vary from country to country but that the the most severe barriers are associated with three aspects: 1) Administrative issues, such as delays in planning and permitting procedures, lack of coordination among authorities, high cost and complexity of procedures as well as insufficient spatial planning; 2) Grid connection issues such as high connection cost, long lead times and insufficient information on grid capacity; 3) Lack of social acceptance and resulting public opposition against RE projects (ECORYS, 2010).

The project 'PV Legal' (PV Legal, 2012) and its successor 'PV Grid' (PV Grid, 2014) focus on the assessment of bureaucratic and grid access barriers for PV applications in the European Member States (project duration: 2009-2012 and 2012-2014). The analyses are based on a comprehensive bottom-up assessment including interviews with stakeholders from the PV sector in each country. The findings are presented in an online database[5].

5 Weblink: www.pvgrid.eu/database.html (last accessed: 14.6.2015)

Results show that the administrative framework conditions for the realization of PV projects vary considerably among the EU Member States. Based on the bottom-up assessment, the barriers were classified into four categories: 1) Permitting procedures (relating to cost, duration and labour requirements for permit approval and spatial planning); 2) Grid connection (related to connection procedures, access cost, capacity shortages or technical requirements); 3) Support schemes (referring to reliability and stability of the regulatory framework); 4) Operation & Maintenance (including administrative and technical requirements for operation of PV systems) (B. Barth, Concas, Binda Zane et al., 2014, p. 8).

As part of the project 'Keep-on-Track!' (Keep-on-Track!, 2014) the progress of the EU Member States regarding the attainment of their RE targets is monitored including annual consultation of national RE stakeholders (project duration: 2013-2015). The interviews serve to identify and assess barriers to RE deployment on national level. For the reporting period 2013/2014, the highest number of barriers across all countries was reported for the following categories (numbers in brackets indicate number of reported barriers): RE strategy (33), RE support scheme (25), administrative issues (21), lack of information & awareness (16), spatial & environmental planning issues (15), non-preferential treatment of RE (13) and grid infrastructure issues (13); whereby spatial planning and grid infrastructure issues were reported to affect particularly wind energy (Najdawi et al., 2013).

European policy documents Another relevant source of information are documents published by the European Commission in order to provide official status reports on the situation of RE in the European Member States. For example, in 2013 the European Commission published a guidance report for the design of RE support schemes which describes best practices for RE policies and includes an overview of major barriers for RE deployment across the European Member States (European Commission, 2013b, annex I & II). The assessment highlights the general relevance of grid-related barriers such as the complexity of connection procedures, long connection lead times, high connection cost, lack of physical grid capacity and virtual saturation of the grid (European Commission, 2013b, annex I). It further presents an assessment of administrative procedures across the EU Member States and shows that there are considerable differences regarding the implementation of best practices relating to the complexity of permitting and spatial planning processes for RE (European Commission, 2013b, annex II). Additional information is provided on market access conditions (e.g. gate closure times) and the stability and design of RE support schemes (European Commission, 2013b, annex I).

Information on barriers and support policies for RE on country level is also compiled in the bi-annual progress reports on the advancement of the EU Member States towards the 2020 targets (available through European Commission (2013c)). The progress reports are prepared by the national governments in line with the Renewable Energy Directive 2009/28/EC (European Commission, 2009a) and report the Member States' advancement towards the 2020 targets (cf. section 1.1). They further describe obstacles which are hindering target achievement as well as measures taken to remove these obstacles. The reports are a useful source of information as they provide first-hand insights into the national frameworks for RE deployment in the EU Member States as well as on legal measures taken during each reporting period to improve the conditions for RE diffusion.

existing composite indicators Several indicators with different thematic and geographic focus have previously been developed to assess and benchmark the framework conditions for RE deployment (see also section 2.2.3 or IRENA (2014) and World Bank (2014)). In the following, some examples of indicators with a high relevance to the present research topic are presented.

The **'Renewable Energy Country Attractiveness Index'** (RECAI) published quarterly by Ernst & Young since 2003 provides a ranking of the RE market attractiveness for 40 countries worldwide. The ranking covers 16 parameters grouped in the three categories: Macro-level-, energy market- and technology-specific indicators (see figure 17) (Ernst & Young, 2014).

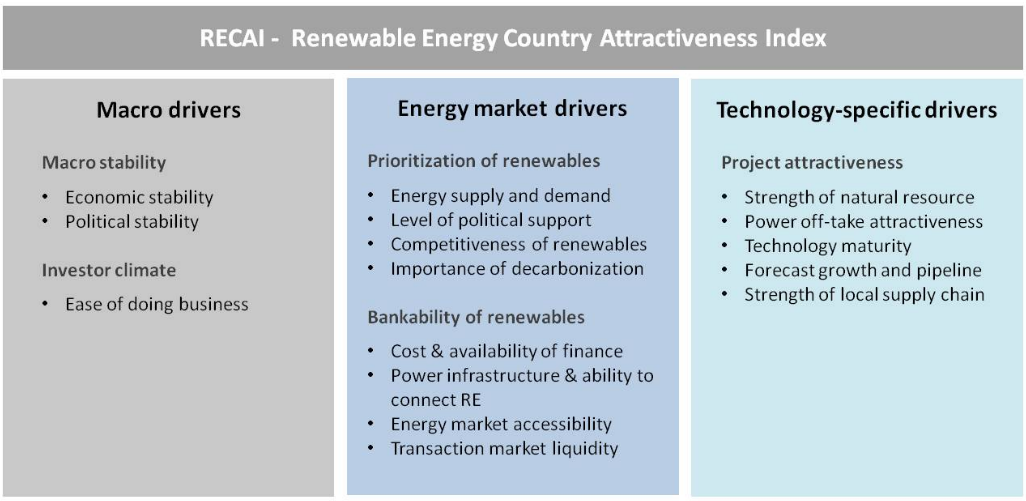

Figure 17: Structure of the 'Renewable Energy Country Attractiveness Index' (RECAI). Source: Own illustration based on Ernst & Young (2014)

The **'Climate Scope Index'** is issued by 'Bloomberg New Energy Finance' and evaluates Latin American and Caribbean countries based on their ability to attract clean energy investments. It assesses 39 indicators in the categories: Enabling framework for RE, availability of clean energy funds, existence of clean energy value chains and climate change mitigation (see figure 18) (BNEF, 2013).

The **'RE Readiness Score'** developed by Mondal et al. (2013) is a benchmarking tool for assessing the readiness to deploy RE in the member countries of the Gulf Cooperation Council (GCC). It comprises three categories of indicators relating to infrastructure

Climate Scope Index			
Enabling Framework (40%)	**Clean Energy Investment & Climate Financing (30%)**	**Low-Carbon Business & Clean Energy Value Chains (10%)**	**Greenhouse Gas Management Activities (20%)**
• Policy framework • Power market structure Level of clean energy capacity online • Other market-size related factors	• Funds deployed in support of clean energy • Availability and cost of local capital including microfinance	• Availability of local manufacturing and supply chains for clean energy goods, services and financing	• Conditions for carbon offset projects • Carbon policies & corporate actions toward mitigating emissions & improving energy efficiency • Other sustainable practices

Figure 18: Structure of the 'Climate Scope Index' including weights of the indicator components in percentage terms.
Source: Own illustration based on BNEF (2013)

(including RE resources, energy demand, grid capacity and market infrastructure), institutions (including institutional framework, RE targets, support policies, financing conditions and the macroeconomic situation) and human capital (including presence of technical and commercial expertise, technology adaptiveness/innovativeness and consumer awareness) (Hawila et al., 2014; Mondal et al., 2013).

The indicator for the **'Readiness for Investment in Sustainable Energy'** (RISE) issued by the World Bank (2014) measures the country performance regarding 28 individual indicators related to energy access, energy efficiency, renewable energy and other, cross-cutting aspects. The individual indicators in each of the fields relate to planning, policies, pricing and subsidies, and the level of procedural efficiency.

The **'Electricity Market Preparedness Indicator'** developed by Held, Ragwitz, Merkel et al. (2010) assesses electricity markets regarding their ability to integrate RE. Thus, it is focused on market design aspects namely the level of unbundling in the electricity transmission sector, the market power in the generation and retail sector, the share of electricity traded at spot markets and gate closure times at electricity exchanges (Held, Ragwitz, Merkel et al., 2010).

The **'Arab Future Energy Index'** (AFEX) for RE benchmarks the member countries of the Regional Centre for Energy Efficiency and Renewable Energy (RCREEE) in the Middle East and North Africa (MENA) region regarding their frameworks for RE development. It covers the areas: Market structure, policy framework, institutional capacity and finance & investment RCREEE (2013). The individual indicators included in these areas are displayed in figure 19.

The **'Renewable Energy Market Competence Index'** developed by Elrefaei, Bida, Hallouda et al. (2013) is a benchmarking tool to compare the attractiveness for RE investments of MENA countries to other countries worldwide. It includes 18 indicators relating to four categories: The political & economic framework, the structure of the energy sector, the financial & environmental framework and technology specific aspects (Elrefaei, Bida, Hallouda et al., 2013). So far it has been applied only to Concentrated Solar Power (CSP) (Elrefaei, Bida, Elsobky et al., 2013).

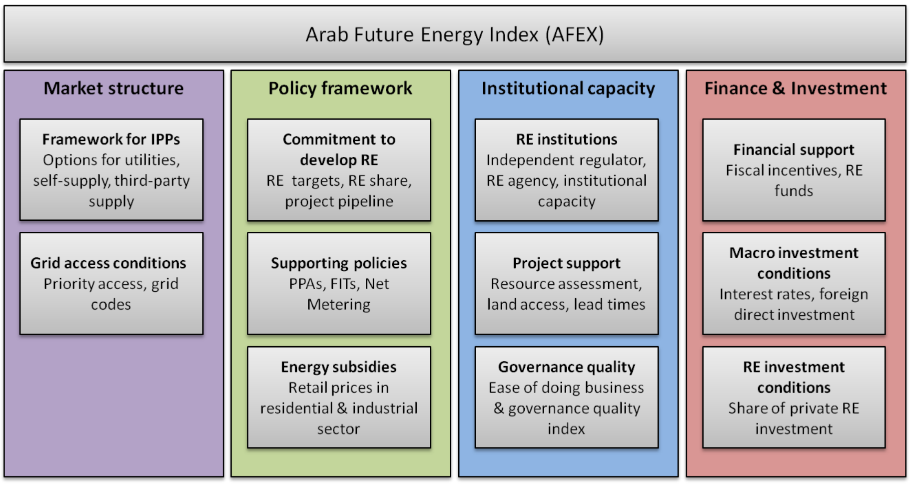

Figure 19: Structure of the 'Arab Future Energy Index' (AFEX).
Source: Own illustration based on RCREEE (2013)

4.2.1.1 *Summary and conclusion*

The review of publications from three major streams of literature, namely publications on case studies and European research projects, EU policy reports and information on existing indicators in the RE sector, has shown that a broad spectrum of parameters influences the market diffusion of PV and wind energy (and RE in general).

Existing case studies and research projects mention a large variety of factors that can drive or inhibit RE deployment. Determinants mentioned most frequently throughout the literature comprise direct economic factors such as the cost of RE technologies, support levels or access to capital for RE projects. However, also the relevance of non-economic factors, such as grid and market access conditions, administrative procedures and spatial planning issues is widely acknowledged (see references in section 4.2.1).

The European Commission highlights the most important elements for successful RE deployment in it's 'Guidance for the Design of Renewables Support Schemes' and emphasizes that, besides an adequate design of financial support instruments, particularly barriers related to grid access, market integration and bureaucratic processes should be addressed to enable broad RE diffusion (European Commission, 2013b).

Existing indicators measuring the framework for RE deployment worldwide consistently consider the existence of an enabling policy framework, such as RE targets, support policies and respective supporting institutions, the availability of finance and the structure of the electricity market. Some also consider the availability of grid infrastructure (Ernst & Young, 2014; Mondal et al., 2013) and the presence of RE value chains and related expertise (BNEF, 2013; Ernst & Young, 2014; Mondal et al., 2013) or include more general, macro-level factors such as the overall political and economic stability (Ernst & Young, 2014; Mondal et al., 2013).

To conclude, the determinants which are most frequently mentioned in the literature and commonly considered in the structure of existing indicators are summarized in table 6.

Table 6: Determinants for RE diffusion mentioned in literature and commonly considered in existing composite indicators

Determinants mentioned in literature/ existing indicators	Source references
Policy framework	
RE targets	Ernst & Young (2014), Hawila et al. (2014), Holburn, Lui and Morand (2010), Mondal et al. (2013), Najdawi et al. (2013), RCREEE (2013) and World Bank (2014)
RE support policies and support levels	Alagappan, Orans and Woo (2011), B. Barth, Concas, Binda Zane et al. (2014), BNEF (2013), Chowdhury et al. (2014), Ernst & Young (2014), European Commission (2013b), Friebe, Von Flotow and Täube (2014), Hawila et al. (2014), Holburn, Lui and Morand (2010), Lüthi and Prässler (2011), Lüthi and Wüstenhagen (2012), Mani (2012), Margolis and Zuboy (2006), Mondal et al. (2013), Najdawi et al. (2013), Painuly (2001), RCREEE (2013) and World Bank (2014)
Institutional set-up / coordination of RE institutions	Hawila et al. (2014), Holburn, Lui and Morand (2010), Mani (2012), Mondal et al. (2013), Painuly (2001) and RCREEE (2013)
Financing conditions / access to financing products for RE	BNEF (2013), Elrefaei, Bida, Elsobky et al. (2013), Ernst & Young (2014), Friebe, Von Flotow and Täube (2014), Hawila et al. (2014), Lüthi and Prässler (2011), Mani (2012), Margolis and Zuboy (2006), Mondal et al. (2013), Painuly (2001) and RCREEE (2013)
Regulatory risk / reliability of the policy framework	B. Barth, Concas, Binda Zane et al. (2014), Chowdhury et al. (2014), European Commission (2013b), Friebe, Von Flotow and Täube (2014), Holburn, Lui and Morand (2010), Lüthi and Wüstenhagen (2012), Mani (2012) and Painuly (2001)
Electricity market	
Accessibility of the market (e.g. gate closure times, priority dispatch)	BNEF (2013), Ernst & Young (2014), European Commission (2013b), Friebe, Von Flotow and Täube (2014), Hawila et al. (2014), Held, Ragwitz, Merkel et al. (2010), Margolis and Zuboy (2006), Mondal et al. (2013), Najdawi et al. (2013), Painuly (2001) and RCREEE (2013)
Market diversification / concentration	Alagappan, Orans and Woo (2011), Held, Ragwitz, Merkel et al. (2010) and Painuly (2001)
Market liquidity	Ernst & Young (2014) and Held, Ragwitz, Merkel et al. (2010)
Conditions for power off-take (PPAs)	Ernst & Young (2014), Holburn, Lui and Morand (2010) and Mani (2012)

Table 6: Determinants for RE diffusion mentioned in literature and considered in existing composite indicators in the energy sector

Determinants mentioned in literature/ existing indicators	Source references
Electricity grid	
Availability of grid capacity	B. Barth, Concas, Binda Zane et al. (2014), Ernst & Young (2014), European Commission (2013b), Friebe, Von Flotow and Täube (2014), Hawila et al. (2014), Holburn, Lui and Morand (2010), Mondal et al. (2013) and Najdawi et al. (2013)
Transparency of future grid development	Alagappan, Orans and Woo (2011), Cena et al. (2010) and ECORYS (2010)
Grid connection cost	Alagappan, Orans and Woo (2011), B. Barth, Concas, Binda Zane et al. (2014), ECORYS (2010), European Commission (2013b) and Lüthi and Prässler (2011)
Complexity/transparency of grid connection procedures (e.g. priority access)	B. Barth, Concas, Binda Zane et al. (2014), Cena et al. (2010), Ernst & Young (2014), European Commission (2013b), Friebe, Von Flotow and Täube (2014), Mani (2012) and RCREEE (2013)
Grid connection lead time	B. Barth, Concas, Binda Zane et al. (2014), Cena et al. (2010), ECORYS (2010) and European Commission (2013b)
Administrative and planning processes	
Duration of administrative procedures	B. Barth, Concas, Binda Zane et al. (2014), Cena et al. (2010), ECORYS (2010), Friebe, Von Flotow and Täube (2014), Lüthi and Prässler (2011) and Lüthi and Wüstenhagen (2012)
Complexity and transparency of administrative procedures	B. Barth, Concas, Binda Zane et al. (2014), Cena et al. (2010), ECORYS (2010), European Commission (2013b), Friebe, Von Flotow and Täube (2014), Holburn, Lui and Morand (2010), Mani (2012) and World Bank (2014)
Cost of administrative procedures	B. Barth, Concas, Binda Zane et al. (2014) and ECORYS (2010)
Spatial planning for RE	B. Barth, Concas, Binda Zane et al. (2014), Cena et al. (2010), ECORYS (2010), European Commission (2013b), Mani (2012) and Najdawi et al. (2013)
Macro-level aspects	
General political stability	Elrefaei, Bida, Elsobky et al. (2013) and Ernst & Young (2014)
Macroeconomic stability	Ernst & Young (2014), Hawila et al. (2014) and Mondal et al. (2013)
Legal security	Friebe, Von Flotow and Täube (2014) and Lüthi and Prässler (2011)
Other factors	
Availability of RE value chains and expertise	BNEF (2013), Ernst & Young (2014), Hawila et al. (2014), Holburn, Lui and Morand (2010), Mondal et al. (2013) and Painuly (2001)
RE potential	Ernst & Young (2014), Friebe, Von Flotow and Täube (2014), Hawila et al. (2014), Holburn, Lui and Morand (2010) and Mondal et al. (2013)
Energy demand	Elrefaei, Bida, Elsobky et al. (2013), Ernst & Young (2014), Hawila et al. (2014) and Mondal et al. (2013)
RE technology cost	Ernst & Young (2014), Margolis and Zuboy (2006) and Painuly (2001)
Social acceptance / consumer awareness	ECORYS (2010), Hawila et al. (2014), Margolis and Zuboy (2006), Mondal et al. (2013) and Najdawi et al. (2013)
Operational requirements for RE	B. Barth, Concas, Binda Zane et al. (2014)

The above compilation of possible determinants was used as a basis for the further process of selecting the components of the composite diffusion indicator. However, the list makes no claim to be exhaustive and determinants could still be added during the subsequent methodological steps, if required.

4.2.2 *Experts' views on the main determinants for renewable energy diffusion*

REVIEW OF PAST EMPIRICAL RESEARCH Following the methodology described in section 3.2.1, the selection of determinants for the RE diffusion indicator was further scrutinised by comparing it to the results of own empirical research carried out prior to this analysis. To this end, in a first step, the previous research results on barriers and drivers for RE deployment were reviewed and evaluated with regard to the frequency with which individual barriers were mentioned (see also Boie, Ragwitz and Held (2015)). The findings originated from consultations with 70 experts from the RE sector (through face-to-face interviews and workshops with 52 participants and the evaluation of contributions via 28 completed questionnaires) from European and North African countries. A description of the project and the methodology is given in section 3.2.1.

The influencing factors that were mentioned most frequently by the stakeholders are listed below. The numbers in brackets indicate the number of stakeholders that considered each factor as relevant.

- Structure and regulation of the electricity market (20)
- Access to finance for RE projects and high cost of RE technologies (11)
- Existence of RE targets and reliable support schemes (11)
- Availability of sufficient grid capacity & favourable grid regulation for integration of RE (9)
- Administrative procedures for RE projects and national RE planning (3)
- Availability of local value chains for RE- and network technologies (3)
- Social issues, public awareness and acceptance of RE (2)
- Technical and operational issues (2)

MODERATED EXPERT WORKSHOPS The final step in selecting the determinants for the RE diffusion indicator was based on group discussions during three workshops with RE experts. The methodology for this step is described in detail in section 3.2.2. The premise for the selection process was that all selected factors should be of direct relevance for a wind or PV developer or investor, respectively, when deciding whether to realize a project or not[6]. Further, the selected determinants should be quantifiable using reliable and transparent data sources and an overlap between individual factors should be avoided.

During the first two workshops, factors considered either as not directly relevant for the decision making process or as not adequately representable by quantitative indicators were excluded. This applies, for example, to the public acceptance for RE projects. It was considered by the participants that a lack of public acceptance would be reflected in lengthy administrative procedures which makes it unnecessary to include it as an additional factor[7]. Similarly, the availability of local value chains was excluded because there was a group consensus that a lack of local suppliers would result in higher technology- or shipping cost, respectively, which would be reflected in a lower relative revenue (i.e. remuneration level in proportion to technology cost). This assumption is further supported by the existing literature (cf. subsection 4.2.1) as the availability of RE supply chains was not mentioned as one of the major barriers to RE deployment in the reviewed studies.

The results of the first workshop were documented by taking notes which were translated into presentation slides (see figures 56 to 59 in annex A.1). During the second workshop, these slides were presented to the participants and the selection was further consolidated through discussion with the experts. Finally, sixteen determinants were selected and grouped into four main fields: Political and economic framework; electricity market structure and regulation; grid infrastructure and grid regulation and administrative procedures. An overview over this result, i.e. the structure of the conceptual model for the RE diffusion indicator, is presented in figure 20.

The third expert workshop was focused on the identification of suitable indicators and data sources for representation of each of the previously selected determinants. To this end, the conceptual model including possible indicators and data sources for each determinant, was presented to the participants and put up for discussion (see exemplary slides presented in figures 60 and 61 in annex A.1). The final indicators and data sources were selected based on the input of the participants and additional follow-up research. The final outcome of the selection process, i.e. the final determinants of the RE diffusion indicator and the suggested data sources for each determinant, is presented in section 4.2.3.

Verification through follow-up interviews In the frame of the three country case studies, 31 interviews were conducted with RE-experts from Germany, Spain

6 Since the results of this thesis aim to contribute to and provide tools for the policy debate, the focus of the analysis is on the political and regulatory environment for RE. Therefore, technical considerations, e.g. regarding resource quality or technological characteristics as well as psychological or socio-cultural aspects were not regarded although they might also play a role in the investment decision.

7 The assessment is focused on wind onshore and utility-scale PV applications. Therefore, factors such as consumer awareness which are highly relevant for the diffusion of household applications, such as small-scale rooftop PV installations, are not considered.

and the UK (cf. table 5 for list of interviews). Apart from retrieving information on the RE framework in the respective country, the interviews were also used to request the feedback of the RE-experts on the selection of the sixteen diffusion determinants. The methodology for this step is described in section 3.2.3 and the used interview guideline is presented in annex A.3.

Most interviewees agreed with the selection of determinants and stated that no important decision factors were missing from their point of view. Only two interviewees suggested additional determinants that could be included in the RE diffusion indicator. One interviewee suggested including the cost of the RE technology (here referring to wind energy) in the specific market, for example, depending on the number of local suppliers or the cost incurred by shipping the equipment (interview 15). Another interviewee stated that not only the existence of supportive policies for RE should be regarded but also the presence of inhibitory regulations for RE, such as fees for usage of the electricity network which apply even to RE applications for self-consumption which do not use the grid (interview 16). Selected interview statements relating to individual determinants are presented and further discussed in section 4.2.3.

4.2.2.1 *Summary and conclusion*

Drawing upon the results of the literature review (cf. section 4.2.1) the consultation with various experts from the RE sector was used to select the sixteen major determinants framing the diffusion of wind onshore and non-residential PV.

The findings from an earlier consultation of various RE-experts through interviews, workshops and questionnaires carried out in 2012 are in line with the results of the literature review (cf. section 4.2.1). They particularly emphasize the importance of the electricity market structure, the regulatory and financial framework as well as grid-related issues for RE deployment. No factors going beyond the ones already mentioned in the literature were suggested by the stakeholders, which supports the outcome of the literature review (cf. table 6). However, in the context of the present research, there are reservations regarding these previous results, since the respondents comprised not only European stakeholders but also RE-experts from North African countries. Consequently, this previous analysis is not focused on the major target group of the present analysis, namely European RE-experts, which might influence the results. Also the analysis was not limited to the assessment of barriers and drivers for RE but had a broader thematic focus (cf. description of the methodology in section 3.2). Nevertheless, the findings can be taken as an indication that, generally, the same factors are relevant for RE diffusion, independent from the geographical region. This is a relevant information with respect to the transferability of the results to other world regions.

Moderated group discussions with European RE-experts (three events in 2013/2014) led to a consensus on the selection of 16 determinants for the diffusion of wind energy and non-residential PV installations. The selected determinants are considered as the most relevant factors for RE market diffusion from the perspective of RE developers or investors. The 16 determinants are structured into four major groups: Political and economic framework; electricity market structure and regulation; grid infrastructure and grid regulation and administrative procedures for RE projects (see figure 20). For each determinant suitable indicators and corresponding data sources were identified to enable a quantitative assessment in form of a composite indicator. The indicators and data sources for each determinant are presented in the subsequent section 4.2.3.

Interviews with RE-experts in Germany, Spain and the UK conducted at a later stage of this research project revealed a broad consent on the previously selected RE diffusion determinants. Only two interviewees out of 31 suggested additional factors, namely the local availability of technology suppliers and potentially resulting variations in technology cost (interview 15) and the presence of actively inhibiting policies and regulations for RE deployment (interview 16). However, as one of the selected indicators represents the relative revenue (i.e. the remuneration level in proportion to the costs) for a particular country and technology (see section 4.2.3.2 below), this aspect is implicitly already covered by the indicator. The issue of actively inhibiting policies and regulations will be considered for inclusion in future versions of the indicator.

On the basis of the above described findings, the final conceptual model for RE diffusion was deduced and confirmed. The model, including the selected indicators and data sources, is presented in detail in the following section.

4.2.3 *Final conceptual model for renewable energy diffusion*

Based on the results of the literature review (section 4.2.1) and the expert consultation (section 4.2.2) the final conceptual model was derived. An overview of the components of the model is presented in figure 20. It consists of four main categories each bundling three to five determinants.

- The category '**political and economic framework**' consists of the following four determinants: I.) The existence and reliability of the national RE strategy and support scheme; II.) The relative remuneration level (for a particular technology under a given support scheme); III.) The revenue risk under the given support scheme; IV.) Access to finance for RE projects.
- The category '**electricity market structure and regulation**' includes three determinants: I.) The general regulation of the electricity sector; II.) The existence of functioning and non-discriminatory electricity markets; III.) The availability of and conditions offered for long-term purchase agreements (PPAs) for RE.

- The category '**Grid infrastructure and grid regulation**' regards five determinants: I.) Grid access cost; II.) Grid access lead time; III.) Predictabilities and transparency of grid access procedures; IV.) Regulations for RES-E dispatch and curtailment; V.) Transparency of future grid infrastructure development.
- The category '**administrative procedures for RE projects**' regards four determinants: I.) The cost of administrative procedures; II.) The complexity of bureaucratic processes; III.) The duration of administrative procedures; IV.) The integration of RE planning in spatial planning.

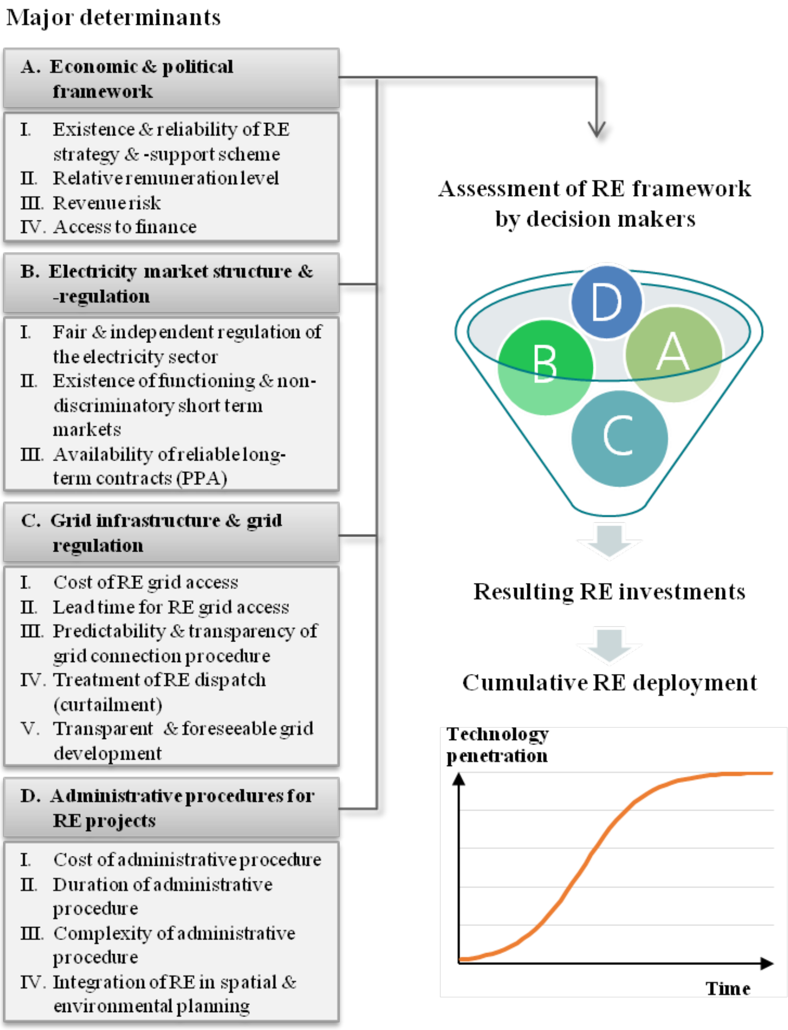

Figure 20: Conceptual model summarizing the major determinants affecting the decision process of RE developers and investors. The assessment of the framework conditions is reflected in the resulting national RE technology deployment.
Source: Adapted from Boie, Ragwitz and Held (2015)

Technical considerations, for example, related to the quality of RE resources or technological particularities of wind energy and PV, as well as individual psychological or socio-cultural characteristics of the decision maker are not part of the assessment. Although these factors certainly play a role in RE project decisions, the results of this thesis mainly aim to provide empirical and methodological contributions to the energy policy debate (cf. section 1.5). Thus, the focus of the analysis lies on the assessment of the factors framing the political and regulatory environment for RE.

In the following, a description of each of the 16 determinants with the underlying indicators and utilized data sources is given. Tables at the end of each section summarize the indicators and data sources for each of the four main categories of determinants mentioned above. In order to provide a coherent presentation of the results and to avoid redundancies, the tables also contain information on the methods used to transform (i.e. normalize) the underlying data into scores for application in the RE diffusion indicator. However, details on the methods for aggregating the indicator scores and their application in the overall composite indicator are provided in a later section (section 4.4, paragraph on normalization of indicator scores).

4.2.3.1 *A. Political and economic framework*

1. Existence and reliability of general RE-strategy and support scheme

The existence of a reliable, supportive policy framework for RE is a basic precondition for the diffusion of RE technologies (Dinica, 2006; Gross and Watson, 2015; Holburn, 2012; Lüthi and Wüstenhagen, 2012; Mani, 2012; Margolis and Zuboy, 2006). It firstly implies that RE targets and support mechanisms are in place and, secondly, that the policy framework has been stable and trustworthy in the past.

Indicators for representation of the existence and reliability of general RE strategy and support scheme comprise the existence, liability and time-frame as well as the technology specification of the national RE targets. Binding long-term targets demonstrate the government's commitment to develop RE and provide a guiding frame for RE developers planning their investments (IEA-RETD, 2016). They should be laid down in national legislation to provide maximum certainty.

Further important indicators are the existence and the reliability of the RE support scheme. A support scheme is relevant as long as RE technologies are not fully cost-competitive with conventional energy technologies. In this regard, the mechanism for adjusting support levels is also relevant as it provides the basis for calculation of future RE investments. Optimally, adjustments of support levels should be based on transparent, scientifically grounded formulas using technology learning rates to ensure investors and project developers that future projects will still receive sufficient support to provide an acceptable rate of return under the current subsidy scheme. In the worst case, support levels would be changed arbitrarily and without pre-announcement.

Further, the frequency of of drastic changes in the RE support scheme serves as an indicator for the reliability of the RE framework. Drastic changes, in the context of this work, refer to modifications of the support scheme itself (e.g.a change of the support mechanism) or to unscheduled reductions of the remuneration level. Retroactive RE policy changes should be avoided in any case as they bear a high and uncontrollable risk for investors.

Finally, as a general indication for the stability and trustworthiness of the national political regime, the overall policy stability (based on the *'Fragile States Index'*) is included as an indicator. Although this aspect is relevant for all types of investments and not specifically for RE, it can have a significant impact on RE investment decisions as it affects the risks associated with all types of business activities.

Figure 21 presents exemplary statements of RE developers and investors from Spain, Germany and the UK which confirm the importance of a reliable strategy and policy framework for RE. Stakeholders from all three case study countries see this determinant as the most important factor for RE development. Under *AI.* table 7 summarizes the indicators, value ranges and data sources for the representation of the reliability of the RE framework.

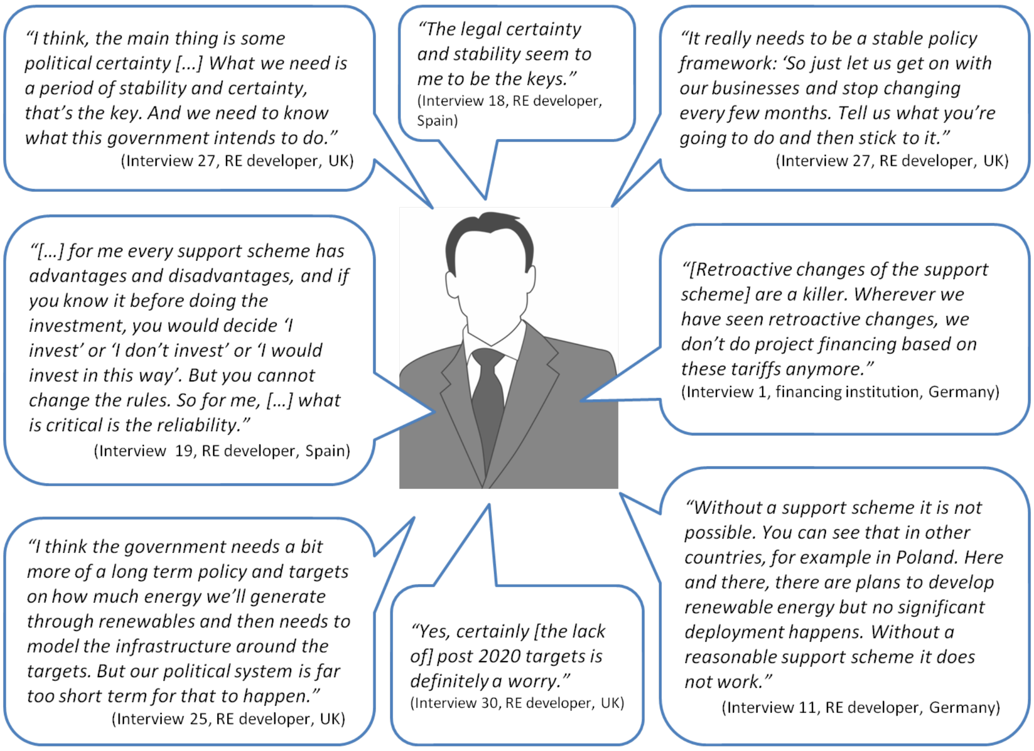

Figure 21: Examples of interview statements confirming the importance of a reliable & stable policy framework for RE (determinant A-I.).

II. RELATIVE REMUNERATION LEVEL FOR RES-E As onshore wind and PV, the two RE technologies in focus of this analysis, are not yet fully cost-competitive with conventional energy technologies in most markets, developers are still reliant on a certain level of economic support to enable RE diffusion. However, the required subsidy level depends on the quality of the RE resource as well as on the technology cost. The indicator representing this aspect is thus defined as the relative remuneration level, which is the average return over the lifetime of a RE plant under given resource conditions and technical performance parameters. A formula for calculating the levelized profit per unit of generated electricity is given in equation 2 (based on Held, Ragwitz and Haas (2006)).

$$A = \sum_{t=0}^{n} \frac{(I_t - E_t)}{(1+i)^t} \cdot \frac{1}{Q} \cdot \frac{(1+i)^n \cdot i}{(1+i)^n - 1} \tag{2}$$

Where:

A = Levelized profit per unit electricity generated [Euro Cent/kWh]

I_t = *Cash inflows (revenues) in t [Euro Cent]*

E_t = *Cash outflows (expenses) in t [Euro Cent]*

Q = Total amount of electricity generated [kWh]

i = Interest rate

n = Lifetime of the plant [years]

The overall remuneration comprises the electricity market price supplemented by the respective subsidies granted to RE. If the remuneration level is not cost covering this would be a rejection criterion for every investor (Lüthi and Prässler, 2011). However, when evaluating the remuneration level, it should be considered that not only a low remuneration level may deter developers from realizing RE projects but that also extremely high remuneration levels might hinder RE deployment as they can imply untrustworthiness and a lack of sustainability of the policy scheme (see also figure 22). Therefore, excessively high remuneration levels should not be particularly rewarded by the indicator. It is thus defined that the maximum score for this indicator is reached if the maximum remuneration is 1.5-times the generation cost.

Remuneration levels for all major RE technologies in the EU Member States can be retrieved from the 'res-legal' database[8] (Eclareon, 2016). Recent analyses of RE technology costs in relation to support levels can also be retrieved through the 'DIA-CORE' database on RES technology costs and remuneration levels[9] (DIA-CORE, 2013).

Figure 22 presents exemplary statements of RE developers and investors from Spain, Germany and the UK relating to the relevance of the remuneration level for RE. Under *AII.*, table 7 summarizes the value ranges and data sources used for representing the remuneration level for RE.

8 The 'res-legal' database is a publicly available online database on support schemes and legal provisions for RE in the European Member States. It includes frequently updated information on the support levels for all major RE technologies.

9 The DIA-CORE database is a publicly available online database providing analyses of RE policy effectiveness and efficiency based on recent trends in technology cost and remuneration levels. The remuneration levels are derived from 'res-legal' (Eclareon, 2016).

Figure 22: Examples of interview statements relating to the relevance of the remuneration level for RE (determinant A-II.)

III. REVENUE-RISK UNDER THE GIVEN RE-SUPPORT-SCHEME Depending on the financial support scheme for RE, fluctuations of the remuneration level can occur over the lifetime of an RE plant. Such variations in the remuneration represent a major risk factor for the plant operator which needs to be regarded when calculating the initial investment. The revenue risk varies significantly under different RE support schemes. Analyses of risks resulting under different RE support schemes have been contributed, for example, by Bürer and Wüstenhagen (2009), Jager and Rathmann (2008), Lüthi and Wüstenhagen (2012), C. Mitchell, Bauknecht and P.M. Connor (2006), Ragwitz et al. (2007) and Rathmann et al. (2011). There is a consensus in the literature that a reduction of revenue- and market risks enhances the effectiveness of RE support schemes.

Under a quota scheme, the overall remuneration is composed of the price of the green certificates and the electricity market price. As both components are subject to fluctuations and depending on the market demand, this implies a significant revenue-risk under this support scheme (cf. e.g. C. Mitchell, Bauknecht and P.M. Connor (2006) and Catherine Mitchell and Peter Connor (2004)). Under a FIP scheme, a support premium is paid on top of the electricity market price. Assuming a fixed FIP, the electricity market price is the only volatile remuneration element which implies a lower risk, compared to the quota scheme. In case of a floating FIP, which covers the difference between the electricity market price and a defined price level (i.e. strike price), the revenue risk is reduced to a minimum as the remuneration remains stable even if the market price drops. The same applies to a fixed FIT, which guarantees a fixed remuneration level over a defined period of time which significantly reduces the revenue risk for the plant operator.

Figure 23 shows selected statements of RE developers and investors from Spain, Germany and the UK referring to the importance of the revenue risk.

In the RE diffusion indicator, the support-scheme inherent revenue risk is represented by risk-multipliers which is an approach that is commonly applied in existing energy economic models. For example, the model 'Green-X', a well established energy economic simulation model developed at the Technical University of Vienna, applies a set of risk-multipliers which reflects the above described considerations (cf. Huber et al. (2004) and Resch (2005, 2015)).

Under *AIII.* table 7 presents the value ranges and data sources used for representing the support scheme inherent revenue risk in the diffusion indicator.

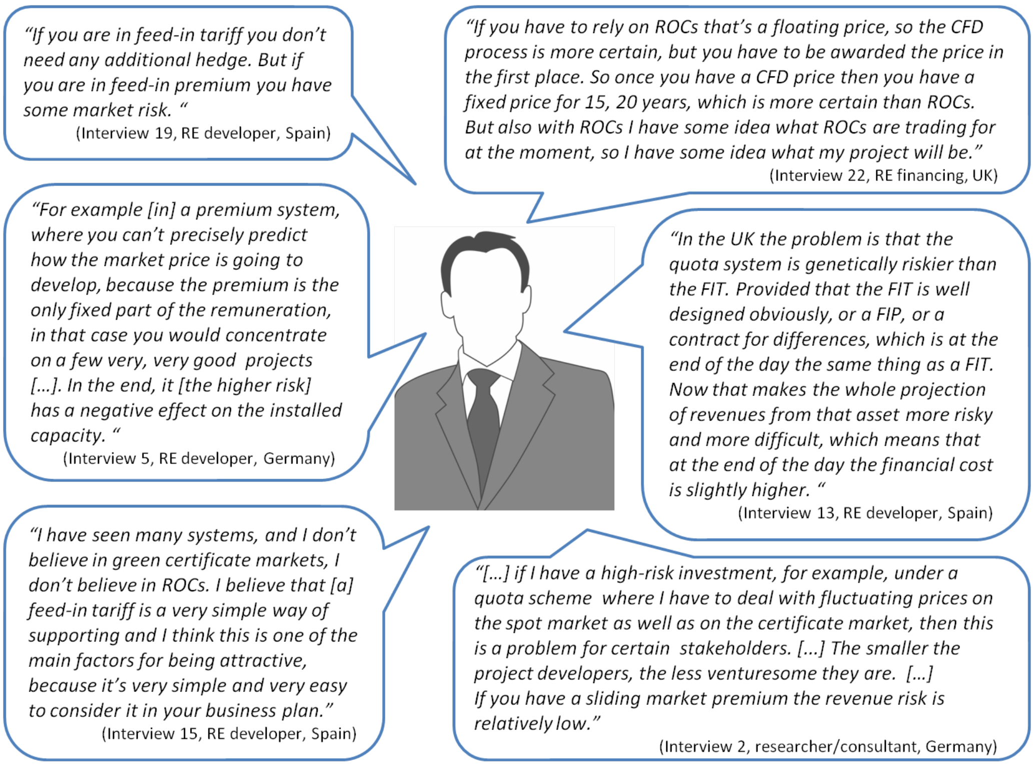

Figure 23: Examples of interview statements relating to the relevance of the support scheme inherent revenue-risk for RE (determinant A-III.).

IV. ACCESS TO FINANCE Access to financing products at favourable terms is important for any kind of large-scale investment but particularly for RE projects which often require high upfront investments in relation to the working capital (Noothout et al., 2016). Important factors that influence the attractiveness of the respective financing market for RE investments include national risk-surcharges and interest rate levels as well as the legal certainty in the financing sector. A recent analysis by Noothout et al. (2016), for instance, highlights that there are significant variations in the attractiveness of the financing conditions for RE even across the EU Member States.

For the RE diffusion indicator, four characteristics were chosen to represent the access to finance for RE projects. Firstly, the national credit rating (based on information provided by the rating agency 'Standard&Poor's') is considered as an indicator for the general stability and trustworthiness of the national financial system.

Secondly, the interest rate on long-term government bonds (regularly provided by EUROSTAT (2014)) is used as a reference to estimate the interest rate level in the private banking sector.

Thirdly, the *'ease of getting credit index'* is included. The index is part of the well established *'doing business index'*, a global benchmarking tool for business development published by the 'World Bank Group' (World Bank Group, 2015). The *'ease of getting credit index'* is an indicator that assesses the legal strength in the financing sector and the availability of information on financing opportunities (World Bank Group, 2015).

These three indicators, although they are not RE-specific, provide relevant information on the maturity and stability of the national financing markets which is important for any kind of long-term investment and thus also for RE project development.

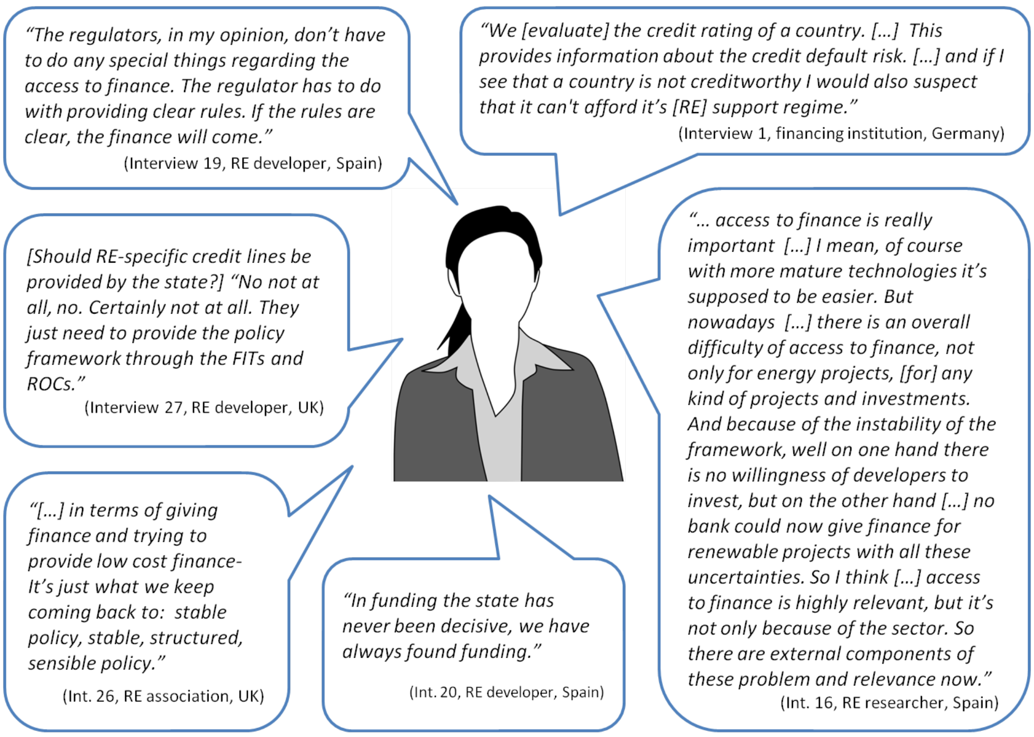

Figure 24: Interview statements relating to the relevance of access to finance for RE projects (determinant A-IV.).

As an additional, RE-specific indicator, the availability of financing schemes specifically designed for RE projects (e.g. specific credit schemes or loans subsidized by the government) is included. This indicator is based on qualitative data sources (e.g. interviews) and review of literature. However, part of the interviewed RE stakeholders stated that such RE-specific financing tools are not essential for RE financing. They explained that, as long as the general political framework for RE is clear and the financing market is developed, access to commercial financing products should generally be possible (see interview statements presented in figure 24).

Under *A IV.* table 7 summarizes the indicators, value ranges and data sources reflecting the access to finance for RE.

Table 7: Indicators, value ranges and data sources for representing the political and economic framework for RE. Individual indicators which can lead to an overall indicator result of zero are marked with an asterisk.

Indicators per sub-determinant	Value ranges and normalized scores	Data sources
A I) Existence and reliability of RE strategy and -support scheme		
General RE target	Existent (=1); Not existent (=0.25)	National legal documentation, policy databases
Liability of RE target	Binding/part of legislation (=1); No binding targets (=0.25)	National legal documentation, policy databases
Technology specification of RE target	Yes (=1); No (=0)	National legal documentation, policy databases
Maximum time-frame of RE targets	Long: $\geqslant$ 15 years (=1); Medium: 5-15 (=0.5); Short: $\leqslant$ 5 years (=0.25)	National legal documentation
RE support scheme	Existent and enforced (=1); Not existent or not enforced (=0.25)	National legal documentation, policy databases
Mechanism for adjustments or changes of the RE support level	Transparent & clear mechanism based on scientific expertise (=1); Non-transparent & no clear mechanism defined (=0.25)	National legal documentation
Frequency of drastic support scheme changes[10]	Stable / good: Max. 1 policy change in past year (=1); Variable / intermediate: Two or more changes (=0.5); Unstable/poor: Retroactive changes of the support scheme (=0.25)	National legal documentation and respective secondary documentation
General policy stability	Risk of political instability ranging from very high alert to very sustainable, Normalization (0-1) across value range of EU Member States.	Fragile States Index published yearly by the 'Fund for Peace'[11]

10 Change of the support mechanism itself or unscheduled changes in the support level.
11 Weblink: http://ffp.statesindex.org/ (last accessed: 20.6.2015)

Table 7: Indicators, value ranges and data sources for representing the political and economic framework for RE. Individual indicators which can lead to an overall indicator result of zero are marked with an asterisk.

Indicators per sub-determinant	Value ranges and normalized scores	Data sources
A II) Relative remuneration level for RE		
Relative remuneration level (average income under the given resource conditions and technical performance parameters)*	Profit level derived from income for a specific RE technology relative to its generation costs: No profit: Max. remuneration < Min. generation cost (= 0); Intermediate: Min. generation cost $\leqslant$ Max. remuneration $\leqslant$ $1.5 \cdot Max.generationcost$ Formula: (Max. remuneration – Min. generation cost)/(1.5 · Max. generation cost – Min. generation cost)); High profit: Max. remuneration > 1.5 · Max. generation cost (=1)	Ranges for generation cost and remuneration levels are based on data compiled on the 'transparency platform on RES technology costs and remuneration' of the DIA-CORE project (DIA-CORE, 2016)
A III) RES-E revenue risk		
RE support scheme inherent risk	Normalized risk factors for different RE support scheme design options ranging from a quota scheme with certificate trading (highest risk =0.25) to a fixed feed-in tariff (lowest risk =1). For intermediate scores see table 26 in annex A.5	Risk assessments provided by scientific literature, reference is made to 'risk multipliers' as applied in the techno-economic modelling tool Green-X (Resch, 2015)
A IV) Access to finance		
National credit rating	Score ranging from the optimum score AAA (=1) to the minimum score D (=0.25). Intermediate scores are interpolated based on a geometric sequence.	International government credit ratings provided by '*Standard & Poor's*' [12]
Interest rates for long-term government bonds	Interest rates are normalized across all EU Member States (min. =1, max. =0, intermediate scores interpolated based on a geometric sequence.)	EUROSTAT, interest rates on long-term government bonds[13]
Ease of obtaining credit (availability of credit information & legal strength in finance sector)	Sum of scores for indices 'depth of credit information' and 'legal strength in finance sector' (range 0-20), values are normalized to a score between min. =0 and max. =1. The intermediate scores are interpolated based on a geometric sequence.	Indicator on 'Ease of Getting Credit' of the 'Doing Business Index' [14]

12 Weblink: www.standardandpoors.com/ (last accessed: 20.6.2016)
13 Weblink: http://ec.europa.eu/eurostat/web/interest-rates/data/main-tables (last accessed: 25.6.2016)
14 Weblink: www.doingbusiness.org/ (last accessed: 14.6.2016)

Table 7: Indicators, value ranges and data sources for representing the political and economic framework for RE. Individual indicators which can lead to an overall indicator result of zero are marked with an asterisk.

Indicators per sub-determinant	Value ranges and normalized scores	Data sources
Availability of financing for RE projects	Good: Access to capital is good and /or dedicated institutions and programs for RE projects are existing & operational (=1); Moderate: Access to capital is limited, specific institutions and programs for RE might exist but are either not operational or not sufficient (=0.5); Poor: Access to capital is very difficult, specific institutions or programs for RE do not exist (=0.25)	Qualitative assessment based on interviews and secondary literature

4.2.3.2 *B. Electricity market structure and regulation*

I. FAIR AND INDEPENDENT REGULATION OF THE ELECTRICITY SECTOR A fair and non-discriminatory regulation of the electricity sector is required to allow operators of RE plants to obtain access to and to operate in the market without being disadvantaged compared to generators of conventional energy. Difficulties entering established electricity markets are frequently mentioned as one of the main obstacles for RE diffusion (Alagappan, Orans and Woo, 2011; Margolis and Zuboy, 2006; Najdawi et al., 2013). Barriers in connection with market regulation relate, for example, to the level of market concentration in the generation, transmission and distribution sector. A high level of vertical integration with only few, dominant companies can pose a significant entry barrier for new generators. Therefore, the level of unbundling of generation, transmission and distribution activities is an important indication for the possibilities of new actors for entering the market (Held, Ragwitz, Merkel et al., 2010).

Non-discriminatory regulation further implies that the market is supervised by an independent and powerful regulatory authority which safeguards a fair competition among all market participants (Holburn, 2012). Although this is a common standard in European countries, it can still be an obstacle in emerging electricity markets where regulatory structures are less established.

Further, the options for RE generators to sell their production either in the market or to use it for their own consumption are another important factor that affects the attractiveness of an electricity market for RE developers. If the possibilities for selling and using electricity from renewable energy sources are limited by unfavourable regulations, a reduced RE diffusion will be the consequence.

A selection of interview quotes highlighting the relevance of a fair electricity market regulation is presented in figure 25.

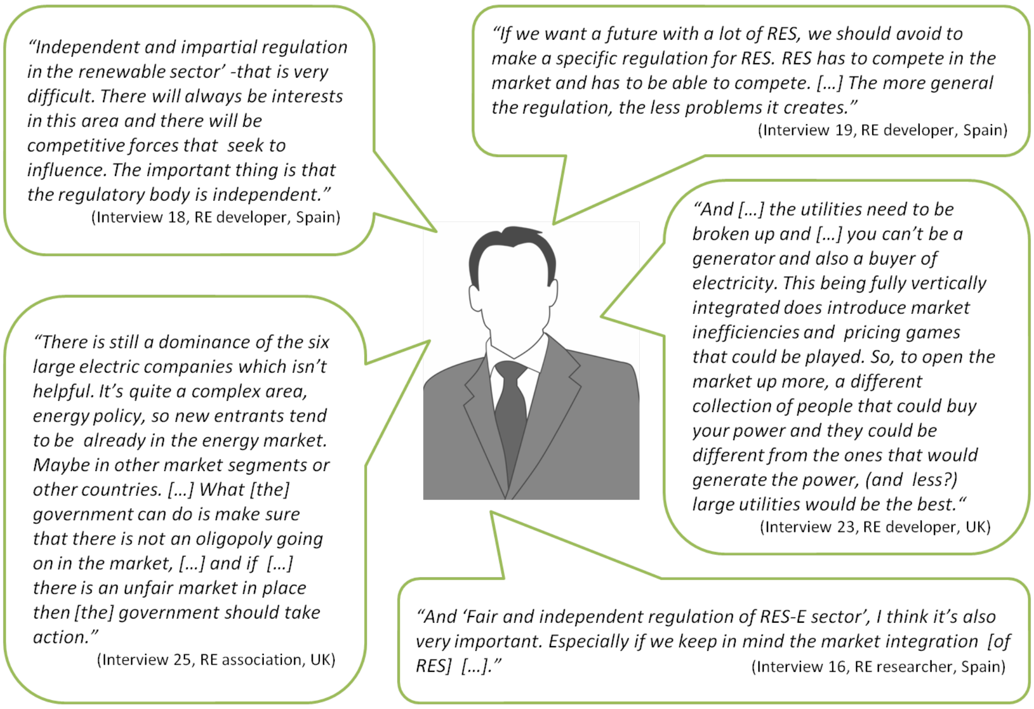

Figure 25: Interview statements relating to a fair and independent market regulation of the electricity sector (determinant B-I.).

To take account of the above, four indicators are regarded to assess the regulation of the electricity sector: the level of unbundling, the existence and level of empowerment of the regulatory authority and the options for independent power producers (IPP's) to participate in the market by selling or consuming their electricity. Under *BI.* table 8 summarizes the indicators, value ranges and data sources for representation of a fair and independent regulation of the electricity sector.

II. EXISTENCE OF FUNCTIONING AND NON-DISCRIMINATORY SHORT TERM MARKETS To facilitate a flexible and profitable marketing of RES-E on spot markets[15]) it is important that the market access conditions are non-discriminatory and enable RE plant operators to compete on a level playing field with conventional energy technologies (Hiroux and Saguan, 2010; Weber, 2010).

In this context, it is particularly important that RE producers can sell their electricity flexibly in the market, since forecasting of production volumes based on fluctuating natural

15 A spot market is defined as a trading platform that hosts day-ahead and intra-day auctions of electricity.

resources is more complex than for conventional energy sources. Hence, the gate closure time, i.e. the time span between the bid and the physical delivery of electricity, in the intra-day (ID) market is a relevant factor for the integration of RE (see also interview quotes presented in figure 26). Gate closure times close to real time operation favour the integration of renewable electricity while longer gate closure times put RE producers at a disadvantage, as meteorological forecast errors can lead to additional balancing cost (R. Barth, Weber and Swider, 2008; Held, Ragwitz, Merkel et al., 2010; Hiroux and Saguan, 2010; Weber, 2010). Further, heterogeneous and uncoordinated gate closure times across the EU form an obstacle for RES integration and market liquidity (ACER/CEER, 2015, p. 16). Therefore, the introduction of close to real time ID gate closure times (⩽1 hour) is also a key element of European electricity market target model (ACER/CEER, 2015, p. 198). Consequently, the gate closure time defined for the intra-day market is regarded as an indicator for the conditions of short-term marketing options for RE.

As a further indicator measuring the possibilities of RE generators to flexibly market their electricity, the liquidity of the intra-day market is evaluated. With increasing volumes of variable RE generation, intra-day markets gain importance as they enable generators to balance their production schedules more efficiently after the closure of day-ahead trading (ACER/CEER, 2015; Hagemann and Weber, 2015). A lack of liquidity resulting in high price volatilities in the intra-day market was also mentioned as a major issue for the integration of RE by some of the interviewed stakeholders (cf. figure 26). Intra-day market liquidity can be expressed as the ratio between traded electricity volumes at the intra-day market and the overall national electricity demand (ACER/CEER, 2015, p.198).

Under *BII.* table 8 summarizes the indicators, value ranges and data sources for representation of the functioning of short-term marketing options for renewable electricity.

III. AVAILABILITY OF RELIABLE LONG-TERM CONTRACTS (PPAS) The availability of liable, power purchase agreements (PPAs) mitigates the risks associated with volatile electricity market prices and provides long-term revenue certainty for RE developers (Dinica, 2006). However, the relevance of PPAs varies depending on the respective RE support scheme. Assuming a Quota or a FIP scheme, the electricity market price is a central part of the overall remuneration and PPAs are of crucial importance to safeguard stable revenues. Under a FIT, all generated electricity receives a previously defined tariff which is usually combined with a purchase guarantee, thus the PPA is inherently included in the support scheme.

However, the reliability of a PPA, even if it is provided as part of a legally binding support scheme, also depends on the stability of the overall political framework as highlighted by a RE developer from Spain: "*[...] you simply have a Royal Decree which guarantees you an income as long as that Royal Decree lasts. Everybody always talks about fifteen, twenty years, but the common rule is that at maximum after six years, this Royal Decree is repealed and replaced* *by another one, therefore no, you cannot say that you have a long-term contract.*". Figure 26 presents further interview statements which emphasize the relevance of both, short-term marketing options and long-term contracts for RES-E.

For the diffusion indicator, the availability of long-term PPAs for RES-E is measured on a scale based on a qualitative assessment (see *B III.* in table 8).

Figure 26: Interview statements relating to the relevance of short and long-term marketing options for RE (determinants B-II. and B-III.).

Table 8: Indicators, value ranges and data sources for representing the electricity market structure and -regulation. Individual indicators which can lead to an overall indicator result of zero are marked with an asterisk.

Indicators per sub-determinant	Value ranges and normalized scores	Data sources
B I) Fair and independent regulation of the electricity sector		
Unbundling of generation, transmission & distribution of electricity	Full (=1); Partial (=0.5); No (=0.25)	National legal / regulatory documents or policy databases, ACER, CEER
Regulatory authority	Existing & fully empowered (=1); Existing but lacking authorisation (=0.5); Not existing (=0.25)	National legal / regulatory documents or policy databases, ACER, CEER
IPP access to the electricity market*	Full: selling to utilities or to 3^{rd} parties without concession (=1); Limited: only to utilities, concession based access (=0.5); Not provided (=0)	National legal / regulatory documents or policy databases, ACER, CEER
Distributed electricity generation for own consumption	Allowed & combined with remuneration scheme (e.g. Net Metering or FIT) (=1); Allowed only for own consumption (=0.5); Not allowed or no legal framework existent (=0.25)	National legal / regulatory documents or policy databases, ACER, CEER
B II) Existence of functioning and non-discriminatory markets		
Liquidity of power exchange (share of national electricity consumption traded at intra-day market)	High liquidity ($\geqslant$ 30%) (=1); Limited liquidity (5 to <30%) (=0.5); Low liquidity ($\leqslant$ 5%) or not implemented (=0.25)	ACER, CEER, European Commission (2014g), national trading platforms
Gate closure times (last bid ahead of delivery in intraday market)	$\leqslant$ 1 hour ahead (=1); 1-3 hours ahead (=0.5); $\geqslant$ 3 hours ahead (=0.25)	ACER, CEER, national electricity trading platforms
B III) Availability of reliable long-term contracts (PPA)		
Availability of long-term PPAs for RE	Good: Sufficient number of off takers available or PPA provided through support scheme (FIT or floating premium) (=1); Medium: Off takers available but high level of market concentration (=0.5); Poor: Availability of off takers for RE insufficient or not provided (=0)	Official legal / regulatory documents and interviews with local stakeholders

4.2.3.3 *C. Grid regulation and infrastructure*

I. COST OF GRID ACCESS Different approaches exist for sharing the economic burden between the operators of the transmission or distribution network, respectively, and the owners of electricity generation units to be connected to the grid. Depending on the cost-sharing mechanism, significant additional expenses for expanding or reinforcing the grid might incur on the side of the RE project developer. Therefore, this factor can be highly relevant for RE investment decisions (Alagappan, Orans and Woo, 2011; González and Lacal-Arántegui, 2016; Swider et al., 2008).

Approaches that imply low additional costs for the project developer are the shallow charging regime, under which the plant operator only pays for the connection to the nearest available grid connection point and the super-shallow approach which entails no cost for the grid connection apart from the plant's substation (González and Lacal-Arántegui, 2016). In contrast, a deep charging regime implies that the plant operator has to pay for the grid connection as well as for potential grid reinforcements required to integrate the new generation unit. Combined, 'shallow-deep' or 'shallowish', charging approaches (i.e. the project developer pays for connection and part of the reinforcements) are also possible.

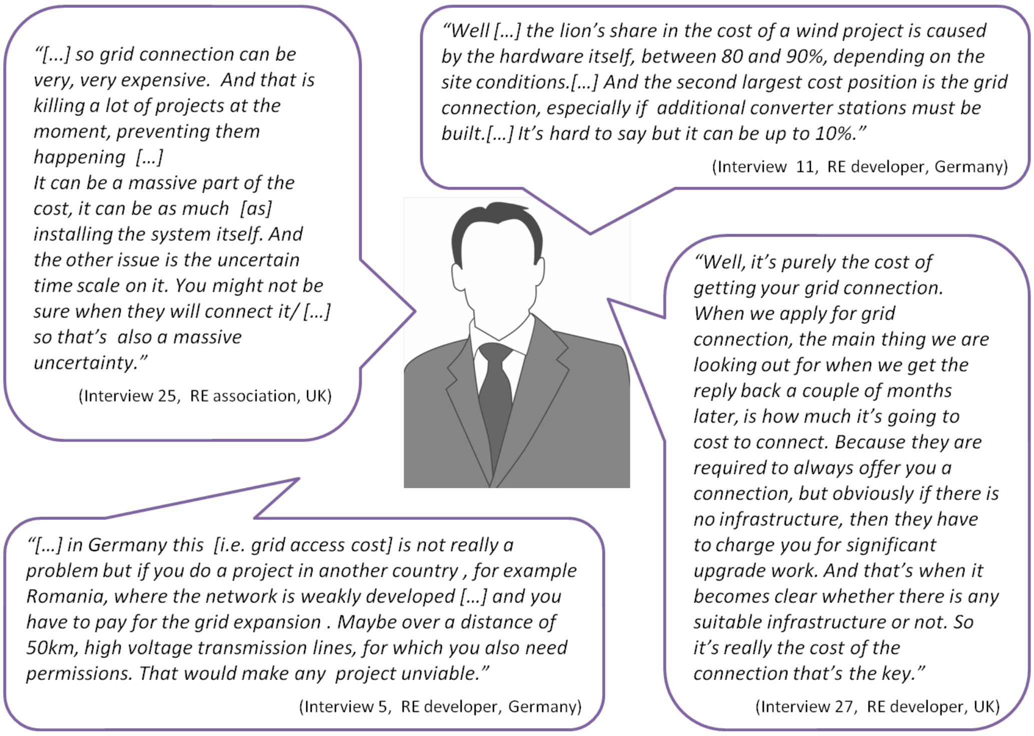

Figure 27: Interview statements confirming the importance of the cost of grid access (determinant C-I.).

Usually, higher grid connection costs (on average 9% of the overall investment) occur for onshore wind energy projects compared to PV projects (2.5% on average), as these are mostly located closer to the existing grid (Swider et al., 2008)[16].

However, a deep charging approach may lead to high extra costs for all types of RE projects, especially if the grid infrastructure is obsolete or weakly developed (cf. interview statements in figure 27). Deep charging is still applied in some EU countries and has been identified as a relevant barrier to RE diffusion by the European Commission (European Commission, 2013b).

For the RE diffusion indicator, the assessment of the grid access cost is based on the charging approach defined under national regulations. Thereby, shallow or super shallow regimes are considered as best practice while deep charging regimes receive the lowest score. Mixed regimes score in between. If regulations do not stipulate an approach and this is decided on a case-by-case basis, it may be necessary to assess earlier projects or consult local stakeholders. However, an unclear approach is usually less attractive to investors and thus receives a low score.

Table 9 summarizes the value ranges and data sources for the cost of grid access under *C-I*.

ii. lead time for obtaining re grid access The lead time for electricity network access and connection is the time between the first application and the actual physical network access (including waiting times). Long lead times can substantially delay the entire implementation process and prolong the period until a project becomes operational and generates revenues. They are therefore a very relevant factor for the overall feasibility of RE projects (Lüthi and Prässler, 2011). Particular relevance must be attached to this aspect, if changes in the remuneration level or in the support scheme itself can be expected, as long lead times increase the risk of revenue losses (see interview statements in figure 28).

Depending on the RE technology and project size, grid access lead times can range from a few weeks to periods exceeding a year. For example, Garbe et al. (2012) indicate average durations of 6-24 weeks[17] for commercial rooftop and ground-mounted PV plants across the EU Member States, whereas Cena et al. (2010) reported an EU average duration of 25.83 months for onshore wind parks.

The composite diffusion indicator reflects the total grid access lead time for each technology (measured in weeks). Thereby, the scoring intervals depend on the RE technology (see table 9). Quantitative assessments of grid access lead times in EU countries have been carried out for PV in projects such as 'PV-Legal and 'PV-Grid' (PV Grid, 2014; PV

16 The results of this study are based on case studies for Germany, the Netherlands, the United Kingdom, Sweden, Austria, Lithuania and Slovenia.

17 An exception applies to Greece with an average duration of 67 weeks (Garbe et al., 2012, p. 24).

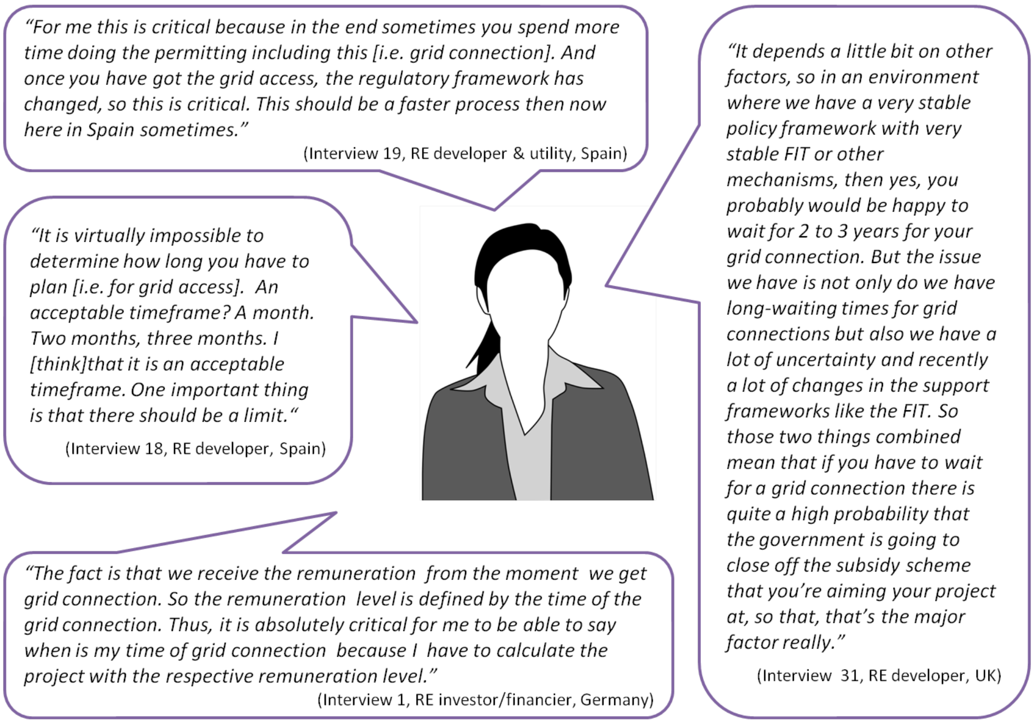

Figure 28: Interview statements confirming the importance of the duration of grid connection procedures for RE deployment (determinant C-II.).

Legal, 2012) and for wind energy in the frame of the project 'Wind Barriers' (Wind Barriers, 2009). Qualitative information is also included in the EU progress reports on the implementation of the EU RES Directive (European Commission, 2013c), in the database of the project 'Keep-on-Track!' (Keep-on-Track!, 2014) or can be retrieved from project developers, RE industry associations and other national RE stakeholders.

Table 9 summarizes the value ranges and data sources for the grid access lead time under *C-II.*.

III. PREDICTABILITY AND TRANSPARENCY OF GRID CONNECTION PROCEDURE The predictability and transparency of the grid connection procedure depend on whether the time and costs until the project is finally connected to the grid can be foreseen by the developer with some degree of certainty. A low variation in the duration and cost of the procedures (i.e. across different RE projects) implies a high level of certainty for the project developer. An unclear and poorly defined procedure, on the contrary, is associated with uncertainty and additional risks for the investor and adversely affects the project's attractiveness (Alagappan, Orans and Woo, 2011; Lüthi and Prässler, 2011). Although the relevance of this factor might vary depending on the RE technology (cf. foregone paragraphs) it has been cited as an important criterion by developers of both wind- (Cena et al., 2010) and PV projects (Lüthi and Wüstenhagen, 2012) and its relevance has been confirmed by the present interview partners (see figure 29).

Figure 29: Interview statements confirming the importance of a predictable and transparent grid connection procedure (determinant C-III.).

An assessment of this indicator can be done based on a review of national regulations regarding the grid connection process (i.e. definitions of statutory requirements for procedures and maximum time-frames) supplemented, where necessary, by consulting local stakeholders (e.g. project developers). For the EU, additional information is also available in the NREAPs (European Commission, 2010) and RE progress reports (European Commission, 2013c) of the individual Member States.

Under *C-III.* table 9 summarizes the value ranges and data sources for representing the predictability and transparency of the grid connection procedure.

iv. treatment of re dispatch (curtailment) The electricity dispatch regime stands for the degree of certainty that generated electricity from RES will be dispatched and remunerated. In favourable cases, RES-E is either dispatched with priority or compensation payments are guaranteed in case of grid-related curtailment (cf. European Commission (2013b, p. 16-17)). A less favourable option, which poses a major risk from the viewpoint of RE developers, would be if no priority dispatch and no entitlement for economic compensation apply (Lüthi and Prässler, 2011). Also the EU Directive 2009/28 EC (European Commission, 2009a, art. 60) on the promotion of the use of energy from renewable sources requests the EU Member States to implement either priority grid access (if fixed PPAs for RE are provided) or guaranteed access (in case that RES-E is sold in the spot market) to support the market integration of RE. Nevertheless, the conditions for grid access and curtailment compensation still vary across the EU Member States (see e.g. European Commission (2013b) and González and Lacal-Arántegui (2016)).

The relevance of grid-related curtailment, however, may also vary depending on the level of RE penetration, the state of the electricity grid and the degree of integration of RES-E in the electricity market. As the interview statements in figure 30 illustrate, curtailment appears to be less relevant if the level of fluctuating generation in the electricity system is still low (and thus grid congestions are rare) or if RES-E is already well established and competitive in the electricity market.

In the context of the diffusion indicator, this aspect is assessed based on an evaluation of the national regulation for RE dispatch and curtailment compensation. Under *C-IV.* table 9 summarizes the value ranges and data sources used for te assessment of the RE dispatch regime.

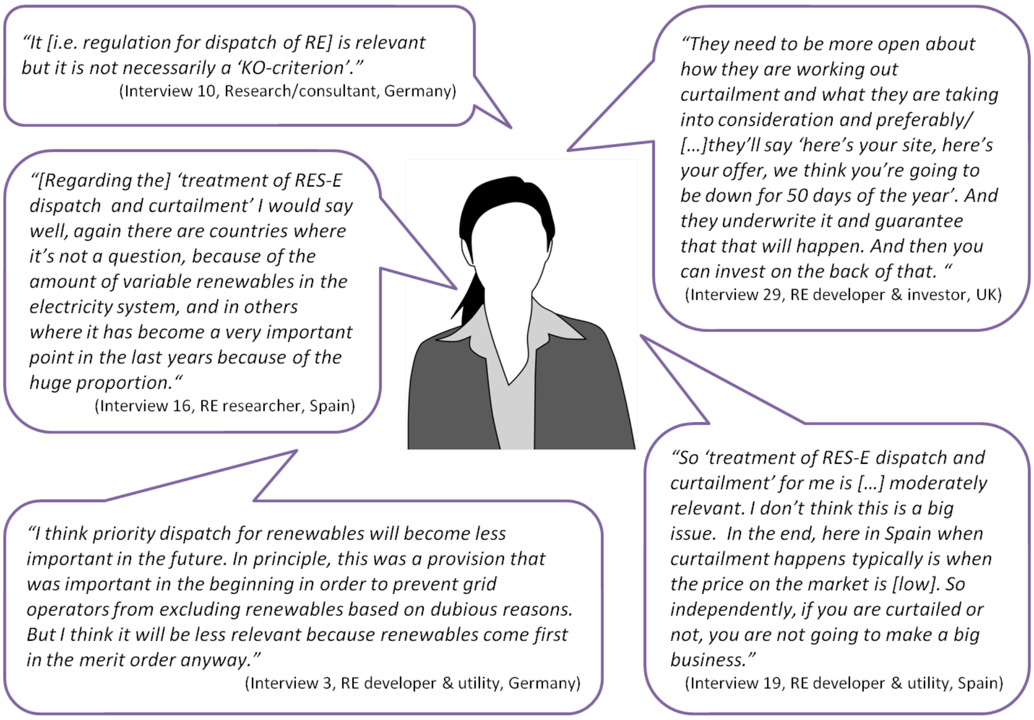

Figure 30: Interview statements relating to the importance of the regulations for dispatch and curtailment of RES-E (determinant C-IV.).

v. transparent and foreseeable grid development The transparency and predictability of future grid developments can be relevant when evaluating potential RE project sites (Alagappan, Orans and Woo, 2011). Developers who want to assess prospective grid connection options are reliant on information describing the future grid development or reinforcements to the existing network. This is particularly valid for wind energy projects, which are often situated in remote areas and thus more reliant on the further development of the medium and high voltage network infrastructure.

An optimal situation, from the viewpoint of RE stakeholders, would be if information on future grid development was publicly available in form of clearly defined mid- and long-term action plans (6-8 years) and if a high degree of compliance with the planned measures was reached with no time lags exceeding 1 year (interview 17). Several interviewees highlighted that a higher level of certainty regarding the future grid development would also improve their general confidence concerning the government's determination to develop RE (e.g. interviews 5, 18, 24, 25, 26, 27, 29). However, planning horizons and implementation time-frames for grid infrastructure development largely vary across the EU Member States (Boie, Fernandes et al., 2014).

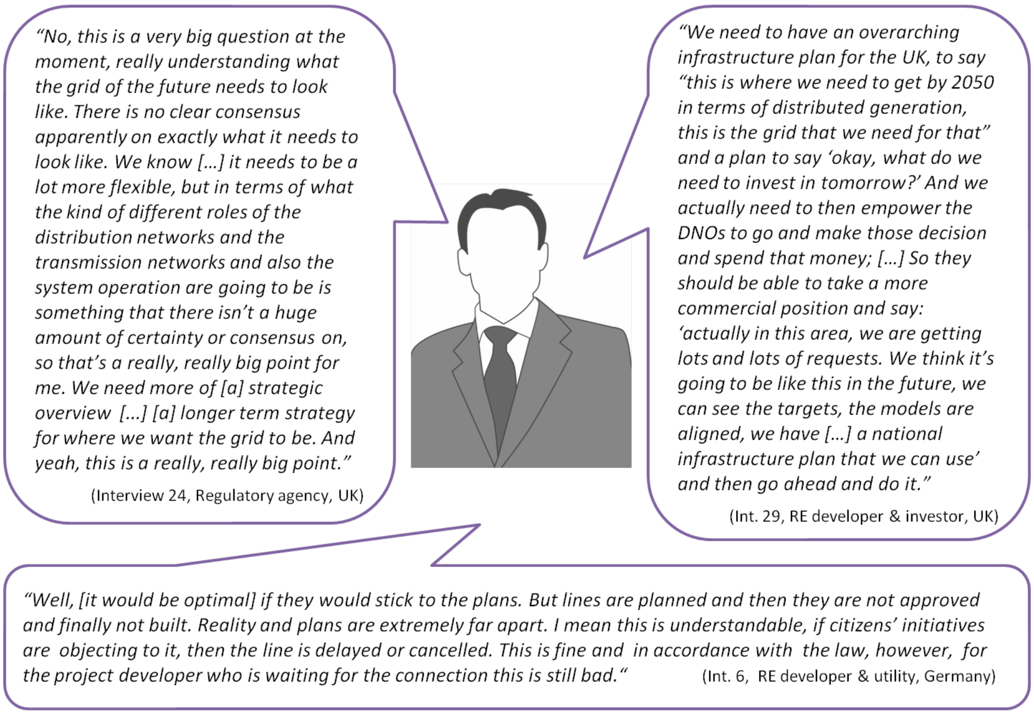

Figure 31: Interview statements confirming the importance of a transparent and foreseeable grid development (determinant C-V.).

Figure 31 presents additional interview statements which relate to the relevance of a transparent and predictable electricity network development for the deployment of RE. The stakeholders' views indicate that the perspectives for future grid development may serve as an indication for the medium to long-term potential for RE development in a country, especially in countries in which the availability of network capacity already becomes a limiting factor for RE deployment.

For the diffusion indicator, the assessment is based on the availability and accessibility of long-term grid development plans at national TSOs or regulatory agencies. Also transnational associations such as the 'European Network of Transmission System Operators for Electricity' (ENTSO-E) or the 'Agency for the Cooperation of Energy Regulators' (ACER) are relevant data sources. Additionally, the perception of national stakeholders should be taken into account.

Under *C V.* table 9 summarizes the value ranges and data sources for representing the transparency of grid development.

Table 9: Indicators, value ranges and data sources for representing grid infrastructure and grid regulation for RE. Individual indicators which can lead to an overall indicator result of zero are marked with an asterisk.

Indicators per sub-determinant	Value ranges and normalized scores	Data sources
C I) Grid access cost		
Charging-/ grid reinforcement approach for access to distribution and transmission grids	Shallow (or super-shallow) approach (developer pays only for connection to the nearest access point) (=1); Mixed (or undefined) approach (=0.5); Deep charging approach (full cost for connection and grid enhancements borne by developer) (=0.25)	National legal/regulatory documentation, supplemented by consultation of local stakeholders, CEER status reports
C II) RE grid access lead time		
Total lead time for obtaining grid access (weeks/ months)	Continuous scale between: Wind: $\leqslant$ 6 months (=1), $\geqslant$ 34 months (=0.25)[18]; PV: $\leqslant$ 1 month (=1); $\geqslant$ 12 months (=0.25)[19]	Past and ongoing projects (e.g. *PV-GRID/PV-LEGAL*[20], *Wind Barriers*[21]), interviews with local stakeholders
C III) Predictability & transparency of grid connection procedures		
Transparency of grid connection procedure (availability of regulations & reliable information on terms & procedures)	Transparent & predictable (=1); Average / medium (=0.5); Non-transparent & unpredictable (=0.25)	Interviews with local stakeholders, supplemented by national legal and regulatory documentation and past and ongoing projects (e.g. *PV-GRID/PV-LEGAL*, *Wind Barriers*, *Keep-on-Track!*[22]), EU RE progress reports

18 Range is based on recommendations given in Cena et al. (2010) to lower grid connection time for wind onshore <6 months and the lead time in the worst performing country across the EU which is 33.5 months.

19 Range is based on the spread of grid connection times across EU countries as given in the *PV Grid* database (PV Grid, 2014), in the best performing country grid connection permit and connection take 3 weeks, in the worst performing country 50 weeks.

20 Weblinks: www.pvgrid.eu, www.pvlegal.eu

21 Weblink: www.windbarriers.eu

22 Weblink: www.keepontrack.eu

Table 9: Indicators, value ranges and data sources for representing grid infrastructure and grid regulation for RE. Individual indicators which can lead to an overall indicator result of zero are marked with an asterisk.

Indicators per sub-determinant	Value ranges and normalized scores	Data sources
C IV) Treatment of RE access and curtailment		
RE grid access regime and regulation for curtailment*	Priority or guaranteed access and full compensation of curtailment (=1); Either priority / guaranteed access or compensation of curtailment (=0.5); No priority or guaranteed access and no compensation of curtailment (=0.25); No grid access possible (=0)	National legal/ regulatory documents
C V) Transparency and predictability of grid development		
Predictability of grid development / availability of information on grid extensions	Transparent & reliable: detailed long-term plans and information publicly available (=1); Average / medium: Plans available but implementation unclear or lack of clarity and level of detail or long-term vision (=0.5); Non-transparent & non-reliable: No credible plans or information available (=0.25)	Grid development plans provided by national TSO's and regulatory agencies, regional associations (e.g. ENTSO-E, ACER), supplemented by consultation of local experts

4.2.3.4 *D. Administrative procedures for RE projects*

I. COST OF ADMINISTRATIVE PROCEDURES Depending on national regulations and administrative practices, the administrative costs associated with the realization of RE projects can constitute a substantial share in the overall development cost of the project and may thus be a decisive factor for a RE project's expected return. In the context of this work, the outlay for administrative procedures is understood as the aggregate of the expenses for obtaining all the required building permits and environmental impact assessments as well as for official administrative processing fees. Unofficial payments due to corruption and bribery, although these may play a role in some countries, are not considered for the indicator.

A broad spectrum of administrative costs can be observed across the European Member States, both concerning the administrative cost associated with PV development (B. Barth, Concas, Binda Zane et al., 2014; PV Grid, 2014) and wind energy development (Cena et al., 2010). The assessments of RE stakeholders contacted in the frame of this thesis indicate that whether the share of administrative costs is perceived as a critical factor primarily depends on the expected profitability of the project and is thus also associated with the reliability and type of the support scheme (e.g. interviews 1, 4, 5, 6, 10, 16, 17, 19, 23). This is further illustrated by a selection of quotes presented in figure 32.

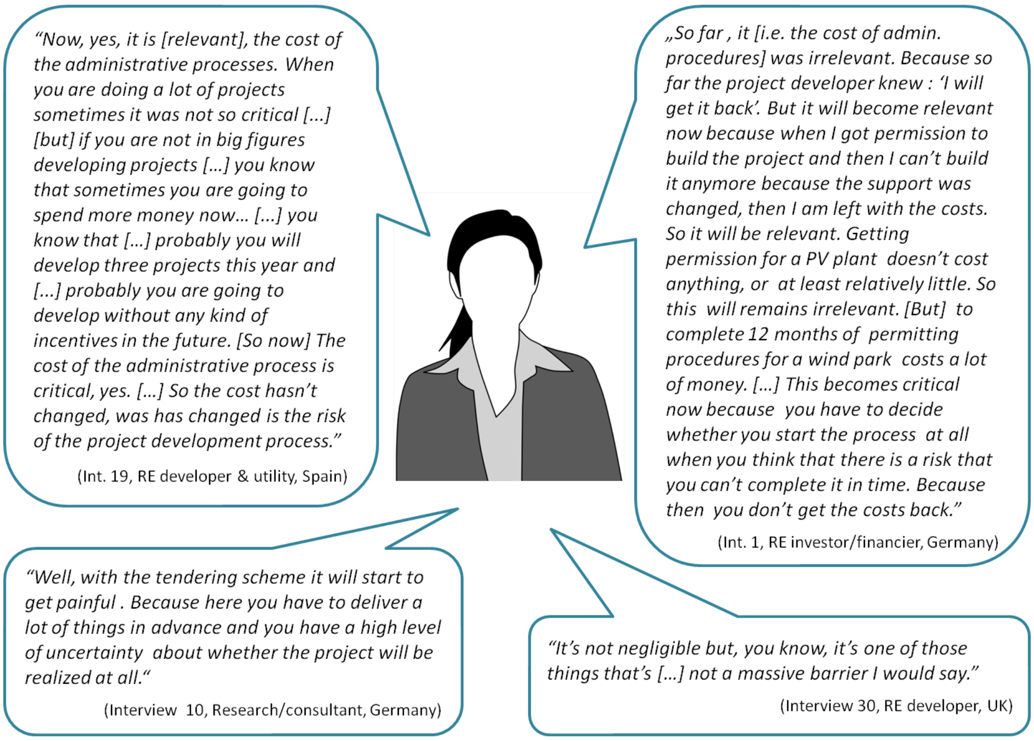

Figure 32: Interview statements relating to the relevance of the cost of administrative procedures (determinant D-I.).

To measure the share of administrative costs, either the share in the project development cost (excluding the power plant itself) or in the overall investment (including hardware cost) can be used as an indicator, depending on data availability. Possible data sources for this indicator include, among others, existing publications and findings from research projects, such as 'PV Grid' (PV Grid, 2014), reports compiled by the EU Commission (e.g. European Commission (2013b)) or the Member States' RE progress reports (European Commission, 2013c). To obtain recent quantitative data and detailed insights, also local stakeholders and national administrations should be consulted. For the indicator evaluation, suitable ranges are defined for each technology, as the cost shares vary depending on the technology concerned.

Under *D-I.* Table 10 summarizes the value ranges and data sources suggested for this indicator.

ii. duration of administrative procedure The implementation of a RE project can be divided into three phases: The planning phase (involving e.g. site selection, resource measurements, feasibility studies and environmental impact assessments), the implementation phase (construction of the power plant having obtained a building permit) and the production phase (generation and sale of electricity after commissioning and physical connection to the grid) (Uyterlinde et al., 2003). In the context of this work, the administrative lead time is understood as the period between the first official inquiry to the responsible authority and the point at which the final decision is taken and all necessary permits to start constructing the power plant are available. In accordance with Cena et al. (2010) and (PV Grid, 2014), this time-frame includes periods of active involvement in the process as well as waiting times.

According to the interviewed RE developers, the process duration can be influenced by a multitude of factors such as the available capacity, experience and procedural efficiency at public authorities as well as by public opposition to RE projects which may interfere with the decision process (especially for wind projects).

Delays in the administrative permitting process can be a substantial risk factor, especially for wind energy projects with already long implementation time-frames (Holburn, Lui and Morand, 2010; Lüthi and Prässler, 2011), but the duration of administrative procedures is also perceived as an important factor in the investment decision process of PV developers (Lüthi and Wüstenhagen, 2012).

Analogue to the significance of the administrative cost share (cf. paragraph D-I.) and the duration of grid access (cf. paragraph C-II) also the duration of administrative procedures depends on the profitability of the project and becomes increasingly important if there are doubts regarding the stability of the political and economic framework for RE (e.g. interviews 1, 4, 5, 8, 10, 11, 19, 20, 27, 29). In this context, the predictability of the duration is critical. Otherwise, most RE developers showed understanding for the duration of administrative procedures and did not see this as a factor which is particularly blocking RE development.
Figure 33 presents a selection of interview quotes which illustrate the perspective of RE developers on this issue.

For the diffusion indicator, the total duration of the administrative process (measured in weeks) is used. Possible sources of information for this indicator comprise the same data sources as mentioned under D-I. For the indicator evaluation, suitable ranges are defined for each technology, as the process duration varies depending on the technology concerned.

Table 10 under *D-II.* summarizes the indicator, value ranges and data sources used to represent the duration of administrative procedures.

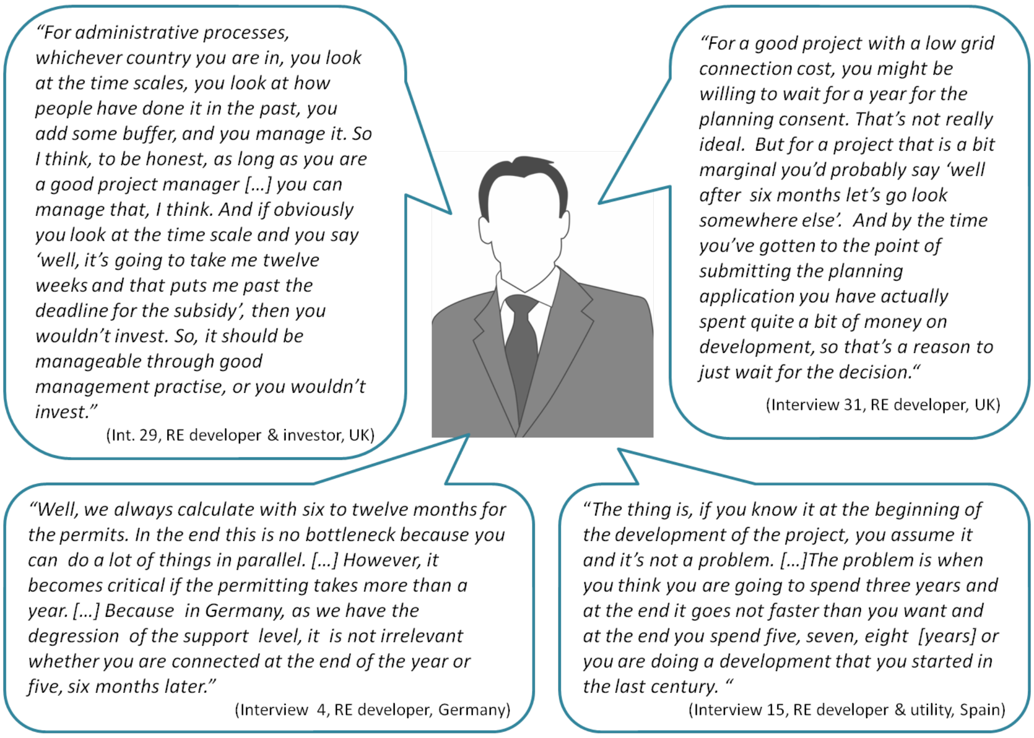

Figure 33: Interview statements relating to the relevance of the duration of administrative procedures (determinant D-II.).

III. COMPLEXITY OF ADMINISTRATIVE PROCEDURES The complexity of administrative procedures determines how much effort is involved for the project developer to obtain all required permits to realize a RE project. This can, but does not necessarily have to be, reflected in the duration of administrative procedures as these can also be prolonged by extensive waiting times.

In line with the best practice guidelines for RE support schemes provided by the European Commission (2013b, p. 34) it is assumed that a transparent administrative process is characterized by clearly defined and manageable requirements in terms of the number of permits and authorities to be contacted, transparent evaluation criteria and reliable time limits on decisions. It may also include online application options to further facilitate the bureaucratic process.

Stakeholders contacted in the frame of this thesis stated that the permitting procedures themselves are not overly complex (e.g. interviews 1, 5, 19, 29). However, they described them as exceptionally difficult in cases when authorities were badly coordinated (e.g. interviews 17, 18, 19, 21), when deadlines for decisions didn't exist or were not met (e.g. interviews 5, 6, 18, 20), when different administrative levels interfered with each other (e.g. interviews 27, 28) or when permitting decisions were opaque, influenced by local politics or based on arbitrary criteria (e.g. interviews 5, 12, 14, 15, 17-20, 22, 23, 28). Especially project developers from Spain reported that sometimes administrative procedures could only be completed if a direct benefit was created for the respective community (interview 13, 14) or if they had a good personal contact in the local administration: "*At the last moment we have to know the Garcia [common surname in Spain] of each place."* (Interview 18). However, on the other hand they admitted that this can also be a benefit as the local authorities *"[...] are more accessible for us. To go the local community [is easier] than to go to the government"* (interview 15).

The administrative complexity may be further aggravated by regional differences regarding the requirements and criteria applied in the permitting procedures (Iglesias, Río and Dopico (2011), interviews 3, 11, 13, 15, 16, 19, 20, 24). Figure 34 presents a selection of interview quotes relating to the relevance of the complexity of administrative procedures for RE projects.

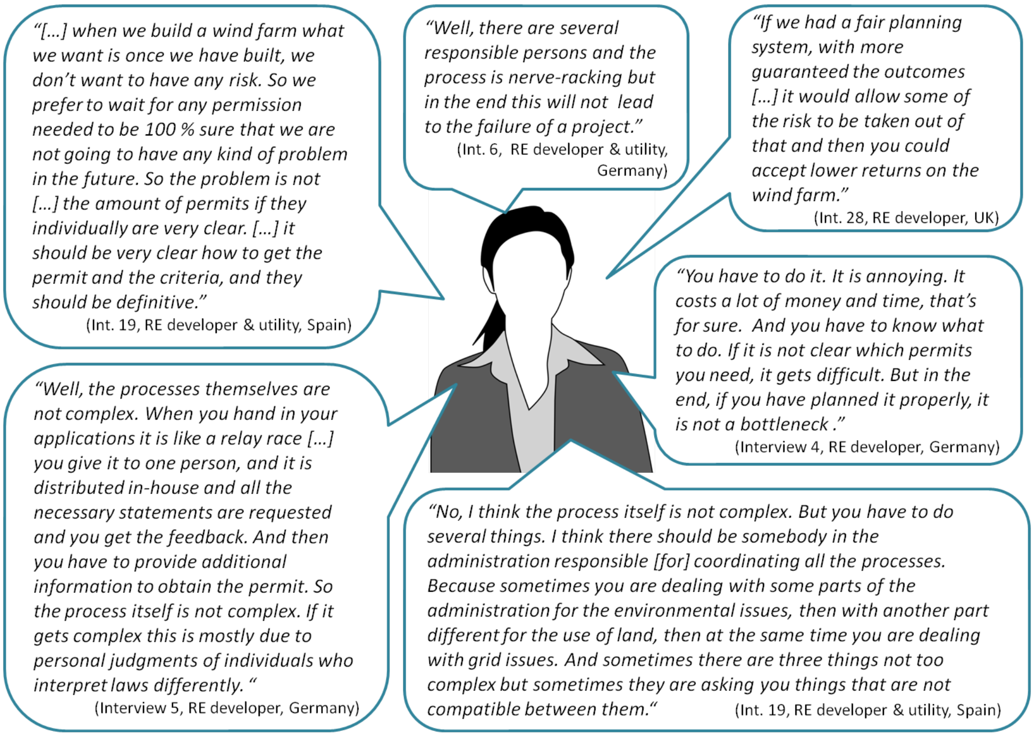

Figure 34: Interview statements relating to the relevance of the complexity of administrative procedures (determinant D-III.).

For the diffusion indicator, the administrative complexity is measured on a qualitative scale and represented by the assessment of local stakeholders complemented by secondary information sources, where available.

Table 10 under *D-III.* summarizes the value ranges and data sources for this indicator.

iv. integration of re in spatial and environmental planning Spatial and environmental planning issues may be the cause of additional delays to RE projects, for example due to conflicts of interest concerning land use or the opposition of other involved parties, such as local residents or advocacy groups (McLaren Loring, 2007). Due to their strong visual and environmental impact, this applies in particular to wind energy projects. To facilitate the siting decisions of RE developers, areas suitable for RE development could be earmarked in regional development plans (Ecofys, 2014). However, obstacles might also arise if areas are reserved but if these are either insufficient or unsuitable for RE development (Ohl and Eichhorn, 2009). Stakeholders contacted in the frame of this thesis reported that further barriers can emerge from an overly restrictive a priori exclusion of specific land use forms or area types (e.g. agricultural land or periphery of settlements) from RE development (e.g. interviews 3, 4, 6, 9, 10) or if the preparation of spatial plans on regional or communal level is subject to delays and legal uncertainties (e.g. interviews 4, 5, 6, 7, 11, 19). The latter is particularly critical for wind energy deployment. Hence the access of RE developers to suitable project sites can become a strongly limiting or even blocking factor for RE deployment.

Figure 35 presents selected interview statements illustrating the views of RE developers on the integration of RE in spatial planning.

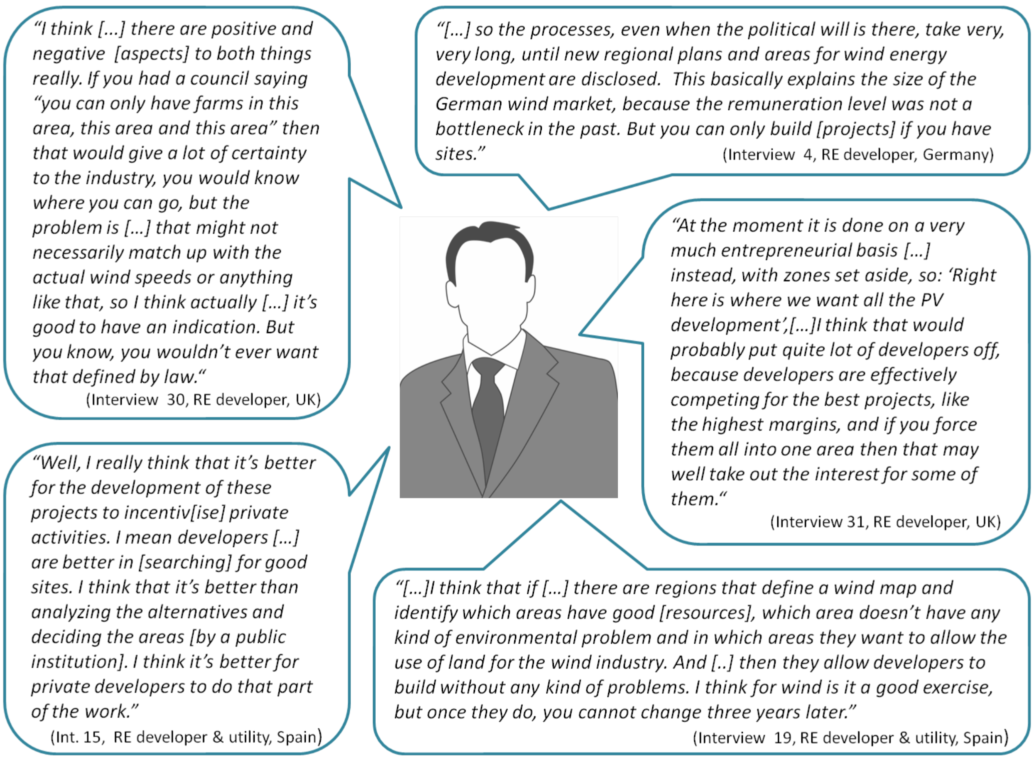

Figure 35: Interview statements relating to the relevance of the integration of RE in spatial planning (determinant D-IV.).

However, it depends on the framework conditions and the preferences of RE developers whether a more guided procedure with pre-defined areas or a more flexible approach with less spatial limitations is perceived as the preferable option. The majority of interviewees expressed their preference for a flexible approach, possibly including a certain guidance but no strict specifications of project sites (e.g. interviews 9, 14, 15, 27, 29 30, 31) while only individual developers would favour more guided spatial planning concepts (e.g. interviews 19, 21).

In the context of the diffusion indicator, this controversial aspect is thus represented by a qualitative assessment of the availability of sufficient suitable areas for RE development based on interviews with local stakeholders supplemented by other information sources, where available.

Table 10 under *D-IV.* summarizes the value ranges and data sources for this indicator.

Table 10: Indicators, value ranges and data sources for representing administrative processes for RE projects. Individual indicators which can lead to an overall indicator result of zero are marked with an asterisk.

Indicators per sub-determinant	Value ranges and normalized scores	Data sources
D I) Administrative cost		
Share of administrative cost in project development cost	Wind : $\leqslant$ 1.5% (=1); $\geqslant$ 20% (= 0.25)[23]; PV: $\leqslant$5% (=1); $\geqslant$ 50% (=0.25)[24] Intermediate scores are interpolated based on a geometric sequence	Past and ongoing projects (e.g. *PV-GRID/PV-LEGAL*, *Wind Barriers*, *Keep-on-Track!*), EU guidance and RE progress reports, consultation of local stakeholders
D II) Duration of administrative procedures		
Total administrative lead time (weeks)	Wind: $\leqslant$ 20 months (=1), $\geqslant$ 60 months (=0.25)[25]; PV: $\leqslant$ 8 weeks (=1); $\geqslant$ 48 weeks (=0.25)[26] Intermediate scores are interpolated based on a geometric sequence	Past and ongoing projects (e.g. *PV-GRID/PV-LEGAL*, *Wind Barriers*), EU guidance and RE progress reports, consultation of local stakeholders
D III) Administrative complexity		
Complexity of the administrative process*	Low complexity (=1); Medium/average complexity (=0.5); High complexity (=0.25); Procedure cannot be completed (=0)	Perception of local stakeholders, supported by national RE information platforms/institutions, EU guidance and RE progress reports, past and ongoing projects (e.g. *PV-GRID/PV-LEGAL*, *Wind Barriers*, *Keep-on-Track!*)

23 Ranges are based on the recommendation given in Cena et al. (2010) to lower the share to 1.5% of the total project cost (incl. hardware cost). The highest reported value across the EU was 5%.

24 Ranges are based on value ranges for development cost (excl. hardware cost) across EU countries as presented in B. Barth, Concas, Binda Zane et al. (2014). The lowest value reported for commercial and industrial applications in the EU is 2%, the highest value is 98% for commercial applications and 36% for industrial applications.

25 Ranges based on the recommendation given in Cena et al. (2010) to lower administrative lead times to a maximum of 20 months. The highest reported value across the EU is 58 months.

26 Ranges are based on own interview results. Interviewees considered a duration of <2 months as acceptable and over 12 months as unacceptable. Average value ranges across EU countries presented by PV Grid (2014) show a spread between 1 week (for 50 kWp systems) up to 39 weeks (for 2500 kWp systems).

Table 10: Indicators, value ranges and data sources for representing administrative processes for RE projects. Individual indicators which can lead to an overall indicator result of zero are marked with an asterisk.

Indicators per sub-determinant	Value ranges and normalized scores	Data sources
D IV) Integration of RE in spatial & environmental planning		
Prioritization of areas for RE development in national spatial planning*	Good: specific and sufficient areas for RE development are reserved, transparent procedures exist (=1); Average/medium: No specific areas reserved but RE friendly attitude in spatial planning (=0.5); Poor: no areas for RE development reserved, developers face difficulties to obtain access to possible project sites (=0.25); No areas available at all (=0)	Interviews with local stakeholders, national legal and regulatory documentation, EU guidance and RE progress reports, policy databases

4.3 RELEVANCE OF THE DETERMINANTS FOR RENEWABLE ENERGY DIFFUSION

This section presents the results of the questionnaire-based assessment of the relative relevance of the diffusion determinants (cf. methodology description in chapter 3, section 3.3). Section 4.3.1 presents the weighting results differentiated by technology and compares the relevance of the determinants from the viewpoint of onshore wind and PV experts. In section 4.3.2 the findings are further segmented according to the institution type and the geographical focus of the respondents. The results of a statistical evaluation of the findings is given in section 4.3.3. Section 4.3.4 concludes with a summary and discussion of the weighting results.

4.3.1 *Relative relevance of the diffusion determinants*

To be able to identify potential differences in the relevance of the determinants depending on the RE technology, the overall dataset is differentiated according to the technological focus of the respondents. The results compare the weights allocated by respondents engaged in onshore wind energy and PV with the results for the overall data set. However, due to the possibility to indicate multiple technologies in the questionnaire, overlaps between the technology groups occur and differences are less pronounced (cf. section 3.3.2). Thus, in order to get a better understanding of the technology differences, the results are also compared to smaller data sub-sets which refer exclusively to wind onshore ('wind focus') or PV large-scale ('PV focus'), respectively (cf. section 3.3.2). A detailed description of the methodology for the data segmentation is given in section 3.3.2.

The results are shown in form of *'box-whisker-plots'* which allow for a detailed graphic representation of the statistical characteristics of the data sample. Thereby, the boxes mark the range that contains 50% of the data points. The upper part of the box indicates the upper quartile and the lower part represents the lower quartile of the data range. The line that separates the quartiles marks the median, i.e. the value which indicates the middle of all values of the dataset if these were arranged in ascending order. The median provides a robust indication for the central tendency of a dataset while the boxes illustrate its skewness. The outer lines (*'whiskers'*) span across 1.5 Inter Quartile Ranges (IQR) from the end of the upper and lower quartile. Data points beyond $1.5 \cdot \mathrm{IQR}$ from the upper and lower quartile are regarded as outliers and are represented by crosses.

Figures 36 to 39 display the weighting results for each determinant. The values on the y-axis represent the relevance of the determinants as specified in the weighting questionnaire and online survey (see annex A.2). They range from 0 = *'not relevant at all'* to 10 = *'extremely relevant'*. An intermediate value of 5 means *'moderately relevant/indifferent'*. The differently coloured box-plots for each determinant refer to the technology-specific data sub-sets as described in in section 3.3.2.

- The green boxplots display the results for the overall data sample (across all technologies).
- The light orange boxplots represent data provided by stakeholders who indicated that they have expertise in PV.
- The dark orange boxplots represent data provided by stakeholders with a focus exclusively on PV.
- The light blue boxplots represent data provided by stakeholders with expertise in onshore wind energy.
- The dark blue boxplots represent datasets provided by stakeholders with expertise exclusively in wind energy.

The underlying data for the graphs is included in table 21 in annex A.4.

GENERAL OVERVIEW As an initial overview, when comparing the results across all determinants and for all technologies (green box-plots in graphs 36 to 39), it becomes apparent that the determinants representing the political and economic framework received the highest median values (median of 8.25 averaged across the four determinants), compared to the other three determinant categories. The 'market structure & market regulation' and 'grid regulation & grid infrastructure' received similar scores with average medians of 7.33 and 7.00, respectively. The determinants representing the administrative procedures were rated lowest with a median relevance of 6.5 on average. In the following, the weighting results for each determinant group will be presented and discussed in detail.

political and economic framework Figure 36 illustrates the weighting results for the determinants representing the political and economic framework for RE. It becomes apparent that, **across all RE technologies** (green box-plots), the existence of a reliable policy framework is the most relevant determinant in this group. Its median relevance scores 9 out of 10 which means that half of the respondents attributed 9 points or more to this aspect. Also 10 points (=*'extremely relevant'*) have been allocated to this determinant frequently.

The remuneration level, the revenue risk and access to finance exhibit equal median relevancies, namely median values of 8. However, the ranges in which 50% of the data points lie (upper and lower quartiles) are narrower for the remuneration level and the revenue risk (7-9) compared to access to finance (5-9) which indicates that there is a wider distribution regarding stakeholders' preferences related to this aspect. Even very low values, as low as zero points (=*'not relevant at all'*), have been awarded by individual stakeholders.

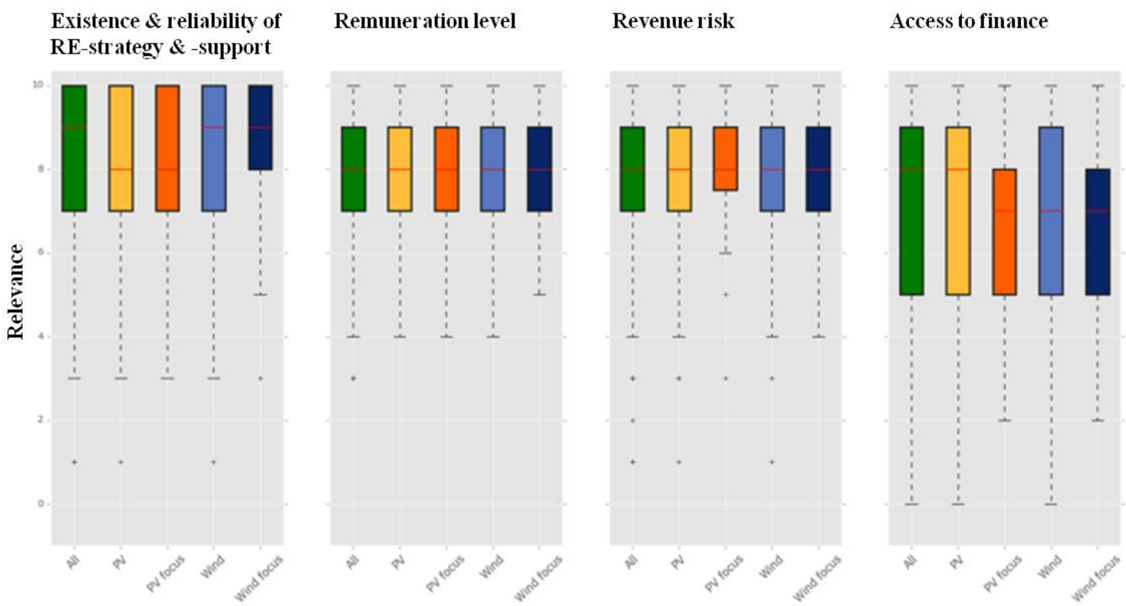

Figure 36: Relevance of the determinants characterizing the political and economic framework for RE. Comparison of scores allocated by stakeholders with varying technological focus: green = across all technologies; light orange = PV; dark orange = exclusively PV, light blue = onshore wind; dark blue = exclusively onshore wind.

The weights attributed by stakeholders with **expertise in PV** (light orange box-plots) show the same ranges and median values as those for the overall data sample. Only the median for the existence of a reliable policy framework is one point lower than for the overall data sample.

The relevance from the viewpoint of stakeholders **focused only on PV** (dark orange box-plots) differs for the revenue risk and the access to finance. For both determinants the value range is narrower compared to the general PV stakeholders. Also the median relevance of access to finance is lower (7 points).

Weights attributed by stakeholders **active in the wind energy** sector (light blue box-plots) show the same ranges as for the overall data sample and for the general PV group. However, just like for PV, the median relevance for access to finance is lower for wind energy than for the overall data sample, 50% of the stakeholders awarded less than 7 points to this determinant.

The median relevance from the viewpoint of actors which are **focused only on wind energy** (dark blue box-plots) is equal to the general relevance for wind energy. Only the value ranges for the existence of a reliable policy framework and access to finance are narrower compared to the general wind energy group.

market structure and market regulation Figure 37 shows the weighting results for the determinants representing the market structure and market regulation. **Across all RE technologies** (green box-plots) the highest relevance is attributed to a fair and independent regulation of the RE sector (median relevance of 8) while flexible short-term markets and reliable long-term contracts score equally with 7 points.

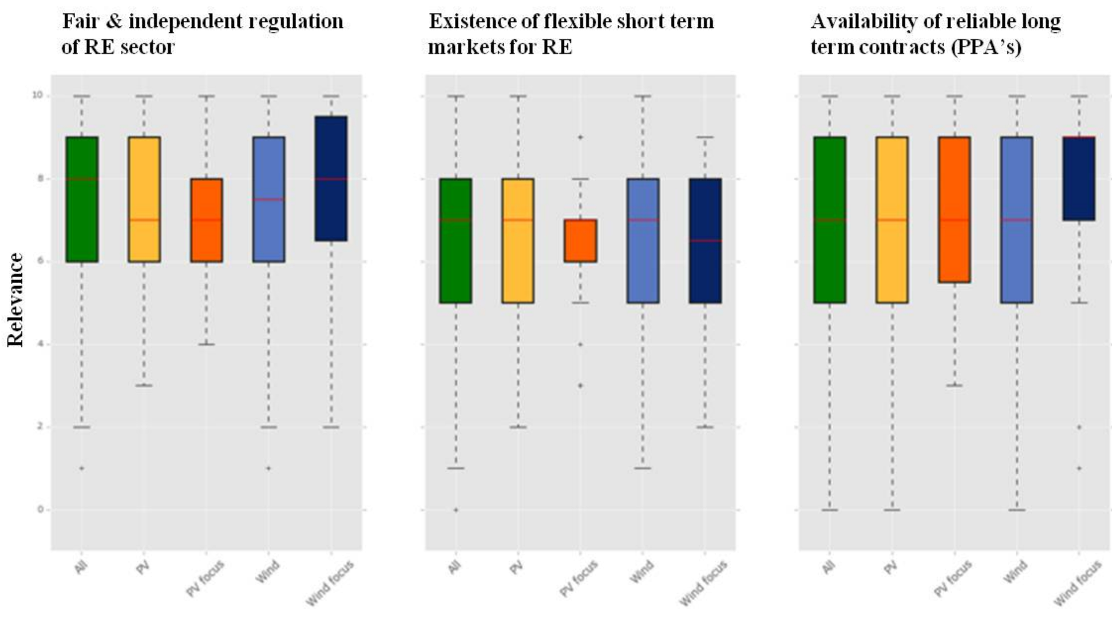

Figure 37: Relevance of the determinants characterizing the electricity market structure and market regulation. Comparison of scores allocated by stakeholders with varying technological focus: green = across all technologies; light orange = PV; dark orange = exclusively PV, light blue = onshore wind; dark blue = exclusively onshore wind.

Weights attributed by stakeholders active in the **PV sector** (light orange box-plots) display the same ranges and median values as for all RES, only the median relevance of a fair and independent regulation is one point lower compared to the overall data sample.

The relevance from the viewpoint of stakeholders **focused only on PV** (dark orange box-plots) is very similar to that of the general PV sector stakeholders and shows identical median values. However, the ranges for all determinants are narrower than for the stakeholders which are also active in other technology sectors. For the existence of flexible short-term markets, the upper quartile of the data is equal to the median value (7).

Weights attributed by stakeholders active in the **wind energy sector** (light blue box-plots) display similar ranges and median values to those for all RES and PV sector stakeholders.

The relevance from the viewpoint of actors which are **focused on wind energy only** dark blue box-plots) is slightly higher than specified by the general wind sector stakeholders regarding a fair and independent regulation of the RE sector and slightly lower regarding the availability of short-term markets for RE. Concerning the availability of reliable long-term sales contracts (PPAs), the median value is notably higher than for all other technology subgroups: 50% of the data points score 9 points or above. Also the upper quartile of the data is equal to the median value (9).

grid regulation and grid infrastructure Figure 38 illustrates the weighting results for the determinants representing grid regulation and grid infrastructure. **Across all RE technologies** (green box-plots) all determinants exhibit the same median relevance of 7 and also the quartile ranges are very similar.

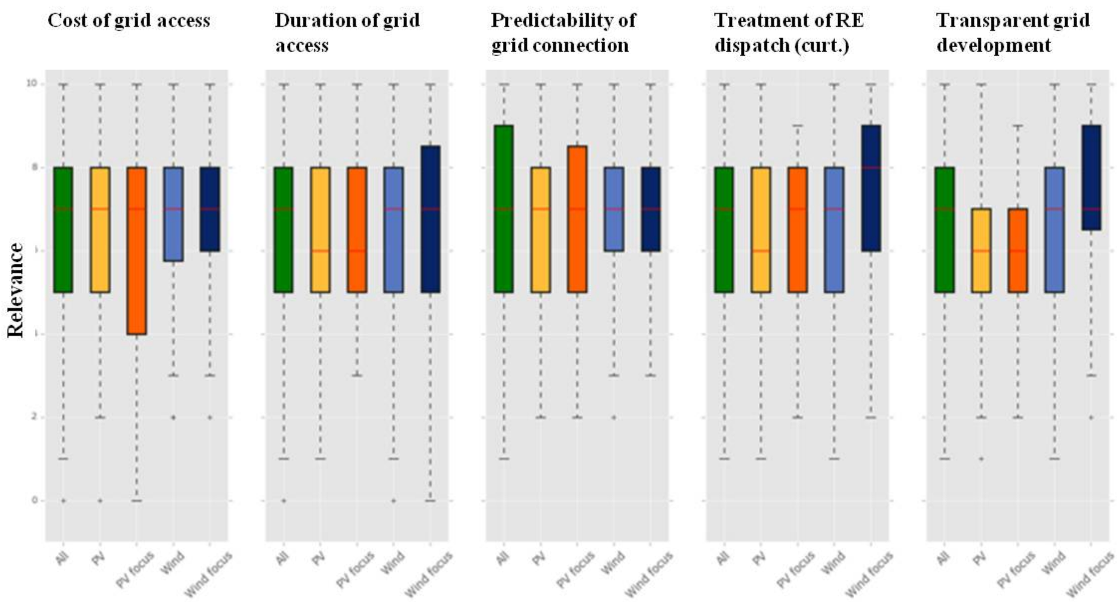

Figure 38: Relevance of the determinants characterizing the grid regulation and grid infrastructure. Comparison of scores allocated by stakeholders with varying technological focus: green = across all technologies; light orange = PV; dark orange = exclusively PV, light blue = onshore wind; dark blue = exclusively onshore wind.

Weights attributed by stakeholders with **expertise in PV** (light orange box-plots) differ from the overall data sample regarding the median relevance of the duration of grid access procedures, the treatment of RE dispatch/ risk of curtailment and the transparency of grid development which all score one point lower with a median relevance of 6.

The relevance of the determinants from the viewpoint of stakeholders **focused only on PV** (dark orange box-plots) merely differs from the general PV sector stakeholders' opinion regarding the median relevance of the treatment of RE dispatch/curtailment, which is one point higher (median relevance of 7) and the quartile ranges which are partly wider.

Values attributed by stakeholders active in the **wind energy sector** (light blue box-plots) indicate the same median relevance of all determinants as for the overall data sample. The quartile ranges are either equal or slightly narrower (cost of grid access and predictability/transparency of grid connection).

The relevance from the viewpoint of actors which are **focused only on wind energy** (dark blue box-plots) primarily deviates from the general wind energy stakeholders regarding the relevance of RE dispatch/ risk of curtailment (median relevance of 8) and the upward shifted quartiles for RE dispatch/ risk of curtailment and the transparency of grid development.

ADMINISTRATIVE PROCEDURES Figure 39 presents the weighting results for the determinants representing the administrative procedures for RE projects. **Across all RE technologies** (green box-plots) the median relevance for the duration and the complexity of administrative procedures, as well as for the integration of RE with spatial planning, is 7. The cost of administrative procedures scores considerably lower than the other determinants of this group with a median relevance of 5 (='*moderately relevant*'). Here, the lower quartile of the data is equal to the median.

The determinant weights attributed by stakeholders with **expertise in PV** (light orange box-plots) differ from the weights across all RES regarding the median relevance of the integration with spatial planning which has a lower median relevance of 6. Otherwise, only the quartile ranges are slightly shifted downwards on the y-axis, compared to the overall data sample.

The relevance from the viewpoint of stakeholders **focused only on PV** varies regarding the duration (one point lower, median = 6) and the cost of administrative procedures (one point higher, median = 6). Also the quartile ranges are slightly narrower for the duration and complexity of the administrative process.

The weights attributed by stakeholders active in the **wind energy sector** indicate an equal median relevance as for the overall data sample: The duration and complexity of

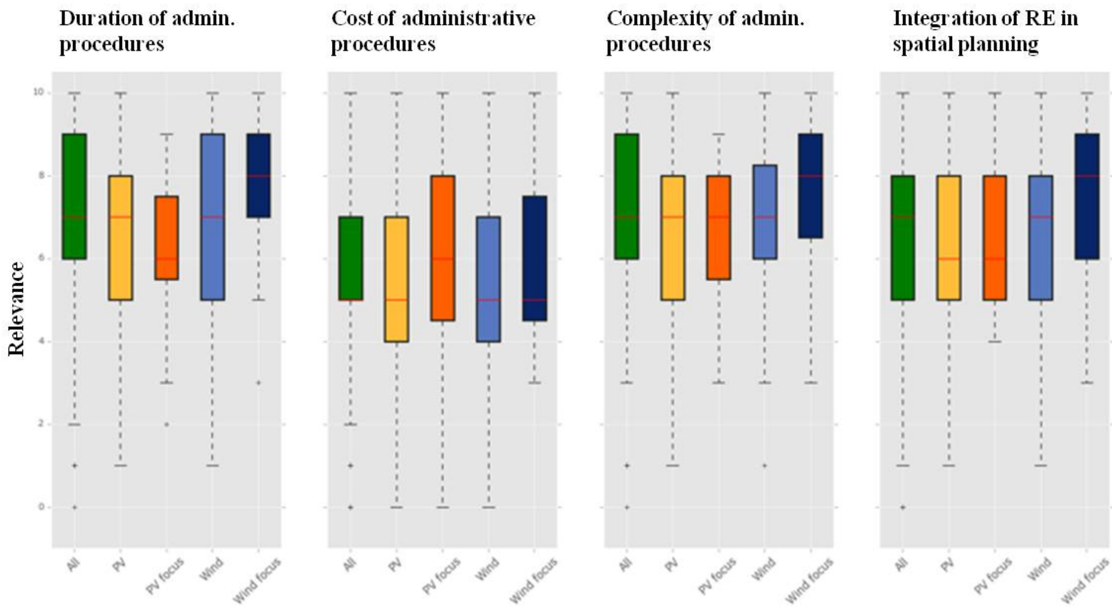

Figure 39: Relevance of the determinants characterizing administrative procedures for RE projects. Comparison of scores allocated by stakeholders with varying technological focus: green = across all technologies; light orange = PV; dark orange = exclusively PV, light blue = onshore wind; dark blue = exclusively onshore wind.

the administrative process score 7 and the cost of the administrative procedures has a median relevance of 5.

The relevance from the viewpoint of actors which are **focused only on wind energy** is higher regarding the duration and the complexity of the administrative process as well as for the integration of RE in spatial planning. All three determinants have a median relevance of 8 which is the highest value of all technologies. The cost of administrative procedures, however, scores only 5 (=*'moderately relevant'*).

4.3.2 *Additional segmentation analysis: Stakeholder- and country specific results*

The major objective of the weighting exercise is to assess the technology-specific relevance of the RE diffusion determinants (cf. section 4.1). However, based on the background information on the respondents that was retrieved with the weighting data (cf. questionnaire in annex A.2) a further segmentation of the results is possible. Interesting questions in this regard relate, for example, to stakeholder-specific differences in the weighting results or to the question whether the home country of the respondents has an impact on their assessment. For both questions exemplary analyses are presented in this section. However, due to the limited sample size for some segments of the dataset, the findings should be considered as indicative examples which point to possible fields of future research rather than as robust results[27].

STAKEHOLDER SPECIFIC RESULTS Different stakeholder groups might have varying viewpoints on the relevance of the RE diffusion determinants. Although RE developers are the major target group of the assessment in this thesis (cf. section 3.3) also other stakeholders from the RE sector participated in the survey (cf. figure 13). A comparative analysis of the ratings provided by different stakeholder groups can be used to identify potential areas of conflict, to which special attention should be paid in the process of policy making. Of particular interest in this regard are differences between the perceptions of those stakeholders who plan and implement RE projects (i.e. RE developers), those who finance them (i.e. financing institutions) and those who define and develop the RE policy framework (i.e. policy makers/national governments). Additionally, also the assessments of researchers and consultants, who advise politicians and thus contribute to the policy making process, are of interest.
Therefore, the overall dataset was differentiated according to the institutional background of the respondents and a comparative analysis for the above mentioned stakeholder groups was conducted.

Figure 40 presents a comparison of the median determinant weights attributed by the above mentioned stakeholder groups. In the radar chart, each of the radii represents one of the 16 determinants. The median relevance of each determinant is specified on a scale from zero (midpoint of the chart) to ten (outer circle of the chart). The number of datasets for each group is specified in the legend. The presented values do not distinguish between technologies or countries.

Figure 40 illustrates that the observed median values largely fall into the same range for all stakeholder groups. In particular, the evaluations of RE developers and actors from the research sector correspond well for most determinants (apart from the availability of PPAs). Here, for several determinants the medians are actually identical. The weightings of energy consultants are also similar but mostly slightly lower than those of RE-developers. Regarding the remuneration level, there is even a consensus among all groups, except financial institutions who rated this determinant one point lower.

However, in some cases there are also notable deviations between the groups. Particularly noteworthy is the fact that several determinants are rated lower by government stakeholders than by RE project developers. This applies, for example, to the cost, duration and complexity of administrative procedures as well as to the transparency of grid development and the integration of RE in spatial planning. Also the relevance of reliable

27 Furthermore, the potential superimposition of technology-specific and country- or stakeholder-specific effects limits the explanatory power of the presented findings. As the data sub-sets are too small for further segmentation (e.g. by stakeholder type and technology) it is not possible to clearly separate technology-specific from country- or stakeholder specific effects.

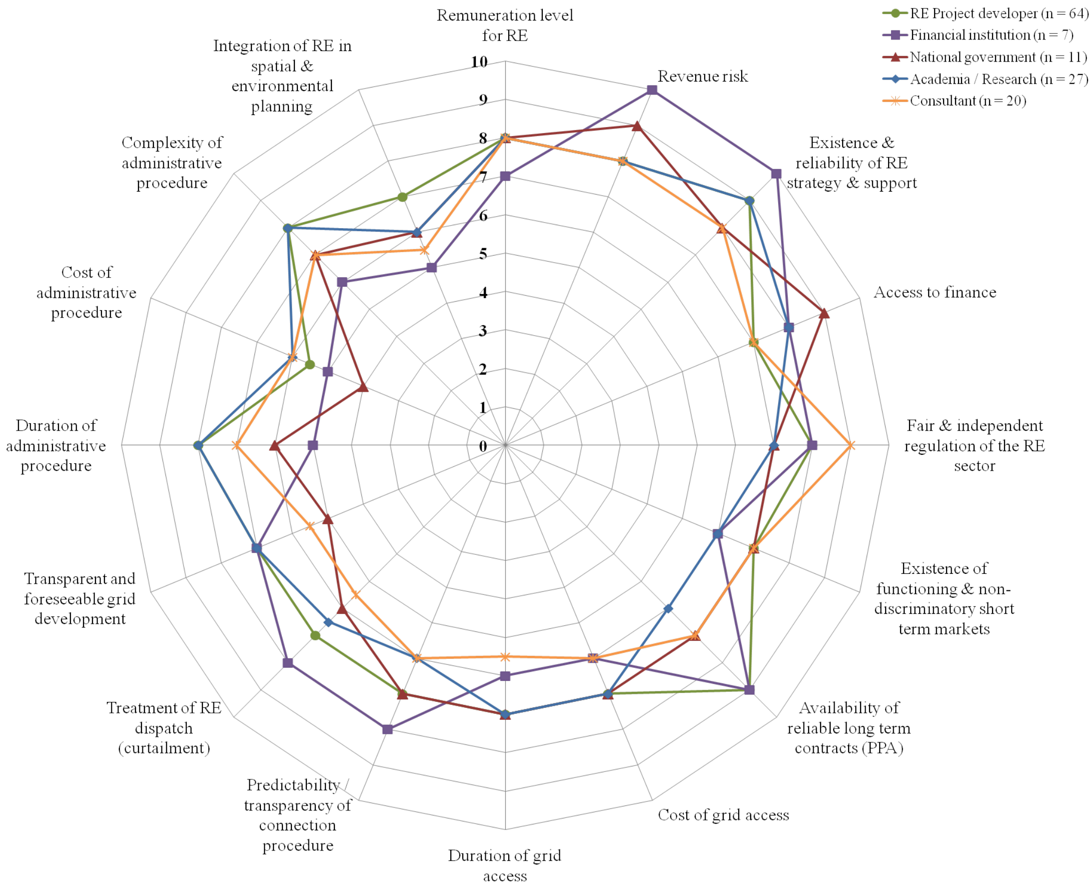

Figure 40: Relevance of the diffusion determinants (median scores) for selected stakeholder groups. The number of datasets per group is indicated in the legend.

long-term contracts for RE is rated lower by government stakeholders (and by researchers) than by RE developers. Financial institutions assigned higher ratings than all other groups to the revenue risk and the existence and reliability of the RE strategy and support scheme as well as to the treatment of RE dispatch and the predictability of grid connection. This indicates that these post-commissioning risk-elements are considered as more relevant by financiers compared to the other stakeholder groups.

COUNTRY SPECIFIC RESULTS The approach for assessing the determinant weights with the questionnaire and the online platform is based on the assumption that a universal decision framework for RE investment decisions exists and that technology-specific weights can be associated to the individual decision factors. In the questionnaire and the online interface, respondents were thus explicitly asked to provide a general assessment which abstracts from the situation in a specific country. Nevertheless, it cannot be precluded that the respondents were still, consciously or subconsciously, influenced by experiences in their respective geographical setting which might lead to a distorted result. Therefore, to investigate whether there is a systematic country-bias visible in the weighting results, the findings for selected countries are compared.

The overall database includes datasets from a large variety of countries (cf. table 4 for a country overview). However, for several countries only a small number of datasets is available. Therefore, to increase the significance of the analysis, only those countries are selected for which at least 10 or more datasets are available.

Figure 41 presents a radar chart with the median weights per determinant attributed by the stakeholders from each of the countries. The radii in the chart represent the 16 diffusion determinants. The median relevance of each determinant is specified on a scale from zero (midpoint of the chart) to ten (outer circle of the chart). The number of datasets for each country is specified in the legend of the graph. The presented values do not distinguish between technologies or stakeholder groups.

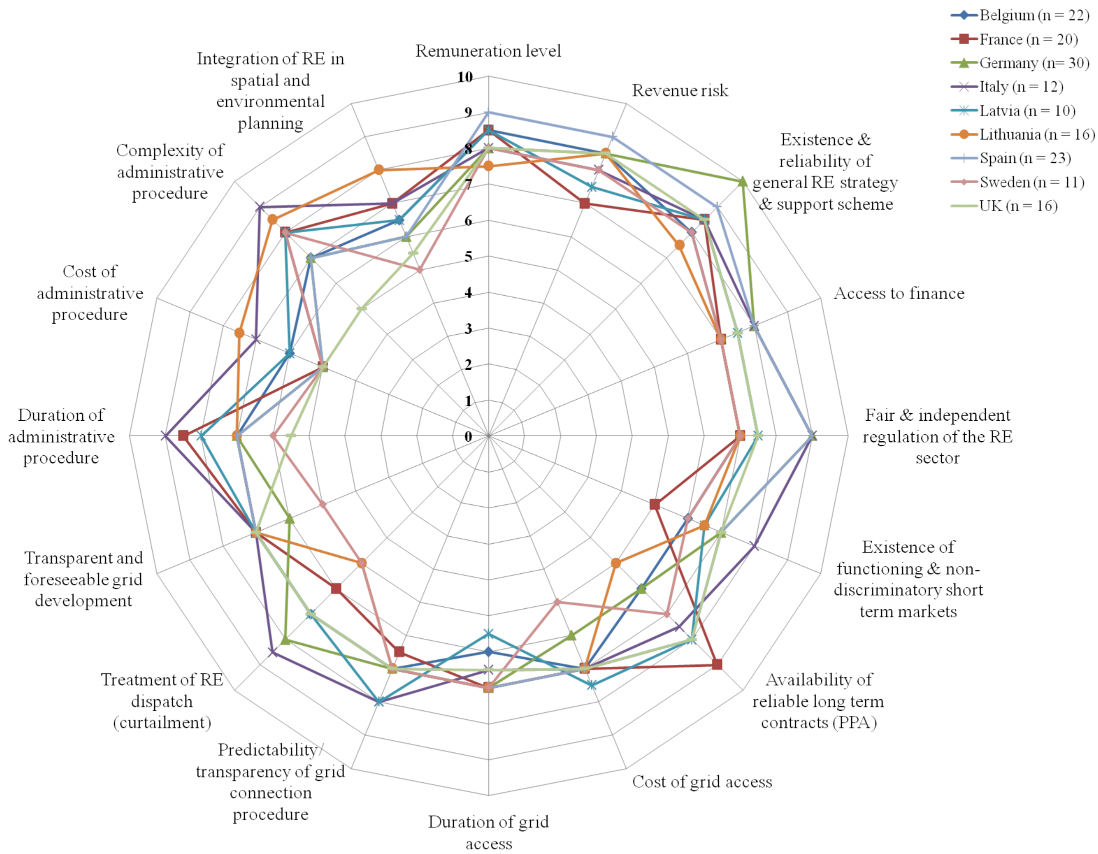

Figure 41: Relevance of the diffusion determinants (median scores) for selected countries. The number of datasets per country is indicated in the legend.

The results presented in figure 41 illustrate that for several determinants the median weights are similar across all countries whereas for others a wider range of ratings can be observed. For example, there appears to be a near-consensus regarding the relevance of the remuneration level, the access to finance and the duration of grid access procedures.

However, notable variations between the national viewpoints exist regarding the relevance of the duration and complexity of administrative procedures. Here, the spread between the highest and lowest median value is 3.5 or 4 points, respectively. The lowest relevance for both determinants is recorded for the UK and the highest for Italy. A spread of 3.5 points also occurs for the treatment of RE dispatch/ risk of curtailment of RE with the highest value for Italy and the lowest for Sweden and Lithuania. Another determinant with rather fragmented weighting results across the selected countries is the availability of long-term contracts for the sale of RE. Here, the lowest value (score of 5) is recorded for Sweden and the highest (score of 9) for France. High scores also occur for the UK and Latvia.

4.3.3 *Statistical evaluation of weighting results*

The observed differences between the weighting scores for wind and PV [28] were investigated with regard to their statistical significance.
To this end, the data were evaluated by means of two-tailed *T-tests* assuming unequal variances of the datasets[29]. A description of the applied methodology is provided in section 3.3.3). A complete overview over the outcomes of the analysis is provided in annex A.4 in tables 22 and 23.

The results indicate that, based on the available data sample, the observed differences between the scores for the two data sub-sets are not statistically significant (i.e. $p > 0.05$, 95% confidence that the difference is not significant) for 14 out of 16 determinants.
However, for the determinants 'duration of administrative procedures' (D-II) and 'transparent and foreseeable grid development' (C-V), the weighting results differ significantly for the technologies (with $p=0.0016$ for D-II and $p=0.0071$ for C-V).

The findings suggest that additional analyses, optimally based on a larger data sample, would be necessary to derive robust conclusions on the technology-specific relevance of the diffusion determinants.

No statistical test were carried out for the stakeholder-specific and country-specific weighting results as the data sub-samples are too small to allow for meaningful results.

4.3.4 *Summary and conclusion on weighting results*

The weighting results presented in section 4.3.1 indicate that, when looking at the overall picture and **across all RE technologies** (cf. figures 36 to 39) the political and economic framework for RE is the most important factor for RE diffusion. All of the underlying determinants score 8 or 9 points, leading to the highest average relevance of this determ-

28 The statistical analysis refers to the data sub-sets focused exclusively on wind and PV as the other datasets overlap (cf. section 3.3.2 for a definition of the data sub-sets).
29 Comparative analyses for all determinants assuming equal variances lead to similar results.

inant group (median 8.25 on average). All other determinants display a median relevance of 7, except for the fair & independent electricity market regulation which scores 8 and the cost of administrative procedures, which scores 5. This makes the market structure & market regulation the second most important determinant group and the grid regulation & grid infrastructure the third most important determinant group (with averaged medians of 7.33 and 7.00, respectively). The determinants grouped under administrative procedures display the lowest average relevance (averaged median of 6.5).

This result appears plausible, as the existence of a reliable political strategy and regulatory framework for RE as well as a non-discriminatory electricity market structure are very basic prerequisites for RE diffusion and are mentioned as such by various literature sources (cf. section 4.2.1) as well as by RE developers and investors questioned in the frame of this research (cf. section 4.2.2). The importance of the cost of administrative procedures, however, depends on the type and size of the RE project and might thus be less relevant compared to the overall project development cost, if large-scale projects are concerned.

Further, the results indicate that all of the selected determinants are actually relevant for the RE diffusion process, as for 15 out of 16 determinants the median relevance is 7 or higher. Only for one of the determinants a median relevance of 5 (=*'moderately relevant'*) occurs (for the cost of administrative procedures). This observation confirms the initial selection of the diffusion determinants (see section 4.2 for the selection process and section 4.2.3 for the selection result).

When looking at the overall data sample, a wide range of scores, sometimes ranging from ten points (*'extremely relevant'*) down to zero points (*'not relevant at all'*), can be observed for several determinants (e.g. for access to finance, cost & duration of grid access or duration & complexity of administrative procedures). These wide ranges can be interpreted as an indication for a broad variety of preferences among the surveyed stakeholders, possibly depending on their institutional or technological background or based on their personal perception. This observation was further investigated by means of a segmentation analysis.

The segmentation of the results based on the **technological background of the respondents** indicates that stakeholders whose expertise is concentrated on one particular technology (i.e. data subsets 'wind focus' and 'PV focus') mostly provide more consistent assessments, reflected by narrower quartile ranges, compared to the overall data sample or the more general groups (i.e. data subsets 'wind' and 'PV'). This observation indicates that investigating more specialized stakeholder groups, leads to a clearer picture regarding the relevance of the determinants, whereas the inclusion of stakeholders with a rather broad technological focus makes it difficult to identify a clear consensus in this respect. Against this background, the results for the specialized technology groups (i.e.

data subsets 'wind focus' 'PV focus') will be used in the further analytical process (see section 4.4).

However, in general the differences between the determinant weights per technology are rather marginal. On the one hand, this appears reasonable considering that both, onshore wind energy and PV, are well established technologies with comparable technical maturity levels. Yet, on the other hand, in view of the size (210 utilized datasets in total but partly small data sub-sets per technology) and the characteristics (overlapping technology subsets) of the data sample (cf. section 3.3.2) there are reservations regarding the observed technology differences. This is also reflected by the results of a statistical analysis (see section 4.3.3) which indicates that the differences between the weighting results for the technology-specific sub-sets of the data sample (i.e. data subsets 'wind focus' and 'PV focus') are largely not statistically significant (apart from two determinants). Larger sample sizes, especially for the stakeholder groups focused exclusively on one technology, would be needed to validate and further refine the results.

Nevertheless, particularly the results for the groups focused on only one technology still indicate that there are differences between the relevance of the determinants for wind and PV, respectively. For example, wind energy stakeholders attached a higher relevance to the duration of grid access as well as to the duration and complexity of administrative procedures whereas the cost of administrative procedures received a lower rating for wind compared to PV (cf. figures 38 and 39). This result appears plausible given that wind energy projects are typically larger and entail more extensive development efforts and longer planning time frames prior to the operational life of the plant. This makes the projects more sensitive to additional delays, especially in view of potential unforeseen changes in the support scheme or the remuneration level which might jeopardize the economic viability of the project if the commissioning is unexpectedly delayed.

Regarding the lower relevance of the administrative costs it is conceivable that, compared to the high overall development cost of a large-scale wind project, the share of the administrative costs plays a slightly smaller role for wind than for a PV project with lower overall development costs.

Another factor that scores higher for wind than for PV is the treatment of RE dispatch and the risk of uncompensated curtailment (cf. figure 38). This may be explained by the strongly fluctuating nature of wind resources which makes wind-based electricity production even less predictable and more volatile than solar-based production. Perhaps more importantly, also the installed capacities of wind energy in most countries are higher than those of PV which leads to a larger share in generation during peak hours. Further, PV plants are often located closer to load centres which facilitates the absorption of the generated electricity while wind parks are often located further away from the demand. This makes wind energy generators more vulnerable to grid-congestions and potential income losses related to uncompensated curtailment.

However, the strongest deviation between the weights for wind and PV (median is 3 points higher for wind than for PV) was observed for the integration of RE planning in spatial and environmental planning (cf. figure 39). A possible interpretation for this effect is that various limitations apply to the selection of suitable sites for wind energy projects, for example, related to the quality of wind resources, environmental protection requirements or the distance to residential areas and visual impacts of the plant. Therefore, site selection and environmental impact assessment are more complex for wind than for PV projects which usually have a lower environmental impact and are often located closer to residential areas, roads or railway tracks. In this respect, also the distance to the electricity grid plays an important role as the connection to the nearest grid connection point is usually paid by the project developer. This is reflected in a higher rating of the transparency of future grid development for wind energy than for PV. The importance of the future grid development for wind energy developers also corresponds with the higher relevance of grid congestions and potential curtailment discussed in the previous paragraph.

A further segmentation of the data sample **by stakeholder groups and countries** (cf. section 4.3.2) has indicated that, although the median values of the determinants' relevance largely fall into the same range, there are differences visible which are worth investigating through future research. Notably, the ratings of government stakeholders, when compared to the ratings of RE-project developers, appear to underestimate the importance of administrative and planning-related factors, such as the duration, cost and complexity of administrative procedures, the transparency of grid development and the integration of RE in spatial and environmental planning (cf. figure 40). Also, government stakeholders allocated lower scores to the existence and reliability of the RE strategy and support scheme than RE-developers.
These observations suggest that the role of long-term reliability of the policy framework, increased planning security and the removal of bureaucratic barriers, although widely acknowledged as important factors, might still be underestimated by policy makers and should be given a higher priority in the policy making process.

The results further imply that financial institutions lay a particular focus on risk elements that can affect RE projects after financial closure, such as the revenue risk and the reliability of the RE support scheme (both scored 10 points), the treatment of RE dispatch or the risk of uncompensated curtailment, respectively. Accordingly, they also place a high priority on the availability of long-term contracts (PPAs) which can help to reduce risks during the operational time of the plant.

Analysis on country-level indicates that, for some determinants, the weighting score cover a broad range while for others a near-consensus is reached (cf. figure 41). A possible explanation for this effect is that the queried stakeholders, although they were requested to provide general, country-independent ratings, might be subconsciously influenced by their geographical focus.

Country-specific aspects that might influence the perceived relevance of individual determinants comprise, for example:

- The present national RE-share and the state of the electricity grid can both affect the occurrence and thus the perceived relevance of curtailment.
- The size and geographical characteristics of a country (e.g. population density) influence the relevance of spatial planning issues for RE projects.
- The type of RE support scheme affects the requirements regarding market participation (e.g. with a guaranteed purchase of RE generation under a fixed FIT vs. direct market participation in a quota scheme) and thus the relevance of market access conditions.
- Occurrence of drastic changes or failures of the RE support scheme in the past might lead to a stronger preference of the stakeholders for a reliable and stable policy framework.
- Other prominent problems in the national RE framework could lead to an overemphasis of the relevance of these particular aspects in the questionnaire.

The country-specific median weights (cf. figure 41) show particularly broad ranges (i.e. a spread of 4 points between the highest and lowest median score) for the availability of power purchase agreements (PPAs) for RE and for the complexity of administrative procedures. Variations of 3.5 points between the highest and lowest score also occur for the duration of administrative procedures and the treatment of RE dispatch/ risk of curtailment. For the integration of RE in spatial planning, the spread is 3 points while for the other determinants the country scores show less deviations.

These observations suggest that country-specific characteristics, like the above listed aspects, might have influenced the weightings. However, as the sample size is too small for a robust analysis of the different segments and a clear separation of country-, stakeholder- and technology-specific effects, the presented results are not interpreted in more detail but only serve as an indication to possible directions for further research.

4.4 Concept of the country-level diffusion indicator

Based on the identified main determinants framing the RE diffusion process (cf. section 4.2.3), a composite diffusion indicator is derived. It is composed of 16 determinants structured into the four major determinant categories: Political and economic framework; market structure and market regulation; grid infrastructure and grid regulation and administrative procedures. Each of the 16 determinants is represented by one or several indicators which are described in tables 7 to 10.

compilation of indicator values To obtain the composite diffusion indicator score for a certain country, year and RE technology, the indicator values for each determinant referring to the respective year are collected from the suggested data sources (cf. tables 7 to 10). All indicator values, including the exact data source and temporal assignment of each data point, are then collected in an *MS-Excel*-based database (cf. section 3.5.3).

normalization of indicator scores The underlying data for the indicators have different formats and value ranges (i.e. numeric values or qualitative valuations). Therefore, they must be transformed into a uniform format to allow for further processing and aggregation of the data to an overall score. To this end, each indicator value is normalized to a score ranging between a minimum score of 0.25 and a maximum score of 1.0, whereby a score of 1.0 represents the optimal manifestation of the indicator.

However, for some indicators it is assumed that a particularly unfavourable manifestation could lead to a complete blockage of RE diffusion (e.g. if the remuneration level for RE was not cost covering or if no grid access for new RE plants was possible). For these indicators which are considered as **potential blocking elements** for RE diffusion, the lowest possible score is set to zero[30]. The highest possible score for these indicators is also 1.0. In tables 7 to 10 these potentially blocking indicators are highlighted with an asterisk.

The definition of the intermediate scores, i.e. between the minimum of 0.0 (for a blocking indicator) or 0.25 (for a non-blocking indicator), respectively, and the maximum of 1.0, depends on the nature of the available data for each indicator. Different approaches have to be applied in order to ensure consistency in mapping the values to indicator scores:

- Indicators (blocking or non-blocking) based on qualitative information (e.g. an assessment differentiating between poor/moderate/good) are mapped directly onto discrete values (e.g. 0.25; 0.5; 1.0 or 0.0; 0.25; 0.5; 1.0 for a blocking element).
- Where the underlying data for a non-blocking indicator is available as a numerical, continuous value and is accessible for all EU Member States (e.g. interest rates on government bonds across the EU Member States), the scores are normalized according to the observed minimum and maximum values[31]. The interpolation of the scores between the best and the worst value is done exponentially (see figure 42, upper left-hand side). This is necessary to obtain an interpolation interval spanning

30 The implications of this definition are further explained in section 4.5. Due to the chosen aggregation approach for the overall composite indicator, namely a multiplicative aggregation, an indicator score of zero leads to an overall composite indicator score of zero.

31 Basing the allocation of the indicator scores, wherever possible, on a relative comparison of minimum and maximum values observed across the EU intends to avoid the potentially arbitrary definition of scoring intervals. With the chosen approach, in contrast, the assessment considers best and worst practices across the EU.

between 0.25 and 1.0 while mapping the centre value to 0.5 which is consistent with the indicators based on discontinuous data.

- Where the underlying data for a potential blocking indicator is available as a numerical, continuous value, a linear function is used to interpolate between the minimum and the maximum value. This is necessary to be able to capture the blocking quality of the indicator (i.e. minimum score of 0.0) while consistently mapping the centre value to 0.5 (see 42, upper right-hand side).
- For (blocking or non-blocking) indicators which are based on quantitative, numerical data but for which a continuous assessment is not possible (e.g. for which no comparative database exists), intervals are defined which are mapped onto discrete values (e.g. 0.25; 0.5; 1.0 or 0.0; 0.25; 0.5; 1.0 for a blocking element). This is illustrated by the graph on the lower left-hand side in figure 42.

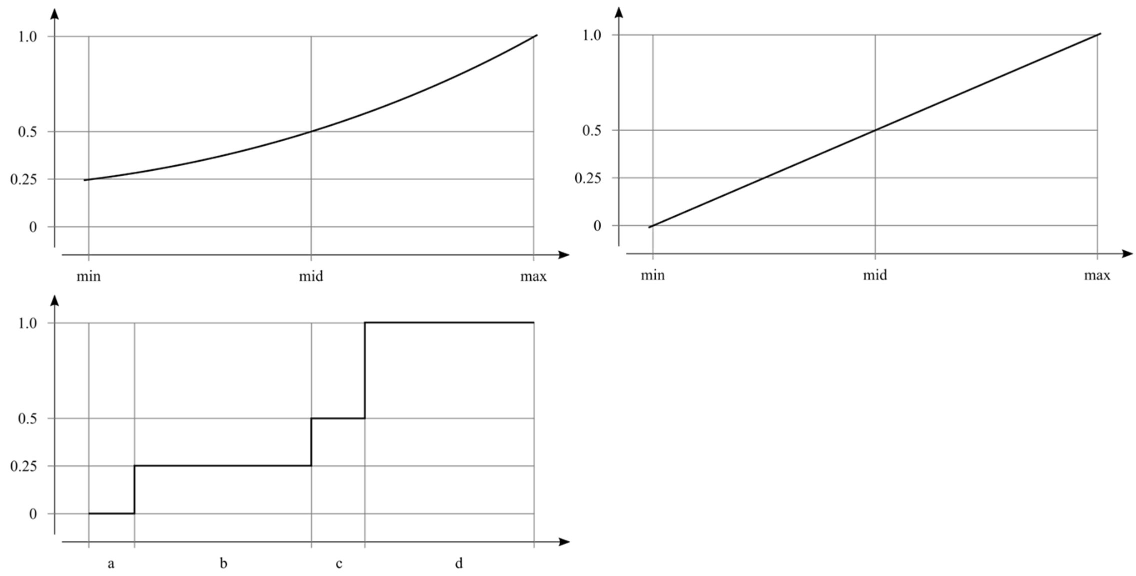

Figure 42: Schematic graphs illustrating the normalization functions applied to the indicator data. Upper left-hand side: Interpolating continuous, numerical values with an exponential function to obtain continuous scores ranging from 0.25 to 1.0; Upper right-hand side: Interpolating continuous, numerical values with a linear function to obtain continuous scores ranging from 0.0 to 1.0; Lower left-hand side: Mapping of numerical values to defined intervals associated with discrete scores ranging from 0.0 or 0.25 to 1.0. Source: Own elaboration.

The means by which the data for each indicator is mapped onto scores are summarized in tables 7 to 10 in section 4.2.3.

DERIVATION OF DETERMINANT SCORES In a next step, the normalized indicator scores are aggregated on determinant level. For this purpose, the normalized values (i.e on a scale from zero to one) for all indicators per determinant are added up. Since the determinants are represented by varying numbers of indicators, the sum of the indicator scores per determinant is then divided by the number of indicators to avoid over-representation of determinants with several indicators compared to determinants with fewer indicators. Consequently, each aggregated determinant score again ranges on a scale between zero and one.

WEIGHTING AND DERIVATION OF THE OVERALL SCORE To reflect the varying relevance of the individual diffusion determinants, the determinant scores are weighted before the final score of the composite indicator is derived. The weighting factors are based on the results of the questionnaire-based survey described in section 3.3 (methodology) and 4.3 (results).

An overview over the applied weighting factors is provided in table 11. Here, the total weights refer to the overall data sample (across all technologies) and are included for informative purposes only. The technology-specific weights refer to the results for the stakeholder groups focused exclusively on onshore wind (i.e. data sub-set 'wind focus') and non-residential PV (i.e. data sub-set 'PV focus') (cf. description of the data sample in section 3.3.2). In the following, the technology-specific values are utilized for weighting the indicator scores. Thereby, the weights are applied as a power function of the determinant scores.

Finally, to derive the overall composite indicator score, the individual determinant scores are aggregated by multiplying the weighted determinant scores (see equation 3). This aggregation approach is chosen because it entails that low scores for individual determinants cannot be compensated by high scores for other determinants. In this way, a score of zero for one determinant would lead to an overall score of zero. This non-compensatory aggregation method safeguards that the actual meaning of the weights is maintained in the aggregation process.

$$CI = D_1^{w_1} \cdot D_2^{w_2} \cdot D_3^{w_3} \cdot ... \cdot D_{16}^{w_{16}} \quad (3)$$

Where:

CI = Composite Indicator score

D_{1-16} = *Score of determinant 1-16*

w_{1-16} = *Weight of determinant 1-16*

A compensatory approach (e.g. by adding up the individual scores), on the other hand, would imply that even a complete failure of one determinant (resulting in a score of zero) could be offset by high scores for other determinants. However, for the present application, a compensatory approach would not reflect realistic conditions because RE diffusion would be severely diminished or blocked completely if one of the determinant scores would equal zero. Situations in which one determinant could become a strong barrier for RE diffusion could be, for example, if the remuneration level dropped below the generation costs thus making RE projects unprofitable or if grid connection of RE projects was entirely impossible. Non-compensatory aggregation of indicators is typically applied when different dimensions (e.g. social-, environmental- or economic factors) are included in one composite indicator because a negative manifestation of one of the dimensions can hardly be offset by a positive manifestation of a totally different dimension (see also Munda and Nardo (2003) or OECD (2008, p. 33)).

Table 11: Weights of the composite indicator components

Sub-determinant / Indicator component		Weight: Total	PV	Wind
A I	Reliable RE strategy and -support scheme	0.9	0.8	0.9
A II	Relative remuneration level	0.8	0.8	0.8
A III	Revenue risk	0.8	0.8	0.8
A IV	Access to finance	0.8	0.7	0.7
B I	Fair & independent regulation of electricity sector	0.8	0.7	0.8
B II	Functioning & non-discriminatory short term markets	0.7	0.7	0.65
B III	Availability of reliable long-term contracts (PPA's)	0.7	0.7	0.9
C I	Cost of RE grid access	0.7	0.7	0.7
C II	Lead time for RE grid access	0.7	0.6	0.7
C III	Predictability & transparency of grid connection	0.7	0.7	0.7
C IV	Treatment of RE dispatch (curtailment)	0.7	0.7	0.8
C V	Transparent & foreseeable grid development	0.7	0.6	0.7
D I	Cost of administrative procedure	0.5	0.6	0.5
D II	Duration of administrative procedure	0.7	0.6	0.8
D III	Complexity of administrative procedure	0.7	0.7	0.8
D IV	Integration of RE in spatial & environmental planning	0.7	0.6	0.8

4.5 FORMAL FRAMEWORK OF THE DIFFUSION FORECAST MODEL

This section describes how the formal framework of the RE-diffusion model is derived based on the mathematical formulation of technology diffusion processes. Individual steps are illustrated by examples for the German case study.

THE LOGISTIC DIFFUSION FUNCTION Extensive scientific evidence has shown that the diffusion of new technologies, techniques or products through a market over time often resembles the shape of an s-curve (cf. e.g. Geroski (2000), Grübler, Nebojsa Nakićenović and Victor (1999), Kemp and Volpi (2008), Pulkki-Brännström and Stoneman (2013), Rao and Kishore (2010) and Rogers (1995)). Thereby, a nearly exponential growth at the start of the diffusion process is followed by linear growth in the mid term, and eventually culminates in a saturation of the market, resulting in a relatively slower growth, in the long term (Rogers, 1995, p. 106).

This common, s-shaped function can be represented mathematically as given in equation 4, where P(t) indicates the technology penetration over time.

$$P(t) = \frac{a}{1 + \exp^{-c\cdot(t-t_0)}} \tag{4}$$

In equation 4 the long-term deployment potential of the technology is indicated by parameter 'a', which represents the saturation level of the s-curve. Parameter $'t_0'$ defines the inflection point of the sigmoid as it indicates the movement along the time axis. Parameter 'c' represents the speed of technology diffusion and defines the steepness or growth rate of the curve. Framework factors that accelerate or decelerate the diffusion process will thus be reflected by parameter 'c'.

In a further step, the logistic function shown in equation 4 can be described as a logistic differential equation as given in equation 5. This again can be expressed in discrete terms as shown in equation 6.

$$\frac{dP}{dt} = c \cdot P \cdot (1 - \frac{P}{a}) \tag{5}$$

$$\triangle P = P_{n+1} - P_n = c \cdot P_n \cdot (1 - \frac{P_n}{a}) \tag{6}$$

Where:

P = Technology penetration

P_n = *Technology penetration in year n*

$\triangle$*P = Additional technology penetration in year n+1*

a = Saturation level of the s-curve (long-term technology deployment potential)

c = Parameter defining the growth rate (steepness) of the s-curve

ANALYSING THE SPEED OF TECHNOLOGY DIFFUSION According to the formal framework presented above, the additional penetration of a technology ($\triangle$P) in one year 'n+1' is a function of the growth parameter (c) and the long-term technology deployment potential (a). Assuming undistorted technology diffusion, 'c' can be interpreted as the maximum growth that can be achieved under optimal framework conditions. This will hardly ever occur under real-life conditions. Nonetheless, historical RE diffusion records do document periods of classical logistic growth patterns which suggest that the economic conditions permitted an attractive rate of return during these periods while at the same time there were hardly any non-economic barriers.

For example, between 1990 and 2003 a logistic growth can be observed for the case of

wind energy deployment in Germany (see figure 43). When a logistic function is fitted to the observed diffusion pattern, the following values result: c = 0.33, t_0 = 19. After 2004, however, the wind energy market in Germany grew much slower than suggested by the logistic curve's fit to the growth parameter observed earlier (see figure 43). One possible explanation is that several economic and non-economic barriers began to constrain the technology diffusion after 2004 and thus reduced the actual growth parameter.
Peter Lund (2006) observed and discussed this phenomenon for several different energy technologies. Lund was able to illustrate that the growth parameter 'c' often falls with rising market penetration of a technology. With respect to RE-technologies it can be figured that, after a certain market share has been reached, restrictions and limitations like grid capacity, budget constraints or administrative capacities start to act as limiting factors to the market diffusion.

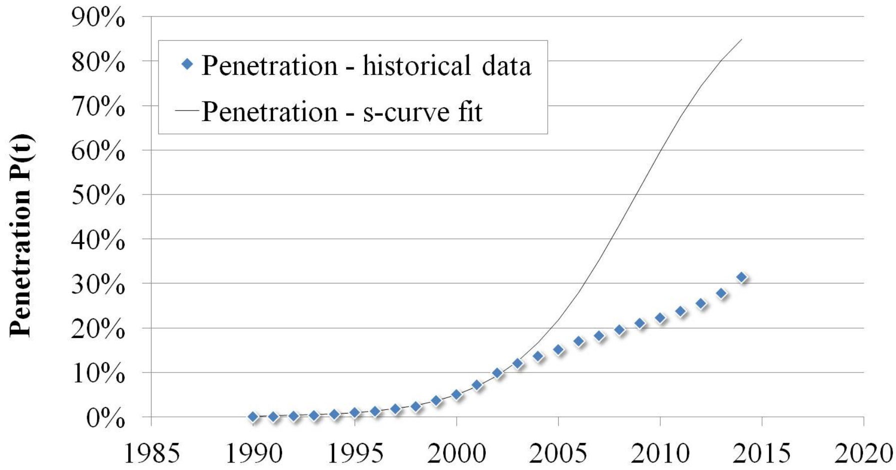

Figure 43: Optimal fit of a logistic curve to the time series of wind energy diffusion in Germany (period of fit 1990-2003).
Source: Own elaboration. Previously published in Boie, Ragwitz and Held (2016).

The above example illustrates that the growth parameter 'c' is not a constant factor, but varies depending on the point in time or the section of the market penetration curve, respectively. This can be further exemplified by analysing 'c' for different fitting intervals. Based on the historical diffusion of wind onshore and PV in Germany, 'c' is calculated starting with a fitting period of ten years (1990-2000). This is then extended by one year in each subsequent step and continued to cover the entire period from 1990 to 2014. The results are shown in figure 44 where each plotted data point represents the value for 'c' that was calculated for the respective time span (all starting in 1990).

The analysis presented in figure 44 highlights that there is notable variation in the values for 'c' depending on the length of the fitting period. This phenomenon was previously observed by Peter Lund (2006), who suggested that c(t) might follow the form of a power curve (c(t) = a · t-b + c). However, Lund was unable to provide evidence for the validity of this assumption. On the other hand, if the varying values for 'c' over time are compared

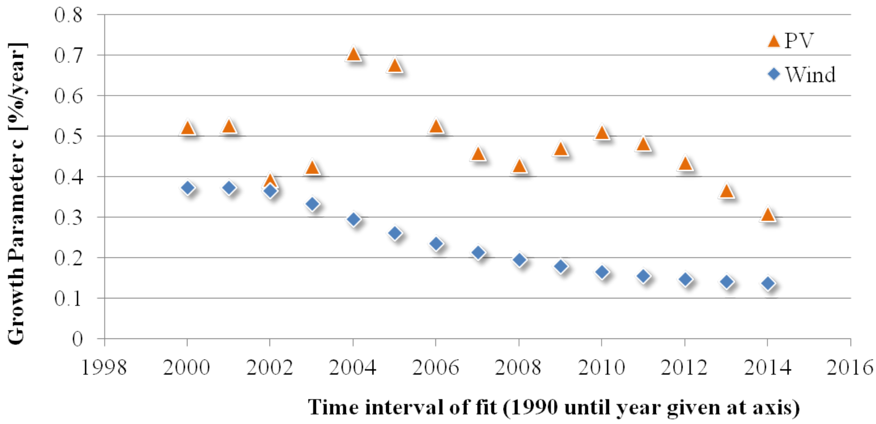

Figure 44: Variation of the growth parameter c with stepwise increase of the fitting period: Analysis of historical wind onshore and PV development in Germany starting with the interval 1990-2000, and gradually extended by one year to cover the period 1990-2014. Source: Own elaboration. Previously published in Boie, Ragwitz and Held (2016).

with the actual deployment of the technologies during the evaluation period (cf. figure 46 for RE deployment in Germany), it becomes apparent that the parameter 'c' increases dramatically when the fitting period includes years with high relative deployment growth. This applies to PV in Germany in 2004 (with >150% growth compared to 2003) and, to a lesser extent, in 2009/2010 (ca. 70% growth compared to the previous years). In comparison, the relative capacity additions for wind energy onshore in Germany in the period 2000-2014 are more moderate and more homogeneous. As a consequence, the 'c' value for wind energy does not fluctuate strongly (cf. figure 44).

representing the re framework in the diffusion function The above findings suggest that 'c' is a function of time (c(t)) and reflects the speed of the market growth. For the diffusion model, it is further assumed that economic and non-economic framework conditions prevalent in a given period are the factors that determine the speed of technology deployment during that time. Finally, it is presumed that the decisive factors framing the diffusion process can be captured by different indicators which can be aggregated to a composite diffusion indicator (CI) as described in section 4.4.
On the basis of these assumptions, the time-dependent growth parameter c_n (i.e. the parameter 'c' in a time-discrete representation) can be expressed as a power function of a time-dependent composite indicator (CI_n) with an exponent β and a constant α. The additional calibration parameters α and β are introduced to represent potential country-specific aspects, such as cultural features, which are not regarded in the CI and are assumed to be non-variable. Equation 7 reflects these assumptions.

$$c_n = CI_n^{\beta} \cdot \alpha \tag{7}$$

According to the above suggested formal notations, temporal changes to the relevant economic and non-economic framework conditions and the impact these have on the speed of technology diffusion are explicitly accounted for in form of the composite indicator CI_n. In contrast to Peter Lund (2006), this approach involves much higher data requirements that rely on detailed bottom-up assessments. However, an in-depth, empirical analysis has the potential to provide a more accurate picture of temporal changes in the growth parameter c_n.

In a next step, equation 6 can be used to estimate a time series of the growth parameter c_n based on historical diffusion data for each technology. This is reflected in equation 8.

$$c_n = \frac{\triangle P_n}{P_n \cdot (1 - \frac{P_n}{a})} = \frac{P_{n+1} - P_n}{P_n \cdot (1 - \frac{P_n}{a})} \tag{8}$$

Where:

c_n = *Growth parameter in year n*

P_n = *Technology penetration in year n*

$\triangle P_n$ = *Additional technology penetration in year n*

a = Saturation level of the s-curve (long-term technology deployment potential)

As an example, the evolution of the time-dependent growth parameter c_n is shown in figure 45 for wind energy onshore and PV in Germany from 2000 to 2014. Unlike figure 44, this graph displays discrete values (c_n) for c(t) that depend on the technology growth in the respective year. It can be observed that c_n increases strongly in years that display marked growth compared to the previous year, (e.g. for PV in 2004 with >150% growth relative to 2003), whereas, c_n decreases during times of declining relative growth.

Once the CI has been calculated, a least square fit, as a standard method in regression analysis, can be applied to the values for CI_n and c_n to determine the country-specific calibration constants α and β. In doing so, a further assumption is made which considers a time delay between the investment decision (financial closure) and the actual implementation (commissioning) of RE projects. This is deemed necessary as the assessment of the framework conditions with the CI relates to the point of the investment decision, while the observed growth refers to the completion of the project (i.e. when projects enter official statistics). Therefore, a time lag of one year is assumed for wind energy projects (i.e. the CI-score for a year (n) relates to the deployment in the subsequent year (n+1))[32]. However, no delay is assumed for PV projects, because they typically have much shorter

32 An even longer time lag might be appropriate for wind energy projects as implementation time-frames may exceed one year. However, as this would entail significant additional requirements regarding the temporal coverage of the data series (for the actual diffusion and the CI-scores), the present approach is based on a one year delay.

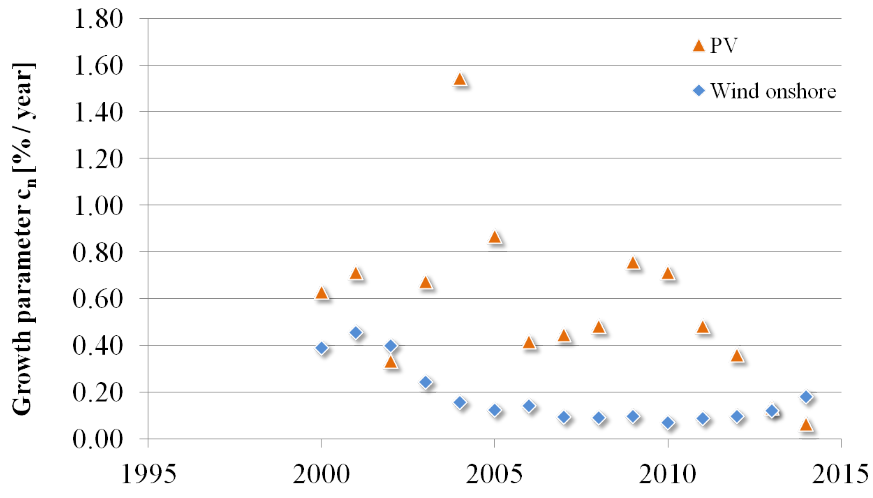

Figure 45: Evolution of the time-dependent discrete growth parameter c_n for wind onshore and PV in Germany for the period 2000 to 2014.
Source: Own elaboration. Previously published in Boie, Ragwitz and Held (2016).

realization time frames than wind parks. It is thus assumed that they can generally be realized within one year.

projection of diffusion processes Having introduced the derivation of the overall modelling framework, now the individual stages of the diffusion analysis will be summarized and exemplified.

In summary, in order to perform a projection of the future diffusion of wind onshore or PV in a specific country, the following steps are performed:

1. Determining the saturation level 'a' (achievable long-term potential) of the respective RE technology in the country.

2. Calculating the time-dependent market growth parameter c_n over the observation period based on the historical technology diffusion curve.

3. Calculating the composite indicator (CI) based on the assessment of the relevant indicators and their weights for the technology (cf. sections 4.2.3 and 4.3).

4. Determining the calibration parameters α and β through a least square fit of c_n and CI with the additional assumption of a one-year time delay between the final investment decision and the installation of wind parks (i.e. the actual growth in 2014 is calibrated with the CI in 2013).

5. Assessing the potential future diffusion of the RE technology based on the foregone steps (under application of equation 12).

6. Applying different scenario assumptions to the original CI scores to evaluate the impact of changes in the economic and non-economic framework conditions (optional).

The individual steps are discussed in more detail below.

1. Determination of the saturation level (a)
The saturation level (a) is understood as the economically feasible long-term deployment potential of a RE technology. Here, 'long-term' refers to the time horizon until 2050. There are several literature references referring to long-term potentials for various RES (see, e.g. Resch et al. (2008) and Vries, Vuuren and Hoogwijk (2007) and citations therein). The *Green-X* database of medium- and long-term RE potentials for the European MS[33] is chosen for this analysis because it is continuously updated and checked with the MS and draws on a broad range of national sources.

2. Calculation of the time-dependent growth parameter c_n
The evolution of the time-dependent growth parameter c_n for each technology is calculated based on analysis of historical deployment data for the respective observation period and applying equation 8.

3. Calculation of the CI-score
As described in section 4.4 the CI is based on an assessment of several individual indicators which are aggregated to the overall composite indicator score. Thereby, the individual indicator values are weighted according to their relevance in the technology diffusion process (cf. section 4.3) and then multiplied to calculate the overall CI-score (see equation 9, cf. section 4.4).

$$CI = D_1^{w_1} \cdot D_2^{w_2} \cdot D_3^{w_3} \cdot ... \cdot D_{16}^{w_{16}} \tag{9}$$

Where:
CI = Composite Indicator score
D_{1-16} = *Score of determinant 1-16*
w_{1-16} = *Weight of determinant 1-16*

This geometric aggregation approach is applied to take into account that RE diffusion would drop to zero if one of the determinants scores zero. This can occur, for example, if generation costs are higher than the remuneration level, if the RE project's connection to the grid is prevented, if the produced electricity can not be marketed or if no suitable sites for RE project development are available (cf. tables 7, 8, 9 and 10).

33 Weblink: http://www.green-x.at/ (last accessed 14.3.2015)

It is assumed that, under these circumstances, the barriers to further RE deployment would be so strong that they could not be offset by other indicators' scores. The multiplicative sub-indicator aggregation method is typically used if sub-indicators are not compensatory, meaning that one factor's poor performance cannot be fully outweighed by another factor's good performance (cf. Munda and Nardo (2003), OECD (2008, p. 33)). Assuming an additive aggregation approach, on the contrary, very low indicator values would be compensated by higher scores for other indicators which would not reflect reality (e.g. insufficient remuneration or unavailability of the grid could theoretically be compensated by favourable conditions in other areas).

4. Calibration of the residual terms α and β

To determine α and β the values of c_n are calibrated with the product $CI^{\beta}_{n-\triangle} \cdot \alpha$ by means of a least square fit (see equation 10). Thereby, for the final year of the observation (i.e. 2014 here), the c_n value is aligned with the the product $CI^{\beta}_{n-\triangle} \cdot \alpha$ (see equation 11). This ensures that the growth parameter c_n matches the final year of the analysed period and that there is no discontinuity of the projected growth rate in the case of a scenario with constant framework conditions (i.e. 'business as usual' case).

$$\min_{\alpha,\beta} = \sum_n (c_n - CI^{\beta}_{n-\triangle} \cdot \alpha)^2 \tag{10}$$

$$c_n = CI^{\beta}_{n-\triangle} \cdot \alpha \qquad\qquad \textit{for } n = 2014 \tag{11}$$

5. Assessing the future technology penetration

Finally, based on equation 12, the penetration in year n+1 can be derived from the penetration in year n, the calibration factors α and β, the long-term deployment potential (a) and the CI score.

$$P_{n+1} = P_n + CI^{\beta}_{n-\triangle} \cdot \alpha \cdot P_n \cdot (1 - \frac{P_n}{a}) \tag{12}$$

6. Scenario analysis

Equation 12 allows for a prognosis for the market diffusion of RE technologies based on the framework conditions as measured by the CI. In the standard case, the projection is based on the assumption that the framework conditions assessed with the CI remain constant in the future (i.e. 'business as usual' scenario). Optionally, different scenarios can be compared to evaluate the impact that changes in the economic or non-economic framework conditions would have on RE diffusion. To this end, individual indicator scores of the CI can be modified to reflect potential changes or political measures. Then equation 12 is applied again, using the adjusted CI score, to obtain a prognosis based on the changed framework assumptions. This approach offers the possibility to investigate a broad spectrum of different policy scenarios and the resulting technology diffusion rates. This is particularly useful to assess and compare the potential impacts of very specific policy measures (i.e. changes in each of the sixteen diffusion determinants) on the potential future technology deployment.

4.6 SUMMARY AND DISCUSSION OF RESULTS

Based on the assumption that the observable diffusion of PV and wind energy on national level reflects the cumulated decisions of individual RE developers and investors, this chapter introduced a **conceptual model (i.e. a general evaluation framework) for the realization of RE projects from the RE developers' perspective**. In a first step, important factors framing RE diffusion were identified based on a systematic review of the existing literature. Relevant sources in this regard comprise scientific publications, the results of relevant research projects and own empirical findings as well as existing benchmarking tools (i.e. indicators) for RE frameworks and official assessment reports issued by the European Commission (see section 4.2.1).

In a next step, the potential diffusion determinants were discussed with experts on the RE sector during moderated group discussions. A consensus was reached over the course of three workshops regarding the selection of quantifiable factors of major, direct relevance for the realization of RE projects. Sixteen diffusion determinants were selected and then grouped into four categories: Political and economic framework; electricity market structure and market regulation; grid infrastructure and grid regulation; administrative procedures[34]. Each of the sixteen determinants is represented by one or several indicators when quantified (cf. section 4.2.3).

Finally, follow-up interviews were used to verify the selection of determinants (see sections 4.2.2 and 4.2.3). The interviewed stakeholders largely agreed with the selection. The vast majority of interviewees stated that no important factors were missing and only two (out of 31) interviewees suggested additional determinants (namely the availability of local value chains and presence of explicitly inhibitory regulations), which could be considered in future versions of the indicator.

To transform the conceptual diffusion model into a benchmarking tool for RE frameworks, i.e. a composite indicator for RE diffusion, the **relevance of the individual factors**

34 Even though additional factors, such as technical considerations (e.g. related to the quality of RE resources or technological considerations) as well as the individual psychological or socio-cultural background of decision makers might also play a role in investment decisions, they are not part of the assessment. As the results of this thesis mainly aim to provide empirical and methodological contributions to the energy policy debate (cf. section 1.5) the focus of the analysis lies on the assessment of the factors framing the political and regulatory environment for RE.

for the resulting diffusion process was determined by analysing the results of an extensive stakeholder consultation. To this end, 210 questionnaires specifying the relative relevance (i.e. the weight) of the diffusion determinants were evaluated (cf. section 4.3. The respondents comprised various RE experts across the EU Member States (cf. section 3.3.2). The results indicate that the highest importance across all RE technologies is attached to determinants representing the political and economic framework (cf. results in figure 36). Among these, the 'existence and reliability of the national RE strategy and support scheme' was identified as a key factor, with the highest median relevance across all determinants (a score of 9 out of 10). All other determinants score between 7 and 8 points, with the exception of the cost of administrative procedures, which was assigned lower relevance (5 points = '*moderately relevant*'). On the one hand, this supports the initial selection of determinants because it shows that all the determinants are actually relevant for RE diffusion. On the other hand, it also demonstrates that a reliable policy strategy and a stable regulatory framework for RE are the major prerequisite for RE deployment and rank even higher than the actual remuneration level (cf. figure 36).

Differentiating the results according to the technological focus of the respondents suggests that there are variations in the relevance of individual determinants for wind and PV (cf. section 4.3). These might be due to the different planning time frames, sizes and investment requirements of wind and PV projects. Wind projects are mostly larger, entail higher overall investment volumes and are more challenging with regard to spatial planning efforts than PV projects. Against this background, administrative procedures and spatial planning issues might be more important from the viewpoint of a wind developer because the projects entail substantial efforts and investments prior to their operational lifetime and are thus particularly sensitive to commissioning delays. The stability of the policy framework could also be more relevant in view of the long planning and amortization periods for wind projects.
The technology-specific weighting results support these hypotheses as they indicate that, compared to PV players, stakeholders focused only on wind energy projects attach slightly higher relevance to the duration of grid access procedures, the duration and complexity of administrative procedures and the existence and reliability of the overall RE policy framework. They also attached a significantly higher relevance to the integration of RE in spatial planning (cf. figures 36, 38 and 39).

The technology-specific findings further indicate that wind energy stakeholders allocate slightly higher scores to the treatment of RE dispatch (i.e. the possibility of uncompensated curtailment) and the transparency of future grid development (cf. figures 37 and 38) which also support the above hypotheses. These observations could be due to the spatial distribution and natural characteristics of wind and solar resources. Attractive and suitable wind project sites are often located in areas far away from the existing grid infrastructure, while even large-scale PV projects can often be realized close to developed areas (e.g. settlements, industrial areas, roads, railway tracks). This might raise

the perceived relevance of the future grid development as far as wind project developers are concerned.
Likewise, the relevance of the treatment of RE dispatch and the potential of curtailment appears to be higher for wind energy developers than for PV developers. This could be attributed to the fact that the installed capacities of wind energy in most countries are still higher than those of PV. This leads to a higher share of wind-based electricity generation (and potential curtailment) during peak hours. Further, PV plants are often located closer to load centres which facilitates the absorption of the solar-based electricity while wind parks are often located further away from the demand and thus more often affected by curtailment. This makes wind energy generators more vulnerable to grid-congestions and potential income losses related to uncompensated curtailment.

However, it should be made clear that the sample size, in particular the sizes of the subsamples for onshore wind and non-residential PV (cf. section 3.3.2), does not allow the derivation of conclusive technology-specific statements (cf. section 4.3.3). Therefore, the technology-specific findings presented here are only indicative and should be consolidated by future research.

An additional perspective on the data was added by performing a **segmentation of the results according to the institutional and geographical background of the respondents** (cf. section 4.3.2). For this purpose, five main stakeholder groups (RE developer, financial institution, national government, academic/research sector and consultant) and nine European countries were distinguished and compared.
Although there are reservations regarding the conclusiveness of the findings in view of the small size of the data segments, the variations in the weights for different stakeholder groups and countries do indicate potential fields for further research.

A notable finding in this regard is the observation that government stakeholders, when compared to RE developers (across all technologies), seem to underestimate the relevance of factors related to bureaucratic processes and planning activities. For example, the duration, cost and complexity of administrative procedures, the transparency of grid development and the integration of RE planning with spatial planning were rated as less relevant by government stakeholders than by RE developers (cf. figure 40 in section 4.3.2). The same applies to the existence and reliability of the overall RE strategy and support scheme. These observations suggest that policy makers tend to underestimate the role of long-term certainty and planning security for the process of RE diffusion.

The country-specific comparison of the weighting results indicates that a near-consensus is reached regarding the relevance of certain determinants (e.g. the remuneration level, access to finance or the duration of grid access procedures), while broader ranges in the ratings for different countries can be observed for other determinants (e.g. the availability of reliable PPAs, the treatment of RE dispatch or the duration and complexity of administrative procedures) (cf. figure 41 in section 4.3.2). One possible explanation is that country-specific elements might consciously or sub-consciously influence the respondents' assessments. Such elements might relate, for example, to the current RE share in the respective national energy mix, which can affect the relevance of certain technical issues (e.g. grid congestion and curtailment), the present RE support scheme and its past stability or the presence of other country-specific characteristics or prominent problems which might therefore be perceived as particularly relevant by local stakeholders (cf. section 4.3.4). However, once again, it must be pointed out that country- and stakeholder-specific differences should be understood as indicative because technology-, country- and stakeholder-specific effects cannot be clearly identified based on the present data sample (i.e. the limited size of the data sub-sets).

On the basis of the conceptual model for RE diffusion, a **composite RE diffusion indicator** was constructed (cf. section 4.4). Suitable data sources were identified to quantify each of the sixteen selected diffusion determinants, and methods were suggested to normalize the data (see summary of indicators in tables 7 to 10).
To derive the overall score of the composite indicator, the values for the individual determinants are weighted with the scores from the questionnaire-based stakeholder consultation (cf. section 4.3.1 and table 11). A multiplicative approach was selected to aggregate the determinant scores to the overall composite indicator score (i.e. multiplying the weighted determinant scores based on equation 3) because it considers that low scores for individual determinants cannot be fully compensated by high scores for other determinants. This retains the actual meaning of the determinant weights in the aggregation process and considers the effect of blocking factors for the diffusion process (e.g. a total abandoning of RE support or a blockage of grid access).
In the context of the present research, the aggregation of the 16 determinant scores to an overall CI is required to be able to reflect the impact of the overall framework conditions for RE investments in the RE diffusion model. Based on the chosen modelling approach an aggregation of the diffusion determinants to a single parameter is required. However, the aggregation of data always implies a reduction of informational detail. Therefore, the different indicator scores themselves should be seen as an important intermediate output of the analysis which can be used for comparative purposes or for benchmarking individual aspects of the framework conditions for RE diffusion in different countries. This is also reflected in the way the indicator results are presented in this thesis, namely the used layout and colour coding of the tables (see e.g. tables 16, 14 or 20 in chapter 5), which aims to allow for an intuitive comparison of indicator values between countries as well as a clear visualization of their changes over time.

Finally, the scores of the composite RE diffusion indicator serve as input data to a **RE diffusion model**, which can be applied to estimate the deployment of wind onshore and PV in the near future (covering a time frame of 1-3 years).
The formal framework of the diffusion model builds on a basic logistic function (cf. equation 4 in section 4.5) which is commonly applied and well established in diffusion

research (see e.g. (Grübler, Nebojsa Nakićenović and Victor, 1999; Kemp and Volpi, 2008; P. Lund, 2010; Peter Lund, 2006; Marchetti and N. Nakićenović, 1979; Meade and Islam, 2006; Resch, 2005)) and on the underlying assumption that the economic and non-economic framework conditions (represented by the composite RE diffusion indicator) are the key parameter for the speed of the observable technology diffusion (i.e. the slope of the logistic curve).

In order to apply the RE diffusion model to a specific country and RE technology, the parameters of the logistic function have to be determined, i.e. the available long-term potential for the technology (i.e. the market saturation level) and the annual CI scores. The expected additional technology penetration under given framework conditions can be calculated by applying linear regression to historical deployment data for the respective RE technology (onshore wind or PV) and the according CI scores for the corresponding time-frame. A detailed description of the approach and the underlying formal framework is given in section 4.5. By varying the indicator scores for individual diffusion determinants the impact of changes in the framework conditions on future RE technology diffusion can be simulated and used for comparative analyses. This possibility of constructing a wide variety of different policy scenarios and to derive the corresponding technology diffusion rates is particularly useful to assess and compare the potential impacts of specific policy measures on technology deployment.

To conclude, by conceptualizing the major determinants of RE diffusion and developing a transparent approach to assess and quantify them, the findings presented in this chapter constitute a relevant contribution to the scientific discourse on the diffusion of RE technologies. The developed approach builds upon established research on technology diffusion, e.g. Geroski (2000), Griliches (1960), Grübler, Nebojsa Nakićenović and Victor (1999), Kemp and Volpi (2008), Mansfield (1961), Meade and Islam (2006), Rao and Kishore (2010) and Rogers (1995), among others, and expands and combines existing approaches (e.g. Resch (2005) and Peter Lund (2006)) for assessing and modelling the diffusion of RE technologies (cf. sections 3.4 and 4.5).

Moreover, the developed composite indicator and the model for projecting RE diffusion are traceable and empirically grounded tools that could facilitate the assessment and benchmarking of RE policies. They could be useful applications for policy makers trying to implement policy frameworks that should have maximum effectiveness and efficiency regarding RE deployment.
In the policy making context, the observed stakeholder-specific differences in the weighting results (cf. section 4.3.2) could also be of interest, as they indicate fields of regulation from which conflicts or barriers to RE development could emerge (i.e. determinants for which the scores show strong deviations among different stakeholder groups). Against this background, the developed weighting questionnaire (or a similar assessment tool) could be used to identify such areas of conflict and facilitate a constructive stakeholder dialogue. Therefore, the methodology developed to assess the relevance of the RE diffu-

sion determinants also contributes methodologically to the field of RE policy (see also section 3.6).

Finally, the findings point to several areas that could be interesting for future research activities, such as more in-depth analyses of technology-, stakeholder- and country-specific preferences or the adaptation and application of the composite indicator and diffusion model to other RE technologies.

5

COUNTRY CASE STUDIES: ASSESSING RENEWABLE ENERGY DIFFUSION ON NATIONAL LEVEL

This chapter presents the results of applying the developed approach of the composite indicator and the RE diffusion model to three country case studies. The chapter is structured as follows: Section 5.1 briefly summarizes the objectives of this chapter and section 5.2 introduces the policy scenarios that are applied for projecting possible future diffusion pathways in the case study countries. Sections 5.3, 5.4 and 5.5 present the findings for the assessment of the RE frameworks in Germany, Spain and the UK. Each country section starts with a presentation of the cornerstones of the legal and regulatory framework for RE, as regarded for the diffusion indicator. For each of the case studies, the outline of the major statutory provisions is complemented by findings from the stakeholder interviews, where necessary. The resulting composite diffusion indicator scores and the results for the diffusion projections complete each country section. Section 5.6 concludes the chapter with a summary and a discussion of the results.

5.1 OBJECTIVE

In order to validate the developed conceptual model for RE diffusion (cf. chapter 4) and to assess its applicability to real life cases, it is employed in three country cases studies (Germany, Spain and the United Kingdom). The countries were chosen in order to obtain contrasting case studies, which vary with regard to their regulatory framework conditions for RE, to examine the transferability and robustness of the developed approach. Based on the collection of data for the quantification of the RE diffusion determinants in each of the three countries (covering the observation period 2012-2014), this methodological step further aims to investigate how different regulatory settings affect the observable RE diffusion and how they reflect in future RE deployment trends. An assessment of the resulting composite diffusion indicator scores helps to identify the major barriers and drivers for the deployment of wind and PV in the national context. Further, the analysis of scenarios representing possible future policy pathways intends to demonstrate the effects that changes in the economic or non-economic framework conditions would have on the resulting RE diffusion. This way, policy measures can be examined with regard to their appropriateness for fostering future RE diffusion. A detailed description of the underlying methodology for the case studies is provided in section 3.5.

When modelling the future diffusion of wind energy onshore and non-residential PV in the three case study countries it is the major aim to assess the expected deployment trends in the near future based on the given economic and non-economic framework conditions. This representation of the baseline conditions allows to provide a short-term market projection assuming that the framework conditions would remain unchanged. This information can be used, for example, to monitor the achievement of RE deployment targets. However, in the context of policy making and the continued efforts of policy stakeholders to enhance the effectiveness and efficiency of the legal and regulatory frameworks for RE, it can also be useful to be able to assess the impact of changes in the regulatory environment on the resulting RE diffusion. Therefore, the diffusion modelling in the frame of the country case studies considers different scenarios with variations in individual framework factors. The policy scenarios are defined in a way that particularly demonstrates the impact of changes in the non-economic framework conditions for RE. Thus, by comparing the scenario results for each case study, the impact of different policy interventions on the potential technology diffusion rate and thus the resulting policy efficiency can be assessed. The policy measures are reflected by variations in the scores for the respective diffusion determinants. The following scenarios are regarded (see also Boie, Ragwitz and Held (2016)):

- **Business as usual (BAU)**: This scenario assumes that the economic and non-economic framework conditions remain unchanged and the baseline conditions (as of 2014) are maintained. This is reflected in a constant score for the composite diffusion indicator for the subsequent years.
- **Longer administrative procedures (Long-Ad)**: This scenario assumes that the duration of administrative procedures increases, implying a duration of $\geqslant 40$ months for wind energy projects and $\geqslant 7$ months for PV projects. This corresponds with a score of 0.5 points for this determinant. For all other determinants it is assumed that the respective baseline conditions in the country remain stable on the 2014 level.
- **Optimized grid development (Opt-Grid)**: This scenario is characterized by an optimized framework for grid development, implying maximum predictability and transparency regarding the availability of future transmission capacities. This is reflected by the optimum score (1.0) for this determinant. All other framework conditions remain on the 2014 level.
- **Optimized spatial planning (Opt-Space)**: This scenario assumes and optimization of spatial planning for RE projects, implying that sufficient and adequate sites for project development are denoted in transparent spatial plans. The respective diffu-

sion determinant receives the optimal score (1.0) while all other framework conditions are assumed to remain stable.

Further scenarios and sensitivities could be derived by varying the scores for other or additional diffusion determinants. In this way, a broad spectrum of different policy interventions or changes in the RE framework conditions over time may be assessed and their impact on the resulting diffusion rate can be compared. However, within the scope of this thesis, the number of scenarios had to be limited and it therefore concentrates on three major non-economic factors for RE deployment (i.e. administrative procedures, grid development and spatial planning).

5.3 CASE STUDY GERMANY

5.3.1 *Framework for RE diffusion in Germany*

The following sections present the information used for calculating the diffusion indicator score for non-residential PV and wind energy (onshore) in Germany for the period 2012-2014. The analysis is based on the data sources specified in chapter 4, section 4.2.3 and the methodology described in chapter 3, section 3.5. Alongside using the defined data sources, 11 semi-structured interviews were conducted between June 2014 and March 2015 with RE sector experts from Germany (see table 5). The following sections are structured according to the sixteen diffusion determinants as introduced in chapter 4, section 4.2.3. An earlier version of this analysis has been presented in Boie, Ragwitz and Held (2016).

5.3.1.1 *Economic and political framework conditions*

RENEWABLE ENERGY STRATEGY AND SUPPORT SCHEME In the European context and in line with Directive 2009/28/EC (European Commission, 2009a) the Federal Government of Germany has prepared a National Renewable Energy Action Plan (NREAP) (Federal Government of Germany, 2009a) which specifies overall and sectoral targets and trajectories for RE deployment until 2020 (cf. section 1.1). To comply with Directive 2009/28/EC, Germany is committed to attain a share of at least 18% RE in total final energy consumption by 2020. Based on a scenario for the development of energy consumption assuming additional energy efficiency measures this translates to 35,492 ktoe of RE generation in 2020 (Federal Government of Germany, 2009a, p. 13). For the electricity sector, RE generation is expected to rise to 18,653 ktoe (or 216,944 GWh) in 2020 (Federal Government of Germany, 2009a, p. 15 and p. 18, Table 4a) which corresponds to 38.6% of electricity consumption based on RE (Federal Government of Germany, 2009a, p. 17, Table 3).

Besides the targets specified in line with the European RE strategy, the German government has formulated national targets for RES deployment which go beyond the NREAP targets. The major legal text in this regard is the 'Renewable Energy Act' (EEG) which defines targets, support measures and conditions for the market access of RE (see Federal Government of Germany (2012a,b, 2014a)). Based on the 2014 amendment of the EEG (Federal Government of Germany, 2014a, §1(2)), Germany aims to reach a share of 40-45% RES in final electricity consumption by 2025, 55-60% by 2035 and a minimum of 80% by 2050. The trajectory for reaching the above targets foresees yearly capacity additions of 2.5 GW wind energy onshore (net), 2.5 GW solar PV (gross) and 100 MW electricity from biomass (gross). For wind energy offshore an expansion of the installed capacity to 6.5 GW in 2020 and 15 GW in 2030 is envisaged (Federal Government of Germany, 2014a, §3).

Figure 46 illustrates the past deployment of wind energy onshore and PV in Germany (1990-2015) and indicates the planned future diffusion under the NREAP (Federal Government of Germany, 2009a) and according to the EEG 2014 (Federal Government of Germany, 2014a) (until 2020).

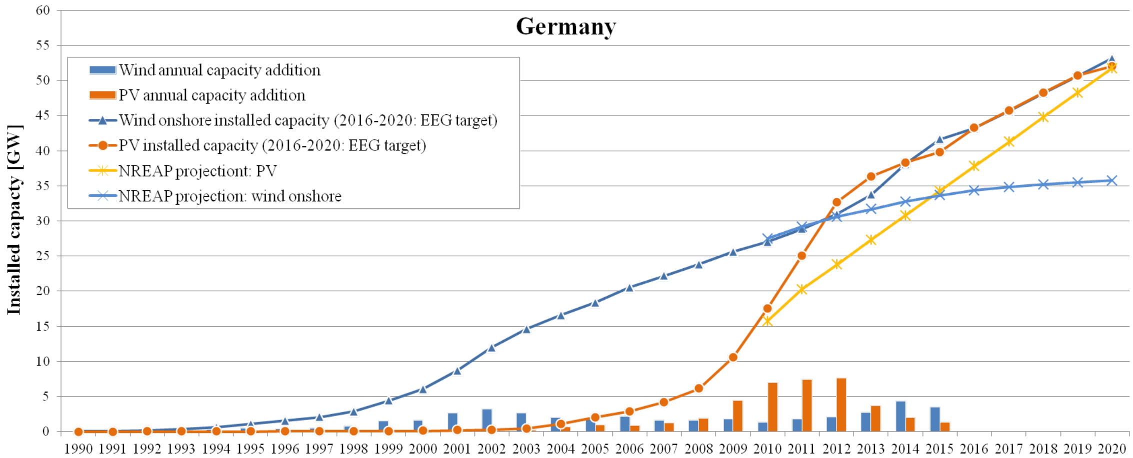

Figure 46: Cumulative installed capacities, annual capacity additions and future deployment targets for wind onshore and PV in Germany (deployment data available until 2015). Source: Own illustration. Actual deployment data based on BMWi (2015), targets according to Federal Government of Germany (2014a) and Federal Government of Germany (2009a).

Financial support to wind onshore and solar PV in Germany is provided mainly through feed-in premiums (FIP) and feed-in tariffs (FIT). The major legal document in this regard is the 'Renewable Energy Sources Act' (EEG) which establishes the statutory framework for economic support and market access of RES (see Federal Government of Germany (2000, 2004, 2008, 2012a,b, 2014a)). Additional support for RE projects exists in form of subsidized loans provided through the public KfW development bank (KfW, 2016).

The EEG was enacted in 2000[1] (Federal Government of Germany, 2000) and is subject to regular amendments (2004, 2009, 2012, 2014, 2017). The major changes in the legal framework for wind and solar energy in Germany during the observation period 2012 - 2014 can be summarized as follows[2]:

- EEG 2012 amendment (Federal Government of Germany, 2012b, enacted 1.1.2012): Legal consolidation of targets for RES in the electricity sector (35% until 2020, 50% until 2030, 65% until 2040 and 80% until 2050); introduction of market premium scheme (participation optional).
- EEG 2012 PV amendment (Federal Government of Germany, 2012a, enacted with effect from 1.4.2012): Unscheduled reduction of support levels for PV, introduction of a target deployment corridor of 2.5-3 GW additional installed PV capacity per year and a maximum of 52 GW total installed capacity eligible for support, introduction of an additional degression mechanism ('flexible cap') in case of deviations from the target corridor (with quarterly review cycles and tariff cuts depending on the degree of deviation).
- EEG 2014 amendment (Federal Government of Germany, 2014a, enacted 1.8.2014): Definition of target deployment corridors for biomass and wind energy, for wind energy onshore annual net capacity additions of 2.5 GW, a tariff reduction ('flexible cap') applies if the deployment target is exceeded, direct marketing of RES-E (i.e. participation in the FIP scheme) becomes mandatory for all RE installations >500 kW.

Based on the 2012 version of the EEG (Federal Government of Germany, 2012b), RES-E generators were able to chose between the FIT and FIP scheme. A change between the systems was possible on a monthly basis (Federal Government of Germany, 2012b, §33). The FIT scheme guarantees a purchase of all eligible RES-E based on a technology-specific rate which is paid over a support period of 20 years (Federal Government of Germany, 2014a, §22).

The FIP scheme offers a technology-specific market premium which is paid on top of the electricity market price and guarantees economic support for a period of 20 years (Federal Government of Germany, 2014a, §22). The level of the market premium is calculated on a monthly basis and refers to a technology-specific support level reduced by the monthly average reference market price at the spot market. The calculation method is defined in detail in the EEG (Federal Government of Germany, 2014a, annex 1).
With the regular EEG amendment enacted in August 2014 (Federal Government of Ger-

1 Prior to the EEG, the 'Electricity Feed-in Law' (enacted 1.1.1991) provided RES-E support through a FIT.
2 Further changes apply to other RE technologies and to residential PV installations which are, however, not in the focus of this work.

many, 2014a), the FIP became the major support instrument for both wind onshore and PV while the FIT was limited to installations with a capacity <500 kW[3].

The degression of support levels over time is defined according to a framework which is set out in part 3 of the EEG. The reduction consists of a basis component (i.e. the basis degression, a reduction by a fixed annual percentage) and a flexible component which is linked to the actual annual RE capacity additions (see above). Thereby, deployment corridors define the aspired technology diffusion and adjustments of the basis degression apply if the deployment exceeds or falls short of the targeted development. With the EEG 2012 (Federal Government of Germany, 2012b) this mechanism was introduced for PV and with the EEG 2014 (Federal Government of Germany, 2014a) also for wind energy onshore.

From 2017 on, financial support for RE installations, other than small-scale applications, will be allocated solely through competitive tendering procedures (Deutscher Bundesrat, 2016).

The reliability of the general RE strategy and the support scheme are rated very high since the EEG has been in place since 2000 (Federal Government of Germany, 2000) (with regular amendments in 2004 (Federal Government of Germany, 2004), 2009 (Federal Government of Germany, 2009b), 2012 (Federal Government of Germany, 2012a,b) and 2014 (Federal Government of Germany, 2014a)) and thus provides a reliable basis for RE support. In 2012, however, an unscheduled reduction of the FIT for PV was announced (Federal Government of Germany, 2012a) in addition to the regular amendment of the EEG (Federal Government of Germany, 2012b), which reduced the attractiveness of the economic framework for PV developers. Nevertheless, remuneration levels still covered generation costs and allowed for adequate rates of return for investors (see next paragraph). Additionally in 2012, a target range with a deployment cap of 2.5-3.5 MW per year was introduced to allow for a better control of the PV development (Federal Government of Germany, 2012a).

Also the overall political environment in Germany is one of the most stable and secure in Europe (Fund for Peace, 2014). The 'Fragile States Index' (FSI)[4] for Germany indicates a very low risk of conflict and a sustainable policy environment (FSI 2012: 31.7; 2013: 29.7; 2014: 30.6, see also table 27 in annex A.5)[5].

remuneration level for renewable electricity The assessment of the relative remuneration level (i.e. the average income under the given resource conditions and

3 From January 2016 on, RES-E plants eligible for the FIT are limited to plants <100 kW (Federal Government of Germany, 2014a, §37). Operators of these smaller RE plants may still switch between FIT and FIP on a monthly basis.

4 The 'Fragile States Index' is a composite indicator that measures the political stability and the risk of political conflicts across 178 countries worldwide (cf. section 4.2.3.1, paragraph I.).

5 Source: Fragile States Index (Fund for Peace, 2014), index range EU: ca. 18-67, globally: ca. 18-114, low values indicate a low political risk.

technical performance parameters, cf. definition in chapter 4, section 4.2.3.1) for wind onshore and non-residential PV indicates an intermediate profitability for wind onshore with an increase from 2012 to 2013 (mainly due to technology cost reductions, cf. table 24) and a slight decrease in 2014[6]. For PV, the data reveals an overall low profitability with a remarkable downward trend from 2012 to 2014 (see remuneration levels in table 24 and resulting indicator scores in table 25, both in annex A.5). The data shows that the remuneration level for RES-E is becoming a limiting factor for RE diffusion, especially for PV. This was also confirmed by the interviewed stakeholders (e.g. in interviews 1, 7, 9, 10).

REVENUE RISK FOR RENEWABLE ELECTRICITY The revenue risk under the present RE support scheme can be considered as minimal as the income risk associated with both, the feed-in tariffs and the market premiums is very low. Financial support under both schemes is guaranteed for 20 years under the EEG (§22 EEG) and tariff degressions are transparently defined (Federal Government of Germany, 2014a, part 3). Thus, there is a very low revenue risk as soon as an eligible RE project has qualified for the respective support scheme[7].

ACCESS TO FINANCE FOR RENEWABLE ENERGY PROJECTS The general stability and reliability of the German economy can be assessed through the sovereign credit rating as provided, for example, by the rating agency *Standard & Poor's* (S&P) (Standard & Poor's, 2015). The German S&P credit rating is stable at a AAA grade since 1983 and thus constant throughout the whole observation period 2012-2014 (Standard & Poor's, 2015). The normalization of the credit ratings for the diffusion indicator is done according to table 30 presented in annex A.5.

As a further indicator for the national financing conditions the interest rate for long-term government bonds can be used which can be retrieved from the EUROSTAT-database (EUROSTAT, 2014). This value, although it refers to government bonds, can be understood as an indication of the level of interest rates for loans in the private sector. During the observation period of this study, the average annual interest rate on long-term government bonds showed a slight increase from 2012 to 2013 (from 1.5% to 1.57%) and a decrease to 1.16% in 2014. This trend further continued in 2015 (cf. table 28 in annex A.5).

Another reference that aggregates information on the ease of obtaining credit is the 'Getting Credit Index' (GCI) which is part of the widely applied 'Doing Business Index' (World Bank Group, 2015). The 'Doing Business Index' is a composite indicator published by the 'World Bank Group' which measures the framework conditions for com-

6 Data on generation cost and remuneration levels was obtained from historical datasets of the web-based database on RES policy performance, technology costs and remuneration of the DIA-CORE project (DIA-CORE, 2016). The profitability is assessed based on formula 2 in section 4.2.3.1, paragraph II.

7 The support scheme-specific risk factors which are applied for the diffusion indicator are presented in table 26 in annex A.5.

mercial activities in 190 countries worldwide (cf. section 4.2.3.1 paragraph IV). For the RE diffusion indicator, two sub-indicators of the GCI are used: The availability of credit information (measuring the coverage, scope and accessibility of credit information available through credit bureaus or -registries, score 0-8) and the legal certainty in finance sector (assessing legal rights in collateral- and bankruptcy law, score 0-12)[8]. The sum of the two sub-indicator scores for Germany amounted to 13 (out of 20) in 2012 and 2013 and increased to 14 in 2014 (cf. table 29 in annex A.5).

According to German RE stakeholders, the availability of financing specifically for wind energy and PV projects was not a bottleneck during the whole observation period (2012-2014). The majority of the interviewees stated that access to finance was either very good (interviews 1, 2, 5, 6), good (interviews 7, 8, 9, 10) or unproblematic (interview 3) and not a critical factor for the deployment of neither wind energy nor non-residential PV. They explained the situation with the stable and reliable economic support for RES and the wide range of financing possibilities through various banks and support programs. Most interviewees reported that the financing conditions did not change significantly between 2012 and 2014 (interviews 1, 2, 5, 6, 7). Even though the economic support for RES became slightly less favourable, this was reportedly outweighed by lower interest rates on loans and a growing experience of banks financing RES. The following statements by German RE stakeholders further illustrate this assessment.

> *"We have much more capital in the market than projects"* (Interview 1, investor/ Financing institution)
>
> *"[The capital availability] is very good. This is also due to the very low interest rates [...] which make wind projects with 5, 6, 7, 8 percent [return] look very attractive. Consequently, the possibilities to collect money for, or to sell wind parks are very good."* (Interview 5, wind developer)
>
> *"Overall, we have a lot of capital which is accessible. And of course, if there is an attractive rate of return, there is an urge to invest in material assets such as PV plants [...]."* (Interview 9, PV developer)
>
> *"A lot of banks have developed expertise in this field [i.e. financing RES]. So there is a lot of experience in the banks. And then, of course, there is the KfW which laid the foundation [i.e. for RES financing] [...]. Also the interest rate level is very good at the moment and the duration of loan agreements is almost the same as for the economic support under the EEG. So this is very, very good."* (Interview 6, wind developer)

8 The methodology of the index is explained in detail at: www.doingbusiness.org/methodology/getting-credit (last accessed 9.4.2016).

5.3.1.2 *Electricity market structure and regulation*

The general regulatory framework governing the German electricity market is well established and reliable and is in line with the European market liberalization strategy (cf. section 1.1). The German 'Energy Industry Act' (EnWG) (Federal Government of Germany, 2005) provides the main legal foundation in this regard and establishes fair competition between conventional and renewable energies as well as unbundling of electricity generation, transmission and distribution activities (Federal Government of Germany, 2005, part 2). Since 2005, the German Federal Network Agency (BNetzA, 2015) is the independent regulatory agency that safeguards fair competition and market access of electricity generators and which monitors the unbundling of electricity market actors (see annual monitoring reports Bundesnetzagentur (2012) and Bundesnetzagentur and Bundeskartellamt (2013, 2014)).

SHORT-TERM MARKETING OF RENEWABLE ELECTRICITY Intra-day electricity trading in Germany takes place at 'EPEX Spot', the joint power exchange of Germany and Austria (EPEX-SPOT, 2016). During the observation period (2012-2014) the gate closure time for operations on the intra-day market was 45 minutes ahead of delivery (ACER-/CEER, 2015; Hagemann and Weber, 2015). In 2015, this period was further reduced to 30 minutes (EPEX-SPOT, 2016). The liquidity (i.e. the traded volume relative to the national electricity consumption) of the combined German and Austrian intra-day markets is rather low but showed an increasing trend from 2.4% in 2012 to 3.4% in 2013 and 4.6% in 2014 (see data in table 31 in annex A.5).

LONG-TERM CONTRACTS FOR RENEWABLE ELECTRICITY GENERATION For RE installations which are eligible for support under the FIT scheme (cf. section 5.3.1.1) a PPA is provided implicitly, as the scheme implies a guaranteed off-take and remuneration of all generated electricity through the grid operator (see Federal Government of Germany (2000, §3), Federal Government of Germany (2012b), Federal Government of Germany (2014a, §11)). Plant operators eligible for support under the FIP scheme (cf. subsubsection 5.3.1.1) are obliged to sell their electricity on the market or to close a direct PPA with a counter-party, such as a bulk consumer or an electricity utility. With the EEG amendment in 2014, this applies to all wind parks and PV plants with a capacity >100 kW. However, as the marginal generation costs of RES-E are low and as the premium guarantees a surcharge on top of the market price up to the defined premium level, generators are able to bid at very low prices and thus do not face problems marketing their electricity (see e.g. Cludius et al. (2013)). Also, before August 2014 (with the EEG amendment 2014) plant operators were able to switch between the FIP and FIT scheme on a monthly basis. Therefore, in case of need, an off-take of the generated electricity could, theoretically, be ensured by switching to the FIT scheme at all times.

5.3.1.3 *Grid infrastructure and grid regulation*

GRID ACCESS COST The framework conditions for the connection of RE plants to the transmission and distribution grids are set out in the EEG. According to §8 of the EEG, network operators are obliged to reinforce their networks to accommodate new RES-E generation units. Thereby, the network operator bears the cost for optimising, reinforcing and further developing the grid while the RES-E plant operator only bears the cost for the connection to the nearest grid connection point as well as the cost for the required equipment for metering the produced electricity (§16-17 EEG). If the network operator offers a connection point other than the economically most suitable one, he is obliged to bear the resulting additional costs (§16 EEG). This approach can thus be considered as a shallow charging approach (cf. section 4.2.3.3, paragraph I.).

GRID ACCESS LEAD TIME According to the EEG, the grid operator is obliged to provide a list of technical requirements, a detailed time plan and cost estimate within a maximum of eight weeks after receipt of a grid connection request (§8 EEG). However, for the actual connection of PV and wind onshore plants, no time limits apply[9].

According to data retrieved from the 'PV-Grid database' (PV Grid, 2014) in 2013 (referring to the assessment period 2012), the average grid connection lead time for large-scale PV applications in Germany was 4.5 months[10]. For 2013, the database did not provide any updated information. For 2014 (data retrieved in June 2015) it again indicates an average duration of 4.5 months.

Regarding wind energy projects, the 'Wind Barriers' project (Cena et al., 2010, p. 11) reports an average grid access lead time for wind energy onshore projects in Germany of 6.59 months. However, the data refers to projects realized before 2010 and has to be understood as a proxy for the past development.

In the frame of the interviews conducted with RE sector stakeholders from Germany, the above information was complemented and updated. However, not all interviewees were able to provide information in this regard, as not all stakeholders were directly involved in the grid connection process of RE projects. Also the interviewees stated that the duration can be very variable depending on the voltage level for the connection and the scope of the grid reinforcements required to integrate the new power plant (interview 6).

9 For wind energy offshore specific regulations apply which entitle the wind park owners to compensation payments in case of income losses due to delayed grid connection (Federal Government of Germany, 2005, §17).

10 The database indicates a duration of 22 weeks for medium to large-scale industrial ground-mounted systems and 15 weeks for small to medium-scale roof-top installations on commercial buildings (PV Grid, 2014). The weighted average of the values has been calculated based on the 2012 market shares of the two technology segments in Germany according to the 'EPIA Global market outlook 2013' (EPIA, 2013).

For example, interviewee 5 (wind energy developer) reports an average duration of 1.5-2 years until onshore wind parks are connected to the grid. This is supported by interviewee 11 (wind energy developer) who mentions an average duration of 1-1.5 years. Another RE developer (wind and PV) and utility (interviewee 6) reports durations of 3 months to 1.25 years and a PV expert (interview 10) stated that the grid connection of large-scale PV projects takes between 1.5 and 12 months. However, several interviewees (4, 5, 7, 10) highlighted that the grid connection lead time has so far not been a critical issue for RE development in Germany. Since the grid connection request is made right at the beginning of the development process, the overall duration of the project implementation period usually exceeds the grid connection lead time and thus the latter does not lead to delays. This is also exemplified by the interview quotes below.

As the quantitative information on grid connection lead times retrieved from the interviewees (especially for PV) is not sufficient to derive robust conclusions, it is assumed that the average duration reported in the frame of the 'PV Grid' project (i.e. 18 weeks) remained stable throughout the observation period. For wind energy, an assumption is derived based on the average lead time specified by Cena et al. (2010) (i.e. 6.59 months) and the indicative time frame for grid connection reported by the interviewees (i.e. between 3 and 24 months). On this basis, an average of 10 months is presumed. Since none of the interviewees reported changes in the grid connection lead time during the observation period (2012-2014) and interviewees 5, 6 and 11 explicitly mentioned that it remained stable, the value is assumed as constant for both technologies.
The below interview quotes further illustrate the assessment.

> *"[...] the request to the regional grid operator is made at a very, very early point in time. [...] Everybody can do that at a very early stage of the development process. And everybody does this. [...] So this is not a limiting factor because it may well be that the plant is commissioned four or five years later. So this is not critical in Germany."* (Interview 4, wind developer)
>
> *"This [i.e. the grid connection lead time] is not a critical issue. I mean, of course, it is not possible to realize a project without it, but in Germany you always have a grid connection. For you the basic question is whether the project is still profitable if you get a certain grid connection point. [...] But the time line is not critical. "* (Interview 5, wind developer)
>
> *"The lead times - as long as the eligibility and the remuneration are clear - are not a real barrier."* (Interview 7, PV/wind developer & utility)
>
> *"Well you have to differentiate. In the planning phase [...] the answer from the grid operator whether or where a connection is possible comes relatively quickly. [...] And when it comes to the realization phase, then it's basically your own completion time frame that you have to take account of. So if you have to build a substation this is not possible from one day to the next. This takes roughly about a year or maybe 12-18 months."* (Interview 11, wind developer)

predictability and transparency of grid connection procedures The grid connection procedures for both, the transmission and distribution grid, are defined by the EEG (Federal Government of Germany, 2012b, 2014a). On this legal basis, the grid operator is bound to connect RE power plants immediately and with priority over conventional power plants to the grid (§8 EEG). In doing so, the grid operator is further obliged to provide the technically and economically most suitable connection point with the closest distance to the RE project site (§8 EEG). A detailed statement of technical requirements and costs and the implementation time plan for the grid connection must be provided immediately and within a maximum of eight weeks after receipt of the initial grid connection request (§8 EEG). In case that grid reinforcements are required to integrate the new RE generation unit, the grid operator is obliged to immediately carry out any necessary optimization or expansion works (§12 EEG). If there is justified doubt that the grid operator has met his obligations to sufficiently reinforce the grid to integrate RE generation, plant operators may request detailed information on the extent to which the grid has been optimized and may claim compensation for potential income losses (§13 EEG). It can be assumed that, in the context of the above statutory provisions, RE generators operate in a fairly transparent and predictable framework with regard to the grid connection.

This assessment is supported by the valuations of the interviewed stakeholders who largely described the grid connection procedure as well defined and transparent and who highlighted that the present statutory framework provides a high level of legal certainty for RE developers (e.g. interviews 2, 4, 5, 6, 7, 11). For PV this aspect appears to be even less critical than for wind energy as usually PV plants can be connected to the distribution grid without the need for significant grid reinforcements (interviews 7, 10).

On this basis it can be concluded that the transparency of the grid connection procedures does not constitute a relevant barrier for neither PV nor wind energy onshore deployment in Germany. This is also illustrated by the selected quotations below.

> *"Well, for us the connection of a PV plant has never been an issue. The capacities of PV plants usually don't cause any problems. Normally, they feed into the distribution grid. Only once, when we built a large, ground-mounted PV plant [...] we had to lay about 150 meters of cable."* (Interview 7, PV/wind developer & utility)
>
> *"Well the grid operator - you hand in a request - and he calculates his grid capacity and then he specifies a connection point. What this [decision] was based on is not always comprehensible [...] but the procedure itself is very clear. You send an inquiry and you get an answer and that's it."* (Interview 5, wind developer)
>
> *"Well in Germany this is very advanced. I get an answer to my request and the grid operators are obliged to provide the information so that I am able to calculate, with the respective expert knowledge, whether it is really the optimal connection point or not. It*

> *might take a while until you get this information but generally you will get it. So in this regard we are really at the forefront."* (Interview 11, wind developer)

Regulations for grid access and curtailment of renewable electricity Electricity generation units based on RES are entitled to priority over conventional power plants with regard to the initial connection of the plant (§8 EEG) as well as regarding the transmission and distribution of all generated electricity (§11 EEG). In case that grid operators are forced to curtail electricity generation in order to guarantee the safety and reliability of the electricity system, they are obliged to curtail conventional power plants prior to RE plants and, in case that RES-E curtailment is inevitable, to provide evidence for the necessity of the measure (§14 EEG). Also, RE plant operators are entitled to receive compensation for the income losses caused by curtailment (§15 EEG).

Transparency and predictability of electricity grid development The development of the electricity grid in Germany is laid out in transparent plans on national level and published by the 'Federal Network Agency' (BNetzA) in an online information portal[11]. The legal basis for electricity grid development in Germany is framed mainly by the 'Energy Industry Act' (EnWG) (Federal Government of Germany, 2005, first enacted 2005, revised 2011 and 2014), the 'Law on Energy Line Extension' (EnLAG) (Federal Government of Germany, 2009c) and the 'Grid Extension Acceleration Act' (NABEG) (Federal Government of Germany, 2011) which provide a clear and positive framework for grid development. For example, based on the 2011 EnWG, TSOs are obliged to provide annually updated grid extension plans in form of a publicly available 'Ten Year Network Development Plan' (TYNDP) and the NABEG defines regulations for grid planning procedures and sets deadlines for the different steps of the process.

However, due to strong public resistance to many transmission projects it is not clear when the planned transmission capacity will actually be available. Several of the announced grid reinforcement projects are already significantly delayed (Bundesnetzagentur, 2015).

On this basis, it is concluded that the overall transparency and predictability of electricity grid development in Germany is on an average/intermediate level.

5.3.1.4 *Administrative procedures for renewable energy projects*

Administrative cost Regarding the share of administrative cost in the overall project development cost for PV, the results of the projects *'PV legal'* and *'PV grid'* suggest a slightly rising trend during the period 2010 to 2014. According to the findings for 2010,

11 Weblink: http://www.netzausbau.de/ (last accessed: 20.7.2016).

the cost share amounted to 8% for all types of non-residential PV installations (EPIA, 2010, p. 34). For 2011, Garbe et al. (2012, p. 40 & 61) mention average cost shares of 8% and 17% for commercial rooftop and large-scale ground-mounted installations, respectively. For 2012, no reliable data is available and for 2013 and 2014 2% and 36% were reported for the latter two technology segments (see Sonvilla, Binda Zane et al. (2013, p. 18) and B. Barth, Concas, Binda Zane et al. (2014, p. 7)).

Of the interviewed stakeholders, only two were able to define cost ranges for the administrative process for PV plants, as not all interviewees were directly involved in the project permitting process. Also, several interviewees stated that the cost share depends strongly on the project type and size which makes it difficult to provide a general statement in this regard. However, interviewee 6 (PV/wind developer & utility) mentioned an average cost share of up to 10% and interviewee 10 (PV research sector) indicated a range of 5-10%, depending on the installation size. Still, a larger number of consultations with stakeholders directly involved in the permitting process would be required to deduce robust conclusions. Therefore, for the indicator, the results of the 'PV legal' and 'PV grid' project are used[12].

Table 12 provides a brief overview of the interview statements relating to the administrative cost share for wind onshore and non-residential PV projects.

Table 12: Interview statements regarding the cost of administrative procedures for PV and wind projects in Germany (2014).

Interview	Technology	Statement
4	Wind	5-40% depending on project size
5	Wind	About 10% of total investment
6	Wind	5-15%
7	Wind	>10% of total development cost
11	Wind	2.5% of overall investment or 50-75% of development cost
6	PV	<10% (permits and assessments)
8	PV	Strongly depends on project size
10	PV	5-10% (depending on plant size)

Regarding onshore wind parks, the interviewees partly reported large ranges for the administrative cost share depending on the project size (e.g. interview 5). This can be explained by the fact that processing fees and expenses for impact studies essentially do not depend on the number of wind turbines to be installed. Therefore, the administrative cost will usually represent a larger proportion of a small wind park compared to a large

12 For the diffusion indicator, the reported values for the two types of non-residential PV installations are averaged and weighted with the share of each segment in the national PV market in the respective year (according to market data provided by EPIA (2012, 2013, 2014)). This allows for the derivation of a general average value for non-residential PV installations.

project. However, cost shares of 2.5 - 15% of the total investment appear to be a common range (cf. table 12). On this basis, a general average of 10% (in 2014) is assumed.

Data collected in the frame of the 'Wind Barriers' project indicates an administrative cost share of 5.3% in the overall investment in wind onshore projects realized in Germany before 2010 (Cena et al., 2010, p. 133). This result suggests a trend of rising administrative costs between 2010 and 2014 which is also supported by the present interview results. Several interviewees (e.g. 4, 5, 7, 11) emphasized that they noticed an increase in administrative requirements, for example, related to environmental impact assessments, other impact studies, compensatory measures and securities for project dismantling, which leads to rising project development costs (see exemplary quotes below). The interviewees further stated that the cost of administrative procedures has not been a significant barrier in the past but might become a limiting factor in the future, especially for wind energy. On this basis, for the diffusion indicator a linear increase from the value reported by Cena et al. (2010) to the 10% deduced from the interview results is assumed.

> *"What we noticed is a significant increase of charges [...]. Also of indirect charges, such as the definition of reinstatement costs for wind power plants or for compensation measures, respectively."* (Interview 4, wind developer)
>
> *"It [i.e. the administrative cost] grows continuously in Germany. Especially the environmental impact assessment gets more and more expensive and it may well take two years now."* (Interview 11, wind developer)
>
> *"Yes it definitely gets more expensive, because more surveys are required, because you need to look more into the details, because the processes are longer. This means that the staff needs more time - internal and external staff. [...] So everything is more intensive and therefore automatically more expensive. "* (Interview 5, wind developer)

DURATION OF ADMINISTRATIVE PROCEDURES In Germany, statutory provisions exist which specify a maximum time span within which authorities are required to decide on an application for wind energy projects. The major legal document in this regard is the 'Federal Immission Control Act' (BImSchG) (Federal Government of Germany, 2014b) which bundles all relevant permits and defines the procedures and requirements for the permitting process. The BImSchG (§10) defines that the responsible authority must provide its decision on a project application within a maximum of seven months after receipt of the complete application documents. However, in case of justifiable complications with the decision making, the authority may repeatedly extend this period by additional three months. Further, the above time limit is not effective from the initial submission date of the application but refers to the confirmation of completeness issued by the respective authority. Therefore, the permitting procedure may easily be extended through additional claims by the authority until the application documents are considered as complete (see also Pietrowicz and Quentin (2015)).

For PV plants no immission protection permit is required. Depending on the site and the type of the installation, building codes or land use regulations as well as municipal ordinances may apply (cf. (PV Grid, 2014)). However, no general statutory provisions exist regarding the duration of the permitting procedure.

Table 13 summarizes statements regarding the duration of permitting procedures made by the German interviewees contacted in the frame of this thesis. Based on the statements of the wind energy experts, although the interview results show some variability, a common average duration of the administrative process of 12 months is assumed. Observations made by Pietrowicz and Quentin (2015), who analysed German onshore wind projects realized between 2005 and 2014, documented a similar range. Their analysis of 104 wind energy onshore projects revealed an average duration of the administrative permitting process of 15 months in 2012, 12 months in 2013 and 21 months in 2014 Pietrowicz and Quentin (2015, fig. 13, p. 31). Consequently, the findings suggest a tendency of growing lead times during this period. However, the interviewees contacted in the frame of this thesis did not provide a clear statement on this issue but reported that the administrative lead time is equal (interviews 1, 4) or even slightly shorter (interviews 4, 6) than three years ago. Only interviewees 11 and 5 mentioned a slight increase in administrative lead times. On this basis it is assumed that the administrative lead time remained constant from 2012 to 2014.

For PV, however, the small number of interview statements is not sufficient to deduce robust conclusions. Therefore, for the diffusion indicator, the results of the *'PV legal'* and *'PV grid'* project are used which indicate an average duration of around 16 weeks for utility scale PV installations during the period 2012-2014[13].

COMPLEXITY OF ADMINISTRATIVE PROCEDURES As mentioned in the previous paragraph, the procedural steps and allocation of responsibilities in the permitting process of wind energy projects are mainly defined by the 'Federal Immission Control Act' (BImSchG) (Federal Government of Germany, 2014b, §10) which bundles the requirements and permits related to the erection of wind parks.

For PV projects, the relevant legislation, and thus the required procedural steps for obtaining a building permit, depend on the type of installation and the site of the project, respectively. In case that the generation unit is integrated into a building, building codes and, where applicable, monument conservation regulations apply, whereas, if the plant is located in an open space, land use regulations as well as municipal ordinances take

13 The 'PV grid' online database (PV Grid, 2014) indicates an overall average duration of administrative processes of 36 weeks for large-scale ground mounted PV installations and 1 week for commercial rooftop installations. This value was reported for the whole period 2012-2014 (data is updated annually). For the diffusion indicator, the reported values for the two types of non-residential PV installations are averaged and weighted with the share of each segment in the national PV market in the respective year (according to market data provided by EPIA (2012, 2013, 2014)). This allows for the derivation of a general average value for non-residential PV installations.

Table 13: Interview statements regarding the duration of administrative procedures for non-residential PV and wind onshore projects in Germany (2014).

Interview	Technology	Statement
1	Wind	12 months, max. 18 months
2	Wind	Minimum 3 months
4	Wind	6-12 months, min. 6 months, max. 18 months
5	Wind	9-15 months, min. 3-4 months, max. 2-3 years
6	Wind	About 12 months, max. up to 7 years
7	Wind	1-3 years
11	Wind	Average 9-12 months, min. 6 months, max. up to 3 years
6	PV	Around 6 months, max. 3 years
7	PV	A few months
8	PV	Depends on size/type: a few weeks (rooftop installation) up to half a year (large ground-mounted plant)
10	PV	1.5 months or even <1 month (smaller-scale project)

effect (cf. PV Grid (2014)). As building law lies within the responsibility of the individual federal states, regulations may slightly vary locally[14]. The 'PV Grid' database (PV Grid, 2014) reports only minor issues related to the administrative processes for commercial rooftop installations in Germany (i.e. related to interactions with building authorities and complications obtaining planning permission) and mentions no administrative barriers for ground-mounted PV installations. Significant barriers for this technology segment were, however, identified in conjunction with the selection of suitable and eligible project sites (see next paragraph).

However, the majority of the interviewed stakeholders evaluated the complexity of the permitting procedures for both, wind onshore and non-residential PV projects, as manageable and acceptable (e.g. interviews 1, 4, 5, 6, 8, 9). Only interviewees 10 (research/-consultant, PV) and 11 (wind developer) described the procedures as complex and interviewee 7 (RE developer & utility, PV & wind) stated that for wind energy projects the complexity is very high whereas for PV it is much lower. Several wind energy developers (e.g. 4, 5, 6) reported that, generally, the legal basis provided through the 'BImSchG' is clear and well manageable.

Regarding the development of the administrative complexity over the recent past (2012-2014), no clear trend can be deduced. Part of the interviewees reported that the process got more complex (interviews 3, 5, 10) or slightly more complex (interview 7), whereas others stated that the complexity stayed the same (interviews 6, 9) or even got less (interview 8) because authorities are more experienced today. The growing complexity was explained mainly by a scarcity of wind energy project sites with simple conditions and thus increasing requirements, for example, related to environmental impact assessments

14 See also: http://www.photovoltaik.org/wissen/baugenehmigung (last accessed: 22.8.2016).

and interactions with the public (interviews 5, 7, 11). The below interview quotes further illustrate the assessments of the interviewed stakeholders.

Also Cena et al. (2010, p. 100), based on their 2010 assessment of the administrative framework for onshore wind energy projects in the EU, report that the conditions in Germany are favourable by European standards as Germany performs slightly above the EU-27 mean regarding the transparency and predictability of authorisation procedures[15].

On the basis of the above information, it is assumed that the complexity of administrative procedures for the authorisation of both wind energy onshore and non-residential PV projects in Germany is moderate (i.e. processes are complex but well defined and manageable), corresponding to an intermediate diffusion indicator score (i.e. 0.5). It is further assumed that the situation was stable between 2012-2014.

> *"You have to do it [i.e. the authorisation process]. It is annoying and it costs money and time. [...] But if you have planned everything correctly, it will not be a bottleneck in the end."* (Interview 4, wind developer)
>
> *"Well, the processes themselves are not complex. If you have submitted your application then it is like a relay race: You give it to one person and that person distributes it in-house, collects all the responses and opinions and then forwards them to you."* (Interview 5, wind developer)
>
> *"Well, there are a couple of contact persons and the process is a bit stressful but this will never cause a project failure."* (Interview 6, wind/PV developer & utility)

Integration of renewable energy planning with spatial and environmental planning Based on the interview results, substantial issues were identified regarding the availability of suitable project sites, especially for PV. Here, the major problem reported by the interviewees was the exclusion of agricultural lands from areas eligible for economic support of ground-mounted PV plants under the 'EEG' which was introduced with the 2009 amendment of the 'EEG' (Federal Government of Germany, 2009b). According to several PV experts (interviews 6, 8, 9, 10) this led to a disproportionally strong limitation of potential project sites and thus created a significant bottleneck for the development of ground-mounted PV in Germany.

Also the identification of so called conversion areas (e.g. military or industrial wastelands), which are eligible sites for PV projects supported under the 'EEG', reportedly poses an obstacle for the development of ground-mounted PV in Germany. Several interviewees (6, 9, 10) mentioned that the eligibility criteria for conversion areas are often

15 The evaluation assesses three parameters on a scale from 1-5 with 5 being the optimal score: The transparency of the authorisation and decision making process (German score: 3.56), the existence and respect of respective deadlines (German score: 3.29) and the authorities' attitude towards wind power (German score: 3.16). The scores for Germany indicate that the framework conditions are in the medium range and slightly better than the EU-27 mean (Cena et al., 2010, p. 100).

not clear which represents an additional risk factor in project development and that the quality of the sites is often low (e.g. due to required site remediation), resulting in a lower economic efficiency of the plants. The interview quotes at the end of this section exemplify the valuations of the German PV experts.

Information provided in the 'PV Grid' database (PV Grid, 2014) supports the above interview statements. The most recent 'PV Grid' analysis results published on-line (update May 2014) show that for industrial ground-mounted PV systems in Germany the most troublesome barrier relates to the site selection (PV Grid, 2014). According to the database, especially difficulties in finding suitable areas and negotiating terms and conditions with land owners and municipalities constitute major bottlenecks in this regard.

In the case of wind energy, part of the interviewees described the situation as rather difficult (interviews 3, 7, 11), whereas others assessed it as fairly good or average (interviews 4, 6) or varying depending on the geographical region concerned (interview 5). Wind project developers further mentioned that especially time delays in the development of regional spatial development plans are critical because they hinder the disclosure of suitable sites for wind project development (interviews 4, 5, 11). An analysis conducted by Pietrowicz and Quentin (2015) confirms this issue and shows that wind energy projects in Germany are often subject to significant delays because of spatial planning issues, particularly within the context of regional spatial plans.

Some developers also lamented that regulations (e.g. regulating the minimum distance between wind turbines and settlements) are not uniform across the German federal states which poses a barrier in those federal states with stricter limitations (interviews 3, 5).

On the basis of the above information it is assumed that the conditions for spatial planning during the observation period were intermediate (medium score) for wind energy onshore and rather poor (low score) for non-residential PV.

> *"The barrier with PV is that you often ask yourself whether a site is eligible for support or not. Then you look into a site for half a year and finally you realize that it is not eligible after you have already spent money on it. because it is just not always clear. [...] Because the law is not clear."* (Interview 6, wind/PV developer & utility)
>
> *"No, it [i.e. the availability of sites] is not sufficient any more. Not for ground-mounted installations. Especially because they excluded agricultural areas. Thereby, they have restricted it too much. [...] Agricultural areas should be eligible for PV development. Under the provision that it will be dismantled after 20, 25 or 30 years."* (Interview 10, PV research/consultant)
>
> *"The allocation of areas is a very, very critical issue. This constitutes a very, very strong barrier. [...] And not only the definition of the [conversion] areas is problematic but also the areas themselves. Because these are often more expensive, which are often associated with high site remediation costs. And often do not have optimal conditions for grid connection. So this means that they entail overall higher costs for grid connection and for*

construction of converter stations. Conversion areas are often located where no one needs the electricity. So from an economic point of view it does not make any sense." (Interview 9, PV developer/manufacturer)

5.3.2 *Diffusion indicator scores for Germany*

The CI scores for PV and wind energy resulting from the assessment of the framework conditions presented in the previous section (section 5.3.1) are presented in table 14. The values shown in the table are the unweighted, normalized indicator scores. To derive the overall CI score, the individual indicator scores are weighted with the technology-specific weighting factors from table 11 and multiplied according to the formula shown in equation 3 (both in in section 4.4). The resulting weighted indicator scores are included in table 32 in annex A.5.

Table 14: Composite diffusion indicator scores (unweighted) for wind energy and PV in Germany (2012-2014).

Indicator component		Scores wind			Scores PV		
		2012	2013	2014	2012	2013	2014
A-I.	Existence and reliability of RES-E strategy & -support scheme	0.87	0.87	0.96	0.81	0.87	0.96
A-II.	Relative remuneration level for RES-E	0.20	0.33	0.29	0.23	0.04	0.002
A-III.	Revenue risk under RES-E support scheme	0.56	0.79	0.56	0.79	0.79	0.79
A-IV.	Access to finance for RES-E	0.90	0.90	0.91	0.90	0.90	0.91
B-I.	Fair and independent regulation of the electricity sector	1.00	1.00	1.00	1.00	1.00	1.00
B-II.	Existence of functioning and non-discriminatory markets	0.63	0.63	0.63	0.63	0.63	0.63
B-III.	Availability of reliable long-term contracts (PPA)	1.00	1.00	1.00	1.00	1.00	1.00
C-I.	Grid connection cost	1.00	1.00	1.00	1.00	1.00	1.00
C-II.	Duration of RES-E grid connection	0.82	0.82	0.82	0.64	0.64	0.65
C-III.	Predictability & transparency of grid connection procedures	1.00	1.00	1.00	1.00	1.00	1.00
C-IV.	RES-E access regime and regulation for curtailment	1.00	1.00	1.00	1.00	1.00	1.00
C-V.	Transparency and predictability of grid development	0.50	0.50	0.50	0.50	0.50	0.50
D-I.	Administrative cost	0.61	0.57	0.53	0.76	0.70	0.72
D-II.	Duration of administrative procedures	1.00	1.00	1.00	0.75	0.76	0.78
D-III.	Administrative complexity	0.50	0.50	0.50	0.50	0.50	0.50
D-IV.	Integration of RES-E in spatial & environmental planning	0.50	0.50	0.50	0.25	0.25	0.25

The **diffusion outlook for non-residential PV** in Germany is shown in figure 47. The graph compared the technology diffusion for the four scenarios as defined in section 5.2.

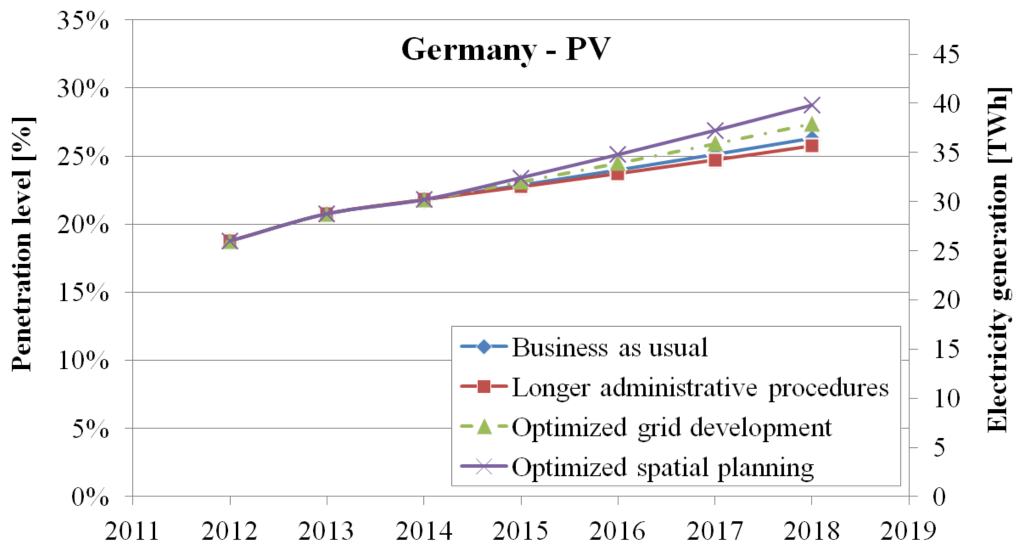

Figure 47: Short term diffusion outlook for non-residential PV in Germany: Expected penetration levels (%) and electricity generation (TWh) until 2018 for four scenarios. An earlier version of this analysis has been presented in Boie, Ragwitz and Held (2016).

The results indicate that 26.3% exploitation of the long-term potential, i.e. an electricity generation of 36.5 TWh and an installed capacity of about 40 GW PV in 2018, would result from the market diffusion based on BAU assumptions. This development would lead to a shortfall regarding the target trajectory of the German NREAP, which foresees an installed capacity of 44.8 GW PV in 2018 (cf. Federal Government of Germany (2009a, pp. 113-114)). Also the target trajectory based on the EEG 2014 (Federal Government of Germany, 2014a), which foresees around 48 GW installed PV capacity in 2018, would not be met.

A slightly lower market growth after 2014 can be observed for the scenario assuming longer administrative procedures (Long-Ad scenario). Here, PV generation declines by about 0.8 TWh in 2018, compared to BAU assumptions. This corresponds to a usage of 25.75% of the economic long term deployment potential and an installed capacity of 39.1 GW. However, the effect is not very marked as this determinant has a relatively low weight for PV (cf. technology-specific weights in table 11).

Optimized grid development (Opt-grid scenario) results in a slight increase in PV diffusion, compared to the BAU scenario. In this scenario, PV generation reaches 38 TWh (41.6 GW installed capacity) until 2018, which is equivalent to a 27.4% exploitation of the long term deployment potential. This result demonstrates that the existence of a transparent, long-term grid expansion strategy still plays a role for the market diffusion of PV, even though this determinant does not constitute the most relevant constraint for this technology (cf. technology-specific indicator weights in table 11).

The strongest impact on PV deployment, however, results in the scenario assuming optimized spatial planning (Opt-Space). According to the scenario results, an enhancement of the availability of project sites for PV plants could lead to a PV-based electricity generation of 39.8 TWh (43.6 GW installed capacity) until 2018. This corresponds to a 28.7% exploitation of the economic long term potential for PV. In this scenario, the indicative NREAP target for PV (44.8 GW PV in 2018) would be nearly met without additional economic support. This result demonstrates that, based on the the modelling approach used here, a reduction of non-economic barriers, namely land-use constraints on large-scale PV installations, could increase PV diffusion and RE support-scheme efficiency substantially.

Figure 48 shows the **short-term diffusion outlook for wind energy onshore** in Germany for the four scenarios.

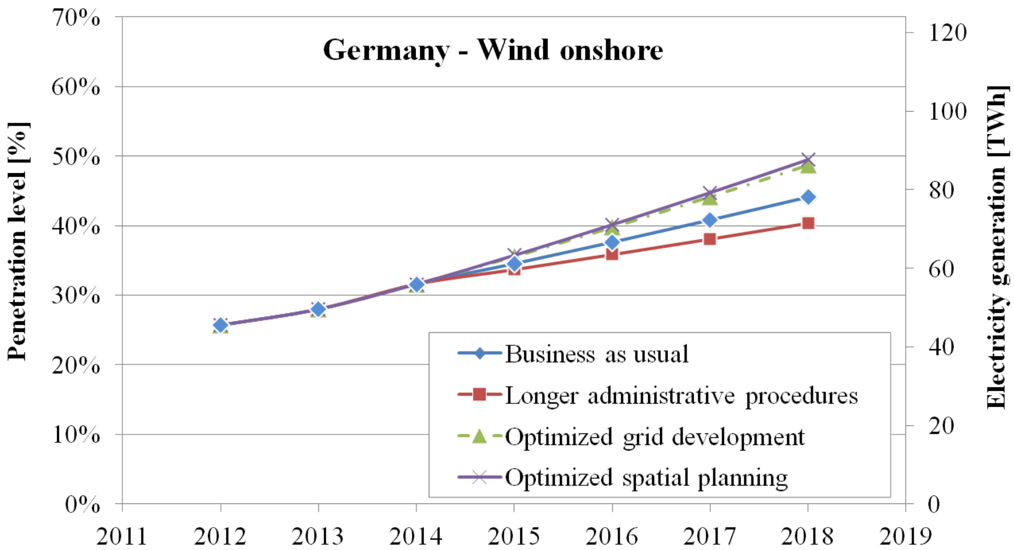

Figure 48: Short term diffusion outlook for wind energy onshore in Germany: Expected penetration levels (%) electricity generation (TWh) until 2018 for four scenarios. An earlier version of this analysis has been presented in Boie, Ragwitz and Held (2016).

The projections indicate that in the BAU scenario 44.1% of the long-term deployment potential, equivalent to an electricity generation of 78.2 TWh (54.4 GW installed capacity), could be reached until 2018. This would surpass the indicative target trajectory of the German NREAP, which foresees an onshore wind energy-based electricity generation of 68.9 TWh by 2018 (cf. Federal Government of Germany (2009a, pp. 113-114)) and the target trajectory of the EEG 2014 (Federal Republic of Germany, 2014), which indicates installed onshore wind capacities of 48.1 GW in 2018.

In the scenario assuming longer administrative lead times, the market diffusion of wind energy is clearly reduced after 2014. Lengthy administrative procedures are a significant risk factor for investment-intensive wind parks (cf. e.g. Lüthi and Prässler (2011)) so this determinant is very relevant for wind energy. This is also reflected in the technology-specific indicator weights (cf. table 11 in section 4.4). As a consequence, in this scenario wind onshore generation drops to 71.5 TWh (equivalent to an exploitation of 40.4% of the long term potential) in 2018.

Assuming an optimized grid development (Opt-Grid scenario) leads to scenario results with a substantial increase in onshore wind energy deployment, compared to the BAU scenario. Here, 48.7% of the long term deployment potential are exploited in 2018, leading to wind-based electricity generation of 86 TWh and an installed capacity of 58.8 GW. This result highlights the importance of transparent, long-term grid expansion plans for onshore wind energy deployment.

The strongest impact on the market diffusion of wind energy onshore is, however, observable assuming optimized spatial planning for RE (Opt-Space scenario). The results for this scenario suggest that, if limitations relating to the availability of project sites for wind parks would be removed, wind-based electricity generation could reach 49.5% of the long term potential, equivalent to 87.7 TWh electricity generation, until 2018. This implies a 5% increase in the exploitation of the economic long term deployment potential for wind energy, compared to the BAU scenario.

5.4 CASE STUDY SPAIN

5.4.1 *Framework for RE diffusion in Spain*

In the following, the information used for calculating the diffusion indicator scores for non-residential PV and wind energy (onshore) in Spain for the period 2012-2014 is presented. The analysis is based on the data sources specified in chapter 4, section 4.2.3 and the methodology described in chapter 3, section 3.5. In addition to the referenced data sources, 10 semi-structured interviews with Spanish RE experts were conducted between June 2014 and March 2015 (see table 5). The following sections are structured according to the sixteen diffusion determinants as introduced in chapter 4, section 4.2.3.

5.4.1.1 *Political and economic framework*

RENEWABLE ENERGY STRATEGY AND SUPPORT SCHEME In line with the European Renewable Energy Directive 2009/28/EC (European Commission, 2009a) Spain has developed a National Renewable Energy Action Plan (NREAP) which defines the RE targets for the period until 2020. The Spanish NREAP specifies a binding target of 40% RE in electricity consumption by 2020 (MINETUR, 2011b, p. 44, table 3). The corresponding installed capacities foreseen for PV and wind amount to 13,445 MW PV and 35,000 MW wind onshore in 2020 (MINETUR, 2011b, p. 153-154, table 10a). The technology-specific trajectories, however, do not have a legally binding character. No technology-specific targets are fixed in the national legislation.
In 2011, an update of the NREAP has been published which reduces the target share of RE in the national electricity consumption to 39% in 2020 (MINETUR, 2011a, p. 69, table 3) and the envisaged installed capacities of PV to 7,250 MW. the target for wind energy remains unchanged.
In the national legislation the Sustainable Economy Law (L2/2011) sets a target of a 20% share of RE in gross final energy consumption (Estado and I, 2011, article 78). For the period beyond 2020, no national RE targets have been defined[16].

An overview of the historical deployment of wind energy onshore and PV in Spain (1990-2014) and the envisaged diffusion until 2020 under the NREAP (MINETUR, 2011a) are presented in figure 49.

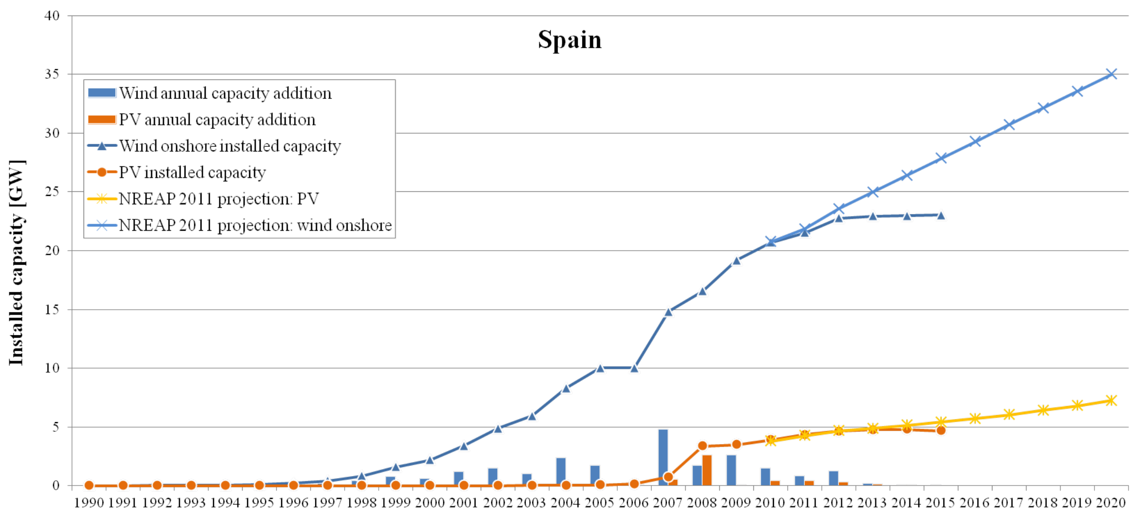

Figure 49: Cumulative installed capacities, annual capacity additions and future deployment targets for wind onshore and PV in Spain (actual deployment data available until 2015). Source: Own illustration. Actual deployment data based on EUROSTAT (2014), targets according to MINETUR (2011a).

16 On EU-level a binding target of 27 % RE in final energy consumption until 2030 has been set by the European Commission (European Commission, 2014a). However, this target is not broken down to binding national targets.

Support for RE in Spain evolved since the end of the 1990's starting with the General Electricity Law 54/1997 which presented a plan for the development of RE until 2010 (Government of Spain, 1997). In the following decade, a financial support scheme based on the combination of a feed-in premium scheme (FIP) and a fixed feed-in tariff (FIT) was developed in which operators of RE plants could chose between the two instruments. The support scheme was highly successful in stimulating RE investments: between 2000 and 2010, the installed capacities of wind and PV increased nearly tenfold and more than 300-fold, respectively (cf. figure 49). However, for economic reasons[17], the Spanish government changed the RE support scheme (starting in 2008) by repeatedly cutting RE support levels, capping the RE volumes eligible for support, shortening the maximum support periods and introducing new fees and taxes on electricity generation. Several of these legal adjustments were applied retroactively, i.e. they affected new as well as existing power plants. Finally, in January 2012, the financial support instruments for RE (FIP, FIT) were suspended. In 2013, the Spanish government implemented a comprehensive reform of the electricity sector within which a new concept for the remuneration of RE was developed (Government of Spain, 2013c). The new scheme is meant to support those RE generation units with costs exceeding the electricity market price and to provide them with a reasonable profit level. 'Reasonable profitability' is defined as a profit margin of 7.4% over the lifetime of the plant. The profit margin is based on the calculation of the average yield of a Spanish sovereign government bond over the past 10 years increased by 3 percentage points (Government of Spain, 2013c, article 9).

The remuneration consists of the regular electricity market price supplemented by a capacity payment and a generation-based premium which are calculated on the basis of technology- and project-specific parameters (see (MINETUR, 2014a)). The level of the profit margin can be reviewed and adjusted every six years (with effect for the following six years). The average electricity market price used for the calculation can be reviewed and adjusted every three years (Government of Spain, 2013c, article 19). The new remuneration scheme became effective in June 2014. Between January 2012 and June 2014, there was effectively no support scheme for newly installed RE in Spain.
A selection of major legislative changes relevant for wind energy and PV in the time frame 2012 to 2014 can be summarized as follows[18]:

- Royal Decree Law 1/2012 (enforced 28.01.2012) (MINETUR, 2012) suspends all former support measures for future RE projects (moratorium). Existing projects are not affected.

17 A substantial deficit emerged in the electricity sector, i.e. electricity prices could not cover the regulated costs of the electricity system. Additionally, electricity production capacities increasingly exceeded the stagnating demand which was further aggravated by the economic recession after 2008.

18 A more detailed overview over the evolution of the legislative framework for RE in Spain is provided, for example, in the 'IEA/IRENA Joint Policies and Measures Database', weblink: www.iea.org/policiesandmeasures/renewableenergy/?country=Spain (last accessed: 8.4.2016). Also, all legal texts can be accessed via the webpage of the Spanish Ministry of Energy and Tourism: www.minetur.gob.es/PortalAyudas/Paginas/legislacion-ayudas.aspx.

- Law 15/2012 (enforced 01.01.2013) introduces a tax of 7% on all electricity sales (Government of Spain, 2012). The change applies to all existing generation units.
- Royal Decree Law 2/2013 (enforced 02.02.2013) changes the approach for adjusting the level of the FIT over time. It affects existing RE plants (Government of Spain, 2013b).
- Royal Decree Law 9/2013 (enforced 14.07.2013) establishes a new regime for the remuneration of RE which is based on the definition of a 'reasonable return' defined as a pre-tax return on investment of 7.39% over the average yield of a RE project over its regulatory lifetime (Government of Spain, 2013c, article 9). Detailed parameters for the remuneration are not yet defined.
- Royal Decree 413/2014 (enforced 11.06.2014) enforces the new remuneration scheme for RE (MINETUR, 2014b).
- Order IET/1045/2014 (enforced 21.6.2014) establishes the calculation parameters for the remuneration of RE plants as laid out by RDL 9/2013 and RD 413/2014 (MINETUR, 2014a). It is applied retroactively.

The information summarized above illustrates the frequency of drastic changes in the Spanish RE framework (cf. also figure 62 in the annex). Especially the frequency of retroactive changes, also in the period before 2012, creates a high level of regulatory uncertainty. The general political stability in Spain according to the 'Fragile States Index' (FSI) lies in the midfield of the EU Member States and remains relatively stable over the observation period (FSI 2012: 42.8, 2013: 44.4, 2014: 43.1[19], cf. table 27 in annex A.5).

REMUNERATION LEVEL FOR RENEWABLE ELECTRICITY As there was no support scheme for RE projects in force between January 2012 and June 2014, no economic support was available for new RE projects additional to the regular electricity market price. Based on data on ranges for generation cost of wind onshore and PV and market price levels[20] it can be concluded that the development of wind onshore and PV projects in Spain was not profitable during the whole observation period.

REVENUE RISK FOR RENEWABLE ELECTRICITY From January 2012, when the support policy for RE was suspended, to June 2014, when the new remuneration scheme was enacted, there was no economic support measure or mechanism to hedge the remuneration risks of new RE projects. Potential new RE installations would have been based

19 Source: Fragile States Index (Fund for Peace, 2014), weblink: http://fsi.fundforpeace.org/, index range EU: ca. 18-67, globally: ca. 18-114
20 Data on generation cost and remuneration levels was obtained from historical datasets of the web-based database on RES policy performance, technology costs and remuneration of the DIA-CORE project (DIA-CORE, 2016). The profitability is assessed based on the formula described in Table 7.

on the electricity market price only. Therefore, the revenue risk during the observation period can be considered as very high.

ACCESS TO FINANCE FOR RE PROJECTS The general stability and reliability of the Spanish economy can be assessed through the sovereign credit rating as provided, for example, by the rating agency *Standard & Poor's* (Standard & Poor's, 2015). By end of 2011 Spain's S&P credit rating was reduced from the previous 'AA' grade to 'AA-' and by beginning of 2012 it was further reduced to 'A'. In April 2012 another downgrade to 'BBB+' took place and by end of 2012 the rating was lowered to 'BBB-'. In May 2013 the rating slightly improved to 'BBB' and remained stable throughout 2013, 2014 and 2015. The normalization of the credit ratings for the diffusion indicator is done according to table 30 in annex A.5.

A further indicator for the national financing conditions is the interest rate for long-term government bonds that can be retrieved from the EUROSTAT-database (EUROSTAT, 2014). This value also gives an indication of the interest rates for loans in the private sector. During the observation period the average annual interest rate on long-term government bonds reduced from 5.85% in 2012 to 4.56% in 2013 and 2.72% in 2014 (cf. table 28 in annex A.5).

Another reference that aggregates information on the ease of obtaining credit is the 'Getting Credit Index' (GCI) which is part of the widely used 'Doing Business Index' (World Bank Group, 2015). For the RE diffusion indicator, two sub-indicators of the GCI are used: the availability of credit information (measuring the coverage, scope and accessibility of credit information available through credit bureaus or -registries, score 0-8) and the legal certainty in finance sector (assessing legal rights in collateral- and bankruptcy law, score 0-12)[21]. The sum of the two sub-indicator scores for Spain amounted to 11 (out of 20) in 2012 and 2013 and increased to 12 in 2014 (cf. 29).

According to Spanish RE stakeholders, the availability of financing specifically for RE projects was very poor over the whole observation period (2012-2014) due to the high legal uncertainty and the lack of economic support for RE. Here, the effects of the economic crisis overlap with the implications of the retroactive changes and the moratorium of the RE support scheme. However, interviewees consistently state that, before the RE support scheme was changed, the access to capital was very favourable as private banks had a positive attitude to financing RE projects. Most interviewees were not aware of options for public support to RE financing (apart from R&D support) or stated that such options do not play a decisive role for RE deployment. The following statements underpin this assessment.

21 The methodology of the index is explained in detail at: www.doingbusiness.org/methodology/getting-credit (last accessed 9.4.2016).

"Yeah, so now the situation is very difficult, because nobody believes or relies in the security of investments. So there have been so many changes and this is going to damage the confidence of investors. As soon as the support is clear, and then the investors have confidence that this support is not going to be changed, which is not the case in Spain, as I said to you. And this is not going to be the case in Spain at least for the next years to come." (Interview 14, RE industry association)

"So we are a big company and we did some projects and we have been able [to develop projects], because we have margin to do. But if you are an independent producer and you want to develop a project, it was not easy to find. [...] Because [of] the general economic situation in Spain, because [of] all the regulatory changes we have been involved in the last three years, the access to finance has been very bad in the last three years." (Interview 19, RE developer & utility)

"There is a difficulty, overall difficulty of access to finance, not only for energy projects, to any kind of projects and investments. And because of the instability of the framework, well on one hand there is no willingness of developers to invest, but on the other hand I would not think that any bank could now give finance for renewable projects with all these uncertainties. So I think access to finance is highly relevant, but it's not only because of the sector. " (Interview 16, research institute)

"So their [i.e. large-scale developers/utilities] difficulties to get financing [were] not such as for example small and medium size enterprises which really were suffering already. You know, from the beginning of the crisis." (Interview 16, research institute)

Interviewee 17 (government stakeholder) also reports that the access to capital for RE projects is very poor due to the legal uncertainty. With regard to wind energy projects particularly the high number of bank guarantees that have to be provided for the implementation of the project (and the related higher development costs) was mentioned as a relevant barrier to getting finance.

Interviewee 18 (RE developer) states that access to finance in general and for RE projects in particular is poor due to the political risk and the legal uncertainty (*"Private funding is absolutely terrified of the risk that exists in Spain and of the legal uncertainty*"). Three years ago (2012) it was even worse. He claims, however, that given a profitable project and a reputable developer it would always be possible to secure financing.

Interviewee 12 (research sector) highlights that access to finance has become a particular bottleneck for small-scale RE developers in Spain. He claims that *"access to finance was excellent 5 years ago or 7 years ago and it led to a big solar PV rush in Spain, apart from other aspects. But now it is a big bottleneck, apart from other factors as well.*".

Interview 13 (RE developer & utility) supports this statement and emphasizes that public financing programs were not required as other sources of capital were abundantly available.

> *"In the last three years it was worse obviously, because the regulatory conditions tightened. And the financial crisis obviously restricted the access to capital for everybody, not just for energy investors, but for everyone in Spain and in general in the south of Europe. So I would say, it has been extremely available. In fact probably too available and some investments should have not been carried out from the financial point of view. But since the regulatory reform started now three years ago and the capital markets and the financial institutions have been under major severe restrictions, then the capital availability has been very low."* (Interview 13, RE developer & utility)

Interviewee 13 further states that *"There was no particular need to have public financial support, because the conditions in the private sector were really efficient. It was not that didn't exist. I think it was just [...] not competitive enough. Someone would actually make a better offer than the public bank."*.

Also interviewee 21 (RE association) reports that before the support scheme was phased out, the financing conditions for RE projects (especially for wind energy) in Spain were *"wonderful"* because the economic support was so favourable. However, today (2014) *"there's no access to capital at all"* due to the economic crisis and the regulatory changes. After the retroactive changes of the regulatory system, banks *"don't believe in the government anymore and they don't want to give a penny on a new renewable investment, so there's no investment, there's no access to finance"*.

5.4.1.2 *Electricity market structure and regulation*

REGULATION OF THE ELECTRICITY SECTOR The Spanish electricity sector is fully liberalized. Since 1998, the energy sector is monitored and regulated by the national energy regulatory authority 'Comisión Nacional de Energia' (CNE) which is a fully independent public body (CNE, 2012; European Commission, 2012b). In 2013, in the frame of a comprehensive energy sector reform, the CNE was merged with several other regulatory authorities (postal services, telecommunication, railways and others) and the new regulatory authority, the 'Comisión Nacional de los Mercados y la Competencia' (CNMC) was created. Also the CNMC is a fully empowered and independent entity (European Commission, 2014e, p. 207).

The Spanish transmission system is owned and operated by Red Eléctrica España (REE). Since 2010, REE is fully independent from other companies in the electricity sector (European Commission, 2012b, p. 98). Also all electricity DSO's are legally and functionally unbundled (European Commission (2012b, p. 98),European Commission (2014e, p. 207)).

short-term marketing of renewable electricity Electricity in Spain is traded at MIBEL (Mercado Ibérico de la Electricidad), an integrated trading platform of Spain and Portugal. The market operator for both, daily and intra-day trading of electricity, is OMIE. Intra-day electricity trading is organized in six auctions per day. (OMIE, 2016) The gate closure time for operations on the intra-day market is 2.5 hours ahead of delivery (ACER/CEER, 2015; Hagemann and Weber, 2015). The liquidity of the Spanish power exchange (i.e. traded volume relative to national electricity consumption) slightly decreased from 19.5% in 2012 to 14.4% in 2013 and 13.7% in 2014 (cf. table 31 in annex A.5).

long-term contracts for renewable electricity generation Before the suspension of the support scheme in 2012, a PPA was guaranteed through the FIT/FIP scheme. Since 2012, with no support scheme in place, the availability of such long-term contracts for RE generation is not provided.

5.4.1.3 *Grid regulation and infrastructure*

grid access cost Regarding the regulation of grid access for power plants based on RES and for power plants in general, the most relevant national legal documents are Law 24/2013 on the Electricity Sector (Government of Spain, 2013a) which was enforced on 28.12.2013 and replaced Law 54/1997 (Government of Spain, 1997) as well as the Royal Decree 1995/2000 on the Transmission, Distribution, Marketing, and Supply of Electricity and the Authorisation Procedure for Electricity Generation Plants (Ministry of Economy Spain, 2000) which entered into force on 16.01.2001. These legal documents provide the general regulations for the access and connection of electricity generation units to the transmission and distribution grid. According to RD1955/2000 (Ministry of Economy Spain, 2000, article 32), the plant operator bears the cost of connection to the transmission or distribution grid. If the connection of an individual generation unit implies the need for grid extensions or the construction of additional substations, the plant operator also has to bear the respective cost (deep charging approach)[22].

grid access lead time The Royal Decree 1995/2000 defines the procedures as well as maximum response times within which the operators of transmission and distribution grid must provide a response to a grid connection request and offer a grid connection contract. These response times are two months for the transmission grid and 15 days for the distribution grid, respectively (Ministry of Economy Spain, 2000, chapters 1 and 2). However, there are no time limits for the actual physical connection of a power plant to the grid.

22 The access conditions for small-scale RE plants (<100 kW) are different and subject to RD1699/2011 (Ministerio de Industria Turismo y Comercio, 2012).

According to data retrieved from the 'PV-Grid database' (PV Grid, 2014) in 2013 (for the assessment period 2012), the average grid connection lead time for large-scale PV applications in Spain was 3.75 months on average [23]. For the year 2011, a duration of 7 months (28 weeks)[24] was reported by 'PV-legal' (Garbe et al., 2012, p. 54), thus indicating a trend of shortening lead times.
Regarding wind energy projects, the 'Wind Barriers' project (Cena et al., 2010) reports an average grid access lead time for wind onshore projects in Spain of 33.50 months (2.8 years). However, the data refers to projects realized before 2010.

In the frame of the interviews conducted with Spanish RE sector stakeholders, this information was complemented and updated. For example, interviewee 17 reports an average duration for PV of 1.5-2 months (in extreme cases up to 3.5 months) and 2.5-6.25 months (in extreme cases up to 48 months/4 years) for wind energy projects. The average duration was said to be constant for both, PV and wind, over the past three years. Interviewee 20 reports that, on average, the duration is around 3 months (referring to various small/medium scale RE applications) and further states that the procedure should not exceed an overall duration of 6-9 months as this would make the projects unattractive. Interviewee 18 reports that, especially when connecting to the distribution network, significant delays occur due to the way the DSO's handle the applications. However, no quantification of the duration is provided. He further emphasize that binding time limits would be very important to provide clarity for developers. This statement is further supported by information provided by interviewee 21 (RE association) who reports that developers of PV systems experience significant delays when applying for connection to the distribution network. DSO's reportedly do not respect response deadlines so that developers face waiting times of up to 1-3 months until their requests are processed and additional 1-4 months until the grid connection is realised.

Regarding wind energy projects, especially large-scale RE developers (which are often also active as utilities), did not mention issues related to the duration of grid connection procedures. Instead, they stated that the negotiation with the grid operator is rapid and straightforward and that the lead time for realizing the physical grid connection is not a critical factor as it coincides with the time for constructing the power plant. Thus, it does not cause commissioning delays. This is demonstrated by the selection of quotes below.

> *"But for wind projects [...] if you are applying in distribution [grid] [...] then it's several months, three months, four months. But for big wind projects, this will take several years*

23 The database indicates a duration of 17 weeks for medium to large-scale industrial ground-mounted systems and 13 weeks for small to medium-scale roof-top installations on commercial buildings (PV Grid, 2014). The weighted average of the values has been calculated based on the 2012 market shares of the two technology segments in Spain according to the 'EPIA Global market outlook 2013' (EPIA, 2013).

24 The report indicates a cumulative average duration for 'grid connection permit and connection' of 28 weeks for medium and large-scale PV plants.

in Spain. [...] It's not months. It's years in Spain, yes. [...] Probably the average is one year and a half, or something like that." (Interview 19, wind developer & utility)

"I mean, the thing is that, depending on the stage of the permitting process, you need different permits from the grid. But it's not long, because in the very beginning of a project, when you see that you have a good place with good conditions, you write a letter to the grid operator and ask him if he has grid access nearby, or the distributors. And they have some time limits to answer you. And then if you have some access then of course you have to make some studies and to get some final permits, but in terms of knowing that you are going to have grid access or not, they are quite rapid. But I mean, I would say that it's a very fast process." (Interview 15, wind developer & utility)

"I don't know if it [the grid access lead time] was favourable, but I think it was never an issue. So I presume that it was very much within [the] expectations. [...] The construction and connection lead times were not particularly heavy or difficult. [...] I would say everything happened in less than twelve months [...]. " (Interview 13, wind developer & utility)

The above findings suggest that difficulties in the grid connection process arise in particular if the distribution grid is concerned whereas the connection process to the transmission grid is less problematic. These findings are consistent with results presented by Sonvilla, Piria et al. (2012, p. 19, 26) who report that the framework for grid connection of RE plants in Spain is better defined at transmission level than at distribution level, due to inhomogeneous technical and administrative requirements put up by the DSO's. Further, it is stated that DSO's lack sufficient personnel to handle large numbers of applications. The consequences are reportedly long grid connection lead times (with a strong regional variation) and sometimes high connection costs at the distribution grid level. The present interview results also give an indication that, especially for large-scale RE developers (here mainly wind energy) with a dual role as electricity utilities, it might be significantly easier to access the electricity grid than for small-scale developers. However, based on the limited number of interviews (10) conducted in the frame of this thesis, no definite conclusions can be deduced in this regard. Further analyses based on a larger data sample would be required to assess in more detail how the grid access conditions vary for the transmission and distribution grid and for different developer types.

None of the interviewees reported significant changes of the duration of the connection process for the observation period (2012-2014). However, due to the low installation rates after the RE support scheme was suspended in 2012, no clear trend can be deduced. Thus, the value is assumed as constant.

Based on the information presented above, as an estimate, an average duration of 1.5 years for the connection of wind projects is assumed throughout the observation period and 3.5 months are presumed for large scale PV projects in 2013 and 2014. For 2012, the adopted value for PV refers to the data provided in the 'PV-Grid database' (PV Grid, 2014) which specifies an average duration of 3.75 months.

PREDICTABILITY AND TRANSPARENCY OF GRID CONNECTION PROCEDURES The grid connection procedures for both, transmission and distribution grid, are transparently defined by articles 52-66 of RD1995/2000 (Ministry of Economy Spain, 2000). Also time limits exist within which the transmission or distribution system operator must respond to the initial requests for grid connection (see indicator 'grid access lead time' above). Grid operators are obliged to justify their decision regarding a specific access point and to suggest alternatives if a connection is not possible. Grid operators are also required to make information on the connection requests in their area of responsibility publicly available. Further details regarding the technical requirements for connection to the transmission grid are specified in the *'Procedimientos de Operación'* (PO12.1 and PO12.2) published by the Spanish grid operator Red Eléctrica España (Ministerio de Industria de España, 2005). A description of the procedural steps is also provided by Sonvilla, Piria et al. (2012, pp. 20).

The assessment of the transparency of the grid connection procedures provided the interviewed stakeholders shows a broad variation. Several interviewees (interviews 13, 14, 15, 16, 17, 19) stated that the transparency of the grid connection procedures is either average or good and thus does not constitute a barrier for RE deployment (neither today, nor in the past years). This valuation is illustrated by the interview quotation below.

> *"We have the collaboration of Red Eléctrica, which is the system operator and then you have also the distributors, so you have two ways of getting the grid. But I think it's understandable and we think it's a good way of getting the grid access. So I wouldn't complain on that, I think it's a very good system. [...] I think that improvements were done in terms of transparency and giving the same opportunities for everybody no matter if you are a traditional energy producer or distributor or a new entrant in the system. So everything is now defined and very transparent. And I think it has improved in these kind of things."* (Interview 15, wind developer & utility)

However, especially if the distribution grid is concerned, the grid connection procedure was also seen as very intransparent and dependent on the cooperativenes of the grid operator by part of the interviewees (interviews 18, 20, 21). This is illustrated by the quote below.

> *"It is not predictable, and transparent. [It depends] On the distributor, or even [on] the person who is in your area, so it is even more unpredictable than that. [...] With Red Eléctrica we clearly didn't encounter so many problems. Red Eléctrica, as operator of the transport network has its procedure, it's all more or less clear. You follow it and do the things. But usually you connect to the distribution grid, so there, yes, we are having*

serious problems. [...] they are supposed to answer, but it is not very clear in which time frame. Then often it goes on forever or they answer you one thing that in the end is not a real answer but they ask you one [another] thing. It goes on forever and it may take even years until you have a definitive answer." (Interview 20, RE developer)

Interviewee 21 further mentioned that the order in which RE projects are getting connected to the grid is very ambiguous and sometimes even subject to corruption. This statement is supported by findings of Sonvilla, Piria et al. (2012, p. 23) who report that, although the actual grid connection procedures in Spain are generally considered as transparent and clear by national stakeholders, especially the procedures for handling a large number of applications given limited grid capacity lack a clear and uniform national approach.

In summary, the observed split in the valuation of the procedural complexity suggests that the transparency depends on the individual case and on whether the connection concerns the transmission or the distribution grid. However, also the size and experience of the RE development company might play a role in this regard as all large-scale developers reported more positive experiences whereas the two small-scale developers complained about intransparency. However, based on the limited number of interviews, these effects cannot be fully explained. Nevertheless, based on the above information, an intermediate transparency is assumed (constant over the whole observation period).

Regulations for grid access and curtailment of renewable electricity According to Law 24/2013 enforced on 28.12.2013 (Government of Spain, 2013a, article 26.2) and the previous Law 54/1997 on the electricity sector (Government of Spain, 1997, enforced 29.11.1997), RE plants are entitled to priority grid connection and priority dispatch of electricity[25].

In case of physical grid congestion or due to technical security issues, and if there is no other possibility to guarantee safe network operation, the grid operator may curtail electricity generation (Ministry of Economy Spain, 2000). No compensation is paid if electricity is curtailed.

Transparency and predictability of electricity grid development The Spanish grid operator Red Eléctrica España (REE) is obliged to present a development plan for the transmission grid every five years (Ministry of Economy Spain, 2000, chapter

25 On European level, Directive 2009/28/EC of the European Parliament of 23 April 2009 on the promotion of the use of energy from renewable sources defines that the EU Member States should ensure that electricity produced from RES are granted priority grid access and priority electricity dispatch and that curtailment is minimized (European Commission, 2009a, article 16.2).

2)[26]. The five year development plans for each autonomous community in Spain are publicly available on the website of REE[27].

Several interviews with Spanish RE sector stakeholders confirm that the procedures of future grid development in Spain are generally traceable and clear. This is illustrated by the following interview statements.

> *"Yeah, there are some plans which are known by the promoters [developers] with some years in advance. So in principle this is transparent [...]. But regarding the plans, the planning of enhancing the grid, this is published every year and I think there is a kind of planning every six years which is known in advance. So you could know what exactly is going to happen."* (Interview 14, RE industry association, solar thermal)
>
> *It's very transparent and it's public, so everybody can see the grid growth and the grid spots that are going to be open in the coming years. So I think it's very, very transparent and public. [...] I think it has been always like this.* (Interview 15, wind developer & utility)
>
> *We have a procedure, which is called indicative planning for grid extension where the projections of demand and the projections of new installed capacity that was in the [...] list of approved investments in the ministry of energy is contemplated by the TSO. Which means that the grid extension is planned, it's indicative but it's very close to what actually happens at the end of the day."* (Interview 13, wind developer & utility)

However, in contrast to the above statements, part of the interviewees reported issues regarding the transparency of future grid development. For example, a written statement (via email) from one interview partner (interview 17, national government) indicates that for wind energy projects the grid development is 'very transparent and foreseeable' whereas for PV projects, the grid development is 'very intransparent and unforeseeable'. Two other interviewees (interview 18 and interview 20), both small/medium-scale RE developers for various RET, also stated that the grid development is 'very intransparent and unforeseeable'.

These observations suggest that problems regarding the transparency of the future grid development primarily concern developers of small-scale projects and, in particular, of PV projects. This, in turn, indicates that the issues might mainly relate to the distribution grid, whereas the development of the transmission grid was largely seen as unproblematic (cf. quotes above).

26 On European level, entso-e, the European Network of Transmission System Operators for Electricity is obliged by Regulation (EC) No 714/2009 on the conditions for access to the network for cross-border exchanges in electricity to provide a ten year network development plan as well as bi-annual outlooks on the adequacy of the planned capacities (European Commission, 2009b, article 8.3). The network development plan, however, has no binding character.

27 Weblink: http://www.ree.es/en/activities/grid-manager-and-transmission-agent/grid-planning-an-development (last accessed: 04.04.2016).

Information provided by interviewee 21 (RE association, all RET) supports this finding and confirms that "*there is a lack of proper incentives to coordinate distribution grid development*". This statement relates to the fact that the activities of Spanish DSO's are regulated by the Comisión Nacional de Energía (CNE) which was established by Law 54/1997 (Government of Spain, 1997) and determines the remuneration for DSO activities by means of a revenue cap system. According to interviewee 21, the capped revenues do not provide sufficient incentives for DSO's to integrate RE generation facilities into the distribution network. Against this background, there seems to be a lack of perspective regarding the future development of the distribution grid.

All interviewees stated that the predictability and transparency of future grid development did not change during the observation period (2012-2014).

5.4.1.4 *Administrative procedures for renewable energy projects*

ADMINISTRATIVE COST Regarding the share of administrative cost in the overall development cost of PV plants, findings of the projects '*PV legal*' and '*PV grid*' indicate a decreasing trend in administrative costs from 2012 to 2013. For 2012, the '*PV grid*' database (intermediate results of end of 2012) indicates a cost share of 75% for utility-scale projects[28], whereas for 2013, Sonvilla, Binda Zane et al. (2013, p. 26) specify a share of 43%[29]. This observation of declining cost shares could possibly be related to the decreasing number of PV projects realized in this time-frame (cf. figure 49) which might lead to a smoother administrative process. However, the strong fluctuation could also be due to varying data quality and the influence of data outliers as also the values for previous years rather suggest erratic fluctuations instead of a clear trend (2010: 33%[30], 2011: 47%[31]).

For 2014, the findings from the ten interviews conducted with Spanish RE experts in the frame of this thesis indicate an even lower share of administrative cost in the overall project development cost. Interviewees 17 and 18 both mention average cost shares for PV of about 10-15%. Thereby, interviewee 18 adds that the majority of these costs can be attributed to staff cost caused by the inefficiency of the administrative procedures ("*my time spent resolving red tape*") (see also quote below). Interviewee 20, although he does not mention specific figures for the actual cost, states that the administrative cost share is small and does not constitute a blocking factor, as long as it does not exceed 10-25% of the development cost. It should, however, be noted that several interviewees did not

28 The values provided by 'PV grid' (PV Grid, 2014) for segments B (50 KWp plants) and C (2500 kWp plants) were weighted with the 2012 market shares for commercial & industrial and ground-mounted installations as given in the 'EPIA Global Market Outlook 2013' (EPIA, 2013).
29 The values provided in Sonvilla, Binda Zane et al. (2013, p. 26) for segments B and C were weighted with the 2013 market shares for commercial & industrial and ground-mounted installations as given in the 'EPIA Global Market Outlook 2014' (EPIA, 2014).
30 Value based on EPIA (2010, p. 29).
31 Value based on Garbe et al. (2012, p. 8).

provide specific numbers for the cost shares with the reasoning that, on the one hand, the cost structure is highly project-specific and, on the other hand, different cost positions in the overall development cost are too difficult to separate. Thus a larger number of consultations would be required to deduce robust average values. Even more importantly, no significant number of new PV projects has been realized in Spain after termination of the support scheme in 2012, which makes a robust assessment of administrative costs in 2014 virtually impossible.

However, on the basis of the above information (interviews 17, 18, 20) an average cost share of 10-15% is assumed for 2014.

> *"The detail of this cost is very variable. Maybe from licensing, compliance with environmental legislation from planning regulations, procedures, techniques from the relevant ministry, licenses. But there is a part that is very important and it is the indirect cost. I noted here: The importance of indirect costs, opportunity costs and hidden costs. That is, how much it takes [employee's name] to argue one week with the government [...]. "*
> (Interview 18, RE developer)

For wind energy projects the administrative cost share appears to be lower than for PV projects, possibly due to the overall higher development cost of wind parks compared to PV plants. For wind energy, no comprehensive database on past cost shares across the EU exists. However, data collected in the frame of the 'Wind Barriers' project indicates an administrative cost share of 4.3% for wind onshore projects realized in Spain before 2010 (Cena et al., 2010, p. 133).

In line with these results, the interviews with Spanish energy sector experts indicate an average share of administrative costs in the project development cost of wind parks of around 5%. For example, interviewee 15 (wind developer & utility) states that the cost share is very low and does not exceed 2-5%. Interviewee 17 (government agency) provides information indicating a similar administrative cost share of 2-4% (stable over the past three years). Interviewee 19 (wind developer & utility) declares that administrative costs account for a maximum of 5-10% of the project cost and remained stable over the past years.

> *"It is a very small share [...] For us it's difficult to estimate the cost, because in our calculations we mix the procedure costs with the developing costs, which include the installation of the wind met mast and the operation and maintenance of those met masts and our energy resource analysis and these kind of things. But the cost of the administrative procedures is really a very small part."* (Interview 15, wind developer & utility)

Regardless of the moderate share of administrative costs in the overall project development cost, some interviewees still emphasize that they can become a critical factor for RE diffusion, especially under conditions of reduced economic support for RE projects.

Further, the volume of the required bank guarantees associated with the administrative process was mentioned as an important issue.

> *"Now that you know that in the future probably you will develop [only] three projects this year and [...] probably you are going to develop without any kind of incentives in the future, the cost of the administrative process is critical, yes."* (Interview 19, wind developer & utility)
>
> "*Regarding 10% - 15% this is not negligible. Put this in relation to the gross margin that I was telling you for a project and you will realize that the administration can break a project."* (Interview 18, RE developer)
>
> *"Sometimes it is not only the cost of the processes. Here in Spain they are asking [for] bank warranties for every administrative step you do. [...] You have one bank warranty for the access to the grid, you have one bank warranty with the local government so that you commit to develop the project. So in the end you realize that you have a lot of money, a lot of financial risk in the form of bank warranties. Sometimes it's not the cost of the projects, it's the amount of bank warranties you have in all the administrative processes."* (Interview 19, wind developer & utility)

DURATION OF ADMINISTRATIVE PROCEDURES The interview results reveal a large variability in the duration of administrative procedures for wind energy projects while for PV projects the bandwidth is lower. The major statements of the interviewees regarding administrative lead times for wind and PV projects are summarized in table 15.

The strong variation in the administrative lead times reported for wind parks can be attributed mainly to regional differences in the bureaucratic procedures. Several interviewees state that the process duration strongly depends on the attitude of the regional community towards RE projects and the cooperativeness of the respective administration as well as on the depth of contacts of the RE developer to the local officials (interviews 13, 15, 17, 18, 20). Here, the major factor determining the duration of the administrative procedure allegedly is *"getting to know the technician in charge of the project evaluation"* (interview 17). In this context, also the size and influence of the RE development company seem to play a significant role for the processing time, implying that large development companies have advantages compared to smaller developers (interview 20). Interviewee 18 also sees major problems in the inflexibility and unclear responsibilities in the local administrations as well as in political power-play on local level.

> *"A large company can always push harder. I mean, I've seen it. If a very powerful company is asking for a permission, they always try to make it a little faster than if it was a small one."* (Interview 20, RE developer)

Further, the insecurity regarding the duration of the process, due to a lack of formal deadlines and the strong variation depending on the regional community, are mentioned as major risk factors for both, wind and solar, especially against the background of an unstable RE policy regime (interviews 13, 15, 20). Also a lack of communication between the concerned administrative departments and the multitude of required permits at different administrative levels were mentioned as significant barriers, for both wind and PV, which lead to delays in the permitting process (interviews 20, 21).

Table 15: Interview statements regarding the duration of administrative procedures for non-residential PV and wind onshore projects in Spain (2014).

Interview	Technology	Statement
13	Wind	average 6-18 months
19	Wind	Average for wind: 2-3 years, estimate for PV: 6-12 months
21	Wind	Up to 4 years
17	Wind	Average 1.8 years (min: about 6 months, max: 3 years or more)
17	PV	Average 6-9 months (depending on size: <100 kW: 6 months, >100 kW: 6-9 months)
18	PV	Average 6-12 months, min. 6-8 weeks (if very good contacts to the local administration exist), max. 3-4 years (for very large plants)
20	PV	Min. 6 months, max. 2-5 years, optimum: max. 6 months

The interview quotes below are characteristic for the experiences of RE developers concerning the duration of permitting procedures for wind and solar projects in Spain.

"And sometimes the administrative local procedures will be related to, let's say, collateral investment in improving for instance equipment for the cities or the towns where the investment was taking place in the form of, for instance, sports facilities or road improvement or that kind of things. And it was some sort of a discretional approach and it was very much in the hands of the city government, mostly mayors, because these are usually small towns, which would negotiate and bargain with investors one by one and the outcome was pretty asymmetrical. And sometimes delays were produced related to that." (Interview 13, wind developer & utility)

"As we have had many experiences, there is a very wide range. [...] we have wind farms that we have developed in two or three years and there are others that we started in 1999 and they are still left. So there is a wide range. Everything depends on if the 'Comunidad Autónoma' wants to develop the project or they don't want to develop the project. If they are interested in developing the wind farm technology, I'm sure that they can do it very, very quickly and they press to the local authorities, they press to the grid company, etc. And you can develop the project so far, in like two, three, four years. If in the 'Comunidad Autónoma' they don't want to develop any project, you can stay for four years." (Interview 15, wind developer & utility)

"One of the big problems is that when you are starting a project, you don't know how long it will take you. It is one of the major problems, this uncertainty [...]. There are no

> *deadlines established or at least it is not very clear what these are or let's say that there are ways for them to avoid the answer or to ask you for additional things, so you never clearly know how long you will need, although if you are very lucky you could solve it in six months or you can go up to two years, three years or you never get the permission. Then, that's a pretty big problem which at least we have encountered."* (Interview 20, RE developer)

Literature, such as the *'Wind barriers'* project final report, indicates an average of administrative lead time of 4.8 years (57.74 months) for wind onshore projects realized in Spain before 2010 (Cena et al., 2010, p. 11). For 2010 (Iglesias, Río and Dopico, 2011) reports average administrative lead times of 5-6 years, however, here it is not clear whether this period also includes the grid connection lead time. Similarly Uyterlinde et al. (2003) report planning lead times (incl. grid access) of 1-8 years.

In the *'PV grid'* and *'PV legal'* project an average duration of 7.25 months (29 weeks) [32] in 2011 and a duration of 26.2 months (105 weeks) [33] in 2012 were identified. For 2013 no data is available from the project.

In summary, for onshore wind energy projects, durations of 0.5-4 years were reported by the interviewees. On this basis, an average duration of 2.5 years is assumed. For PV projects the duration reportedly ranges from 6-12 months (average: 9 months).
Regarding changes in the duration over the last 3 years, it is difficult to deduce a clear trend since only very few projects have been developed since the RE support scheme was suspended in 2012. Therefore, it is assumed that the situation for wind projects was constant throughout the observation period. For PV the 2012 'PV Grid' data is used and for 2013 the same value is assumed as for 2014. To verify these working assumptions, further research covering a larger number of wind and solar project developers would be needed. Thereby, particular focus should be on the examination of potential patterns depending on the type of RE development company.

COMPLEXITY OF ADMINISTRATIVE PROCEDURES The responsibilities for the realization of RE projects in Spain are located at different levels namely national (central government), regional (autonomous communities) and local level (municipalities). The three levels have different competencies whereby the major responsibility for the authorization process is anchored at the regional level. Here, the autonomous communities are in charge of spatial and environmental planning and the authorisation of RE plants

32 The value is based on the average duration of admin. process given in the PV legal final report (Feb. 2012) (PV Legal, 2012). The values for segments B and C were weighted with the 2011 market shares for commercial and industrial & ground-mounted installations as specified in the 'EPIA Global Market Outlook 2012' (EPIA, 2012)

33 Average duration of admin. process based on 'PV Grid' intermediate results (Q4 2012) Segm. B and C weighted with 2012 market shares for commercial & industrial and ground-mounted as specified in the 'EPIA Global Market Outlook 2013' (EPIA, 2013)

<50 MW. The authorisation is organized through public tenders in which RE developers compete for the project approval. At municipal level, communal land-use plans are developed and building permits for RE plants are granted. At the national level, RE targets, the RE support scheme and the general electricity sector legislation are developed (see Iglesias, Río and Dopico (2011) for a detailed description).

Complex authorisation procedures, in particular related to the regional tenders, have been identified as a critical factor for wind energy deployment in Spain. For example, Rio and Unruh (2007) and Iglesias, Río and Dopico (2011) point out that the lack of harmonization of permitting procedures and formal requirements among the autonomous regions as well as the intransparency of the selection criteria in the tendering process constitute major obstacles for wind energy in Spain. Cena et al. (2010, p. 133), based on their 2010 assessment of the administrative framework for onshore wind energy projects in the EU, report that authorisation procedures in Spain are fairly transparent but that the respect of deadlines in the decision making process is rather poor by European standards[34]. Regarding PV projects, the 'PV Grid' database indicates that obtaining the approval for a PV project on regional level involves moderate difficulties. Main problems mentioned are regional differences regarding the requirements relating to site specifications (PV Grid, 2014).

Hamelinck et al. (2012, pp. 183-200) provide an assessment of the administrative procedures for RE in the EU MS on behalf of the European Commission. For Spain the assessment shows that the administrative framework still needs improvement, especially with regard to the harmonization of regional bureaucratic regimes (Hamelinck et al., 2012, p. 199). An update of the assessment in 2014 (Ecofys, 2014, pp. 163-169) comes to a similar conclusion and again points out that the administrative system for RE in Spain needs improvement. The evaluation is based, among others, on the finding that there are no time limits or automatic approval deadlines for permitting procedures, no online application for permits is implemented, there is a lack of streamlining and coordination between different administrative procedures and no specific geographic sites for RE are dedicated (Ecofys, 2014, p. 164).

The majority of the RE experts interviewed in the frame of this thesis, and in particular those who are directly involved in permitting processes for either wind or PV projects, classify the complexity as either moderate or high. The majority of interviewees described the procedures as 'moderately complex', 'manageable' or 'not particularly complex but intransparent' (interviews 15, 17, 19, 20). According to interviewees 18 (RE developer) and 21 (RE association), the processes are very complex and critical, especially for large-scale projects (all RET). Interestingly, only stakeholders who are not directly

34 The evaluation assesses three parameters on a scale from 1-5 with 5 being the optimal score: The transparency of the authorisation and decision making process (score 3.57), the existence and respect of respective deadlines (score 2.53) and the authorities' attitude towards wind power (score 3.47). The scores for Spain indicate that the transparency and attitude are in the range of the EU-27 mean while the respect of deadlines clearly performs below the EU-27 mean (Cena et al., 2010, p. 133).

involved in the realization of RE projects claim that the complexity of administrative procedures is not a critical issue (interviews 12 and 16 (researchers), interview 14 (RE association)).

The selected interview quotes below represent the viewpoint of the RE experts on the administrative complexity in Spain. Further quotes have been presented in the foregone paragraph on the duration of administrative procedures.

> *" It [i.e. the complexity of admin. procedures] was bearable from a point of view of finance but it was discretional, because there was no common setting, regulation or approach. It was a classic example of local governments and cities and towns, basically speaking with investors to get a marginal profit on an approved investment. [...] Anything related to fixing the river bed to making a sports facility would be bargained."* (Interview 13, wind developer & utility)
>
> *"Yes, it is complex. In both cases there are a high number of authorities involved and a lot of permits required. In general, everything could be simplified by the use of a one-stop-shop. It would be something essential and a solution."* (Interview 17, government agency)
>
> *"There are autonomous [communities] which ask you for some things, at a time of the project and others ask you for the same things at the end of the project, therefore it can be more complicated. I think it should be perfectly clear: Requirements, deadlines and procedures, which everyone should know and should be able to realize a project under good conditions."* (Interview 20, RE developer)
>
> *"It's really complex, because there's a lack of communication between the departments of the government, so at the end everything is blocked because there's one more department who has to say a yes, for example [to the] ecological impact [assessment]. So the order is different from every single region and from time to time they also ask for different permits."* (Interview 21, RE association)
>
> *"It happens also for every single permit, if you are friend of the mayor it helps you, otherwise you're put in line, you are in the line and you have to wait, so at the end everybody has a friend in the mayor or the government [...] At the end then you need local people in every single place to develop. [...] You need to have the local feeling and the local taste. "* (Interview 21, RE association)

On the basis of the above information a moderate/average complexity of administrative processes is assumed for both, wind onshore and non-residential PV. The information provided by the interviewees further indicates that dealing with the administrative procedures might imply more difficulties for RE developers who do not possess local experience and direct local contacts, which might be a disadvantage, for example, for international companies compared to local stakeholders. However, this needs to examined further through future research. It is further concluded that the level of complexity was constant throughout the observation period (based on statements of interviewees 12, 17-20).

Integration of renewable energy planning with spatial and environmental planning As mentioned above, spatial planning for RE projects is handled at regional level by the autonomous communities. No national plan or guideline exists regarding suitable sites for RE plants. No specific sites or geographical areas are earmarked for the development of RE (see also Ecofys (2014, p. 164)). Consequently, the availability of suitable sites for RE projects depends on the willingness of the autonomous communities to indicate and provide these areas.

Interviewees report that the level of detail and professionalism in spatial planning for RE development varies strongly between the regional communities. In some autonomous communities detailed plans have been developed which provide a useful planning base for RE developers, in others no such plans exist (see quote below). Interviewees report that this can even lead to project failure in the course of the planning process.

> *"Sometimes here in Spain [it] has happened that you start doing the preparation in an areas that are supposed to be compatible with wind and in the end you find [that] somebody will tell that not. But then you have spent several years trying to develop a project. The problem here it has been a question of the responsibility of the local government. And [...] some of them have been better than others doing this. [...] There are regions that are doing average and others definitely have a lot of margin to this."* (Interview 19, wind developer & utility)

Interviewee 17 (government agency) provides information indicating that the spatial planning needs improvement for both, PV and wind. Especially land use conflicts and environmental issues complicated the planning of RE projects in the past. A suggested measure is to establish 'compatible areas' (based on an assessment of RE potential and consultation with RE experts) and announce these areas to RE developers.

Interview 16 (research institute) reports that such planning and earmarking of areas exists in some regions and suggests that a similar approach would facilitate the development in other regions as well.

However, based on their past experience, some RE developers (interview 13) do not see spatial planning as a critical issue.

> *"[...] [there are] areas protected because of its natural value. And areas protected because of stringent rules, urban siting. But I don't think that's really an issue, I think it's a country that has plenty of space and the rules when it comes to the use of land are pretty clear. I don't see that as a major problem."* (Interview 13, wind developer & utility)

5.4.2 *Diffusion indicator scores for Spain*

The CI scores (unweighted) for PV and wind energy for the period 2012-2014 are presented in table 16. To derive the overall CI score, the individual indicator scores are weighted with the technology-specific weighting factors from table 11 and multiplied according to the formula shown in equation 3 (both in in section 4.4). The resulting weighted indicator scores are included in table 33 in annex A.5.

From the results it becomes apparent that, due to the lack of economic support for RE (determinant A-II), the overall indicator score, i.e. the product of the individual determinants (cf. equation 3 in section 4.4), equals zero (cf. table 33 in annex A.5 for the weighted indicator scores). On this basis, with an overall CI score of zero, also the projected diffusion equals zero (cf. equation 12 in section 4.5) and therefore the technology penetration remains constant. Consequently, in this case, the lack of economic support acts as a blocking factor in the model that prevents any further diffusion.

Table 16: Composite diffusion indicator scores (unweighted) for wind energy onshore and non-residential PV in Spain (2012-2014).

		Scores wind			Scores PV		
Indicator component		2012	2013	2014	2012	2013	2014
A-I.	Existence and reliability of RES-E strategy & -support scheme	0.50	0.50	0.59	0.50	0.50	0.59
A-II.	Relative remuneration level for RES-E	0.00	0.00	0.00	0.00	0.00	0.00
A-III.	Revenue risk under RES-E support scheme	0.25	0.25	1.00	0.25	0.25	1.00
A-IV.	Access to finance for RES-E	0.52	0.50	0.53	0.52	0.50	0.53
B-I.	Fair and independent regulation of the electricity sector	0.81	0.81	0.81	0.81	0.81	0.81
B-II.	Existence of functioning and non-discriminatory markets	0.38	0.38	0.38	0.38	0.38	0.38
B-III.	Availability of reliable long-term contracts (PPA)	0.25	0.25	0.25	0.25	0.25	0.25
C-I.	Grid connection cost	0.25	0.25	0.25	0.25	0.25	0.25
C-II.	Duration of RES-E grid connection	0.55	0.55	0.55	0.74	0.73	0.73
C-III.	Predictability & transparency of grid connection procedures	0.50	0.50	0.50	0.50	0.50	0.50
C-IV.	RES-E access regime and regulation for curtailment	0.50	0.50	0.50	0.50	0.50	0.50
C-V.	Transparency and predictability of grid development	0.50	0.50	0.50	0.50	0.50	0.50
D-I.	Administrative cost	0.77	0.77	0.77	0.25	0.44	0.79
D-II.	Duration of administrative procedures	0.71	0.71	0.71	0.62	0.38	0.38
D-III.	Administrative complexity	0.50	0.50	0.50	0.50	0.50	0.50
D-IV.	Integration of RES-E in spatial & environmental planning	0.50	0.50	0.50	0.50	0.50	0.50

5.4.3 *Projections of RE diffusion for Spain*

As laid out in the previous section 5.4.2 the insufficient remuneration for both PV and wind energy throughout the observation period leads to a score of zero for determinant A-II., the 'relative remuneration level for RES-E'. According to the formal framework of the RE diffusion model (cf. section 4.5) this implies a blockage of the diffusion process also for the following years as the projected future diffusion is based on the CI assessed for the last year of the observation period (cf. equation 12 in section 4.5). Thus, this determinant becomes a blocking factor resulting in no future diffusion (cf. figure 6 in section 2.2.1.1).

In order to be able to perform a diffusion forecast for PV and wind energy in Spain which does not project a stagnation of the development due to the insufficient remuneration, a hypothetical scenario is regarded which assumes that the RE support scheme was not suspended in 2012. Ito this end, the remuneration levels and support scheme parameters of the period 2009-2011 are utilized to generate a hypothetical diffusion forecast for the period 2012-2014. Thereby, the actual market penetration in the years 2009-2011 is used to estimate the market growth parameter c_n which is then fitted to the CI scores assessed for the period 2012-2014 (applying equations 8 and 10 both in section 4.5). In doing so, the indicator scores describing the RE support scheme are adjusted accordingly to represent a continuation of the previous RE support scheme (scores A-I = 0.63, A-II 2012/'13/'14 wind: 0.12/0.11/0.14, PV: 0.26/0.38/0.47[35], A-III = 0.56[36] and B-III = 1). All other indicator scores remain on the same level as assessed for the period 2012-2014 (cf. table 16). The projection resulting from these assumptions indicates which diffusion rate could have occurred if the RE support scheme would have been continued after 2011.

As a variation of this theoretical scenario, the scores for the hypothetical remuneration (determinant A-II) are reduced by 50% to compare the diffusion assuming a reduced profitability for both, PV and wind energy projects. This scenario intends to demonstrate the effect which a reduction of the RES-E support levels, instead of a suspension of the overall support scheme, could have had.

As a further variation, a third hypothetical scenario is regarded which simulates the impact of 50% shorter administrative procedures compared to the actual situation (i.e. indicator scores for determinant D-II 2012/'13/'14 wind: 1/1/1, PV: 0.25/0.71/0.71). The remuneration levels are identical to those in the previous case (i.e. 50% reduced remuneration compared to the actual remuneration in 2009-2011). The results of this variant are meant to illustrate the impact of a reduction of non-economic barriers on the RE market diffusion.

35 See remuneration levels in tables 24 and 25 in annex A.5
36 Assuming a fixed support premium, see table 26 in annex A.5

The results of all three scenario variants are shown in figure 50 for non-residential PV and in figure 51 for wind energy onshore. In the graphs, the hypothetical diffusion under the three scenario variants is compared to the actual technology deployment during the period concerned.

The results suggest that, assuming a continuation of economic support for PV and wind energy after 2011, nearly 7.7% of the long-term potential for PV (i.e. 10 TWh generated electricity) and 22.4% for wind energy (i.e. 50.9 TWh generated electricity) could have been exploited until 2014. The actual deployment in 2014 amounted to only 20.4% of the economic long-term potential for wind and 6.3% for PV. The slight growth in the actual deployment after 2011 can be attributed to the implementation of projects that were already approved and planned before the RE-support scheme was suspended. Due to this system inertia, the actual deployment after the suspension of the support scheme is still higher in 2012 than for the the hypothetical scenarios.

The second scenario variant shows that, even under conditions of significantly reduced economic support for wind and PV, a slightly higher deployment of both technologies could have been achieved than observed in reality. Here, 20.7% of the long term wind potential (47.1 TWh) and 6.5% of the long-term PV potential (8.4 TWh) are exploited until 2014.

Under the assumption of reduced economic support but 50% shorter administrative lead times for the approval process of PV and wind energy projects, a substantially higher diffusion rate results compared to the previous scenario. Here, by 2014, 21.4% of the wind energy potential (i.e. 48.6 TWh) and 7.2% of the PV potential (i.e. 9.3 TWh) are exploited.

The findings indicate that with reduced but continuous economic support for RE, combined with a reduction of non-economic barriers, still a steady deployment could have been reached for both technologies. Especially the comparison between the second (reduced remuneration) and third (reduced remuneration and shorter administrative lead times) scenario variant highlights the role of non-economic barriers for the effectiveness and efficiency of RE-support policies. However, there are reservations regarding the results of these hypothetical scenarios as the actual indicator scores for the time-frame 2009-2011 are not available and the analysis is based on the scores for the time-frame 2012-2014. A detailed assessment of the historical CI scores before 2012 would be required to derive more accurate projections of the diffusion.

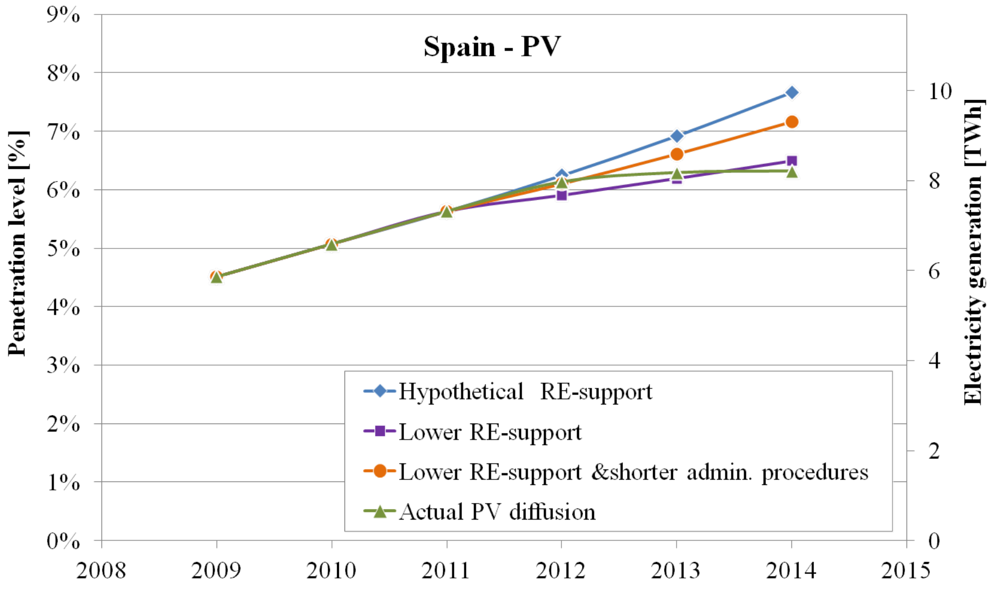

Figure 50: Hypothetical diffusion scenarios for non-residential PV in Spain: Penetration levels (%) and electricity generation (TWh) 2012-2014 for three hypothetical cases assuming a continuation of RE-support.

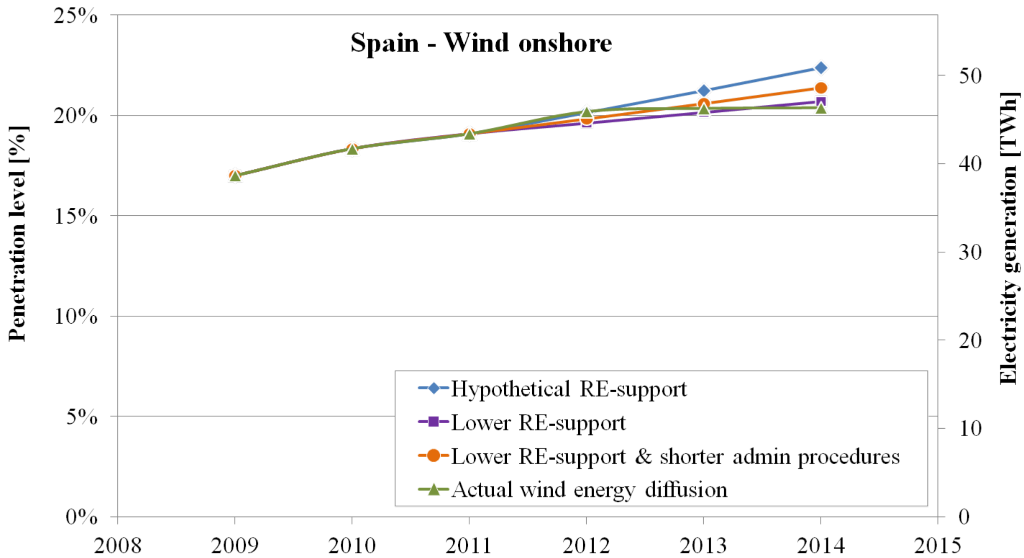

Figure 51: Hypothetical diffusion scenarios for wind energy onshore in Spain: Penetration levels (%) and electricity generation (TWh) 2012-2014 for three hypothetical cases assuming a continuation of RE-support.

5.5.1 *Framework for RE diffusion in the United Kingdom*

The following section presents the information used for calculating the diffusion indicator scores for non-residential PV and wind energy (onshore) in the United Kingdom (UK) for the period 2012-2014. The analysis is based on the methodology described in chapter 3, section 3.5 and follows the structure of the sixteen diffusion determinants as introduced in chapter 4, section 4.2.3. In addition to the referenced data sources, the analysis draws upon 10 semi-structured interviews with RE experts from the UK which were conducted between June 2014 and March 2015 (see table 5).

5.5.1.1 *Political and economic framework*

renewable energy strategy and support scheme The major legal basis for the UK RE strategy and RE targets was created with the 2008 'Climate Change Act' which includes a legally binding target of cutting carbon emissions by 80% by 2050 relative to 1990 levels. By 2020, carbon emissions are expected to be reduced to 34% of the 1990 level. (UK Parliament, 2008, 1(1))
Further, the UK 'Low Carbon Transition Plan' indicates that the power sector plays a major in role in this regard and foresees a share of 30% RES-E by 2020 (DECC, 2009b, 2011).
In the European RE context based on the EU Directive 2009 (European Commission, 2009a) the UK Government has prepared a National Renewable Energy Action Plan (NREAP) (DECC, 2009a). The NREAP sets a legally binding target of 15% RE in total final energy consumption by 2020 (DECC, 2009a). Apart from the indicative deployment trajectories for the different RE technologies in the NREAP, the UK does not have binding, technology-specific RE targets (DECC, 2009a, p. 109). However, the NREAP projects an indicative capacity of 2680 MW PV and 14890 MW wind onshore by 2020 (DECC, 2009a, Tables 10a/10b). While the observed development of wind onshore is close to the target trajectory, the actual PV capacity installed between 2010 and 2014 substantially exceeded the aspired quantities for 2020 EUROSTAT (2014). An overview of the historical deployment of wind energy onshore and PV in the UK (1990-2014) and the envisaged diffusion until 2020 under the NREAP are presented in figure 52.

In the time-frame 2012-2014 **financial support to RE** in the United Kingdom was provided through three main instruments: The 'Renewables Obligation' (RO), a feed-in tariff (FIT) for small-scale RE applications and, since end of 2014/beginning of 2015, remuneration through 'Contracts for Difference' (CFD) (DECC, 2016a). Further support exists in form of different tax-based instruments and loan schemes (DECC, 2016a).

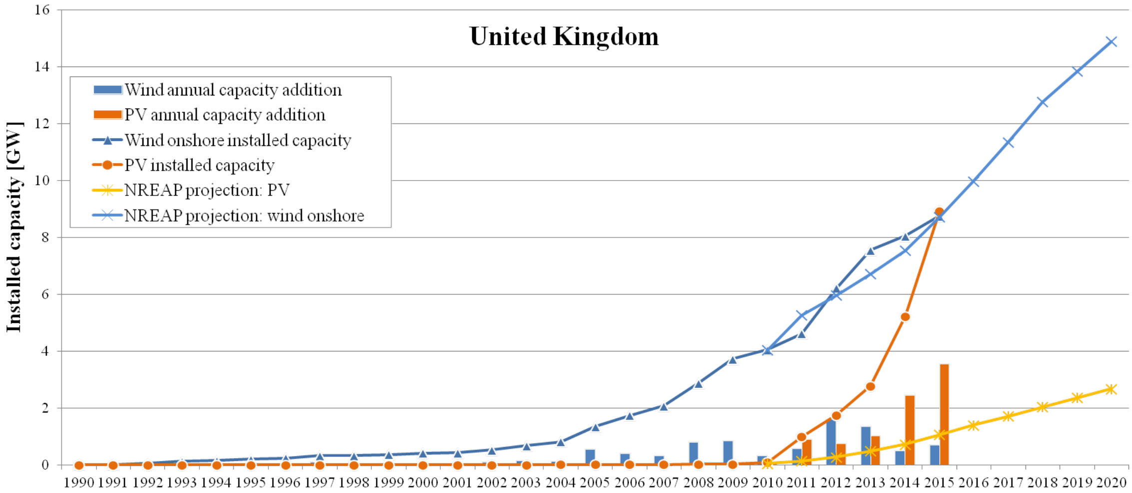

Figure 52: Cumulative installed capacities, annual capacity additions and future deployment targets for wind onshore and PV in the UK (actual deployment data available until 2015). Source: Own illustration. Actual deployment data based on EUROSTAT (2014), targets according to (DECC, 2009a).

The **RO scheme** was the major financial support instrument for large-scale RE since its introduction in 2002 until in 2014 the CFD scheme (see paragraph below) was introduced (CMA, 2016; DECC, 2016a; Ofgem, 2016d). The RO scheme obliges electricity suppliers to provide an annually defined share of electricity from RES. Certificates are provided to the generators per generated unit of renewable electricity and can be purchased and traded by the suppliers. The number of these Renewable Obligation Certificates (ROCs) issued per MWh of electricity is differentiated depending on the RE technology in order to take account of varying cost and maturity levels of the different technologies. The support level for new installations is reviewed and adjusted annually to take account of technology cost reductions. Instead of presenting the required number of ROCs the suppliers can also make a 'buy-out payment' by paying a fixed sum (adjusted annually) into a fund from which the money is distributed among those suppliers who have met their RE obligations. (Ofgem, 2016d)

The support under the RO scheme is granted for a period of 20 years, however, in 2013 it was announced that after March 31st 2017 the scheme will be closed for new projects. In 2037 it will be terminated completely[37]. (CMA, 2016; Ofgem, 2016d)

Regarding the period 2012-2014, the RO scheme can be considered as the major relevant support scheme for wind energy in the UK with more than 60% of the ROCs being issued to wind energy of which almost half refer to onshore installations (Ofgem, 2016a). The share of PV projects remunerated under the RO scheme was less than 1% in 2012/2013 and remained below 1.5% in 2013/2014 (Ofgem, 2016a).

37 In 2015, due to higher than expected deployment rates, the UK government decided to close the RO scheme earlier than originally planned to new large-scale PV (in April 2015) as well as to PV <5 MW and onshore wind plants (in April 2016) (DECC, 2016a).

The **FIT scheme** was introduced in Great Britain in 2010, mainly to stimulate the deployment of various small-scale RE installations. Eligible technologies for the FIT are generation units of PV, wind, hydro power and anaerobic biomass digestion (AD) $\leqslant$5 MW capacity as well as micro combined heat and power (CHP) plants $\leqslant$2 kW capacity (Ofgem, 2011a, 2013b, 2015b). For these technologies the FIT provides a guaranteed remuneration per generated MWh of electricity that is fed into the grid or consumed directly on-site. The tariff level is differentiated by technology and installation size and linked to an inflation-index. (Ofgem, 2016c)

During the observation period (2012-2104) the FIT scheme was modified several times with major changes especially in 2012. As a reaction to high installation rates and decreasing technology cost a first reduction of the tariff level for PV was made already in 2011 (Ofgem, 2011a). In 2012, however, not only only the tariff level was adjusted but a major revision of the FIT scheme took place ('Feed-in Tariffs Order 2012'). As a consequence, an automatic tariff degression mechanism was introduced for PV which implied a mandatory degression every nine months and an automatic degression coupled to the deployment rate. Also the support period was shortened from previously 25 years to 20 years for those projects implemented after August 2012 (Ofgem, 2013b). The deployment thresholds and the corresponding degression rates are set annually by the Secretary of State (Ofgem, 2014b). The degression mechanism has led to several tariff reductions for PV in 2013 and 2014 (Ofgem, 2014b). In 2014, for example, especially the FIT for PV systems >50 kW was cut drastically after reaching three degression thresholds (50/100/150 MW installed capacity). This led to a tariff reduction of 14% for these systems (Ofgem, 2015a). Apart from the scheduled tariff cuts, the FIT scheme for PV remained stable after 2012. In July 2013 the scheme was adapted through 'The Feed-in Tariffs (Amendment) Order 2013' but the changes referred mainly to the operating conditions of power suppliers under the FIT scheme and did not entail negative implications for PV generators (Ofgem, 2014b). In 2014 two minor modifications of the FIT legislation were made which refereed to the FIT accreditation process (only affecting hydro power) and the publication of tariff tables (Ofgem, 2015a, p. 32).

The major legislative documents governing the FIT scheme between 2012 and 2014 are as follows:

- The Feed-in Tariffs Order 2012[38]
- The Feed-in Tariffs (Amendment) Order 2013[39]
- The Feed-in Tariffs (Amendment) Order 2014[40]
- The Feed-in Tariffs (Amendment) (No2) Order 2014[41]

38 http : //www.legislation.gov.uk/uksi/2012/2782/pdfs/uksi$_2$0122782$_e$n.pdf
39 http : //www.legislation.gov.uk/uksi/2013/1099/pdfs/uksi$_2$0131099$_e$n.pdf
40 http : //www.legislation.gov.uk/uksi/2014/1601/pdfs/uksi$_2$0141601$_e$n.pdf
41 http : //www.legislation.gov.uk/uksi/2014/2865/pdfs/uksi$_2$0142865$_e$n.pdf

PV plants constitute the vast majority of generation units participating in the FIT scheme with nearly 99% of the installations or 82% of the installed capacity, respectively, between 2012 an 2014 (DECC, 2016b; Ofgem, 2016b). Less than 1% of the installations (11.4% of the installed capacity) remunerated under the FIT were wind turbines (Ofgem, 2016b). This is due to the fact that until 2012 PV development in the UK was mainly driven by small-scale installations in the residential segment and, to a smaller extent, by small to medium-scale rooftop installations in the commercial and industrial sector (EPIA, 2012, 2013, 2014; SolarPower Europe, 2015). After 2012, however, a stronger uptake of large-scale (>5 MW) ground-mounted installations could be observed (EPIA, 2014; SolarPower Europe, 2015), whereby also the RO scheme became relevant for PV (Westacott and Candelise, 2016). Therefore, regarding the observation period covered by this case study (2012-2014), the FIT scheme can be considered as the major relevant support instrument for PV in 2012 and a combination of FIT And RO scheme applies in 2013 and 2014.

In October 2014, the **CFD scheme** was launched as part of a comprehensive electricity market reform in order to successively replace the RO scheme and to provide financial support for low-carbon electricity generation technologies (DECC, 2015a, 2016a). In the frame of the market reform it is envisaged that, from April 2017 on, the CFD scheme will be the major support mechanism for all new medium- and large-scale RE generation units $\geqslant$5 MW (CMA, 2016). The first CFD auction was completed in March 2015 (DECC, 2016a).

Under the CFD scheme RE generators apply for a contract which guarantees a fixed price per MWh of generated electricity from eligible energy sources for a period of 15 years. Eligible generation technologies under the CFD scheme are divided into three categories: 'established technologies' (onshore wind, PV, CHP and hydro), 'less established technologies' (offshore wind, wave and tidal energy) and biomass. For each category there is a maximum budget which is allocated through competitive bidding rounds. The financial incentive under the CFD scheme is provided in form of a premium complementing the electricity market price (reference price) up to a defined level called the 'strike price'. The strike price for each project is defined through an auctioning process. In case the electricity market price (reference price) exceeds the strike price, the generator is obliged to pay back the difference. Thus, the CFD scheme is effectively comparable to a feed-in tariff as it guarantees a fixed remuneration level over a defined support period. (DECC, 2015a, 2016a)

The CFD scheme was officially launched in October 2014 but the first CFD auction was only completed in March 2015 (DECC, 2016a). As an instrument for transitioning towards the CFD scheme, a limited number of eight 'Final Investment Decision Contracts' was awarded already in May 2014, however, none of them referred to wind onshore or PV (NAO/DECC, 2014, 2016). Consequently, in the context of the assessment for the diffusion indicator, the CFD scheme is not considered for the deployment of PV and wind energy onshore as it was not applied to these technologies during the observation period. Nonetheless, the announced changes in the policy regime undoubtedly had an impact on investor's behaviour. However, as the indicator only captures applicable laws and regulations, it, by design, cannot take anticipated changes and respective strategic behaviour into account.

The risk of political instability in the UK according to the 'Fragile States Index' (FSI) was in the lower medium range compared to the EU average during the whole observation period (FSI UK 2012: 35.3, 2013: 33.2, 2014: 34.3, see also table 27 in annex A.5) [42].

REMUNERATION LEVEL FOR RENEWABLE ELECTRICITY The assessment of the relative remuneration level for wind onshore and PV (i.e. the average income under the given resource conditions and technical performance parameters per RE technology) indicates an intermediate profitability for wind onshore with a slight upward trend over the observation period (2012-2014)[43]. For PV, the data reveals an overall low profitability with a downward trend from 2012 to 2014 (see tables 24 and 25 in A.5).

REVENUE RISK FOR RENEWABLE ELECTRICITY The revenue risk for PV projects remunerated under the FIT scheme can be considered as very low because as soon a a project is accredited, the scheme guarantees a fixed remuneration level over the whole support period. Wind onshore generators participating in the RO scheme, however, face a slightly higher revenue risk as they are exposed to price risks on the electricity and certificate markets. The risk multipliers assumed for the support schemes are summarized in 26 in A.5.

ACCESS TO FINANCE FOR RENEWABLE ENERGY PROJECTS The sovereign credit rating serves as an indicator for the general stability and reliability of the national economic framework. *Standard & Poor's* assessment for the UK indicates an optimal 'AAA-rating' for the whole observation period (stable since 1978) (Standard & Poor's, 2015). For the diffusion indicator, the credit rating is normalized according to table 30 in annex A.5.
As a further indicator for the national financing conditions, the interest rate for long-term government bonds provided in the EUROSTAT-database (EUROSTAT, 2014) is retrieved. It is considered as a proxy variable for loan interest rates in the private sector. During the observation period the average annual interest rate on long-term government bonds in the UK slightly increased from 1.74% in 2012 to 2.03% in 2013 and 2.14% in 2014 (EUROSTAT, 2014) which suggests a slight deterioration of the financing conditions. However, the interest rates remain low, compared to other European markets (cf. table 28 in A.5.
Another data source that provides aggregated and regularly updated information on ac-

42 Source: Fragile States Index (Fund for Peace, 2014), weblink: http://fsi.fundforpeace.org/, index range EU: ca. 18-67, globally: ca. 18-114, high values indicate high risks.

43 Data on generation cost and remuneration levels was obtained from historical datasets of the web-based database on RES policy performance, technology costs and remuneration of the DIA-CORE project (DIA-CORE, 2016). The profitability is assessed based on the formula described in Table 7.

cess to finance is the 'Getting Credit Index' (GCI) which is part of the 'Doing Business Index' (World Bank Group, 2015). For the RE diffusion indicator, two sub-indicators of the GCI are particularly relevant: the availability of credit information (measuring the coverage, scope and accessibility of credit information available through credit bureaus or -registries, score range 0-8) and the legal certainty in finance sector (assessing legal rights in collateral- and bankruptcy law, score range 0-12)[44]. The sum of the two sub-indicator scores for the UK amounts to a score of 15 (out of 20) in 2012 and a score of 16 in 2013 and 2014 (cf. table 29 in A.5).

Based on the interviews with UK RE stakeholders, the conditions for financing of RE projects in the UK can be considered as generally favourable. Eight out ten interviewees[45] evaluated the financing conditions for RE as very good (interviews 26, 27, 29, 31) or good (interviews 22, 23, 24, 25). The UK capital market is generally perceived as strong and well developed with a large variety of stakeholders. None of the interviewees sees access to capital as a general barrier for RE deployment. However, three interviewees (22, 24, 25) mentioned that financing of small-scale PV projects can be an issue as investors focus mainly on the medium to large-scale segment and suggested that more specific programs should target this segment. Interviewee 22 also mentioned that financing of very large projects (>100 mio. £) can sometimes be difficult. A high importance is also attached to a stable and reliable policy framework

Further, several stakeholders declared that access to finance for RE developers got easier between 2012 and 2014 (interviews 22, 23, 25, 26, 27, 29), especially for PV (interview 31). This was explained by the following trends: the financing conditions generally improved after recovery from the global economic crisis; new investors and investor types, such as pension funds and specialized RE-funds, were entering the UK market; established investors became more experienced and open to RE investments (in particular to PV). Against this background, more and more attractive financing products became available for wind onshore and for PV.

The following examples of interview statements from UK stakeholders substantiate the above assessment.

> *"No, I think it [i.e. the availability of financing] is fine. I think it's a shortage of good projects not a shortage of funding. [...]*
> *It [i.e. availability of financing] got better, I think after the credit crunch."* (Interview 22, RE financing & Consultant)
>
> *"There is plenty of money for financing large-scale projects and there is plenty of money for financing rooftop projects. The problem is there [are] not enough projects. [laughs] There's a bit of a bubble. So people are paying too much money for projects. Which then*

44 The methodology of the index is explained in detail at: www.doingbusiness.org/methodology/getting-credit (last accessed 9.4.2016).
45 Two stakeholders did not provide an evaluation of this aspect.

the government gets nervous about and thinks it's too much money for the FIT, the ROCs. There's a bit of a vicious circle. But there's no shortage of money at all." (Interview 27, PV developer)

"I think it [i.e. financing RE projects] has become [. . .] almost mainstream. [...] Pension companies [are] moving in there. It is becoming very established, but I think the policy changes over the past year will have worried quite a lot of people. [...]
In terms of giving finance and trying to provide low cost finance, it's just what we keep coming back to: stable policy, stable, structured, sensible policy." (Interview 26, RE association, PV)

"And also there is some cheaper funding coming [...] into the market now as well so you are looking at lower cost of capital, funding from infrastructure [funds] and things like that. [...] I'll say the cost of funding with the Euro exchange rate and the turbine technology is helping [to] improve things." (Interview 23, wind developer)

According to some of the interviewed stakeholders (interviews 24, 25, 27), public financing instruments for RE, such as government-supported loan programs and credit lines, did not play a relevant role for wind onshore and PV development in the UK. Financing products offered by private banks and funds are perceived as sufficient or more attractive.

"There is something called the 'Green Deal', which hasn't been very successful so far. [...] The cost of capital was far too high, and there are a number of other issues that made it not very well received by the market. So there's again an intention to do these sort of things [but] in terms of how it's been implemented up to date there is significant room for improvement." (Interview 24, Regulation & Research, PV)

" [The Green Investment Bank] is basically a government owned bank, a bit like KfW, [...] they've got very set criteria about what they will and won't invest in. And they mostly invest in large scale projects (..) so smaller developers find it much, much harder to access [...] the funding and at the moment they only invest in certain technologies. They don't invest in [all] renewable technologies. So that is a barrier and we think that they should be allowed to borrow in the market, in the open markets and that they should have a wider investment brief, including cheap credit lines to all renewable [...]" (Interview 25, RE association, PV)

"We don't need it [i.e. the 'Green Investment Bank']. We can borrow cheaper." (Interview 27, PV developer)

5.5.1.2 *Electricity market structure and regulation*

REGULATION OF THE ELECTRICITY SECTOR In line with the European market liberalization strategy (cf. section 1.1), the UK has realized a far-reaching privatization and liberalization of the electricity sector (CMA, 2016, p. 11-15). Based on the 'Electricity Act

1989'[46] private companies can engage in the generation, transmission, distribution or supply of electricity based on respective licenses granted by OFGEM (CMA, 2016, p. 7-8, 15-16). Full unbundling of electricity generation, transmission and distribution activities was realized when in November 2011 the 'Electricity and Gas (Internal Markets) Regulations 2011' were enforced (Ofgem (2012, p. 12-13), Ofgem (2013a, p. 19-20), Ofgem (2014a, p. 11-12)). In 2000, based on the 'Utilities Act 2000' (UA00)[47] the independent national regulatory authority 'Office of Gas and Electricity Markets' (OFGEM) was created (CMA, 2016, p. 2)[48]. OFGEM is responsible for protecting the interests of energy consumers and safeguarding fair competition among energy suppliers and generators (OFGEM, 2016).

SHORT-TERM MARKETING OF RENEWABLE ELECTRICITY Intra-day electricity trading in the UK takes place at the 'APX Power' exchange (APX Power, 2016). The gate closure time for operations on the intra-day market is 60 minutes ahead of delivery (ACER/CEER, 2015; Hagemann and Weber, 2015). The liquidity (i.e. traded volume relative to national electricity consumption) of the UK intra-day market is rather low but showed a slightly increasing trend from 4.3% in 2012 to 4.4% in 2013 and 4.8% in 2014 (see data in table 31 in annex A.5). The limited liquidity of the UK wholesale electricity market has also been reported as a relevant barrier to new RE generators by Baringa (2013, p. 32) as it restricts the possibilities to compensate imbalance risks when marketing their electricity.

LONG-TERM CONTRACTS FOR RENEWABLE ELECTRICITY GENERATION For installations <5 MW capacity, which are eligible for support under the FIT scheme (cf. subsubsection 5.5.1.1) a PPA is provided implicitly, as the FIT implies a guaranteed off-take and remuneration of the generated electricity. This applies to the majority of PV installations, especially before 2013, as participation of large-scale PV in the ROC scheme started not until 2013 (DECC, 2016b). For installations >5 MW eligible under the ROC scheme (cf. subsubsection 5.5.1.1), a PPA needs to be closed with a counter-party, such as a bulk consumer or an electricity utility. This applies to most wind parks and to large-scale PV plants.

In their study on the availability of long-term PPAs for independent RE generators in the UK, Baringa (2013) report a reduction of PPA availability as well as a reduced attractiveness of terms and conditions for PPAs offered by large utilities between 2010 and 2013. The main causes for the deterioration were identified as follows: A decreasing demand on the part of PPA suppliers (i.e. utilities) was caused by the announced closure of the ROC scheme and a growing uncertainty about the development of the regulatory environment for RE in general. Regulatory uncertainty further caused a deterioration

46 Weblink: http://www.legislation.gov.uk/ukpga/1989/29 (last accessed: 27.07.2016)
47 Weblink: http : //www.legislation.gov.uk/ukpga/2000/27/pdfs/ukpga$_2$0000027$_e$n.pdf (last accessed: 26.07.2016)
48 For Northern Ireland: 'Northern Ireland Authority for Utility Regulation' (NIAUR).

of contract terms and a reduced willingness of PPA suppliers to hedge regulatory and market price risks.

However, according to evidence from interviews with UK stakeholders conducted in the frame of this thesis, the availability of PPAs did not constitute an obstacle for RE generators during the whole observation period (2012-2014). Instead, the stakeholders consistently reported that long-term PPAs offered by the large, vertically integrated utilities largely meet their needs and, additionally, new entrants offering a variety of short-term contracts have entered the market lately (2014/2015)[49]. Also, direct agreements between generators and industrial consumers or local communities are reportedly growing in importance and several interviewees (interviews 26, 27, 31) suggested that these types of contracts should be supported by the government (e.g. by providing standard terms and conditions and creating more regulatory certainty). Generally, the perceived availability of PPAs is reportedly improving.
The below interview quotes from UK RE stakeholders illustrate this assessment.

> *"I think it is sufficient, you can get PPAs for up to 15 years. It's getting quite sophisticated now, there is all different types of PPAs you can have with different providers, the main issue with PPAs is the bankability of the counter party, and then it's just down to negotiating with commercial terms. So there's no real shortage of PPA providers or ways to conclude a PPA. [...] I think it has changed over the last, let's say three years, because PPAs tended to be for much larger projects [...] now, if you approach them with a 5 MW PV project, they're very happy to give you a PPA offer and they are completely set up to do that. So that has changed quite a bit."* (Interview 31, PV & wind developer)
>
> *"There is not too much concern with being able to sell the power. It will definitely be sold. In fact if anything, people are talking about potential power shortages. [...] But, yeah, I don't think there is concern from the PPA front."* (Interview 28, wind developer)
>
> *"I think it is sufficient. At the moment we have long-term PPAs on all of our sites. We normally run a tender, and normally 50% of the people that we ask to bid come back and give us an offer. So, I think that they are very available at the moment in the UK. [...] It's perfect for us. There is actually a very good market in the UK."* (Interview 29, PV developer & investor)
>
> *"Not at all, [...] it has never been a problem, there has always been a PPA available for the investor. I would say, the only way that this is going to change is, if we rely more on PPA and less on FITs and ROCs. When the PPA becomes the only way of funding a project, then that becomes more important. But it hasn't been important until now. There have been enough PPAs available for the investors. [...] It's been enough for now, because otherwise the market wouldn't have grown so hugely. You know, [if] PPAs would have been a problem, then we wouldn't have seen this huge growth in the PV division. "* (Interview 27, PV developer)

49 By end of 2015, the UK government additionally introduced the 'Offtakers Last Resort (OLR)' scheme, to offer RE generators under the CFD scheme a way of getting a backstop PPA in case that fail to secure a contract otherwise (DECC, 2016a, p. 18).

5.5.1.3 *Grid regulation and infrastructure*

GRID ACCESS COST When connecting to the transmission or distribution network, RE generators are subject to the same regulations as conventional electricity generators (DECC, 2009a, p. 96). The 'Connection and Use of System Code' (CUSC) lays out the rules for economic burden sharing between the transmission system operator and generators seeking to connect to the grid (National Grid, 2015). Plant operators bear all costs for new power lines and related assets that have to be built solely to realize the connection of their power plant to the transmission network. However, if new transmission lines or related assets will also be used by subsequent connectees, the costs are borne by the TSO and levied upon all network users (DECC, 2009a, p. 90-91).
On distribution system level, the general principles for cost allocation are defined by the 'Distribution Connection and Use of System Agreement' (DCUSA) (DCUSA, 2016). Further, DSOs are required to publish a detailed statement of the methodology and charges for connection to their network on their websites. The costs of additional assets required only to connect the new generation unit are fully charged to the generator. This includes costs for the initial installation and any future operation and maintenance costs of the equipment. The costs associated to reinforcements of the existing grid infrastructure, if needed to integrate the new generation unit, are split between the DSO and the generator. (UK Power Networks, 2016)
A partial refund of the connection costs is possible if further generators connect at the same distribution network point within a time-frame of five years (DECC, 2009a, p. 90-91). This approach can be considered as a mixed charging approach.

However, very high grid connection costs, partly exceeding the overall value of the project by far and making it commercially unviable, have been reported by the interviewed stakeholders (see interview quotes below). This is due to strong regional disparities regarding the state of the distribution network infrastructure which partly entail substantial reinforcement needs.

High costs for grid connection on distribution system level have previously been mentioned as a barrier for RE deployment in the UK, for example, by Swider et al. (2008), R. Cossent et al. (2009), Simonds and Hall (2013) and Lockwood (2014).

> *"Well, we tend to aim for about 50,000£per megawatt. It's the cost that is viable. I mean, you can go higher than that, but generally that's our target. And when we started out doing our project development in 2010/11, well, most of the projects we applied for, I would say, had connection cost in that sort of area. In these days I would say maybe one in five has that kind of cost. The rest are all much more expensive, mostly unviable."*
> (Interview 27, PV developer)
>
> *" [...] And you don't need to have planning permission before you can apply [for] a grid connection. So a lot of people will be holding on to grid connection offers they won't*

use, because their project may never happen. So [...] the best thing would be, almost to guarantee that, if you got a project permission, you can get connected. " (Interview 23, wind developer)

"[...] to give you an example of how different it [the situation in Germany] is from here: We recently applied for a 3 MW connection, [...] and the nearest point of connection was about 50 meters [away]. But in the end they quoted us for [a] 24 km connection. [laughs] The quote was for/ I think it was 20 million £or something. For three megawatt. So that shows the difference between [what] they quote you for the whole upgrade, whereas in Germany just for the nearest point of connection." (Interview 27, PV developer)

" [...] the other thing that would help is to find a way to enable multiple parties to get together and fund an upgrade, so for example, let's say we've got 10 PV developers all in the same area who all need a grid connection, they all apply for a certain amount of capacity, they all get the same offer, it doesn't work for their projects individually, but together and working jointly they probably could easily fund the upgrade between the 10 projects. At the moment, from today's point of view, that's almost impossible to do [...]." (Interview 31, wind developer)

GRID ACCESS LEAD TIME Only part of the interviewees were able to provide information on the conditions for grid connection in the UK, as not all of them were personally involved in this aspect of the project life-cycle. Also, the interview findings indicate a strong variation in the duration of grid access procedures depending on the geographic region and the type and size of the project as well as depending on the network and voltage level concerned. However, an issue that was mentioned consistently by all interviewees is that during the last years, especially since 2013/2014, the grid capacity in the UK has become a major bottleneck for wind and PV deployment and that it leads to significantly longer grid connection times or even inhibits project development completely. For example, a PV developer (interview 31) reports that the average grid connection lead time increased substantially from 6-12 months 2-3 years ago to 24-36 months in 2015. Further, the interviewees reported that particularly severe capacity constraints relate to the distribution system infrastructure which inhibits the development of distributed RE generation (interviews 24, 25, 26, 27). Major concerns were also raised regarding the combination of long waiting times for grid connection with changes in economic support instruments for RE (see quotes below). This issue highlights the outstanding role of supportive and stable regulatory framework conditions to realize a high effectiveness and efficiency of economic support schemes for RE.

"[...] time-scales for connection are very important, because it dictates which feed-in tariff rate or renewable obligation rate that you secure." (Interview 27, PV developer)

"But the issue we have is not only do we have long-waiting times for grid connections but also we have a lot of uncertainty and recently a lot of changes in the support frameworks

> *like the FIT. So those two things combined mean that if you have to wait for a grid connection there is quite a high probability that the government is going to close off the subsidy scheme that you're aiming your project at, so that's the major factor really."*
> (Interview 31, PV developer)

The main information provided by the interviewees on the duration of grid access procedures is briefly summarized in table 17 and further supported through selected quotes in the text below.

Table 17: Interview statements regarding the duration of grid connection procedures for PV and wind projects in the UK (2014).

Interview	Technology	Statement
22	All RET	Large variation across the country depending on the capacity of the regional grid
23	Wind	Strongly depending on the region, up to 6-7 years to get the connection, three months to get the initial reply from the grid operator
24	PV	Depending on region and type of project, about 6-12 months if the network is not constrained or if connecting to lower voltage levels, 3-6 years if grid upgrades are required or if connecting to higher voltage levels
25	PV	High uncertainty regarding time-frame and cost of grid connection depending on region and grid capacity, 4-6 years (in areas with constrained grid, e.g. in the South of England)
26	PV	Ranging from a few months to 12-18 months
27	PV	Up to three months for the initial reply, 6-12 months for the physical connection on a low voltage level (11-33kV), 12-18 months on higher voltage levels (132kV)
31	PV	Total lead time today ca. 24-36 months, 6 months is the absolute minimum, sometimes up to 5 years, lead time 2-3 years ago ca. 6-12 months

The results of the '*PV Grid*' project correspond with the above described trend. According to data of (PV Grid, 2014), the average cumulative process duration for obtaining the grid connection permit and to realize the actual physical grid connection of PV installations in 2012 was 22 weeks for large-scale installations (2500 kWp) and 7 weeks for smaller, commercial rooftop systems (50 kWp)[50]. By 2014, the grid access lead time remained the same for commercial rooftop systems but had increased to 47 weeks for large-scale ground-mounted installations (PV Grid, 2014). However, especially regarding large-scale ground mounted installations maximum durations of up to 100 weeks are reported.
Based on the information retrieved from the interviews backed by the information from the 'PV Grid' database it is assumed that, in 2014, it took on average 12 months (48 weeks) to obtain grid connection for a utility scale PV project. Corresponding with the

50 The values are based on intermediate results retrieved from the '*PV Grid*' database in 2013. The data was based on surveys conducted end of 2012.

reported trend of lengthening processes during the past three years, the value for 2013 is interpolated using the 'PV Grid' data for 2012.

For wind energy, the information retrieved from the interviews is too limited to deduce reliable conclusions. Only one interviewee provided statements specifically referring to wind energy. However, if wind turbines are to be connected to the distribution network, generally the same process durations can be expected as for large-scale PV plants connecting to higher voltage levels of the distribution network (1-6 years, cf. table 17). According to Cena et al. (2010, p. 9) the grid access lead time for onshore wind projects in the UK before 2010 was 8.36 months on average, which was well below the EU-27 average of 25.83 months at that time.
As more recent information on common grid access lead times for wind energy projects in the UK is not available, it is assumed that the grid connection lead time successively increased from the value reported by Cena et al. (2010) to a national average of three years (36 months) in 2014. Translated into the indicator, this value takes account of the fact that the duration of grid connection can act as a significant barrier to RE deployment in the UK. Nevertheless, it should be noted that the strong regional disparities regarding grid capacity and resulting connection lead times (and costs) can not be reflected by the indicator in its present form.

> *"I mean, again it varies depending on the area and so basically six different areas, geographically, in the UK and each one has its own separate conditions and that's one problem actually. There's no uniform set of requirements across the entire country. So the time scales could vary massively. So for example, in the Southwest of England, near Bristol [for] any connection above 11 Kilowatts, the delay is between 4 and 6 years to connect to the grid [laughing] quite amazingly. [...] However somewhere else, like say the Northeast of England, you might be able to connect very quickly and at a much lower cost, so it really varies."* (Interview 25, RE association)
>
> *"It's getting longer and longer now [...] it used to be, my understanding was, in a matter of months, but sometimes it's up to/ Especially some very big projects have been trying to connect to transmission lines, not just distribution lines, and those connections, the big ones, can take up to a year, a year and a half. So the general trend is it's lengthening."* (Interview 26, RE association, PV)
>
> *"[A waiting time of 5 years] For a PV project [...] kills a PV project. Nobody is interested in a project that can't be sold for 5 years. For wind projects [this] is a little bit different, because [...] for a very large wind project, maybe an offshore wind project, the time scales are much longer and waiting 5 years for grid connection is not really ideal but it may be possible from a project point of view."* (Interview 31, PV developer)

Predictability and transparency of grid connection procedures According to DECC (2016a) several measures have been put in place to ensure that TSOs and DSOs provide all necessary information on cost-estimates and timetables for grid connection to all generators seeking to connect to the grid. The terms and conditions for connecting to the UK transmission grid are defined in detail by the 'Connection and Use of System Code' (CUSC) (National Grid, 2015). For connections to the distribution network, the 'Distribution Connection and Use of System Agreement' (DCUSA) describes the general procedures and responsibilities for all users of the distribution grid (DCUSA, 2016). Statutory provisions oblige 'National Grid' to provide a connection offer including the prospected date of connection and the related costs, within three months after receipt of an application (DECC, 2016a, p. 25). Likewise, DSOs are obliged by the 'Distributed Generation Standards' to provide all necessary information to generators willing to connect to the network and to respond to connection requests within time-scales defined for each type of informational service (Ofgem, 2011b). In accordance with these standards, all DSOs provide connection guidelines, charging methodologies, network availability maps and application forms on their websites. However, the clarity and user-friendliness of the provided information reportedly varies between the different DSOs (Simonds and Hall, 2013).

However, although the procedural steps and statutory provisions for connecting to the UK electricity grids are clearly defined and broadly communicated, the transparency of the process could still be substantially improved. All of the interviewed stakeholders expressed strong concerns about the transparency of the grid connection procedure, especially regarding the connection charges and time-frames for grid connection. The situation reportedly exacerbated drastically between 2013 and 2014 as grid capacity becomes increasingly scarce. The interview quotes presented below illustrate the situation.

The interview findings highlight that, firstly, the present connection procedure does not provide generators with a realistic estimate of the connection cost because the calculation is done on the basis of a queue (i.e. 'first-come-first-serve principle') which also considers hypothetical projects which might actually not be built but still increase the projected connection costs for all subsequent projects. Likewise, the present process does not allow for a potential coordination and bundling of projects seeking to connect in the same area, which would entail greater cost transparency and possibly economic benefits for the involved project developers. Further, although generators seeking connection to the grid may chose between different types of information offers (i.e. quotes) for connection to the grid, an iterative optimization of the connection characteristics is not possible. This means that the generation unit to be connected to the grid can not be optimized with regard to the available grid capacity in order to minimize connection costs (see also Simonds and Hall (2013)).

> *"Yeah in terms of a simple process of applying, there are now rules in place, but again they're not necessarily uniform across all of the, all of the grid companies. They each have their own policy basically."* (Interview 25, RE association)

> *"No, it definitely doesn't work well. The biggest problem is that you effectively go into the queue for grid, which is over-subscribed. And the problem with the queue is that a lot of those people in the queue, including yourself probably, may or may not have planning permission. So you don't know whether or not that is a realistic queue or not. But of course the grid operator has to treat it as if it is. So you might appear that you are a long way back in the queue or you might have an unrealistic grid connection cost. "* (Interview 28, Wind developer)
>
> *"The whole process for getting a grid offer is quite transparent, I mean. The only thing you can't see is how far in the queue you are, you can't see who is above you. What the likelihood of you getting capacity any time soon is."* (Interview 29, PV developer)
>
> *"So when you now apply for a grid offer, you typically get either a very, very expensive connecting, because of the upgrades that are needed. So that's option one, you get a very expensive connection. Option two, you get a connection which is an active connection, which means you'll be connected any time there is not a problem on the grid. But there is no estimation of the time that you will actually spend connected and disconnected to the grid, that can be relied upon. Nothing is underwritten. So you never even know, if you are going to be online ninety-nine percent of the time, or if you are going to be offline ninety-nine percent of the time. They give you an estimate. But that's all it is. It's an estimate, but it's not underwritten or anything. Or thirdly, they just say: "we can't connect you"."* (Interview 29, PV developer)
>
> *"It's guesswork. [laughs] It's strange, but when we look at the project, there is absolutely no way of telling whether we've got a good chance [to get grid connection] or not, until we write to them and then wait for their answer. It's absolutely guesswork."* (Interview 27, PV developer)

Regulations for grid access and curtailment of renewable electricity Conventional and RES-based generators in the UK are equally entitled to a guaranteed connection to and use of the electricity grid (DECC, 2009a, p. 89). Thereby, electricity generated from RES is not eligible for priority dispatch[51]. However, in case that curtailment of electricity generation is required to ensure system stability, all affected generators are compensated for their losses (DECC, 2009a, p. 89).

Transparency and predictability of electricity grid development Grid expansion plans on transmission and distribution level are prepared by the respective network operators and monitored by OFGEM to ensure that the planned investments are in the interest of consumers (DECC, 2016a, p. 18-19). The present plans cover the period 2013-2021.

The plans for the development of the distribution network are provided by the individual DSOs on their respective websites but partly only upon request or against payment. Fur-

51 In Northern Ireland, generation units using energy from RES are dispatched with priority (DECC, 2016a, p. 23).

ther, a ten-year outlook on the development of the transmission network under different energy scenarios is provided annually by the British TSO 'National Grid'. The report as well as maps and underlying data are publicly available on the web page of 'National Grid'[52].

The stakeholders contacted in the frame of this study evaluated the transparency and predictability of the grid development largely as acceptable or average but not fully satisfying. For example, several interviewees (interviews 24, 26, 27, 29) lamented that the grid development plans lack a strategic long-term vision, especially with regard to the integration of distributed RE generation. Other interviewees (interviews 25, 31) mentioned that the available plans are quite complex and difficult to understand, especially for smaller, less experienced RE developers. The interviewees consistently stated that the transparency and predictability of the electricity grid development in th UK did not change between 2012 and 2014 (interviews 24, 27, 29, 31). The below quotes illustrate this assessment.

> *"Yeah, they have their network plans. But generally they are dealing with known demand today and not future-proofing the network. It's quite disappointing as a plan and that they know that they got people like us queuing up for connection, so they are being asked by the government to just do enough connectable under the current plans. But they are not doing anything to build extra capacity. [...] I think the government needs a bit more of a long term policy and targets on how much energy we'll generate through renewables and then needs to model the infrastructure around the targets. But our political system is far too short-term for that to happen. It tends to evolve around five year cycles these days and we need a twenty year plan."* (Interview 27, PV developer)
>
> *" We need to have an overarching infrastructure plan for the UK, to say "this is where we need to get by 2050 in terms of distributed generation, this is the grid that we need for that" and a plan to say "okay, what do we need to invest in tomorrow?". And we actually need to then empower the DNOs to go and make those decision and spend that money [...] "* (Interview 29, RE developer & investor, PV)
>
> *"The information for that is publicly available [...] you can actually see what's going on, but how that actually translates to exactly which areas could be having a better grid connection by which date, that is still a bit difficult to anticipate for developers. And even the network operators don't always know exactly where the first upgrades would be done in program. So I'd say it's partially transparent."* (Interview 31, RE developer, PV & wind)

52 Weblink: http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Electricity-ten-year-statement/ETYS-Archive/(last accessed: 04.08.2016)

5.5.1.4 *Administrative procedures for renewable energy projects*

ADMINISTRATIVE COST Only half of the interviewees provided information on the administrative cost share in the overall development cost of RE projects. This was partly because some stakeholders did not posses this information and partly because the broad variety of the projects (e.g. regarding sizes and site conditions) did not allow them to make general statements. An overview over the statements in given in table 18.

Table 18: Interview statements regarding the cost of administrative procedures for PV and wind projects in the UK (2014).

Interview	Technology	Statement
25	PV	Depending on project size and location (10K-100K£)
27	PV	About 25% (for a 5 MW project, about 25K£)
31	PV	12-15% of development cost (about 5£/KWp)
23	Wind	About 300-500K£, 50-75% of soft costs[53]
30	Wind	Up to 10% of the development cost[54]

Based only on the limited information from the interviews it is not possible to deduce a reliable conclusion on the common administrative cost share. However, assessments of the administrative procedures for PV were also carried out in the frame of the '*PV Grid*' and '*PV Legal*' projects. Repeated surveys among project developers and RE associations conducted between 2012 and 2014 revealed an average share of administrative cost in the overall project development cost (excl. hardware) for non-residential PV installations[55] of 23% in 2013 and 2014 (Sonvilla, Binda Zane et al. (2013, p. 28), B. Barth, Concas, Binda Zane et al. (2014, p. 7)). In this context, the present results appear plausible, as they indicate a similar range (12-25%) for different sizes of non-residential PV installations. Thus, based on the broader empirical evidence presented by Sonvilla, Binda Zane et al. (2013) and B. Barth, Concas, Binda Zane et al. (2014), an average share of 23% is assumed for the period 2012-2014.

Regarding wind energy, Cena et al. (2010) conducted an assessment of wind onshore projects in the EU Member States. For the UK, they found that the average administrative cost as percentage share of the overall project cost (including hardware costs) was 2.67%, which corresponds to the average value for the EU-27 (Cena et al., 2010, p. 139). The interview findings, however, indicate a cost share of up to 10% of the overall project cost (interview 30) or 50-75% of the development cost (interview 23), respectively, which is well in line with the recent findings for Germany and Spain (cf. sections 5.3.1 and

53 This figure refers to the share of administrative cost in the project development cost, excluding hardware cost.

54 This figure refers to the share of administrative cost in the overall project cost, including hardware cost.

55 The data indicates a cost share of 36% for commercial systems with a capacity of <1000 KWp and 12% for large-scale ground-mounted systems >1000/2500 KWp. A weighted average of these values was derived based on the respective market share of the segments.

5.4.1). Concerning the trend over the past years, several interviewees (23, 27, 28) reported that the requirements, especially regarding impact analyses such as bird studies, have increased which lead to higher personnel cost and thus higher overall administration costs (see quote below). A similar trend has been observed in Germany (cf. section 5.3.1). On this basis, as long as no better data is available, it is assumed that the administrative cost share has increased linearly from 2.67% in 2010 to 10% in 2014, which is comparable to the development in Germany.

> *"Yeah, I mean, it's just going up. In a general sense, because there [are] more things to study, longer periods for which to study. So, if you look at, let's say, five years ago or longer, you usually got away with one year of bird surveys, whereas now it is accepted that you have to do two [...]. In addition, things like the number of different environmental considerations you have to think about have increased, which means that the general costs are going up. And then, because it's taking longer, there will be more project management costs as well."* (Interview 28, wind developer)

Further, interviewees stated that, although the administrative cost showed a growing trend, it still does not constitute a significant barrier for the development of wind energy onshore, as demonstrated by the below interview quotes.

> *"It's not negligible, but it's one of those things that is [...] not a massive barrier I would say."* (Interview 30, wind developer)

Duration of administrative procedures Several statutory provisions regulate the duration of administrative procedures in the UK. For onshore RE projects >50 MW, the 'National Planning Act 2008' applies, which specifies that the process from receipt of the application at the authority to the final decision should take less than one year (DECC, 2009a, p. 45, 55). For smaller generation units (<50 MW), country-specific local planning regulations apply (cf. subsequent paragraph) under which separate time-limits are defined. For example, in the 'Town and Country Planning (General Development Procedure) Order 1995'[56], which is the relevant planning regulation for England[57], the following time-limits are defined: Minor applications shall be processed within a maximum of eight weeks after receipt of the application, larger projects shall receive notice within 13 weeks and applications involving Environmental Impact Assessments (EIA) shall be processed within a maximum of 16 weeks (DECC, 2009a, p. 55). Further, for applications which require more processing time than defined by the statutory time-limits, a 'planning guarantee' is given, which specifies that no local authority should take longer than 26 weeks to take their final decision (including appeal processes) on a project (DECC, 2013, p. 27).

56 Weblink: http://www.legislation.gov.uk/uksi/1995/419/contents/made (last accessed: 4.8.2016).
57 Separate regulations and time-frames apply in the rest of the UK (see DECC (2009a, p. 52-54)).

Detailed information on the performance of the UK RE planning system can be retrieved from the publicly available 'Renewable Energy Planning Database (REPD)' (DECC, 2015b). The database specifies the application and approval or repeal dates, respectively, for all RE projects that require planning permission (i.e. all projects >10kW).
According to REPD-data, the average duration for obtaining a planning decision for PV projects was 14.3 weeks in 2012, 14 weeks in 2013 and 16 weeks in 2014. In case that a project was initially rejected and an appeal was filed[58] the time-frames extended to three to four times the duration of a normal decision process (i.e. 69 weeks in 2012, 58.3 weeks in 2013 and 45.3 weeks in 2014).
For wind energy onshore, the average time-frame between application and approval of a project was 10.3 months in 2012, 11.5 months in 2013 and 8.6 months in 2014. In case of appeal processes[59], the duration amounted to 20.2 months in 2012, 20.6 months in 2013 and 13.2 months in 2014.

The findings from the interviews conducted in the frame of this thesis correspond with the information provided by DECC (2015b). Based on the statements of the UK interviewees, average durations of 12 months for wind energy and around 14 weeks for non-residential PV installations are assumed for 2014. The respective statements of the interviewees are summarized in table 19.

Table 19: Interview statements regarding the duration of administrative procedures for PV and wind projects in the UK (2014).

Interview	Technology	Statement
24	PV	About 12 weeks
25	PV	A few weeks to a few months, generally 12-16 weeks are realistic
26	PV	Not specified
27	PV	12-16 weeks, up to 2 years in case of appeal process
29	PV	12-16 weeks (for free-built projects)
31	PV	20-24 weeks (5-10 MW projects), bigger projects might take longer
22	Wind	About 6-12 months
23	Wind	About 12 months, maximum up to 3 years
28	Wind	6-12 months (depending on project size)
30	Wind	Strongly depends on project size & complexity, max. up to 4 years

Regarding the development over the past years, the data provided by (DECC, 2015b) suggests unchanged conditions for PV and a slightly decreasing trend for wind energy. With respect to the duration of appeal procedures, both technologies show a decreasing trend. However, this information partly contradicts the evaluations by the interviewed stakeholders. Three interviewees (23, 27, 28) reported that the procedures got longer due to more complex requirements and overloaded authorities, two (30, 31) stated that the

58 Appeal processes were filed for around 8-10% of the initial PV project applications between 2012 and 2014 (DECC, 2015b).

59 Appeal processes were filed for around 20-30% of the initial wind onshore project applications between 2012 and 2014 (DECC, 2015b).

duration did not change while only one interviewee (29) reported a trend towards shorter procedures as authorities get more experienced. On the basis of this partly inconsistent information, stable values (12 months for wind energy and 14 weeks for PV) are assumed for the period 2012-2014.

Assessments of the administrative procedures for PV were also carried out in the frame of the *'PV Grid'* and *'PV Legal'* projects. Surveys conducted between 2012 and 2014 revealed an average duration of the administrative permitting processes of 24 weeks for large-scale ground mounted PV projects, 8 weeks for commercial rooftop installations and 2-4 weeks for small residential systems (PV Grid, 2014)[60]. Accordingly, the average for non-residential installations (rooftop and ground-mounted) would be 16 weeks, which corresponds well with the ranges mentioned by the interviewees (cf. table 19) and provided by (DECC, 2015b).

COMPLEXITY OF ADMINISTRATIVE PROCEDURES Administrative procedures for RE projects in the UK are governed by the planning system. Thereby, the applicable procedure and responsible authority depends on the size of the RE project and the RE technology. For onshore RE projects, the following applies[61]:

- Projects $\leqslant$ 50 MW across the UK fall within the responsibility of local planning authorities under the 'Town and Country Planning Act 1990'[62] (England and Wales), the 'Town and Country Planning (Scotland) Act 1997'[63] and the 'Planning (Northern Ireland) Order 1991'[64];
- Projects >50 MW in England and Wales are subject to the 'Planning Act 2008'[65]. They are first examined by the 'National Infrastructure Planning' (NIP) authority and the final decision is taken by the Secretary of State for Energy and Climate Change;
- Projects >50 MW in Scotland are handled by the Scottish Government according to Section 36 (S36) of the 'Electricity Act 1989'[66];
- Projects in Northern Ireland are processed by the government department of Enterprise, Trade & Investment.

60 Data was retrieved from the *'PV Grid'* database in 2013 and 2015 (PV Grid, 2014) and intermediate results were obtained directly from the project coordinator Eclareon. No changes were reported during the assessment period.
61 Separate regulations apply to offshore generation units DECC (2014, p. 1).
62 Weblink: http : //www.legislation.gov.uk/ukpga/1990/8/pdfs/ukpga$_1$9900008$_e$n.pdf (last accessed: 5.7.2016).
63 http : //www.legislation.gov.uk/ukpga/1997/8/pdfs/ukpga$_1$9970008$_e$n.pdf
64 Weblink: http://www.legislation.gov.uk/nisi/1991/1220/made (last accessed: 5.7.2016).
65 Weblink: http : //www.legislation.gov.uk/ukpga/2008/29/pdfs/ukpga$_2$0080029$_e$n.pdf (last accessed 5.7.2016)
66 Weblink: http://www.legislation.gov.uk/ukpga/1989/29/contents (last accessed: 5.7.2016).

A comprehensive overview of the planning-related regulations and their regional applicability is provided in DECC (2009a, table 4.2.1(a)). Information on the details of the local authorisation process and application requirements must also be published by the local planning authorities on their websites (DECC, 2009a, p. 52). Additional to the websites of the local planning authorities, the 'Planning Portal'[67] provides comprehensive guidance on the application process in England and Wales. There is no one-stop-shop arrangement for the authorisation of RE projects and several statutory consultees must be contacted in the course of the procedure (DECC, 2009a, p. 54).

The majority of the interviewed stakeholders described the authorisation procedures as well manageable and of average complexity (interviews 23, 24, 25, 27, 29, 30, 31). The administrative complexity reportedly increases with the size of the RE project and is particularly low for small-scale projects operating under the FIT scheme (interviews 24, 25, 26). Some stakeholders (interviews 23, 27, 28, 31) reported issues related to the opposition of local politicians or other local stakeholder groups against RE projects (especially wind farms) or due to a lack of qualifications or capacities for handling applications at the local authorities (interviews 27, 30). Other interviewees (27, 28) reported issues related to the interference of different levels of administration, namely conflicts between decisions on local and central level (i.e. approvals being granted by local authorities which were revoked by the Secretary of State).
Overall, the present administrative complexity is evaluated as average/medium for all types of large-scale projects (wind and PV). For domestic-scale PV projects eligible for the FIT, the complexity is low. This result is also in line with the findings of the 'Wind Barriers' project (Cena et al., 2010) which, among others, comprised an assessment of the administrative framework for onshore wind energy projects in the EU. Cena et al. (2010, p. 139) report that the conditions in the UK are fairly positive by European standards as the UK performs above the EU-27 mean regarding the transparency of authorisation procedures and the authorities' attitude towards wind energy[68].

Some interviewees (28, 31) reported that, over the past years, although the administrative procedures generally stayed the same, the overall administrative process got more complex due to growing local opposition and stricter requirements for environmental permits or that more projects are being rejected today (interview 27). Interviewee 30 stated that the complexity did not change. Interviewees 24 and 25 claimed that, with the introduction of the CFD scheme (in 2014/2015), the administrative complexity for projects eligible for CFDs was further increased. However, this change does not fall within the observation period of this thesis (2012-2014). Against this background, no clear tendency regarding the administrative complexity can be deduced and it is thus assumed

67 Weblink: https://www.planningportal.co.uk/ (last accessed: 06.08.2016)
68 The evaluation assesses three parameters on a scale from 1-5 with 5 being the optimal score: The transparency of the authorisation and decision making process (score 3.67), the existence and respect of respective deadlines (score 3.11) and the authorities' attitude towards wind power (score 3.67). The scores for the UK indicate that the framework conditions are favourable and within the range of or even better than the EU-27 mean (Cena et al., 2010, p. 139).

that the complexity was in the medium range over the whole observation period. The below interview quotes illustrate the above assessment.

> *"It [the administrative process] takes too long and it's very expensive. You have to jump through a lot of hoops and it's a very uncertain process. [...] It's about finding the right balance and probably it's too much at the moment, but obviously we need to make wind farms that can stand on their own two feet and don't have much environmental impact, or the impact is balanced. So, I don't think it's necessarily a bad thing that you have to go through quite a process to get there."* (Interview 28, wind developer)
>
> *"For administrative processes, whichever country you are in, you look at the time scales, you look at how people have done it in the past, you add some buffer, and you manage it. So I think, to be honest, as long as you are a good project manager [...] you can manage that, I think."* (Interview 29, PV developer & investor)
>
> *"Then there's the [...] administration of the planning system in this country through the local authorities. And [the] central government has intervened too many times in local authority decisions on solar. So we'd rather [have] that the decision is made locally and if they approve then that should be fine, and the central government shouldn't intervene in those decisions."* (Interview 27, PV developer)
>
> *"Some local authorities are more positive about RE projects than others. So it really depends on the political make-up of the area."* (Interview 27, PV developer)
>
> *"[...] it's increasingly more difficult to get through the planning process, just because of all the things that we have to consider. When you see [...] the local decision makers are starting to become more anti, I think in the general sense"* (Interview 28, wind developer)
>
> *"It's not just the actual procedure of applying but it's the policy framework, i.e. what is and isn't acceptable from different perspectives so land use, ecology, visual impact, noise, all of these different things that are becoming a lot more onerous."* (Interview 31, wind developer)

INTEGRATION OF RENEWABLE ENERGY PLANNING WITH SPATIAL AND ENVIRONMENTAL PLANNING In the UK, spatial planning generally falls within the responsibility of the local planning authorities who prepare their own local development plans (DECC, 2009a, p. 49-50). On central level, there are no dedicated areas for RE development, however, areas which have to be excluded from RE development (e.g. due to environmental reasons) are disclosed by the environmental authorities.

Several of the interviewed stakeholders (interviews 23, 24, 27, 30, 31) stated that there is no strategic integration of RE planning in spatial planning in the UK at all. However, for the most part, the stakeholders (interviews 23, 24, 29, 30)[69] do not see this as a barrier to RE deployment. Although reportedly most local councils provide indications on

69 Interviewees 22, 25, 26 and 28 did not provide a statement on spatial planning issues.

preferential areas for wind development, RE developers broadly appreciate the flexibility of choosing the most suitable sites which is illustrated by the below selection of interview quotes. Against this background it is assumed that the integration of spatial and environmental planning in the UK is acceptable for both, wind and PV developers.

> *"There isn't any [integration of RES and spatial planning] anymore now. [...] It is all done in a very ad hoc basis. [...] some people have done recommended areas and in Wales there are areas where you should be [...] focusing your efforts. But it's mostly on a rather ad hoc basis and the developers go where they think they can get a project to work. [...] Yeah, that's fine I think. I'm happy for us to let the developers find the sites [...] Yeah, we choose those what we think are the best ones developing wind farms and that should be fine."* (Interview 23, wind developer)
>
> *"There are areas where you definitely couldn't go, but there are no, kind of development zones for renewables, for PV anyway. [...] Instead with zones set aside, so: 'Right here is where we want all the PV development', then that would actually be a much more coordinated approach, but I think that would probably put quite [a] lot of developers off, because developers are effectively competing for the best projects, like the highest margins, and if you force them all into one area then that may well take out the interest for some of them."* (Interview 31, PV developer)
>
> *"I don't think it [spatial planning] is necessarily a barrier at the moment. I think it's a point that should be considered from [...] sort of [a] wider systems perspective. [...] I think there's currently a bit of a lack of this kind of wider planning approach. But I don't see it as a barrier at the moment, more of an area for improvement in the future."* (Interview 24, Regulatory agency & research, PV)

5.5.2 *Diffusion indicator scores for the United Kingdom*

The CI scores (unweighted) for PV and wind energy (2012-2014) resulting from the assessment described in section 5.5.1 are presented in table 20. To derive the overall CI score, the individual indicator scores are combined with the weights from table 11 and multiplied according to the formula shown in equation 3 (both in section 4.4). The resulting weighted scores and the overall product are included in table 34 in annex A.5.

The scores shown indicate that in the UK especially the grid connection has become a major barrier for RE diffusion in recent years. This applies to both, wind onshore and non-residential PV installations, and is particularly reflected in the low scores for determinants C-II and C-III. However, it has to be noted that the scores for the cost of grid access (determinant C-I) are not able to reflect the sometimes extraordinarily high grid reinforcement costs reported by UK RE developers (cf. section 5.5.1.1) as the score is based on an assessment of the cost sharing approach as defined by regulation and does not consider the actual cost share in individual cases (cf. table 9).

For PV, also the remuneration level became a critical factor when the FIT levels were cut in 2012. However, with the increasing development of utility-scale PV projects in 2013/2014, the RO scheme became more relevant for PV and allowed for more attractive revenues[70].

Table 20: Composite diffusion indicator scores (unweighted) for wind energy onshore and non-residential PV in the UK (2012-2014).

		Scores wind			Scores PV		
Indicator component		2012	2013	2014	2012	2013	2014
A-I.	Existence and reliability of RES-E strategy & -support scheme	0.80	0.80	0.80	0.74	0.80	0.80
A-II.	Relative remuneration level for RES-E	0.56	0.75	0.73	0.01	0.03	0.15
A-III.	Revenue risk under RES-E support scheme	0.40	0.40	0.40	0.79	0.50	0.44
A-IV.	Access to finance for RES-E	0.93	0.92	0.87	0.81	0.92	0.87
B-I.	Fair and independent regulation of the electricity sector	1.00	1.00	1.00	1.00	1.00	1.00
B-II.	Existence of functioning and non-discriminatory markets	0.63	0.63	0.63	0.63	0.63	0.63
B-III.	Availability of reliable long-term contracts (PPA)	1.00	1.00	1.00	1.00	1.00	1.00
C-I.	Grid connection cost	0.50	0.50	0.50	0.50	0.50	0.50
C-II.	Duration of RES-E grid connection	0.39	0.30	0.25	0.67	0.41	0.25
C-III.	Predictability & transparency of grid connection procedures	0.50	0.25	0.25	0.50	0.25	0.25
C-IV.	RES-E access regime and regulation for curtailment	0.50	0.50	0.50	0.50	0.50	0.50
C-V.	Transparency and predictability of grid development	0.50	0.50	0.50	0.50	0.50	0.50
D-I.	Administrative cost	0.67	0.60	0.53	0.57	0.60	0.69
D-II.	Duration of administrative procedures	1.00	1.00	1.00	0.81	0.81	0.81
D-III.	Administrative complexity	0.50	0.50	0.50	0.50	0.50	0.50
D-IV.	Integration of RES-E in spatial & environmental planning	0.50	0.50	0.50	0.50	0.50	0.50

70 It should be noted that the indicator score is based on the calculation of a weighted average remuneration level according to the actual participation of PV in the FIT and the RO scheme, respectively. The resulting remuneration levels are shown in table 24 in annex A.5

Based on the indicator scores presented in section 5.5.2 and the modelling approach introduced in section 4.5, the short term diffusion outlook for non-residential PV and onshore wind energy in the UK is derived.

Figure 53 shows the **projected diffusion for non-residential PV** for the four scenarios defined in section 5.2.
Overall, the model results suggest that, based on the pronounced growth of the UK PV market during the observation period (cf. figure 52 in section 5.5.1), a vigorous development would also continue in the subsequent years, even assuming unchanged framework conditions (BAU scenario)[71]. In this scenario, up to 76% of the long-term deployment potential (equivalent to 105.4 TWh electricity generation or 115.6 GW installed capacity) could be exploited by 2018.

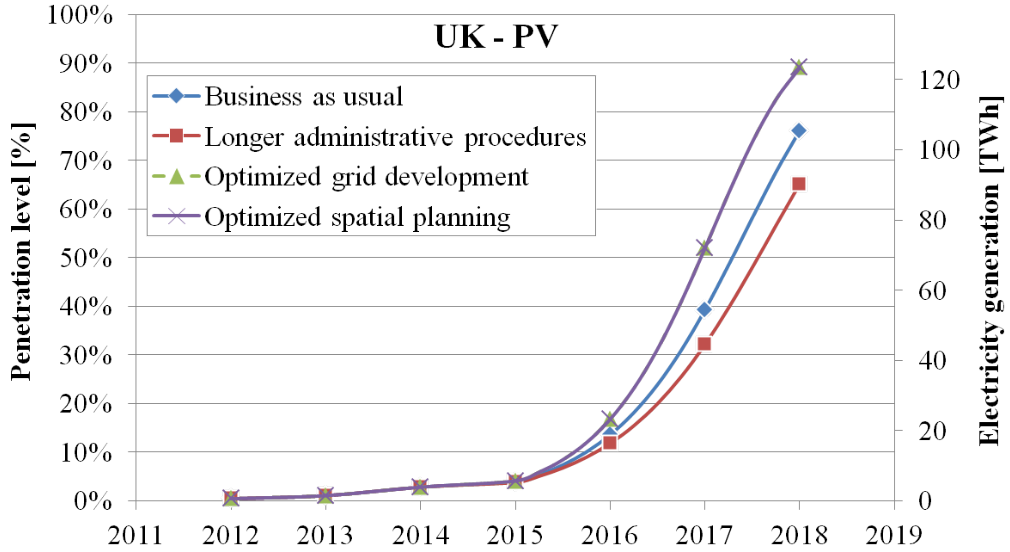

Figure 53: Short term diffusion outlook for non-residential PV in the UK: Expected penetration levels (%) and electricity generation (TWh) until 2018 for four scenarios.

In the scenario assuming longer administrative procedures, the deployment is slightly decreased compared to BAU assumptions. Consequently, in 2018, only 65.2% of the potential (about 90 TWh electricity generation or 99 GW installed capacity) would be exploited.

The scenarios assuming optimized grid development or optimized spatial planning, respectively, lead to identical results, as in the case of the UK, both scenarios lead to an

71 It should be noted that the BAU assumptions are based on a continuation of the 2014 RE policy framework. The changes in the RE support scheme after 2014, i.e. the introduction of the CFD scheme at the end of 2014/beginning of 2015 and the early termination of the RO for newly installed RE plants (i.e. for large scale PV in April 2015, for PV <5 MW and onshore wind in April 2016 (DECC, 2016a)) are not considered in the analysis.

increase in the CI score by 0.5 points. This is reflected by a 17% increase in PV electricity generation compared to the BAU scenario. In both scenarios 89.2% of the long term potential would be exploited by 2018. These findings imply that an optimized grid development could have a significant impact on PV deployment in the UK. This result is in line with the interview findings which highlight that the availability of transmission capacity in the distribution network is currently one of the major bottlenecks for PV deployment in the UK (cf. section 5.5.1). The relevance of optimized spatial planning, however, might be overvalued based on the indicator structure, as this issue was not mentioned as a major barrier for RE deployment in the UK.

Particularly in these two scenarios, which display the strongest projected technology diffusion, the shape of the diffusion curve suggests that it is already approaching its saturation point with a decreasing growth rate in 2018 until the maximum potential will be reached. In all four scenarios the indicative NREAP targets for PV would be exceeded by far (cf. figure 52).

Figure 54 shows the **diffusion projections for wind energy onshore** under the four scenarios defined in section 5.2.
Based on the observed growth rates of wind energy onshore in the UK, with decreasing annual capacity additions between 2012 and 2014 (cf. figure 52), the projections for the possible future market growth are more moderate compared to the projections for PV presented above.

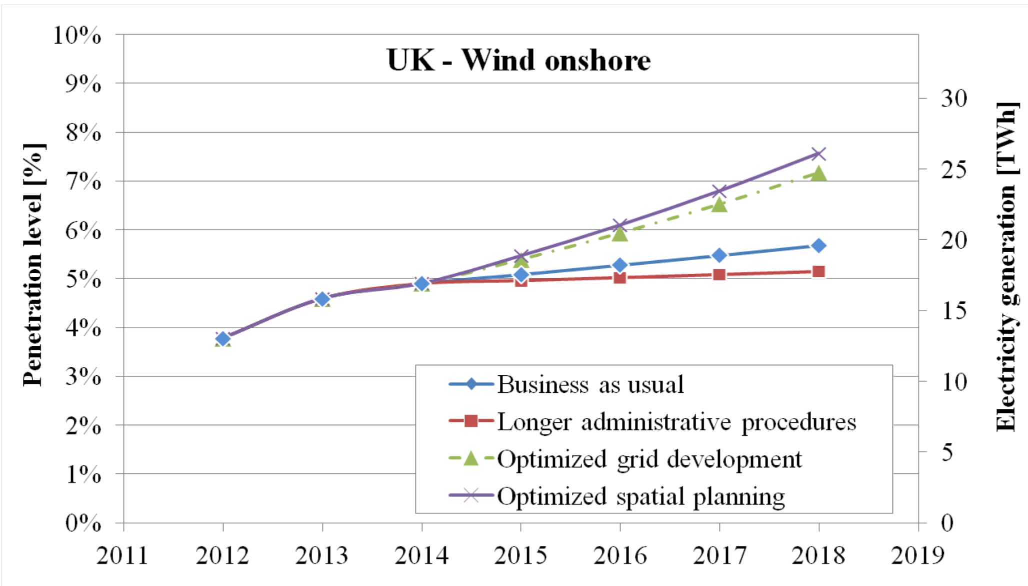

Figure 54: Short term diffusion outlook for wind energy onshore in the UK: Expected penetration levels (%) and electricity generation (TWh) until 2018 for four scenarios.

In the BAU scenario, which assumes static economic and non-economic framework conditions after 2014, around 5.7% of the overall long-term potential (equivalent to 9.35 GW installed capacity and 19.6 TWh generated electricity) for onshore wind would be exploited by 2018.

Assuming a prolongation of the administrative processing times for the approval of wind energy projects, the diffusion process would be slightly slowed down resulting in a reduction of the technology penetration by 0.5% in 2018 (i.e. 17.8 TWh electricity generation), compared to the BAU scenario.

A significantly stronger effect is visible in the scenarios assuming optimized spatial planning (Opt-Space) and optimized grid development (Opt-Grid). Based on the indicator weights (cf. table 11 in section 4.4) that were derived through the consultation of PV and wind energy experts, these two indicators have a higher relevance for wind energy than for PV. Thus, an enhancement of these framework factors (i.e. an increase of the indicator scores for these determinants) leads to a significantly higher technology deployment, compared to the BAU case. In the Opt-Space scenario, 7.6% of the long-term potential (i.e. 26 TWh electricity generation) and in the Opt-Grid scenario 7.2% of the long-term potential (i.e. 25 TWh electricity generation) are exploited. Under all four scenarios the indicative NREAP target for wind onshore would be fulfilled.

5.6 Summary and discussion of results

The results presented in this chapter demonstrate that the approach for the CI and the diffusion model developed in the frame of this thesis (cf. chapter 4) are generally applicable to different country contexts. Overall, the findings highlight the impact that also non-economic determinants, such as administrative barriers, spatial planning or grid issues, can have on the diffusion of PV and wind energy. In this context, the results also demonstrate the influence that these determinants can have on the efficiency of RE-support policies by demonstrating that, assuming a static support level for RES-E, the removal of non-economic barriers could still lead to an enhanced RE diffusion. Thus the findings emphasize that an optimization of RE policy strategies can only be achieved if the interplay of the various economic and non-economic determinants is considered in policy making. The individual case studies further show that the decisive factors for the RE diffusion process may vary depending on the particular country setting.

The **German case study** mainly demonstrates the consequences that a very stable and advanced legal and regulatory framework for RE has on the resulting RE technology diffusion. Here, the modelling results for PV (cf. figure 47) suggest that even under a BAU scenario (i.e. assuming static frameworks conditions), 26.3% of the long-term deployment potential could be exploited until 2018. Assuming further improvement of the non-economic framework conditions, namely optimized grid development or optimized spatial planning for RE, penetration levels of about 27.4% and 28.7%, respectively, could be reached by 2018. The strong impact of an enhanced availability of project sites

for PV is in line with the interview results, which pointed out that at present this is a major barrier for non-residential PV development in Germany (cf. section 5.3.1). Here, the scenario results particularly emphasize the significant impact that a removal of non-economic barriers could have on the efficiency of RES-E support: Under the Opt-Space scenario (without additional economic incentives) the indicative NREAP target for 2018 would be nearly met, while the BAU scenario results in a target shortfall. Longer administrative procedures, on the other hand, would lead to a slightly lower penetration level (i.e. 27.4%) in 2018. However, the effects of this change are small as for PV already the actual score was moderate.
For wind energy (cf. figure 48), the BAU scenario indicates that 44.1% of the German long-term deployment potential could be exploited by 2018. The scenario assuming longer administrative procedures for the official approval of wind parks indicates that a significantly slower market diffusion would result, leading to a utilization of only 40.4% of the long term deployment potential until 2018. Optimized grid development, on the contrary, could lead to an exploitation of 48.7% of the long term potential until 2018. However, the strongest effect on the projected technology diffusion can be observed assuming an optimization of spatial planning for wind energy. This scenario leads to an exploitation of 49.5% of the long-term deployment potential by 2018. These modelling results are backed by findings from the stakeholder interviews which revealed that, apart from the remuneration level, spatial planning and the availability of adequate project sites belong to the most relevant limiting factors for wind energy deployment in Germany (cf. section 5.3.1).

The **Spanish case study** illustrates the effect that blocking factors, i.e. determinants which can lead to a complete blockage of RE deployment (cf. figure 6 in section 2.2.1.1) have in the diffusion model and thus serves as an exemplary application of the model to an extremely negative case. Based on the Spanish CI scores as assessed for the observation period (2012-2014), no additional RE diffusion is projected for the future. Due to the suspension of RE-support at the beginning of 2012, the score for determinant A-II (relative remuneration level for RES-E) equals zero for the whole observation period because neither wind nor PV were able to compete given the regular electricity market prices. Therefore, as a consequence of the chosen multiplicative aggregation approach for the overall CI score (cf. equation 3 in section 4.4), the CI score equals zero (cf. weighted CI scores in table 33 in annex A.5). Thus, as the projections under BAU conditions are based on the observed CI scores, no additional diffusion beyond 2014 is projected (cf. equation 12 for projection of future diffusion). This result can be considered as a realistic representation of the actual circumstances as in absence of profitable remuneration no additional technology deployment can be expected, even if all other parameters remain in a favourable state.
This finding supports the chosen non-compensatory aggregation approach for the overall CI score, as it realistically reflects how individual factors can act as blocking factors for future technology diffusion. A compensatory aggregation approach, on the contrary,

would lead to a completely different result. For the Spanish case, for example, as most determinant scores lie in an intermediate range (cf. table 16 for unweighted CI scores) a zero score for the remuneration level would still lead to a mediocre overall CI score if the scores would be added up. On this basis, a moderate technology diffusion would be projected for the future which would not reflect real-world conditions. Consequently, the findings support the chosen non-compensatory aggregation method which takes into account that individual factors can have a blocking effect.

As an alternative analysis for the Spanish case, three hypothetical scenario variants for the deployment of non-residential PV and wind energy onshore were regarded which assume that the support scheme would have been continued after 2012. In doing so, the scenarios project the hypothetical diffusion in 2012-2014 based on the actual 2009-2011 remuneration levels and the assumption that the CI scores in 2009-2011 were identical to those in 2012-2014 (apart from the determinants related to the support scheme, cf. section 5.4.3). Two further variants of this hypothetical support scenario assume a lower remuneration level of which one is combined with 50% shorter permitting procedures for wind and PV projects.
The results of this additional scenario analysis indicate that, assuming a continuation of the support scheme after 2012, 22.4% of the long term wind energy potential and 7.7% of the PV potential could have been exploited by 2014. This compares to the actual deployment in 2014 which only lead to a utilization of 20.3% (wind) and 6.3% (PV) of the economic long term potential. Assuming a continuation of RE support but a drastic reduction of support levels (i.e. a reduction of this determinant's score by 50%) this results in a usage of only 20.7% (wind) and 6.5% (PV) of the long term potentials. However, presuming a lower economic support for Wind and PV combined with a reduction of bureaucratic barriers (i.e. shorter administrative lead times), still a steady market growth could have been achieved for both PV and wind energy. This scenario resulted in a 21.4% exploitation of the long term potential for wind and a 7.2% usage of the potential for PV until 2014.
However, there are reservations regarding the results of this hypothetical analysis as it is not based on actually observed CI scores for the years 2009-2011 but subject to assumptions and simplifications (see above). A detailed assessment of the historical CI scores before 2012 would be required to derive more accurate projections of the technology diffusion.

Further, the comparison of the actual diffusion rate of non-residential PV and wind energy onshore in Spain in 2012-2014 with the hypothetical modelling results shows that a time-lag in the diffusion (i.e. a further diffusion after termination of the support scheme) occurs which can be explained by system inertia. Projects which are already approved or partially developed at the time of a change in the regulatory framework might still be built afterwards. This leads to deviations, especially for wind energy, as wind parks usually have longer implementation time-frames than PV plants.

The **UK case study**, and particularly the case of solar PV in the UK, demonstrates the impact that extremely high annual growth rates during the observation period have on the projection results. In the BAU scenario, a projected penetration level of 76% (equivalent to 105.4 TWh electricity generation or 115.6 GW installed capacity) is reached for PV by 2018. The results further suggest that longer administrative procedures (Long-Ad scenario) would lead to a slight decrease in PV deployment but still project an exploitation of 65.2% of the long-term potential for PV by 2018. Even more optimistic projections result under the scenarios that assume an optimized grid development (Opt-Grid) or optimized spatial planning (Opt-Space). Here, the removal of grid constraints and spatial limitations leads to an exploitation of 89.2% of the PV long-term potential and indicates an installed capacity of 135 GW by 2018.

The above results should, however, be seen against the backdrop of the diffusion model logic. Based on the present model implementation, the deployment growth rates (i.e. c_n values) witnessed during the observation period (2012-2014) serve as an input parameter for the determination of the projected future development (cf. equations 11 and 12). In the UK, the annual growth rates of non-residential PV were particularly high in 2013 and 2014 leading to extraordinarily high c_n values of 1.31 and 1.55, respectively[72]. Thus, in cases with a very strong historical market growth and assuming unchanged or even improved framework conditions in the subsequent years, highly optimistic growth paths result.
These projections, although they are in line with the general concept of the s-shaped diffusion curve (cf. sections 2.1 and 3.4), probably do not correspond fully with reality conditions. An exhaustion of nearly 90% of the overall long-term deployment potential of a technology within a short time-frame of only four years (as projected for PV in the Opt-Grid and Opt-Space scenarios in the UK) could not be observed in reality, so far. This suggests that the present model set-up might have a limited applicability when it comes to cases with periods of extremely strong market growth. To moderate the projected technology deployment in such extreme cases, namely in periods following times with exceptionally high annual growth rates, additional limitations could be implemented in the diffusion model. Such limitations could, for example, limit the projected annual capacity additions to a defined maximum share of the overall long-term potential to artificially slow down the diffusion process. However, on the one hand, this would modify the original s-curve model which has proved as a suitable approach to explain technology diffusion processes in various cases (cf. section 2.1). On the other hand, to determine appropriate constraints or auxiliary conditions on a sound empirical basis, a larger number of observations (i.e. a higher number of case studies testing the applicability of the model) covering longer observation periods would be needed. Another possibility to obtain projections which are closer to reality would be to shorten the time intervals of the

72 This compares to c_n values between 0.1 and 0.4 for the other case studies.

projection and to perform six-monthly, quarterly or even monthly projections. However, this would also entail significantly more extensive data requirements.

The projections for wind energy onshore in the UK are more moderate than the scenarios for PV, as the growth of the wind energy market during the observation period was decreasing (c_n values ware 0.27 for 2012, 0.19 for 2013 and 0.07 for 2014). On this basis, the BAU scenario indicates that 5.7% of the long-term wind energy potential (i.e. 9.35 GW installed capacity) could be exploited by 2018 while a deterioration of administrative processing times (Long-Ad scenario) would only lead to a slight reduction of the deployment (5.2% of the long-term potential by 2018). A noteworthy effect, however, can be observed assuming optimized grid- or spatial planning (Opt-Grid and Opt-Space scenarios). Here, the results suggest that in the enhanced spatial planning scenario 7.6% (i.e. 26 TWh electricity generation) and in the optimized grid development scenario 7.2% (i.e. 25 TWh electricity generation) of the long-term wind energy potential could be exploited. This outcome highlights the relevance of both, strategic spatial planning and grid development for wind energy deployment in the UK. This finding has already been demonstrated for wind energy diffusion in general by the assessment of the indicator component weights (cf. section 4.3 and table 11) and has also been pointed out by various RE stakeholders (cf. figures 31 and 35). Also several UK interviewees that were contacted in the frame of this thesis confirmed that the deficit in strategic network development in the UK has a strongly limiting effect on the deployment of wind energy (cf. section 5.5.1). The effect of the, in some cases extremely high, grid connection costs for wind and PV projects which have been reported by UK stakeholders, however, may not be represented adequately in the present results. According to the current structure of the composite diffusion indicator, the assessment of the grid access cost is based on an evaluation of the cost sharing approach (i.e. between grid operator and project developer) as defined by the national regulation (cf. table 9) but does not consider the actual cost share in individual cases. In the case of the UK, a mixed (or 'shallowish') approach applies, which translates to an intermediate CI score of 0.5. However, according to several interviewees the grid connection costs constitute a major bottleneck for RE deployment in the UK and hinder the realization of both wind and PV projects. For a further development of the diffusion indicator it could thus be considered to adapt this indicator in order to reflect the actual cost share. However, this would also entail more extensive data requirements (i.e. additional interviews with project developers).

6 SUMMARY, CONCLUSIONS AND OUTLOOK

This chapter summarizes and critically reflects upon the research presented in this thesis. Section 6.1 recapitulates the motivation and research objectives and section 6.2 gives a brief summary of the main outcomes. Section 6.3 discusses the relevance of the findings in the energy policy context. Finally, section 6.4 provides a critical reflection on the presented work by highlighting its contributions to the scientific knowledge base (subsection 6.4.1) and pointing out its limitations and possible directions for future research (subsection 6.4.2).

6.1 REVIEW OF MOTIVATION AND OBJECTIVES

Renewable energy (RE) technologies are becoming increasingly important for electricity generation in the European Union (EU) to achieve the objectives of security of supply, global climate protection and realizing an ecologically sustainable and integrated European energy sector (cf. section 1.1). The development of RE technologies in the EU Member States takes place within the framework of the European RE strategy, which defines a binding EU-wide target of at least 20% RE share in final energy consumption by 2020 (European Commission, 2009a) and at least 27% by 2030 (European Commission, 2014d). The actual deployment of RE technologies, however, is shaped mainly by the national framework conditions for implementing RE projects. Here, national support schemes play an important role (cf. section 1.2) but so do other framework factors that are not necessarily related to economic support (such as e.g. administrative barriers or planning issues) (cf. section 1.3).

The relevance of fair and undistorted competitive conditions for positioning RE in the European electricity market is further underlined by the growing use of competitive bidding processes for RE support observable across the EU Member States in recent years. This development is in line with the European Commission's 'Guidelines on State aid for environmental protection and energy 2014-2020' (European Commission, 2014c), which demand a shift towards competitive, market-based RE support schemes by 2017. In order to ensure the proper functioning of such schemes, it is crucial to identify factors that might distort the determination of competitive prices and to be able to anticipate realistic future RE technology deployment, for example, when determining auction volumes or defining quota targets.

In this context, this thesis aims in particular at contributing to a more integrated understanding of RE technology diffusion processes by closing the gap between economic modelling concepts for the diffusion of RE technologies and qualitative approaches analysing the preferences and decision-making processes of RE developers and investors (cf. sections 2.1 and 2.2).

More precisely, the major objectives of this thesis are:

- Systematize the most relevant determinants for RE diffusion from the RE developers' / investors perspective (i.e. develop a general conceptual framework);
- Operationalize these determinants in the form of a composite indicator (CI) for the evaluation of the country-specific framework conditions for RE diffusion;
- Combine the findings in a diffusion model to allow for quantitative projections of the expected future RE market growth under different framework conditions (i.e. allow for assessment of policy scenarios).

Correspondingly, the central research questions of this thesis can be formulated as follows:

1. Which are the major determinants framing the diffusion of wind energy onshore and non-residential PV and how can they be conceptualized?
2. What is the relevance of these determinants from the RE developer's / investor's perspective?
3. How can the determinants be characterized in a quantitative manner and utilized for benchmarking purposes (i.e. an indicator)?
4. How do the determinants reflect in the resulting RE technology diffusion?

A secondary research question relates to the issue how policies and support measures should be designed in order to adequately address the identified determinants for RE diffusion.

To be able to take account of technology-specific characteristics and requirements, the research regarding the above objectives and research questions is concentrated on two RE technologies, namely onshore wind and non-residential PV. The approach is applied to three European case study countries, namely Germany, Spain and the UK.

With the CI and the diffusion model, this thesis intends to contribute to the knowledge base of researchers and policy makers. It aims to support a better understanding of the diffusion processes of RE technologies and to facilitate the identification of policy measures that enable technology deployment in a cost- and time-efficient way. This objective, in particular, implies that the research approach should be transparent and traceable and optimally applicable to different country contexts (i.e. ensure the transferability of the approach to various baseline conditions). Further, it is crucial that the analysis is grounded on a broad empirical basis to avoid biased or arbitrary assessments.

6.2 SUMMARY OF RESULTS

In this thesis a composite indicator (CI) was developed to identify and operationalize the major framework factors relevant for the diffusion of non-residential PV and onshore wind (see chapter 4, sections 4.2-4.4). This outcome covers the first two objectives of this thesis and answers research questions 1-3 relating to the identification and conceptualization of the major determinants for the diffusion of onshore wind energy and non-residential PV (cf. research questions in section 6.1 above).

Further, building on existing modelling approaches for technology diffusion, a logistic diffusion model (i.e. an s-curve model) was developed, which integrates the CI as the major parameter determining the speed of technology diffusion. On this basis, the course of RE diffusion processes can be explained and projected and the impact of individual policy measures on future RE deployment can be evaluated (see section 4.5). The CI and the RE diffusion model were applied to three contrasting case studies for Germany, Spain and the UK to validate the approach in different country settings (see chapter 5). With the diffusion model and its application to the country case studies the third objective of this thesis is covered and an answer is provided to the fourth research question on how the determinants reflect in the technology diffusion process (cf. research questions in section 6.1 above). Further, the country case studies provide examples of how policy measures could be designed to address the identified barriers to the diffusion of onshore wind energy and non-residential PV. This contributes some insights into the secondary research question on how policies should be designed to effectively and efficiently stimulate the diffusion of wind energy and non-residential PV.

COMPOSITE INDICATOR For the CI, sixteen determinants were selected, which are of major, direct relevance for the realization of non-residential PV and onshore wind projects. The selected diffusion determinants can be grouped into four categories: Political and economic framework; electricity market structure and market regulation; grid infrastructure and grid regulation and administrative procedures (see conceptual model in figure 20). Each of the sixteen determinants is represented by one or several indicators by which it can be quantified (see results in section 4.4). At this stage of the research, an intense stakeholder involvement ensured that the conceptual framework for the CI is based upon a sound empirical basis and captures the perspectives of RE-experts (see description of methodology in section 3.2).

The individual indicator scores are aggregated to an overall CI score to represent the general attractiveness of the national RE framework from the viewpoint of PV and onshore wind project developers. For the aggregation of the indicator scores, to take account of the relative relevance of the diffusion determinants for the decision process, weighting factors are applied (see table 11). The weighting factors are the result of an extensive empirical assessment drawing upon a questionnaire-based stakeholder consultation with RE stakeholders across Europe. The survey resulted in the collection of 210 datasets specifying the relative relevance (i.e. the weight) of the individual diffusion determinants in the CI (see methodology description in section 3.3.1. The survey results clearly highlight the outstanding importance of a reliable and stable policy framework which is ranked the highest of all determinants and even higher than the actual remuneration level (see results in section 4.3.1).

A further segmentation of the results according to the technological focus of the respondents suggests that there are variations in the relevance of individual determinants for PV and for wind energy (see results in section 4.3.2). On this basis, technology-specific indicator weights were deduced for wind and PV, which are applied to the CI. Additional variations in relevance are observed depending on the institutional and geographical background of the stakeholders (cf. section 4.3.2). However, further analyses based on a larger dataset would be required to deduce robust, differentiated conclusions in this regard.

When aggregating the individual determinant scores to obtain the CI score, a multiplicative approach is chosen because it considers that low scores for specific determinants cannot be fully compensated by high scores for other determinants. The chosen approach also takes into account that individual factors such as the suspension of RE support or blocking grid access might bring RE diffusion to a standstill (cf. section 4.4).

DIFFUSION MODEL To be able to provide short-term forecasts for the deployment of PV and wind energy based on the analysis of the national RE framework, a diffusion forecast model was developed (see section 4.5). The model is based on a basic logistic function which is commonly applied and well established in technology diffusion research (cf. section 2.1). The concept developed in this thesis draws particularly on the approach of Peter Lund (2006), who analysed the historical diffusion patterns of different energy technologies by fitting them to a logistic function and assessing the growth rate coefficients of the diffusion curves. Peter Lund (2006) observed that this parameter often shows a decreasing tendency over time and suggests using a temporally decreasing functional form of the growth parameter for technology diffusion forecasts. However, Lund does not further examine the causes of his observation or the impact of different market and policy environments on technology diffusion. Also in this thesis, historical technology diffusion patterns were analysed and the growth parameters (i.e. c_n values) determined by fitting a logistic function to historical deployment curves for wind onshore and non-residential PV (cf. section 4.5). However, the approach developed here significantly expands the idea of Peter Lund (2006) and assumes that mainly the political and regulatory framework conditions determine the observable penetration rate by either accelerating or curbing technology deployment. It is further assumed that these framework conditions are reflected in the CI score (cf. paragraph above).

On this basis, the future diffusion of PV and wind energy is estimated for given framework conditions by projecting the slope of the diffusion curve according to the corresponding CI score. In doing so, a discretised logistic function is applied to assess the additional technology penetration for the subsequent years (see equation below which repeats equation 12 from section 4.5). The projection regards the assumed future CI score (depending on the scenario) as well as the economically feasible long-term potential of the respective technology (i.e. the saturation level of the diffusion curve). With this model the impact of changes in the framework conditions on future RE diffusion can be simulated by varying the scores for individual components (i.e. determinants) of the CI. Thus the effect of policy measures or changes in the regulatory environment can be assessed through analyses of different diffusion scenarios.

$$P_{n+1} = P_n + CI^{\beta}_{n-\triangle} \cdot \alpha \cdot P_n \cdot (1 - \frac{P_n}{a})$$

Where:

P_n = *technology penetration in a given year 'n'*

P_{n+1} = *technology penetration in year 'n+1'*

CI = Composite Indicator score (defining the growth rate of the s-curve)

α / β = *calibration factors*

a = long-term technology deployment potential (i.e saturation level)

COUNTRY CASE STUDIES To verify the developed concept of composite diffusion indicator and diffusion model, it is applied to three case study countries: Germany, Spain and the United Kingdom. Three case study countries with contrasting regulatory framework conditions for RE (in terms of the type of support scheme and the historical development of the RE environment) were chosen to verify the transferability and applicability of the CI approach to different country contexts. For all three case study countries, the CI indicator scores were assessed and quantified. Quantitative and qualitative data were collected by reviewing databases, legal texts and other public information sources as well as conducting semi-structured stakeholder interviews in each country (cf. methodology description in section 3.5). In total, 31 phone interviews were conducted, mainly with PV and wind energy developers, as well as with RE investors and stakeholders from the government and RE research sector (cf. Table 5). On the basis of the identified CI scores, diffusion projections for the period 2015-2018 were made assuming different policy scenarios that represent variations in individual framework factors (cf. scenario description in section 5.2).

Overall, the case study results demonstrate the strong impact that non-economic framework factors such as administrative procedures, spatial planning or grid issues can have on the diffusion of PV and wind energy. The findings stress that the interplay of the various economic and non-economic framework factors should be considered in policy making to achieve the maximum efficiency of support policies.

Further, the individual case studies reveal the consequences that different configurations of the regulatory framework have on the diffusion modelling.

The **German case study** (see section 5.3) serves as an example of a highly stable and advanced legal and regulatory environment resulting in strong and steady RE deployment with an exploitation of 26-29% of the long-term potential (i.e. the economically feasible deployment potential until 2050 based on Resch (2015)) for non-residential PV and 40-50% for wind energy onshore until 2018, depending on the policy scenario. For wind energy, the strongest impact on the diffusion rate is achieved by assuming an improved framework for spatial planning; a finding that is supported by statements of the interviewed wind energy developers.

The **Spanish case study** (see section 5.4) provides a contrasting picture and illustrates the effect that individual blocking factors can have on the overall diffusion process. Here, due to the suspension of the Spanish RE-support scheme at the beginning of 2012, the score for the determinant 'relative remuneration level' (A-II) becomes zero for the whole observation period. As a consequence of the multiplicative aggregation approach for the overall CI score (cf. equation 3), the CI also equals zero (cf. tables 16 and 33) which, assuming a continuation of this situation, leads to a prediction of no further technology diffusion beyond 2014. This result realistically represents the actual circumstances as, in the absence of profitable remuneration, no additional technology deployment can be expected, even if all the other parameters are favourable. Therefore, the findings for the Spanish case study support the non-compensatory aggregation method chosen for the CI score (cf. equation 3).

The **case study for the UK** (see section 5.5), especially the case of PV here, illustrates the consequences that strong fluctuations have on the projection results; in this case, extremely high annual market growth rates during the observation period. Based on the formal framework applied in the diffusion model, the deployment growth parameters (i.e. c_n values) witnessed during the observation period (2012-2014) serve as an input parameter to determine the projected future development (cf. equations 11 and 12). The annual growth rates of non-residential PV were extremely high in the UK in 2013 and 2014 (resulting in high c_n values of 1.31 and 1.55, respectively) so that a technology penetration of 76-89% is projected until 2018 (depending on the scenario). Although such developments seem unrealistic and have not been observed in reality so far, they are in line with the general concept of the s-shaped diffusion curve under the assumption that all framework conditions remain constant (cf. sections 2.1 and 3.4).

To moderate the projection results in cases of very strong historical market growth for a RE technology, additional limitations could be implemented in the diffusion model to artificially slow down the diffusion process. This could be done, for example, by limiting the projected annual capacity additions to a defined maximum share of the overall long-term potential. However, such modifications would affect the original s-curve model, which has already proven a suitable approach to explain technology diffusion processes in various cases (cf. section 2.1). To avoid arbitrariness in adjusting the modelling framework, which would reduce the transparency of the modelling approach, integrating any additional constraints or auxiliary conditions would have to be based on a sound empirical analysis, namely a larger number of observations in the form of additional case studies covering longer observation periods. Another way to enhance the numeric precision of the projections would be to shorten the time intervals of the analysis and perform six-monthly, quarterly or even monthly projections instead of annual outlooks. However, this would also entail significantly more extensive data requirements. Therefore, both options were not feasible within the frame of this thesis.

6.3 Implications for renewable energy policy

The CI and the diffusion model by themselves are policy-relevant outputs of this thesis as they offer the possibility to assess national RE frameworks and evaluate the potential effects of changes in policy or regulations on future technology diffusion. These contributions are discussed in section 6.4.1 below.

Beyond this, other findings of this research raise issues which are of particular relevance in the RE policy context. The most prominent policy-relevant issues are discussed in the following paragraphs. They can be summarized as follows:

1. An integrated view of the framework conditions for RE diffusion is of key importance to reach RE targets cost-efficiently.
2. The reliability and stability of the RE policy framework are essential for steady RE diffusion.
3. Renewable energy technologies show varying sensitivities to certain framework conditions, which may affect their position in competitive processes (i.e. auctions for economic support).
4. Different stakeholder groups have divergent opinions about the importance of specific determinants for RE diffusion. This could be understood as an indication of RE policy fields where more intensive stakeholder dialogue is required.

1. Key importance of an integrated view of the RE framework The empirically-based selection of CI determinants shows that a broad range of parameters from different fields (i.e. the political & economic framework, the market structure &

regulation, grid infrastructure & regulation and administrative & planning issues) affects RE diffusion (cf. chapter 4 sections 4.2 on conceptual model and 4.4 on CI).

Further, the outcome of assessing the relative relevance of the diffusion determinants (cf. weighting results in section 4.3) reveals that actually all the determinants are important for the RE diffusion process. This is shown by the finding that all the determinants except one received median scores of 7-9 points[1] which marks them as highly relevant parameters for RE diffusion (cf. figures 36, 37, 38 and 39 in chapter 4). The only exception is the cost of administrative procedures, which scored a median of 5 points which indicates that this determinant is only moderately relevant. These findings, i.e. the fact that all the determinants are highly relevant for RE diffusion, highlights the necessity of taking an integrated view of the supportive framework for RE deployment. This is required to be able to address non-economic barriers to RE diffusion as well and thus achieve the maximum efficiency of RE policies.

Non-economic obstacles often concern administrative and spatial planning issues as well as the access to grid infrastructure for RE installations. Here, the country case study results presented in chapter 5 (sections 5.3, 5.4 and 5.5) provide vivid examples of the impact that, besides others, spatial planning (Germany) or grid access (UK) can have on the resulting RE diffusion. These findings particularly highlight the relevance of an overall enabling environment for energy system change which goes beyond the provision of economic support for individual technologies and which addresses a wide range of factors that influence the competitiveness of RE technologies with conventional electricity generation technologies (e.g. related to market design, administrative and institutional issues or network regulations). The presented diffusion modelling results indicate that RE deployment could be reached more cost-efficiently if non-economic barriers were removed (i.e. the same RE targets could be reached with lower support levels).

Finally, against the background of the growing importance of competitive tendering procedures for RE energy, which is also driven by the EU strategy to shift RE support to more market-based schemes (cf. sections 1.1 and 1.2), the creation of a level playing field and undistorted competitive conditions for RE technologies becomes even more significant. In this context, the presented results provide evidence to focus the policy debate more on the enhancement and harmonization of a broader range of framework factors for RE deployment beyond those directly related to RE support schemes.

2. CRUCIAL ROLE OF THE RELIABILITY AND STABILITY OF RE POLICY Pursuing the issue of the importance of an integrated view of RE frameworks discussed above, another relevant finding in the energy policy context is the outstanding role of the reliability and stability of the policy framework. Here, especially the assessment of the relative

1 With the scale ranging from zero points indicating that the determinant is 'not relevant at all', five meaning 'average/median relevance' up to ten points indicating that the determinants is 'extremely relevant' for RE diffusion.

relevance of the diffusion determinants illustrated how crucial this aspect is for RE diffusion as it was ranked even higher than the remuneration level (cf. weighting results in section 4.3.1, i.e. figure 36). Various interviewees also clearly expressed that a reliable policy framework is of the utmost importance for the decision whether to develop a RE project or not. This is further illustrated by the quotes shown below of RE developers from Germany, Spain and the UK (partly repeated from figure 21 in chapter 4).

This finding underpins that a stable and reliable policy framework is an essential factor for RE deployment and that RE policy should have a strong focus on continuity and transparency.

> *"So I think you can invest in very different regulatory frameworks, and we are doing wind power in different parts of the world. [...] But what is important is once we decide to invest in one place we trust the regulatory framework, that it doesn't change in the middle."* (Interview 19, RE developer & utility, Spain)
>
> *"A central advantage in Germany is the grandfathering [of RE support] which should be maintained in any case. Otherwise expectations for return on equity will shoot up immediately."* (Interview 6, RE developer, Germany)
>
> *"It really needs to be a stable policy framework: So just let us get on with our businesses and stop changing [it] every few months. Tell us what you're going to do and then stick to it."* (Interview 27, RE developer, UK)
>
> *"The legal certainty and stability seem to me to be the keys."*
> (Interview 18, RE developer, Spain)

3. DIFFERENT SENSITIVITIES OF RE TECHNOLOGIES The results of the questionnaire survey assessing the relative relevance of the diffusion determinants also indicate that, beyond the fact that all of the selected framework factors bar one have high median relevance (cf. paragraph 1. above), some determinants vary in their importance depending on the RE technology concerned (cf. chapter 4 section 4.3.1 for the overall results and section 4.3.2 for the technology-specific analysis).

Even though there are reservations regarding the robustness of the technology-specific results due to the limited size of the respective data subsets (cf. statistical analysis in section 4.3.3), the findings do indicate that wind onshore and PV have diverging sensitivities to specific framework conditions, i.e. that the developers of these technologies attach varying importance to these issues. For example, compared to PV developers, the surveyed wind energy developers attached slightly higher relevance to the duration and complexity of bureaucratic procedures and spatial planning issues as well as to the treatment of RE dispatch and the transparency of future grid development (cf. figures 38 and 39 in chapter 4). Such differences might be even more pronounced for other technologies which were not included in this analysis (e.g. hydro power, biomass or wind energy offshore).

In the context of RE-policy, this result suggests the particular sensitivity of wind energy projects to certain determinants, which may place them at a competitive disadvantage compared to other RE technologies if barriers exist in these areas. This aspect could become especially relevant if several RE technologies have to compete for RE subsidies under the same scheme (e.g. in cross-technology competitive auctions or technology-neutral quota schemes). Therefore, such technology-specific sensitivities should be evaluated further (including additional technologies as well) and taken into account, especially if RE support instruments contain competitive elements addressing different RE technologies.

4. VARIETY OF STAKEHOLDER PERSPECTIVES OF RE FRAMEWORKS A further finding of this thesis is that different RE stakeholder groups have partly diverging perspectives of the relevance of individual determinants for RE diffusion.

For example, the survey assessing the relative relevance of the diffusion determinants (cf. chapter 4, section 4.3.2) indicates that, compared to RE developers, government stakeholders appear to underestimate the importance of barriers related to bureaucratic processes, and planning processes, such as grid planning and spatial planning (cf. figure 40). This finding suggests that policy makers undervalue the role that these risk elements play for RE developers. However, the stakeholder-specific survey results must be interpreted as indicative due to the limited size of the data sub-sets, which does not allow robust conclusions (cf. statistical analysis in section 4.3.3).

Also several interviewees mentioned that, for example, smaller RE development companies are more vulnerable to regulatory risk factors than larger companies or developers which are also active as utilities. This is further illustrated by the interview quotes shown below indicating that smaller developers face greater difficulties when handling administrative hurdles because they usually have fewer resources.

Therefore, stakeholder-specific differences in the valuations should be taken into account in the RE policy making process as they can indicate policy areas where a more intensive dialogue between stakeholders is required. In this respect, surveys similar to the one applied in this thesis could also be used during workshops or discussion rounds to assess the perspectives and preferences of different stakeholder groups and to direct the discussion to the most critical issues and thereby facilitate consensus-building. Robust empirical results for different groups of RE developers could also be used to design tailored measures to facilitate their participation in the RE diffusion process, i.e. to support vulnerable but strategically important groups in RE development activities (e.g. small RE development companies).

"We are a big utility, so we [...] also have a position in supply. So I think we are able to adapt [...] we are able to work in different frameworks [...]. I understand that we have capacities that other players don't have and we can adapt to different support schemes." (Interview 19, RE developer & utility, Spain)

"We're really worried about that mechanism [i.e. the CFD scheme]. I mean (a) because there is so little money in the pot and (b) it works really badly for smaller-medium-sized companies, because you have to sink a lot of costs before you can even bid. So it's very discriminatory towards new entrants and smaller players." (Interview 26, RE association, UK)

"Of course as we have big resources for this kind of things we can analyse it or contract an external company to analyse the complexity of the [administrative] procedure of each of the countries, when for a small developer of course this can be a problem." (Interview 15, RE developer & utility, Spain)

"A large company can always push harder. I mean, I've seen it. If a very powerful company is asking for a permission, they always try to make it a little faster than if it was a small one." (Interview 20, RE developer, Spain)

6.4 Contributions and limitations

6.4.1 *Contributions*

This thesis makes a scientific contribution primarily in three ways: It expands the empirical basis of research on RE deployment in Europe, it adds to the methodological approaches to analysing and modelling technology diffusion processes, and it provides instrumental support for the evaluation of the framework conditions for RE deployment.

Empirical contribution This thesis provides an empirical contribution to the knowledge base on RE deployment in the EU Member States by providing a detailed assessment of the RE frameworks in the three case study countries Germany, Spain and the United Kingdom. More precisely, the thesis enhances the knowledge base by analysing the interrelations between changes in the regulatory and political framework and the observed diffusion patterns of non-residential PV and onshore wind energy in these countries. Here, notably the findings from the 31 in-depth interviews with RE stakeholders but also the data collected from a broad range of secondary data sources add first-hand insights to the body of literature.

Further, the survey-based findings regarding the relative relevance of the diffusion determinants enrich the knowledge base about the decision procedures and policy preferences of different RE stakeholder groups (cf. results in section 4.3.2). This knowledge, derived from comprehensive empirical data, could serve as input to the ongoing debate about the effectiveness and efficiency of RE policies and as a starting point for further research (cf. section 6.4.2 below).

METHODOLOGICAL CONTRIBUTION The conceptualization of the major determinants for RE diffusion and the development of a transparent and traceable approach to assess and quantify them in a CI constitute a relevant contribution to the scientific and political discourse on the diffusion of RE technologies. The major methodological added value in this regard lies in using a bottom-up approach to assess the relative relevance of the indicator components by means of proven stated preference methods (i.e. through a standardized weighting questionnaire) and then using this information to determine the weights of the individual indicator components. This way, the aggregation of the CI is based on sound empirical results rather than on subjective judgements or an arbitrary equal weighting approach. Several researchers (e.g. Böhringer and Jochem (2007), Freudenberg (2003) and Sharpe (2004)) have argued that the lack of empirical backing for selecting, weighting and aggregating composite indicator components is a major shortcoming and that especially the *"arbitrary nature of the weighting process by which the variables are combined"* (Sharpe, 2004, p. 5) poses a methodological deficiency in this field (cf. chapter 2 section 2.3). In this regard, the present approach makes an important methodological contribution to the construction of composite indicators.

Further, the approach developed in this thesis to project RE technology deployment based on an s-curve model expands existing models as it integrates empirical, bottom-up information in the form of the CI to reflect the speed of technology diffusion (cf. section 4.5). This goes beyond approaches as put forward, for example, by Peter Lund (2006) who observed that the speed of technology diffusion (i.e. the growth parameter of the diffusion curve) is not constant over the course of the diffusion process but did not provide an explanation for his observation (cf. section 4.5).

To the best knowledge of the author, the concept of combining a CI with a logistic diffusion model to analyse and project technology diffusion processes is a novel approach and therefore adds methodologically to the field of diffusion research. With the above contributions this thesis could help other researchers to advance approaches for combining energy economic modelling and innovation diffusion modelling and to improve the representation of technology diffusion processes in energy economic models.

CONTRIBUTION TO THE EVALUATION OF RE FRAMEWORKS As pointed out in section 6.3, this thesis provides a number of findings which are particularly relevant in the energy policy context. By providing a transparent benchmarking tool for RE frameworks in form of the CI and by developing a method to use the CI for short-term diffusion projections in a diffusion model, this thesis provides valuable tools for the evaluation of policy measures and the enhancement of support frameworks for RE. The possibility of assessing the impact of individual changes in the framework conditions, especially the variation of non-economic parameters such as the duration of administrative procedures or the conditions for spatial planning, could be useful for policy makers trying to implement policy frameworks that have maximum effectiveness and efficiency regarding RE deployment. Here, the weighted aggregation of individual indicators to an overall CI score allows for a comprehensive analysis of individual policy changes on the overall policy performance. Further, the non-aggregated indicator scores represent an important intermediate result which can be used for benchmarking or comparing indicator values between different countries as well as for an intuitive and clear visualization of changes in individual indicator scores over time.

Also, it is widely acknowledged in the literature that the effects of policy measures and changes in the regulatory framework conditions for RE should be given more consideration in energy economic models (see e.g. Barreto and Kemp (2008) and Worrell, Ramesohl and Boyd (2004)). Although the diffusion model that is developed in this thesis builds upon the very basic approach of the logistic function, the general approach of conceptualizing and assessing various framework factors for RE diffusion in the form of a CI and then using it for modelling purposes could also be employed in other, more complex modelling approaches. In this context, the method presented in this thesis might serve as a starting point to develop more standardized frameworks for the inclusion of non-economic factors in energy economic models in order to improve modelling accuracy.

Both the empirical findings and the approach developed in this thesis may further contribute to a deeper understanding of RE technology innovation systems by providing insights into and a methodology for the assessment of investor's rationalities with regard to investments in RE technologies. By shedding light on the decision criteria and preferences of RE investors and developers this work provides an important vantage point on RE technology diffusion and helps to identify actions for policy makers to create a more enabling environment for the establishment of sustainable energy technologies and to support the transition to a more sustainable energy system.

6.4.2 *Limitations and outlook*

The research performed in this thesis highlighted several issues which indicate possible directions for future research.

Firstly, the assessment in this thesis is limited to two technologies, non-residential PV and wind energy onshore. To represent other RE technologies in the indicator, the components and structure of the CI might have to be adapted to the rationality of the respective technology or technology segment. Interesting further applications could be, for example, small-scale PV installations, biomass power plants or offshore wind power.

Also, the approach has so far only been applied to three EU Member States. Testing its applicability to other world regions, especially countries with a lower level of electricity market liberalization and RE development, could thus be of interest. Although the CI has been designed in a way that should generally allow broad applicability to different country situations, this still has to be demonstrated in additional case studies.

The weighting results suggest there might be systematic differences between the assessments of different stakeholder groups, but the small size of the individual data sub-sets does not allow robust conclusions in this regard. However, such stakeholder-specific preferences could be of interest for the policy dialogue, as they point to aspects of policy and regulation from which conflicts or barriers for RE development could emerge and which require particular attention. Against this background, the developed weighting questionnaire (or a similar assessment tool) could be used to conduct additional surveys of specific stakeholder groups to identify such areas of conflict and facilitate a constructive stakeholder dialogue.

Further research could also integrate the concept put forward by Rogers (1995), who differentiated stylized adopter types of innovations based on their innovativeness and risk-affinity (cf. section 2.1). Assuming that information on the distribution of the major adopter groups in a specific population was available, their role during different stages of the diffusion process could be integrated in the diffusion model. This could be realized by a further differentiation of the indicator weights, for example, according to the risk-affinity of different RE developer groups (i.e. large-scale vs. small-scale development companies). This could lead to further refinement of the diffusion prognoses and allow a more precise representation of the impact of individual policy measures.

The same applies to potential country-specific distortions in the weighting results that may stem from national factors or conditions which, consciously or sub-consciously, influence stakeholders in their assessments. Such factors might relate, for example, to the current RE share in the national energy mix, which can affect the relevance of certain technical issues (e.g. grid congestions and curtailment). Other factors could include the present RE support scheme and its evolution or the presence of country-specific problems which might consequently be perceived as particularly relevant by local stakeholders. However, due to the limited number of datasets for each country, no robust conclusions could be drawn about such country-specific biases in this thesis (cf. section 4.3.2). Further research could evaluate this effect via a systematic comparison of datasets provided by similar stakeholder groups from different countries. If a systematic country bias were identified, this could be considered in the weighting of the CI components.

Regarding the country case studies, the results are clearly limited by the short observation period of just three years (2012-2014). It should further be considered that changes in the policy frameworks of the case study countries that took place after 2014 are not included in the analysis as data collection was limited to the time-frame 2012-2014. Here, the quality of the diffusion analysis could be enhanced if longer time frames were covered by the assessment, and if the analyses were updated and continued up to the present.

A

APPENDIX

A.1 SLIDES USED FOR EXPERT GROUP DISCUSSIONS

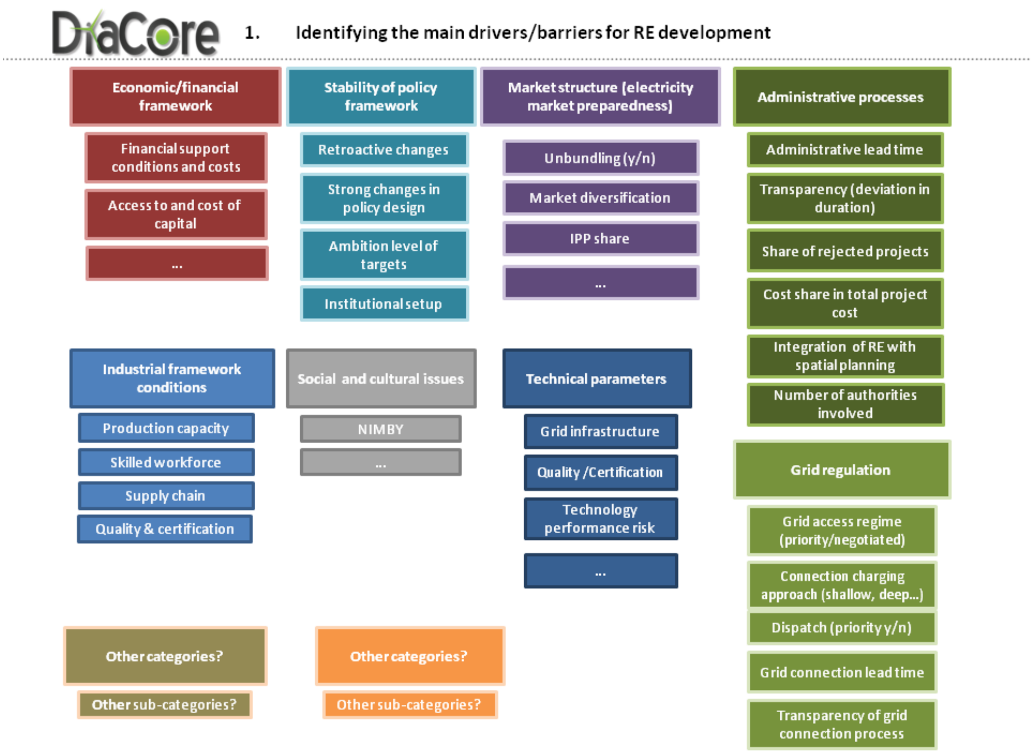

Figure 55: Exemplary slide used during the first expert workshop (11/07/2013, Berlin) to stimulate the discussion about the major determinants for RE diffusion. Suggested determinants were slightly pre-structured but the selection explicitly allowed for re-structuring and changing of the parameters.
Source: Own elaboration

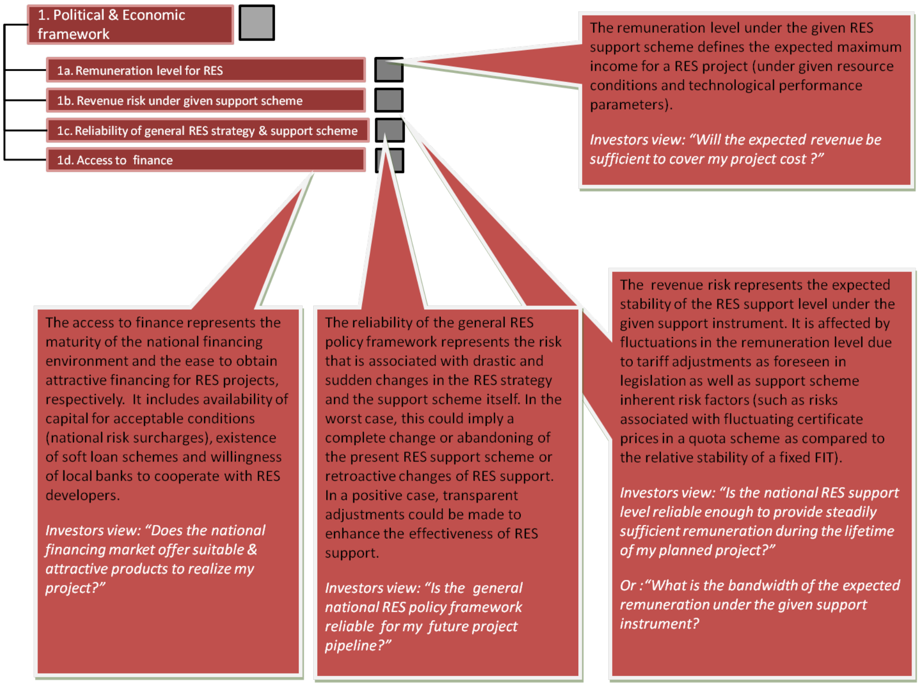

Figure 56: Exemplary slide used during the second expert workshop (15/08/2013, Berlin) to present and consolidate the selection and grouping of the diffusion determinants based on the first workshop.
Source: Own elaboration

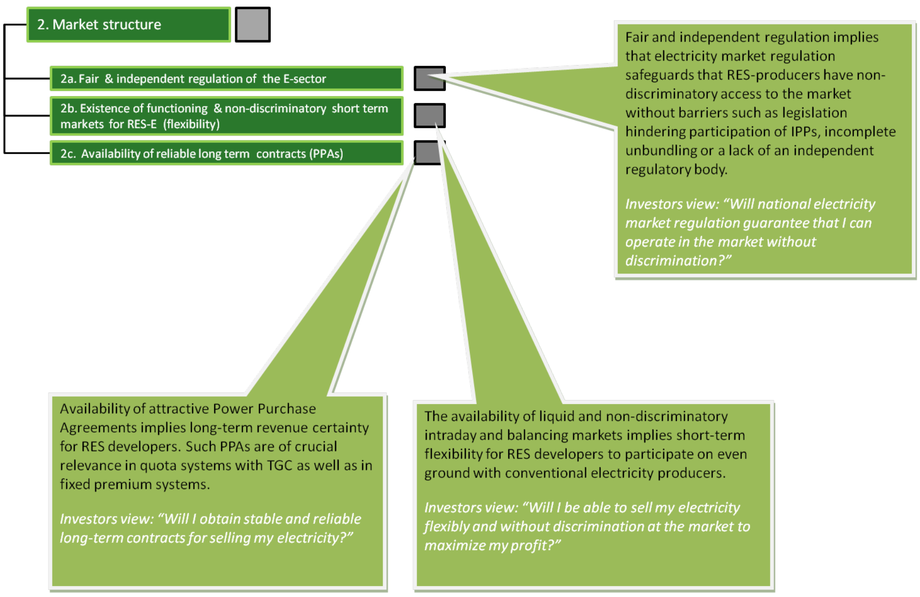

Figure 57: Exemplary slide used during the second expert workshop (15/08/2013, Berlin) to present and consolidate the selection and grouping of the diffusion determinants based on the first workshop.
Source: Own elaboration

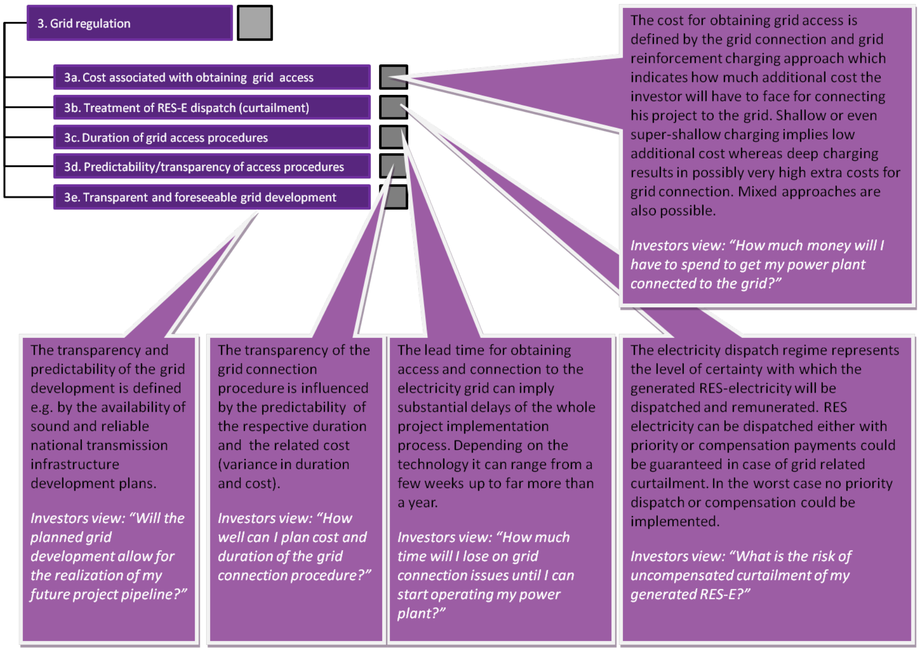

Figure 58: Exemplary slide used during the second expert workshop (15/08/2013, Berlin) to present and consolidate the selection and grouping of the diffusion determinants based on the first workshop.
Source: Own elaboration

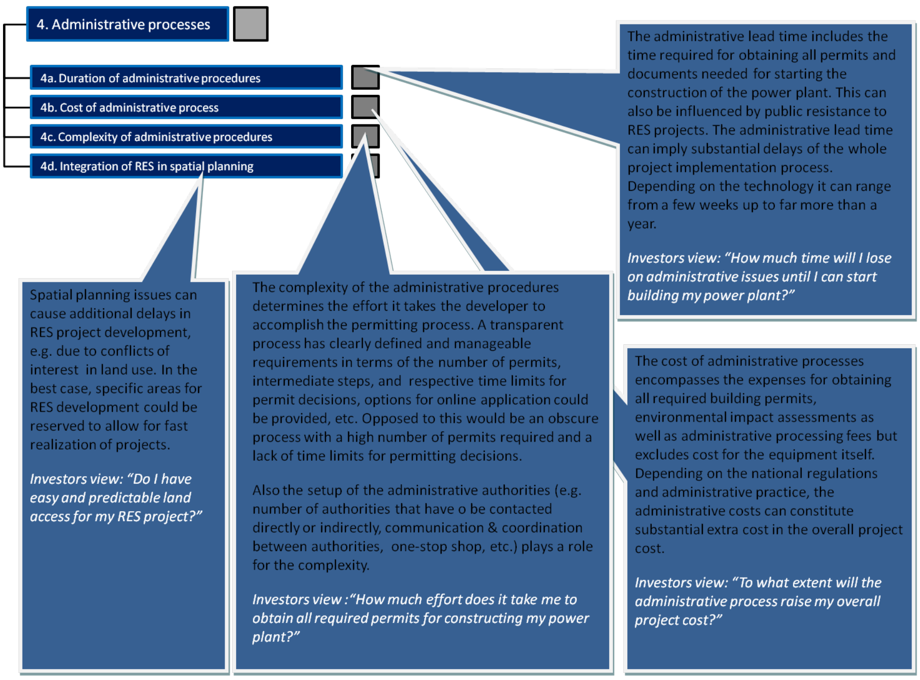

Figure 59: Exemplary slide used during the second expert workshop (15/08/2013, Berlin) to present and consolidate the selection and grouping of the diffusion determinants based on the first workshop.
Source: Own elaboration

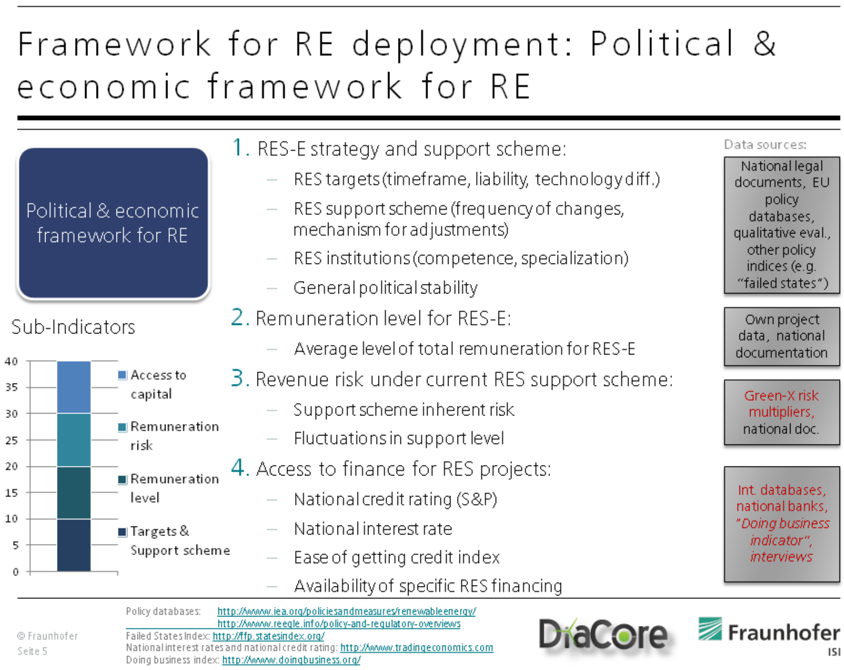

Figure 60: Exemplary slide used during the third expert workshop (30/01/2014, Vienna) to discuss possible indicators and data sources for the diffusion determinants.
Source: Own elaboration

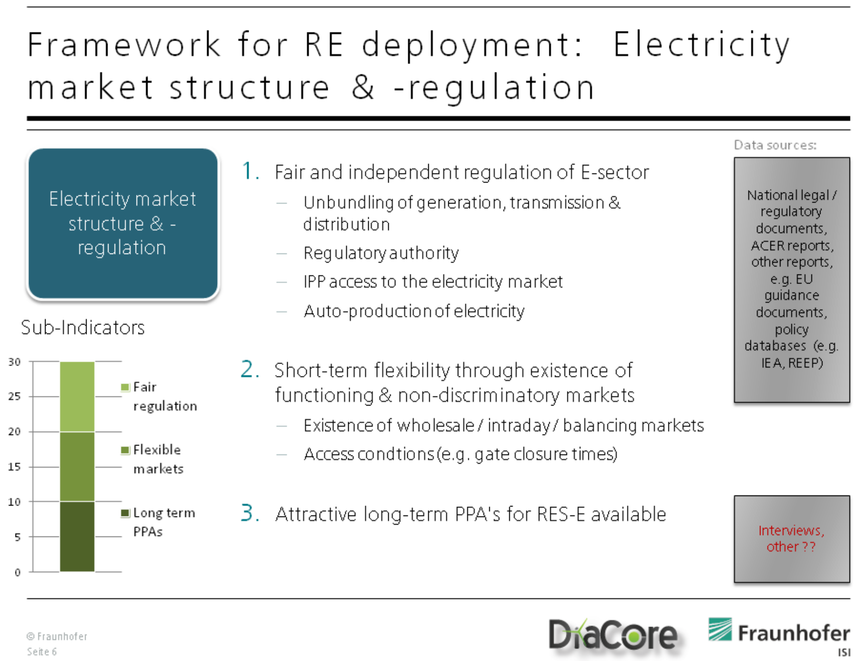

Figure 61: Exemplary slide used during the third expert workshop (30/01/2014, Vienna) to discuss possible indicators and data sources for the diffusion determinants.
Source: Own elaboration

A.2 WEIGHTING QUESTIONNAIRE

Your opinion counts: What is the relevance of individual barriers & drivers framing renewable energy (RE) development?

Background: This questionnaire is associated to the project ***re-frame*** and the related EU-project ***DiaCore*** which aim at:

- ✓ Recording the most important drivers and barriers framing the diffusion of different RE technologies via an online database.
- ✓ Assessing the relevance and resulting impact of these barriers and drivers in order to facilitate efficient policy design.

The following short exercise, for which we would like to ask you for your kind support, focuses on renewable electricity technologies and its goal is to deepen the understanding of major factors framing RE technology diffusion. Results shall help to estimate future deployment trajectories of RE technologies and support RE policy design. Therefore, the input of a broad variety of international experts is crucial.

Filling out the questionnaire will only take a few minutes. You can also return your answers by mail to: ***barriersurvey@diacore.eu***

You will be able to access the final results as well as additional and comprehensive, country specific information on barriers and drivers for RE via the website: ***www.re-frame.eu***

All results will be anonymized and aggregated on country-level; no contact information will be passed on or published at any time.

Procedure: Several factors might influence the investment decision for RE-projects and thus impact the resulting RE technology diffusion. Some major factors mentioned by energy experts and in literature are assembled in the hierarchical list shown on page 2. You will probably find from your experience that not all of these factors are equally important for RE development.

- → Please specify for the categories and subcategories how relevant you consider the individual items **with regard to the RE-technology you are mainly involved with**. If you wish to provide information for different technologies, please use separate questionnaires or add respective comments where the rating might differ.
- → **Please note that the rating shall not reflect the current manifestation of the items in a specific country but their general relevance for RE technology investments.** Illustrative example: *"The duration of administrative procedures is in general highly relevant for RE project development and thus gets 10 points"* ***NOT*** *"the duration of administrative procedures in country xy is very long and thus gets 10 points".*
- → Finally, please provide information on your professional background on page 3.
- → We would highly appreciate the opportunity to discuss further details on drivers and barriers for RE deployment in a face-to-face interview with you. If you are willing to do so, please give us an indication and provide your contact details on page 3. If you do not wish your company's name to appear in the final report please also indicate so.

If needed, you will find additional explanations for each category and sub-category on page 4.

Please specify the general relevance for RES-E technology diffusion:

1. **Start here** by allocating points to each category according to its relevance for the diffusion of one RE technology.

2. **Continue** with the same procedure for each sub-category group.

10 = Extremely relevant
5 = Moderately relevant (indifferent)
0 = Not relevant at all

The Rating shall not reflect the current country situation but the general relevance!

Technology: _____

Category	Points	Sub-category	Points
Grid regulation & infra-structure		Treatment of RES-E dispatch (curtailment)	
		Cost of RES-E grid access (charging approach)	
		Duration of RES-E grid access	
		Predictability / transparency of grid connec-tion procedure	
		Transparent & foreseeable grid development	
Administrative processes		Duration of administrative procedure	
		Cost of administrative procedure	
		Integration of RES-E in spatial & environ-mental planning	
		Complexity of administrative procedure	
Political & economic framework		Access to finance	
		Existence & reliability of general RES strategy & support scheme	
		Revenue risk under given support scheme	
		Remuneration level for RES-E	
Market structure		Availability of reliable long-term contracts (PPA)	
		Existence of functioning & non-discriminatory short term markets for RES-E	
		Fair & independent regulation of RES-E sector	

Your profile: To enable us to maximise the benefits from your contribution, please fill out the following information on your professional expertise (please decide on the most appropriate option and avoid multiple answers). You can but you do not have to provide your contact details; all contact information will be kept strictly confidential.

What is you technological focus?

Wind energy
- ☐ onshore
- ☐ offshore

☐ Biomass
☐ Hydro
☐ Geothermal

PV large scale
- ☐ ground mounted
- ☐ rooftop

☐ PV small scale (mainly rooftop)
☐ CSP
☐ Other: ___

In which country(ies) are you mainly active?

☐ EU (please specify):___

☐ Other (please specify):___

What kind of institution do you represent?

☐ RE Project developer
☐ RE technology manufacturer
☐ RE industry association
☐ Conventional energy industry or industry association
☐ Academic /Research institution
☐ NGO
☐ Financial institution
☐ Other (please specify):___

☐ Policy sector / public body
- ☐ National government
- ☐ Administration
- ☐ European policy body

☐ Utility / Generator
☐ Regulatory agency
☐ Grid operator

Thank you very much for your support!

Please indicate if we might contact you for an additional interview (face to face or by phone): ☐ Yes ☐ No

Your contact details (optional): ____

Room for your comments and suggestions (e.g.: Tell us which are currently the major barriers for RE in your country. What are your suggestions to remove them?): ____

Explanatory notes for the categories and sub-categories

Grid regulation & infrastructure --

- **Treatment of RES-E dispatch (curtailment):** Determines the level of certainty that generated RES-electricity will be dispatched and remunerated. Either RES-E priority dispatch or compensation payments in case of grid-related curtailment could be granted or RES-E could receive no priority dispatch and no compensation.
- **Cost of RES-E grid access:** Direct cost for connecting a RES-project to the grid. Depends on the charging approach: Shallow (only cost for connection to nearest point), super-shallow (no cost for connection), deep charging (for connection and grid reinforcement) or mixed approaches possible.
- **Duration of RES-E grid access:** Lead time for obtaining access and physical connection to the electricity grid.
- **Predictability / transparency of connection procedure:** Certainty that procedure, duration & cost for obtaining grid connection will turn out as anticipated (variance in duration and cost).
- **Transparent and foreseeable grid development:** Certainty about future grid development. Determined by availability of information on / existence of grid development plans. Might be relevant for evaluation of potential RES project sites.

Administrative processes --

- **Duration of administrative procedure**: Time required for obtaining all permits & documents required for starting the construction of the power plant.
- **Cost of administrative procedure:** Expenses related to obtaining all required building permits, environmental impact assessments and administrative processing fees. Excludes costs for the RE-equipment itself.
- **Integration of RES-E in spatial and environmental planning:** Inclusion of RES deployment in the overall spatial planning strategy (e.g. pre-reservation of areas for RES projects) might influence emergence of land use conflicts.
- **Complexity of administrative procedure:** Effort (not necessarily duration) for passing the permitting process. Could be influenced by No. of required permits, time limits for permit decisions, options for online application or general setup of administrative authorities, e.g. No. of authorities to be contacted directly or indirectly, communication & coordination between authorities, availability of one-stop shops.

Political and economic framework --

- **Access to finance:** Maturity of the national financing environment & ease to obtain attractive financing for RES projects. Includes availability of capital and respective financing costs (incl. national risk surcharges), existence of soft loan schemes and willingness of local banks to cooperate with RES developers.
- **Existence & reliability of general RES-E strategy & support scheme:** Risk of drastic & sudden changes in overall RES strategy & support scheme itself. In the worst case, this could imply a complete shift in or abandoning of RES targets or support scheme or retroactive changes of support. In a positive case, transparent adjustments could be made to improve RES support conditions.
- **Revenue risk under given support scheme:** Expected stability of RES support level under the given support instrument. May be affected by fluctuations in the remuneration level due to tariff adjustments (as foreseen in legislation) or risk factors inherent to the type of support scheme (e.g. risk associated with fluctuating certificate prices in a quota scheme vs. the relative stability of a fixed FIT).
- **Remuneration level for RES-E:** Expected income for a RES project under the given support scheme, resource conditions and technological performance parameters. In case of a quota or feed-in premium it comprises the overall remuneration available for RES, including certificate price/premium and final energy price.

Market structure --

- **Availability of reliable long term contracts (PPA):** Attractive Power Purchase Agreements (PPAs) may mitigate risks associated with volatile electricity prices and provide long-term revenue certainty for RES developers. PPAs are of crucial relevance in support schemes where the electricity price is part of the overall remuneration, such as quota systems with tradable green certificates (TGC) or premium systems.
- **Existence of functioning & non-discriminatory short term markets for RES-E**: Flexibility for RES developers to participate on even ground in wholesale, intraday and possibly balancing markets. E.g. liquidity of markets and gate closure times may affect the integration of variable RES-E.
- **Fair & independent regulation of the RES-E sector:** Implies non-discriminatory access of RES-producers to the market. It is provided through existence of the legal basis for participation of independent power producers (IPPs), unbundling and empowerment of an independent regulatory body.

A.3 INTERVIEW GUIDELINE

Interview guideline - Relevance of barriers & drivers framing renewable energy (RE) development

INTRODUCTION

This interview guideline is related to the EU-project ***DiaCore*** and the associated project ***re-frame*** which aim at:

- ✓ Recording the most important drivers and barriers framing the diffusion of different RE technologies via an online database.
- ✓ Assessing the relevance and resulting impact of these barriers and drivers in order to facilitate efficient policy design.

In general, the goal of this interview is to deepen the understanding of major factors framing RE technology diffusion on a national level. Results shall help to estimate future deployment trajectories of RE technologies and support RE policy design. Therefore, the input of a broad variety of international experts is crucial.

The assessment is based on two steps:

1. An evaluation (weighting) of previously identified determinants and sub-determinants for RE diffusion. This is done via a short questionnaire in which stakeholders are asked to attribute weights to possible determinants accounting for their relevance for investment decisions in RE.

2. In-depth interviews with selected country experts that have previously completed the weighting exercise. The interviews aim at reflecting on the results from the weighting exercise and gaining a better understanding about the background and reasoning for the allocation of the weights.

This guideline is related to the second step and structures the intended content of the interview. It comprises two main parts:

- A few general, overarching questions
- Detailed questions about individual determinants of the weighting questionnaire.

Thereby, two types of questions will appear:

➲ "***Value questions***" aim at retrieving concrete, quantitative information on the manifestation of the attributes in a specific country. If you do not have the information to answer these questions, e.g. because you are not directly active in RE project development, please skip the respective question.

✪ "***Context questions***" shall help to improve the general understanding of the broader context and background of certain aspects. Therefore a more open discussion on these questions is intended.

Explanations and explanatory graphs for the determinants mentioned are provided in the Annex of this document. The overall interview is intended to take about 60 minutes. If you agree, we would like to record the interview in order to avoid a loss of important information and to facilitate the evaluation. All recordings will be saved inaccessible by third persons and will be deleted after completion of the project[1]. Please let us know if you do not consent to this. However, we can assure you that **all results will be anonymized** and aggregated on country-level; **no contact information will be passed on or published at any time.**

You will be able to access the final results as well as additional and comprehensive, country specific information on barriers and drivers for RE via the website: ***www.re-frame.eu***

[1] If necessary, this procedure can be confirmed by signature if the interviewer.

YOUR PROFILE

Interview conducted by:

Date:

Name of interviewee (as indicated on the weighting questionnaire):

The interview refers to:

RE-Technology: ____

Country: ____

FIRST PART – WEIGHTING RESULTS / OVERARCHING QUESTIONS

1. Feedback to the previously completed weighting exercise

1.1 Was the weighting procedure well understandable & the explanation clear?	
1.2 Are important aspects missing from your point of view?	

2. Overarching questions to the weighting exercise

2.1 Among the listed parameters are there any „KO Criteria“ (absolute “*must haves*”) which are mandatory for any RE-deployment to take place? If yes, which ones?	
2.2 Are there aspects for which the relevance strongly differs between RE technologies?	
2.3 With regard to which technology (and segment) would you like to answer the questions?	

SECOND PART - DETAILED QUESTIONS ABOUT THE DETERMINANTS

Note: 'Your country' always refers to the major target market or the country for which you would like to answer the questions, respectively. All answers should refer to the technology chosen in the beginning or differentiate between technologies where necessary.

A. Administrative processes

(1) Duration of administrative procedures for renewable energy projects

(*Time in weeks needed to complete all required legal-administrative steps for starting the construction of a RE project, e.g. acquisition of building- & environmental permits, incl. waiting times but excluding grid connection permit and electricity production license, see also* **Figure 1**)

A(1) a)	➲What is the current typical administrative lead time for RE projects in your country?	weeks
A(1) b)	➲Which minimum and maximum durations did you experience in the last year?	Minimum: weeks Maximum: weeks
A(1) c)	➲What is an acceptable duration from your perspective?	weeks
A(1) d)	➲Under which conditions (temporal limit) would you restrain from project development in a country (threshold)?	weeks
A(1) e)	✪Based on your experience, what are the major factors determining the duration of the administrative procedure?	
A(1) f)	✪Is the total duration of the administrative procedures more relevant or is the predictability of the duration more relevant (in terms of planning security)?	
A(1) g)	➲Compared to today, how was the duration of administrative procedures 3 years ago?	☐ shorter ☐ equal ☐ longer ☐ no opinion

(2) Cost of administrative procedures for renewable energy projects

(Note: The share of legal-administrative cost as % of RE project development cost includes permits, EIA and official administration fees, but excludes the project equipment cost/hardware).

A(2) a)	➲What is the current typical share of administrative cost in the total project development cost in your country?	%
A(2) b)	➲Which minimum and maximum cost shares did you experience in the last year?	Minimum: % Maximum: %
A(2) c)	➲What is an acceptable cost share from your perspective?	%
A(2) d)	➲Under which conditions (cost-limit) would you restrain from project development (threshold)?	%
A(2) e)	➲Compared to today, how was the cost of administrative procedures 3 years ago?	☐ lower ☐ equal ☐ higher ☐ no opinion

(3) Integration of renewable electricity generation in spatial & environmental planning

A(3) a)	➲How do you evaluate the current integration of RE development in spatial planning in your country?	☐ good ☐ average/medium ☐ poor ☐ no opinion
A(3) b)	✪If you experienced problems in terms of integration of RE in spatial planning in the past, which were the reasons (e.g. difficulties finding suitable project sites, land use conflicts, no/too little areas reserved for RE projects, reserved areas were not suitable, other issues)?	
A(3) c)	✪What would be the best solution to optimally integrate RE planning into spatial planning, from your point of view?	

A(3) d)	➲Compared to today, how was the integration of RE planning in spatial planning 3 years ago?	☐ better ☐ equal ☐ worse ☐ no opinion

(4) Complexity of administrative procedures for renewable energy projects

A(4) a)	How would you evaluate the current complexity of the administrative procedures for RE projects in your country?	☐ not complex ☐ average/medium ☐ very complex ☐ no opinion
A(4) b)	✪If you experienced problems related to the administrative process for RE projects in the past, which were the reasons (e.g. high number of authorities involved, unclear responsibilities, incompetency, lack of communication among authorities, other issues)?	
A(4) c)	➲How many permits are currently required to complete the administrative process?	permits
A(4) d)	➲What is an acceptable number of permits in your opinion?	permits
A(4) e)	➲How many authorities do you currently have to contact during the process?	authorities
A(4) f)	✪Would online application platforms and/or definition of time limits (maximum durations with automatic approval) facilitate the process?	
A(4) g)	✪Would a one-stop-shop approach be a suitable solution?	
A(4) h)	✪What characterizes the optimal administrative framework for RE project development, from your point of view?	
A(4) i)	➲Compared to today, how was the complexity of administrative procedures 3 years ago?	☐ better ☐ equal ☐ worse ☐ no opinion

B. Grid regulation & infrastructure

(1) Treatment of RES-E dispatch (curtailment)
(2) Cost of RES-E grid access (charging approach)

(3) Duration of RES-E grid access

(Note: The time comprises the weeks between first request for grid access permit and moment when the RE project obtains physical grid access.)

B(3) a)	➲What is the current typical time for obtaining grid access for RE projects in your country?	weeks
B(3) b)	➲Which minimum and maximum durations did you experience in the last year?	Minimum: weeks Maximum: weeks
B(3) c)	➲What is an acceptable duration from your perspective?	weeks
B(3) d)	➲Under which conditions (temporal limit) would you restrain from project development in a country (threshold)?	weeks
B(3) e)	➲Compared to today, how was the duration of grid access procedures 3 years ago?	☐ shorter ☐ equal ☐ longer ☐ no opinion

(4) Predictability / transparency of grid connection procedure

B(4) a)	➲How would you evaluate the current predictability of grid connection procedures in your country?	☐ very predictable & transparent ☐ average/medium ☐ very intransparent & unpredictable ☐ no opinion
B(4) b)	➲Compared to today, how was the transparency of grid connection procedures 3 years ago?	☐ better ☐ equal ☐ worse ☐ no opinion

(5) Transparent & foreseeable grid development

B(5) a)	➲How transparent & foreseeable is currently the future grid development in your country?	☐ very transparent & forseeable ☐ average/medium ☐ very intransparent & unforseeable ☐ no opinion
B(5) b)	✪What characterizes the optimal framework for a transparent & foreseeable grid development, from your point of view?	
B(5) c)	➲Compared to today, how was the transparency of grid development 3 years ago?	☐ better ☐ equal ☐ worse ☐ no opinion

C. Market structure

(1) Availability of reliable long-term contracts (PPA) for renewable electricity

C(1) a)	➲How would you evaluate the availability of reliable long-term contracts for renewable electricity in your country?	☐ completely sufficient ☐ average/medium ☐ not sufficient at all ☐ no opinion
C(1) b)	✪Based on which type of contract do you receive remuneration from the electricity market, besides the income from the support scheme / RE premium (long term contracts, spot market, day-ahead market, other)?	
C(1) c)	➲Compared to today, how was the availability of reliable long-term contracts for RE in your country 3 years ago?	☐ better ☐ equal ☐ worse ☐ no opinion

(2) Existence of functioning & non-discriminatory short term markets for RE

C(2) a)	➲How well do current short-term markets reflect the needs of generators of variable renewable electricity?	☐ completely sufficient ☐ average/medium ☐ not sufficient at all ☐ no opinion
C(2) b)	✪ Which options do you use to manage short-term fluctuations in your RE plant output (intraday markets, balancing markets, other)?	
C(2) c)	➲Compared to today, how was the availability of liquid markets for RE in your country 3 years ago?	☐ better ☐ equal ☐ worse ☐ no opinion

(3) Fair & independent regulation of renewable energy sector

C(3) a) ➲How would you evaluate the regulation of the renewable energy sector in your country, e.g. in terms of IPP access to the market and possibilities for auto production of RE?	☐ very favourable & supportive for RE ☐ average/non-discriminatory for RE ☐ very unfavourable & discriminatory for RE ☐ no opinion
C(3) b) ➲Compared to today, how was the regulation of the RE sector in your country 3 years ago?	☐ more favourable ☐ equally favourable ☐ less favourable ☐ no opinion

D. Political & economic framework

(1) Access to finance for renewable energy projects

D(1) a) ➲How do you evaluate the <u>general</u> capital availability in your country?	☐ very good ☐ average/moderate ☐ poor ☐ no opinion
D(1) b) ✪Which are currently the major characteristics of the financing market that impede and/or support the access to capital for RE-project development in your country?	
D(1) c) ➲How do you evaluate the <u>availability of specific RE financing programs</u> in your country?	☐ very good ☐ average/moderate ☐ poor ☐ no opinion
D(1) d) ➲Compared to today, how was the capital access for RE projects in your country 3 years ago?	☐ better ☐ equal ☐ worse ☐ no opinion

(2) Existence & reliability of general renewable energy strategy & support scheme

D(2) a)	➲How do you evaluate the reliability of the general RE strategy in your country?	☐ sufficient ☐ average/moderate ☐ insufficient ☐ no opinion
D(2) b)	✪Which are currently the major characteristics of the national RE strategy and support scheme that impede and/or support RE development?	
D(2) c)	➲Compared to today, how was the reliability of the RE strategy & support in your country 3 years ago?	☐ better ☐ equal ☐ worse ☐ no opinion

(3) Revenue risk under the given renewable energy support scheme

D(3) a)	➲How do you evaluate the current revenue risk under the present RE support scheme in your country?	☐ low ☐ medium ☐ high ☐ no opinion
D(3) b)	✪Why / Which are the factors justifying your assessment under D(3)a)?	
D(3) c)	➲How important is the risk of fluctuations compared to the expected medium remuneration level from your point of view?	☐ very important ☐ medium/indifferent ☐ of low importance ☐ no opinion
D(3) d)	✪ Why / Which are the factors justifying your assessment under D(3)c)?	
D(3) e)	➲Compared to today, how was the revenue risk for electricity from RE in your country 3 years ago?	☐ lower ☐ equal ☐ higher ☐ no opinion

(4) Remuneration level for electricity from renewable sources

D(4) a)	➲Do you consider the current remuneration level for electricity from renewable energy sources in your country as:	☐ rather high ☐ sufficient ☐ rather low ☐ no opinion

THIRD PART - CLOSING

1. Do you have any additional comments or questions?
2. Do you have specific preferences regarding the anonymity of the information you provided?

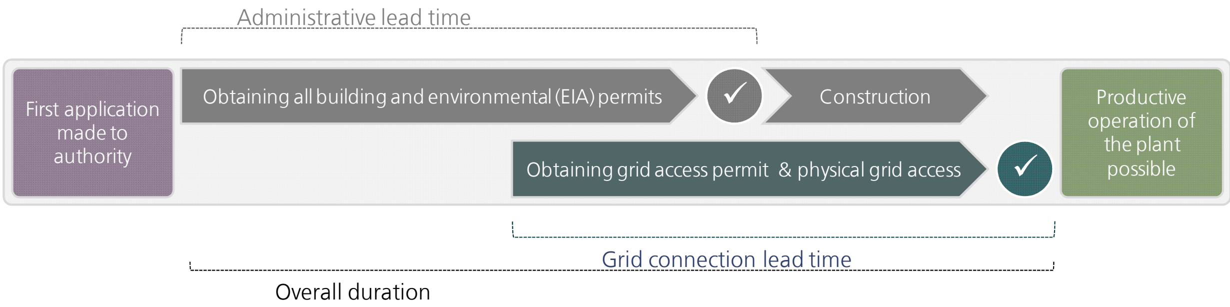

Figure 1 Schematic illustration of the major steps defining the duration of administrative procedure and grid connection procedure. The overall duration is not necessarily equal to the sum of the individual procedures.

Box 1 Glossary

Explanatory notes for the categories and sub-categories

Grid regulation & infrastructure --

- **Treatment of RES-E dispatch (curtailment):** Determines the level of certainty that generated renewable electricity will be dispatched and remunerated. Either RES-E priority dispatch or compensation payments in case of grid-related curtailment could be granted or RES-E could receive no priority dispatch and no compensation.
- **Cost of RES-E grid access:** Direct cost for connecting a RES-project to the grid. Depends on the charging approach: Shallow (only cost for connection to nearest point), super-shallow (no cost for connection), deep charging (for connection and grid reinforcement) or mixed approaches possible.
- **Duration of RES-E grid access:** Lead time for obtaining access and physical connection to the electricity grid.
- **Predictability / transparency of connection procedure:** Certainty that procedure, duration & cost for obtaining grid connection will turn out as anticipated (variance in duration and cost).
- **Transparent and foreseeable grid development:** Certainty about future grid development. Determined by availability of information on / existence of grid development plans. Might be relevant for evaluation of potential RES project sites.

Administrative processes --

- **Duration of administrative procedure**: Time required for obtaining all permits & documents required for starting the construction of the power plant.
- **Cost of administrative procedure:** Expenses related to obtaining all required building permits, environmental impact assessments and administrative processing fees. Excludes costs for the RE-equipment itself.
- **Integration of RES-E in spatial and environmental planning:** Inclusion of RES deployment in the overall spatial planning strategy (e.g. pre-reservation of areas for RES projects) might influence emergence of land use conflicts.
- **Complexity of administrative procedure:** Effort (not necessarily duration) for passing the permitting process. Could be influenced by No. of required permits, time limits for permit decisions, options for online application or general setup of administrative authorities, e.g. No. of authorities to be contacted directly or indirectly, communication & coordination between authorities, availability of one-stop shops.

Political and economic framework --

- **Access to finance:** Maturity of the national financing environment & ease to obtain attractive financing for RES projects. Includes availability of capital and respective financing costs (incl. national risk surcharges), existence of soft loan schemes and willingness of local banks to cooperate with RES developers.
- **Existence & reliability of general RES-E strategy & support scheme:** Risk of drastic & sudden changes in overall RES strategy & support scheme itself. In the worst case, this could imply a complete shift in or abandoning of RES

targets or support scheme or retroactive changes of support. In a positive case, transparent adjustments could be made to improve RES support conditions.

- **Revenue risk under given support scheme:** Expected stability of RES support level under the given support instrument. May be affected by fluctuations in the remuneration level due to tariff adjustments (as foreseen in legislation) or risk factors inherent to the type of support scheme (e.g. risk associated with fluctuating certificate prices in a quota scheme vs. the relative stability of a fixed FIT).
- **Remuneration level for RES-E:** Expected income for a RES project under the given support scheme, resource conditions and technological performance parameters. In case of a quota or feed-in premium it comprises the overall remuneration available for RES, including certificate price/premium and final energy price.

Market structure ---

- **Availability of reliable long term contracts (PPA):** Attractive Power Purchase Agreements (PPAs) may mitigate risks associated with volatile electricity prices and provide long-term revenue certainty for RES developers. PPAs are of crucial relevance in support schemes where the electricity price is part of the overall remuneration, such as quota systems with tradable green certificates (TGC) or premium systems.
- **Existence of functioning & non-discriminatory short term markets for RES-E**: Flexibility for RES developers to participate on even ground in wholesale, intraday and possibly balancing markets. E.g. liquidity of markets and gate closure times may affect the integration of variable RES-E.
- **Fair & independent regulation of the RES-E sector:** Implies non-discriminatory access of RES-producers to the market. It is provided through existence of the legal basis for participation of independent power producers (IPPs), unbundling and empowerment of an independent regulatory body.

Table 21: Descriptive statistics for the weighting data sample: Overall dataset and technology subsets

Overall data sample

Determinant	A-I	A-II	A-III	A-IV	B-I	B-II	B-III	C-I	C-II	C-III	C-IV	C-V	D-I	D-II	D-III	D-IV
Observations	209	208	209	209	209	208	208	208	209	209	208	209	209	209	209	209
Mean	8.1962	7.9760	7.8086	7.1770	7.5024	6.5481	7.0192	6.8462	6.5742	7.0383	6.7500	6.5933	5.7464	7.0909	7.1100	6.6507
Standard deviation	1.9721	1.7922	1.9319	2.0990	1.9639	1.9079	2.2967	2.0372	1.9941	1.9754	2.1139	1.9519	2.1186	2.1205	2.0714	2.1455
Minimum	1	3	1	0	1	0	0	0	0	1	1	1	0	0	0	0
25% quartile	7	7	7	5	6	5	5	5	5	5	5	5	5	6	6	5
50% quartile (median)	9	8	8	8	8	7	7	7	7	7	7	7	5	7	7	7
75% quartile	10	9	9	9	9	8	9	8	8	9	8	8	7	9	9	8
Maximum	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

PV large scale

Determinant	A-I	A-II	A-III	A-IV	B-I	B-II	B-III	C-I	C-II	C-III	C-IV	C-V	D-I	D-II	D-III	D-IV
Observations	93	92	93	93	93	93	93	93	93	93	93	93	93	93	93	93
Mean	8.0968	7.8043	7.9140	7.2258	7.2473	6.6667	6.7957	6.6667	6.3978	6.8602	6.3978	6.2796	5.6667	6.5806	6.7957	6.4086
Standard deviation	1.9730	1.8232	1.9430	2.2512	1.8572	1.8494	2.3199	2.0869	1.9789	2.0140	2.1576	1.8787	2.1636	2.1535	1.9199	2.1071
Minimum	1	4	1	0	3	2	0	0	1	2	1	1	0	1	1	1
25% quartile	7	7	7	5	6	5	5	5	5	5	5	5	4	5	5	5
50% quartile (median)	8	8	8	8	7	7	7	7	6	7	6	6	5	7	7	6
75% quartile	10	9	9	9	9	8	9	8	8	8	8	7	7	8	8	8
Maximum	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

Wind onshore

Determinant	A-I	A-II	A-III	A-IV	B-I	B-II	B-III	C-I	C-II	C-III	C-IV	C-V	D-I	D-II	D-III	D-IV
Observations	124	123	124	124	124	123	123	124	124	124	124	124	124	124	124	124
Mean	8.2581	7.9350	7.9597	7.1855	7.3710	6.6585	7.1220	6.8468	6.6613	7.0403	6.6532	6.7097	5.5968	7.1290	7.0887	6.7258
Standard deviation	1.9207	1.7403	1.7916	2.0217	2.0540	1.8414	2.2601	1.7717	2.0157	1.8231	2.1224	1.9329	1.8953	2.0952	1.9213	2.0771
Minimum	1	4	1	0	1	1	0	2	0	2	1	1	0	1	1	1
25% quartile	7	7	7	5	6	5	5	5.75	5	6	5	5	4	5	6	5
50% quartile (median)	9	8	8	7	7.5	7	7	7	7	7	7	7	5	7	7	7
75% quartile	10	9	9	9	9	8	9	8	8	8	8	8	7	9	8.25	8
Maximum	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

PV focused (exclusively PV large-scale)

Determinant	A-I	A-II	A-III	A-IV	B-I	B-II	B-III	C-I	C-II	C-III	C-IV	C-V	D-I	D-II	D-III	D-IV
Observations	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
Mean	8.1579	7.7368	8.0000	6.5263	7.2632	6.3684	6.9474	6.2105	6.3684	6.6316	6.7368	5.8947	6.0526	6.1579	6.7895	6.5263
Standard deviation	1.8934	1.5218	1.8257	2.4122	1.7270	1.7065	2.3915	2.6579	2.0058	2.4086	2.1303	1.7287	2.5922	1.9225	1.8732	1.9824
Minimum	3	4	3	2	4	3	3	0	3	2	2	2	0	2	3	4
25% quartile	7	7	7.5	5	6	6	5.5	4	5	5	5	5	4.5	5.5	5.5	5
50% quartile (median)	8	8	8	7	7	7	7	7	6	7	7	6	6	6	7	6
75% quartile	10	9	9	8	8	7	9	8	8	8.5	8	7	8	7.5	8	8
Maximum	10	10	10	10	10	9	10	10	10	10	9	9	10	9	9	10

Wind focused (exclusively wind onshore)

Determinant	A-I	A-II	A-III	A-IV	B-I	B-II	B-III	C-I	C-II	C-III	C-IV	C-V	D-I	D-II	D-III	D-IV
Observations	43	43	43	43	43	42	42	43	43	43	43	43	43	43	43	43
Mean	8.6512	8.1395	8.1163	6.9535	7.7209	6.5952	7.8333	7.1628	7.0233	7.2791	7.3721	7.3023	5.7674	7.9302	7.6047	7.3721
Standard deviation	1.7979	1.4071	1.5152	1.8381	2.1528	1.6683	2.1404	1.7034	2.1875	1.7365	1.9398	1.9338	1.7435	1.7375	1.8276	1.9521
Minimum	3	5	4	2	2	2	1	2	0	3	2	2	3	3	3	3
25% quartile	8	7	7	5	6.5	5	7	6	5	6	6	6.5	4.5	7	6.5	6
50% quartile (median)	9	8	8	7	8	6.5	9	7	7	7	8	7	5	8	8	8
75% quartile	10	9	9	8	9.5	8	9	8	8.5	8	9	9	7.5	9	9	9
Maximum	10	10	10	10	10	9	10	10	10	10	10	10	10	10	10	10

Table 22: Results of t-tests for significance of technology-specific differences in weighting scores (1/2). Two-sample t-test assuming unequal variances and independent samples.

Existence & reliability of RE strategy & support scheme

	PV focus	*Wind focus*
Mean	8.157894737	8.651162791
Variance	3.584795322	3.23255814
Observations	19	43
Hypothesized Mean Difference	0	
Df	33	
t Stat	-0.960295938	
P(T<=t) one-tail	0.171945008	
t Critical one-tail	1.692360258	
P(T<=t) two-tail	0.343890016	
t Critical two-tail	2.034515287	

Revenue risk under given RE support scheme

	PV focus	*Wind focus*
Mean	8	8.11627907
Variance	3.333333333	2.295681063
Observations	19	43
Hypothesized Mean Difference	0	
Df	29	
t Stat	-0.243079516	
P(T<=t) one-tail	0.404827488	
t Critical one-tail	1.699126996	
P(T<=t) two-tail	0.809654977	
t Critical two-tail	2.045229611	

Remuneration level for RE

	PV focus	*Wind focus*
Mean	7.736842105	8.139534884
Variance	2.315789474	1.980066445
Observations	19	43
Hypothesized Mean Difference	0	
Df	32	
t Stat	-0.982669512	
P(T<=t) one-tail	0.166570938	
t Critical one-tail	1.693888703	
P(T<=t) two-tail	0.333141875	
t Critical two-tail	2.036933334	

Access to finance

	PV focus	*Wind focus*
Mean	6.526315789	6.953488372
Variance	5.81871345	3.378737542
Observations	19	43
Hypothesized Mean Difference	0	
Df	28	
t Stat	-0.688608933	
P(T<=t) one-tail	0.248367914	
t Critical one-tail	1.701130908	
P(T<=t) two-tail	0.496735829	
t Critical two-tail	2.048407115	

Fair & independent regulation of the RE sector

	PV focus	*Wind focus*
Mean	7.263157895	7.720930233
Variance	2.98245614	4.634551495
Observations	19	43
Hypothesized Mean Difference	0	
Df	43	
t Stat	-0.889672596	
P(T<=t) one-tail	0.189296119	
t Critical one-tail	1.681070704	
P(T<=t) two-tail	0.378592238	
t Critical two-tail	2.016692173	

Existence of functioning & non-discriminatory short term markets

	PV focus	*Wind focus*
Mean	6.368421053	6.595238095
Variance	2.912280702	2.783391405
Observations	19	42
Hypothesized Mean Difference	0	
Df	34	
t Stat	-0.484071816	
P(T<=t) one-tail	0.315719221	
t Critical one-tail	1.690924198	
P(T<=t) two-tail	0.631438442	
t Critical two-tail	2.032244498	

Availability of reliable long term contracts (PPA)

	PV focus	*Wind focus*
Mean	6.947368421	7.833333333
Variance	5.719298246	4.581300813
Observations	19	42
Hypothesized Mean Difference	0	
Df	32	
t Stat	-1.383485661	
P(T<=t) one-tail	0.088046095	
t Critical one-tail	1.693888703	
P(T<=t) two-tail	0.17609219	
t Critical two-tail	2.036933334	

Cost of RES-E grid access

	PV focus	*Wind focus*
Mean	6.210526316	7.162790698
Variance	7.064327485	2.901439646
Observations	19	43
Hypothesized Mean Difference	0	
Df	25	
t Stat	-1.436765237	
P(T<=t) one-tail	0.08159126	
t Critical one-tail	1.708140745	
P(T<=t) two-tail	0.16318252	
t Critical two-tail	2.059538536	

Duration of RES-E grid access

	PV focus	*Wind focus*
Mean	6.368421053	7.023255814
Variance	4.023391813	4.785160576
Observations	19	43
Hypothesized Mean Difference	0	
Df	37	
t Stat	-1.152135065	
P(T<=t) one-tail	0.128327828	
t Critical one-tail	1.687093597	
P(T<=t) two-tail	0.256655655	
t Critical two-tail	2.026192447	

Predictability & transparency of grid connection procedure

	PV focus	*Wind focus*
Mean	6.631578947	7.279069767
Variance	5.801169591	3.015503876
Observations	19	43
Hypothesized Mean Difference	0	
Df	27	
t Stat	-1.056710426	
P(T<=t) one-tail	0.15000371	
t Critical one-tail	1.703288423	
P(T<=t) two-tail	0.300007421	
t Critical two-tail	2.051830493	

Table 23: Results of t-tests for significance of technology-specific differences in weighting scores (2/2). Two-sample t-test assuming unequal variances and independent samples.

Treatment of RE dispatch (curtailment)	*PV focus*	*Wind focus*
Mean	6.736842105	7.372093023
Variance	4.538011696	3.763012182
Observations	19	43
Hypothesized Mean Difference	0	
Df	32	
t Stat	-1.111988794	
P(T<=t) one-tail	0.137213827	
t Critical one-tail	1.693888703	
P(T<=t) two-tail	0.274427653	
t Critical two-tail	2.036933334	

Transparent and foreseeable grid development	*PV focus*	*Wind focus*
Mean	5.894736842	7.302325581
Variance	2.988304094	3.739756368
Observations	19	43
Hypothesized Mean Difference	0	
Df	38	
t Stat	-2.848119998	
P(T<=t) one-tail	0.003529696	
t Critical one-tail	1.685954461	
P(T<=t) two-tail	0.007059391	
t Critical two-tail	2.024394147	

Duration of administrative procedures	*PV focus*	*Wind focus*
Mean	6.157894737	7.930232558
Variance	3.695906433	3.018826135
Observations	19	43
Hypothesized Mean Difference	0	
Df	32	
t Stat	-3.444670401	
P(T<=t) one-tail	0.000808441	
t Critical one-tail	1.693888703	
P(T<=t) two-tail	0.001616881	
t Critical two-tail	2.036933334	

Cost of administrative procedure	*PV focus*	*Wind focus*
Mean	6.052631579	5.76744186
Variance	6.719298246	3.03986711
Observations	19	43
Hypothesized Mean Difference	0	
Df	25	
t Stat	0.437800171	
P(T<=t) one-tail	0.332645211	
t Critical one-tail	1.708140745	
P(T<=t) two-tail	0.665290422	
t Critical two-tail	2.059538536	

Complexity of administrative procedures	*PV focus*	*Wind focus*
Mean	6.789473684	7.604651163
Variance	3.50877193	3.339977852
Observations	19	43
Hypothesized Mean Difference	0	
Df	34	
t Stat	-1.591530104	
P(T<=t) one-tail	0.060373261	
t Critical one-tail	1.690924198	
P(T<=t) two-tail	0.120746522	
t Critical two-tail	2.032244498	

Integration of RE in spatial and environmental planning	*PV focus*	*Wind focus*
Mean	6.526315789	7.372093023
Variance	3.929824561	3.810631229
Observations	19	43
Hypothesized Mean Difference	0	
Df	34	
t Stat	-1.556009968	
P(T<=t) one-tail	0.064483084	
t Critical one-tail	1.690924198	
P(T<=t) two-tail	0.128966169	
t Critical two-tail	2.032244498	

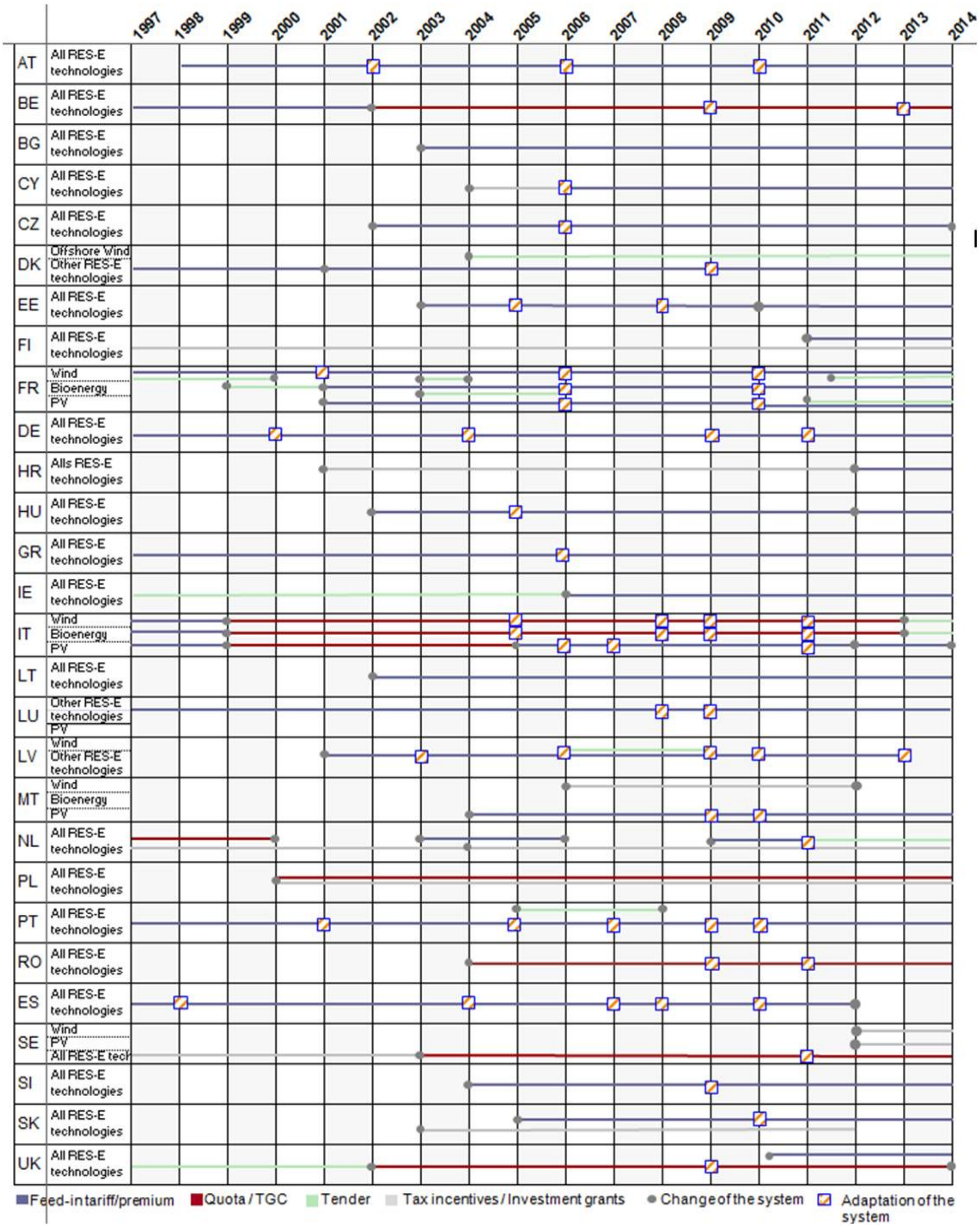

Figure 62: Overview over the development of RE support schemes in the EU Member States (1997-2014). Source: (Boie, Ragwitz, Steinhilber et al., 2015, p. 38)

Table 24: Remuneration levels and generation costs [€ct/kWh] for non-residential PV and wind energy onshore in Germany, Spain and the UK as applied for calculation of the CI. Calculated based on remuneration levels and technology cost according to DIA-CORE (2013).

Country	Technology	Parameter [€cent/kWh]		2009	2010	2011	2012	2013	2014
DE	Wind Onshore	Remuneration Level	Min Remuneration	6.05	6.06	6.06	6.35	6.36	6.30
DE	Wind Onshore	Remuneration Level	Max Remuneration	7.89	8.21	8.53	8.02	7.90	7.59
DE	Wind Onshore	Remuneration Level	Average Remuneration	6.97	7.13	7.29	7.19	7.13	6.95
DE	Wind Onshore	LCOE	Min Cost	6.94	7.31	7.26	6.38	5.52	5.52
DE	Wind Onshore	LCOE	Max Cost	10.85	11.42	11.34	9.75	8.45	8.45
DE	Wind Onshore	LCOE	Average Cost	8.68	9.14	9.07	7.89	6.84	6.84

Country	Technology	Parameter [€cent/kWh]		2009	2010	2011	2012	2013	2014
DE	PV	Remuneration Level	Min Remuneration	27.23	22.62	18.00	15.30	9.03	7.66
DE	PV	Remuneration Level	Max Remuneration	36.67	30.59	24.50	21.56	12.19	10.42
DE	PV	Remuneration Level	Average Remuneration	31.95	26.60	21.25	18.43	10.61	9.04
DE	PV	LCOE	Min Cost	27.45	22.75	19.86	14.52	10.82	10.35
DE	PV	LCOE	Max Cost	56.29	46.94	40.96	30.38	27.66	26.49
DE	PV	LCOE	Average Cost	33.13	27.52	24.03	17.65	14.07	13.46

Country	Technology	Parameter [€cent/kWh]		2009	2010	2011	2012	2013	2014
ESP	Wind Onshore	Remuneration Level	Min Remuneration	6.20	6.43	6.66	4.77	4.64	4.80
ESP	Wind Onshore	Remuneration Level	Max Remuneration	7.39	7.66	7.94	4.85	4.64	4.80
ESP	Wind Onshore	Remuneration Level	Average Remuneration	6.79	7.05	7.30	4.81	4.64	4.80
ESP	Wind Onshore	LCOE	Min Cost	6.16	6.49	6.44	5.68	4.91	4.91
ESP	Wind Onshore	LCOE	Max Cost	10.78	11.36	11.27	9.69	8.38	8.38
ESP	Wind Onshore	LCOE	Average Cost	8.21	8.65	8.59	7.49	6.48	6.48

Country	Technology	Parameter [€cent/kWh]		2009	2010	2011	2012	2013	2014
ESP	PV	Remuneration Level	Min Remuneration	27.84	19.47	11.10	5.63	4.64	4.80
ESP	PV	Remuneration Level	Max Remuneration	29.54	28.36	27.17	5.63	4.64	4.80
ESP	PV	Remuneration Level	Average Remuneration	28.69	23.91	19.14	5.63	4.64	4.80
ESP	PV	LCOE	Min Cost	19.66	16.29	14.23	10.40	7.75	7.41
ESP	PV	LCOE	Max Cost	38.27	31.91	27.85	20.65	18.80	18.01
ESP	PV	LCOE	Average Cost	22.92	19.03	16.62	12.20	9.68	9.26

Country	Technology	Parameter [€cent/kWh]		2009	2010	2011	2012	2013	2014
UK	Wind Onshore	Remuneration Level	Min Remuneration	8.70	9.31	9.91	10.00	10.37	10.49
UK	Wind Onshore	Remuneration Level	Max Remuneration	9.04	10.21	11.37	10.56	10.64	10.49
UK	Wind Onshore	Remuneration Level	Average Remuneration	8.87	9.76	10.64	10.28	10.50	10.49
UK	Wind Onshore	LCOE	Min Cost	5.44	5.73	5.69	5.20	4.51	4.51
UK	Wind Onshore	LCOE	Max Cost	10.25	10.79	10.71	9.79	8.49	8.49
UK	Wind Onshore	LCOE	Average Cost	7.26	7.64	7.59	6.66	5.77	5.77

Country	Technology	Parameter [€cent/kWh]		2009	2010	2011	2012	2013	2014
UK	PV	Remuneration Level	Min Remuneration	12.03	17.66	23.29	11.88	7.05	13.15
UK	PV	Remuneration Level	Max Remuneration	34.75	50.77	50.77	15.70	12.39	14.63
UK	PV	Remuneration Level	Average Remuneration	23.39	34.22	37.03	13.79	9.72	13.89
UK	PV	LCOE	Min Cost	29.07	24.18	21.18	15.49	11.60	11.02
UK	PV	LCOE	Max Cost	50.27	42.09	36.87	27.35	24.90	23.69
UK	PV	LCOE	Average Cost	32.49	27.09	23.74	17.43	13.90	13.20

Table 25: Normalized indicator scores representing the remuneration levels for PV and wind energy onshore in Germany, Spain and the UK (based on data from (DIA-CORE, 2013), cf. Table 24).

		Year					
Country	Technology	2009	2010	2011	2012	2013	2014
DE	Wind Onshore	0.10	0.09	0.13	0.20	0.33	0.29
DE	PV	0.16	0.16	0.11	0.23	0.04	0.002
ESP	Wind Onshore	0.12	0.11	0.14	0.00	0.00	0.00
ESP	PV	0.26	0.38	0.47	0.00	0.00	0.00
UK	Wind Onshore	0.36	0.43	0.55	0.56	0.75	0.73
UK	PV	0.12	0.68	0.87	0.01	0.03	0.15

Table 26: Policy design options and associated policy risk levels as used for the Composite Indicator (based on Resch (2015)).

Support instrument	Risk multiplier	Normalized score
Floating Premium	0.90	1.00
Feed-in Tariff with frontloading	0.93	0.93
Fixed Feed-in Tariff	1.00	0.79
Fixed Premium with frontloading	1.08	0.66
Fixed Premium	1.15	0.56
Quota with banking and borrowing	1.23	0.47
Quota & Tradable Green Certificates	1.30	0.40
No economic support	1.50	0.25

Table 27: General political stability of Germany, Spain and the United Kingdom based on the 'Fragile States Index' (FSI) (2012-2014). Original FSI score (data source: Fund for Peace (2014)) and normalized value for CI.

Country	2012		2013		2014	
	FSI	Normalized score	FSI	Normalized score	FSI	Normalized score
Germany	31.73	0.71	29.72	0.72	30.60	0.72
Spain	42.78	0.51	44.40	0.47	43.10	0.50
UK	35.30	0.63	33.16	0.65	34.30	0.64
Max. EU	66.77	0.25	66.96	0.25	67.90	0.25
Min. EU	19.97	1.00	18.05	1.00	18.70	1.00

Table 28: Interest rates on long-term (10 years) government bonds in Germany, Spain and the United Kingdom (2010-2015). Annual averages. Data source: EUROSTAT (2014).

Country	Average 2012	Normalized 2012	Average 2013	Normalized 2013	Average 2014	Normalized 2014
Germany	1.50	0.99	1.57	1.00	1.16	1.00
Spain	5.85	0.75	4.56	0.61	2.72	0.69
UK	1.74	0.98	2.03	0.93	2.14	0.79
Max. EU	22.50	0.25	10.05	0.25	6.93	0.25
Min. EU	1.40	1.00	1.57	1.00	1.16	1.32

Table 29: Scores of the World Bank's 'Doing Business Index' - sub-indicators 'Legal strength in financial sector' and 'Depth of credit information' for Germany, Spain and the United Kingdom. Data source: World Bank Group (2015).

Country	Year	Strength of legal rights index (0-12)	Depth of credit information index (0-8)	Sum (0-20)	Normalized score (0.25-1)
Germany	2012	7	6	13	0.62
Germany	2013	7	6	13	0.62
Germany	2014	6	8	14	0.66
Spain	2012	6	5	11	0.54
Spain	2013	6	5	11	0.54
Spain	2014	5	7	12	0.57
UK	2012	10	6	16	0.76
UK	2013	10	6	16	0.76
UK	2014	7	8	15	0.71
MIN				0	0.25
MAX				20	1

Table 30: Normalization of Standard & Poor's international country credit rating categories. Data source: (Standard & Poor's, 2015).

S&P category	#	Normalized
AAA	1	1.00
AA+	2	0.94
AA	3	0.88
AA-	4	0.82
A+	5	0.77
A	6	0.72
A-	7	0.67
BBB+	8	0.63
BBB	9	0.59
BBB-	10	0.55
BB+	11	0.52
BB	12	0.48
BB-	13	0.45
B+	14	0.42
B	15	0.40
B-	16	0.37
CCC+	17	0.35
CCC	18	0.33
CCC-	19	0.30
CC	20	0.29
C	21	0.27
D	22	0.25

Table 31: Intra-day market liquidity in Germany (+ Austria), Spain and the UK between 2012 and 2014 (data sources: traded volumes on intra-day market based on public data underlying the figures of the 'ACER / CEER Annual Report on the Results of Monitoring the Internal Electricity and Gas Markets in 2014' (ACER/CEER, 2015) provided by CEER (ACER/CEER, 2016) and APX Power (2014), national electricity consumption based on EUROSTAT (2014)).

Country	Year	Traded volume at intra-day exchange (TWh)	Total electricity consumption (TWh)	Intra-day market liquidity (traded volume / consumption)
Germany (+ AT)	2012	14.1	586.9	2.4%
	2013	19.7	584.2	3.4%
	2014	26.4	573.3	4.6%
Spain	2012	46.9	240.2	19.5%
	2013	33.2	230.1	14.4%
	2014	31.1	226.9	13.7%
UK	2012	13.6	318.1	4.3%
	2013	14.0	317.1	4.4%
	2014	14.6	303.6	4.8%

Table 32: Composite diffusion indicator scores (weighted) for wind energy and PV in Germany (2012-2014). The weighting is based on the values given in table 11 according to equation 3.

		Scores wind			Scores PV		
Indicator component		2012	2013	2014	2012	2013	2014
A-I.	Existence and reliability of RES-E strategy & -support scheme	0.99	0.99	1.00	0.98	0.99	1.00
A-II.	Relative remuneration level for RES-E	0.90	0.93	0.92	0.90	0.80	0.64
A-III.	Revenue risk under RES-E support scheme	0.96	0.98	0.96	0.98	0.98	0.98
A-IV.	Access to finance for RES-E	0.99	0.99	0.99	0.99	0.99	0.99
B-I.	Fair and independent regulation of the electricity sector	1.00	1.00	1.00	1.00	1.00	1.00
B-II.	Existence of functioning and non-discriminatory markets	0.97	0.97	0.97	0.97	0.97	0.97
B-III.	Availability of reliable long-term contracts (PPA)	1.00	1.00	1.00	1.00	1.00	1.00
C-I.	Grid connection cost	1.00	1.00	1.00	1.00	1.00	1.00
C-II.	Duration of RES-E grid connection	0.99	0.99	0.99	0.98	0.98	0.98
C-III.	Predictability & transparency of grid connection procedures	1.00	1.00	1.00	1.00	1.00	1.00
C-IV.	RES-E access regime and regulation for curtailment	1.00	1.00	1.00	1.00	1.00	1.00
C-V.	Transparency and predictability of grid development	0.96	0.96	0.96	0.96	0.96	0.96
D-I.	Administrative cost	0.98	0.98	0.97	0.99	0.98	0.98
D-II.	Duration of administrative procedures	1.00	1.00	1.00	0.98	0.99	0.99
D-III.	Administrative complexity	0.96	0.96	0.96	0.96	0.96	0.96
D-IV.	Integration of RES-E in spatial & environmental planning	0.96	0.96	0.96	0.93	0.93	0.93
	Product	**0.70**	**0.74**	**0.72**	**0.68**	**0.60**	**0.49**

Table 33: Composite diffusion indicator scores (weighted) for wind energy and PV in Spain (2012-2014). The weighting is based on the values given in table 11 according to equation 3.

		Weighted scores wind			Weighted scores PV		
Indicator component		2012	2013	2014	2012	2013	2014
A-I.	Existence and reliability of RES-E strategy & -support scheme	0.95	0.95	0.96	0.95	0.95	0.96
A-II.	Relative remuneration level for RES-E	0.00	0.00	0.00	0.00	0.00	0.00
A-III.	Revenue risk under RES-E support scheme	0.91	0.91	1.00	0.90	0.90	1.00
A-IV.	Access to finance for RES-E	0.96	0.96	0.96	0.96	0.96	0.96
B-I.	Fair and independent regulation of the electricity sector	0.99	0.99	0.99	0.99	0.99	0.99
B-II.	Existence of functioning and non-discriminatory markets	0.95	0.95	0.95	0.94	0.94	0.94
B-III.	Availability of reliable long-term contracts (PPA)	0.90	0.90	0.90	0.92	0.92	0.92
C-I.	Grid connection cost	0.92	0.92	0.92	0.92	0.92	0.92
C-II.	Duration of RES-E grid connection	0.97	0.97	0.97	0.98	0.98	0.98
C-III.	Predictability & transparency of grid connection procedures	0.96	0.96	0.96	0.96	0.96	0.96
C-IV.	RES-E access regime and regulation for curtailment	0.96	0.96	0.96	0.96	0.96	0.96
C-V.	Transparency and predictability of grid development	0.96	0.96	0.96	0.96	0.96	0.96
D-I.	Administrative cost	0.99	0.99	0.99	0.93	0.96	0.99
D-II.	Duration of administrative procedures	0.98	0.98	0.98	0.97	0.95	0.95
D-III.	Administrative complexity	0.96	0.96	0.96	0.96	0.96	0.96
D-IV.	Integration of RES-E in spatial & environmental planning	0.96	0.96	0.96	0.96	0.96	0.96
	Product	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Table 34: Composite diffusion indicator scores (weighted) for wind energy and PV in the UK (2012-2014). The weighting is based on the values given in table 11 according to equation 3.

		Weighted scores wind			Weighted scores PV		
Indicator component		2012	2013	2014	2012	2013	2014
A-I.	Existence and reliability of RES-E strategy & -support scheme	0.98	0.98	0.98	0.98	0.98	0.98
A-II.	Relative remuneration level for RES-E	0.96	0.98	0.98	0.71	0.78	0.87
A-III.	Revenue risk under RES-E support scheme	0.94	0.94	0.94	0.98	0.95	0.94
A-IV.	Access to finance for RES-E	1.00	1.00	0.99	0.99	0.99	0.99
B-I.	Fair and independent regulation of the electricity sector	1.00	1.00	1.00	1.00	1.00	1.00
B-II.	Existence of functioning and non-discriminatory markets	0.97	0.97	0.97	0.97	0.97	0.97
B-III.	Availability of reliable long-term contracts (PPA)	1.00	1.00	1.00	1.00	1.00	1.00
C-I.	Grid connection cost	0.96	0.96	0.96	0.96	0.96	0.96
C-II.	Duration of RES-E grid connection	0.95	0.93	0.92	0.98	0.95	0.93
C-III.	Predictability & transparency of grid connection procedures	0.96	0.92	0.92	0.96	0.92	0.92
C-IV.	RES-E access regime and regulation for curtailment	0.96	0.96	0.96	0.96	0.96	0.96
C-V.	Transparency and predictability of grid development	0.96	0.96	0.96	0.96	0.96	0.96
D-I.	Administrative cost	0.98	0.98	0.97	0.97	0.97	0.98
D-II.	Duration of administrative procedures	1.00	1.00	1.00	0.99	0.99	0.99
D-III.	Administrative complexity	0.96	0.96	0.96	0.96	0.96	0.96
D-IV.	Integration of RES-E in spatial & environmental planning	0.96	0.96	0.96	0.96	0.96	0.96
	Product	**0.62**	**0.60**	**0.58**	**0.47**	**0.48**	**0.52**

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