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Risks and Risk Management of Renewable Energy Projects: The Case of Onshore and Offshore Wind Parks

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RISKS AND RISK MANAGEMENT OF RENEWABLE ENERGY PROJECTS: THE CASE OF ONSHORE AND OFFSHORE WIND PARKS

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ABSTRACT

Wind energy is among the most relevant types of renewable energy and plays a vital role in the projected European energy mix for 2020. The aim of this paper is to comprehensively present current risks and risk management solutions of renewable energy projects and to identify critical gaps in risk transfer, thereby differentiating between onshore and offshore wind parks with focus on the European market. Our study shows that apart from insurance, diversification, in particular, is one of the most important tools for risk management and it is used in various dimensions, which also results from a lack of alternative coverage. Furthermore, policy and regulatory risks appear to represent a major barrier for renewable energy investments, while at the same time, insurance coverage or alternative risk mitigation is strongly limited. This emphasizes the need for new risk transfer solutions to ensure a sustainable growth of renewable energy.

Keywords: Wind park, renewable energy, insurance, policy risk, diversification

1. INTRODUCTION

According to the projected energy mix for 2020 in Europe, which aims to supply 20% of energy consumption from renewable energy, wind and solar energy will become increasingly relevant as a key element of future power generation.[1] To achieve these goals, considerable investment volumes are needed by federal, institutional and private investors. For instance, the European Wind Energy Association (EWEA, 2014a, p. 3) estimates that investments in European offshore wind parks alone may reach a total of USD 90 to USD 124 billion during the period from 2013 to 2020, wherein private and institutional investments are expected to be the most relevant sources of finance.[2] Drivers of renewable energy growth include policy incentives by means of support schemes (e.g., feed-in tariff) as well as improved and more reliable technology.[3] However, the risks to investments in renewables are also becoming

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[1] Blanco (2009, p. 1373), EU (2009, p. 46).

[2] EWEA (2013, p. 21).

[3] Turner et al. (2013, p. 6).

increasingly complex and the availability of adequate insurance and risk management instruments is vital to de-risk cash flows, which is especially relevant for institutional investors like insurers and pension funds, and to thus ensure a sustainable growth of renewable energy.[4]

In particular, wind energy plays a major role for the energy turnaround due to the higher efficiency of energy production originating from lower electricity generation costs in the long-run.[5] Besides the further growth of well-established onshore wind energy, particularly in recent years, the wind energy industry has increasingly moved towards offshore wind parks, aiming to achieve stronger and more stable wind speeds.[6] However, especially offshore wind parks are associated with considerable risks due to their higher complexity and still limited insurance solutions.[7] In this regard, emerging markets such as China, one of the fastest growing wind power industries, require adequate insurance and risk management services. This is one of the upcoming large future markets for wind energy insurance solutions.[8] According to Turner et al. (2013, p. 14), the growth of renewable energy along with increasing market risk exposures, a more complex financing situation and changing regulations (support schemes) will also imply an increase in the estimated annual expenditure on risk management services including insurance solutions of up to USD 3.7 billion in 2020.

Against this background, the aim of this paper is to contribute to the literature by comprehensively presenting and assessing the current risks and risk management solutions for wind park projects from the investor's perspective with focus on the European market based on a review of the present academic and industry literature and to identify critical gaps in risk transfer, which concern policy and regulatory risks in particular.[9] We explicitly differentiate between onshore and offshore wind parks and discuss insurance solutions, full service agreements, alternative risk transfer including financial derivatives, and other (qualitative) risk mitigation approaches. Based on a comparative analysis of industry surveys, we further obtain insights regarding which risks are particularly critical from the industry's perspective. The analysis is of high relevance when considering the importance of wind development in Europe. Furthermore, by focusing on Europe as a mature market with respect to onshore and

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4 Gatzert and Kosub (2014), Turner et al. (2013, pp. 8, 9, 13).

5 Turner et al. (2013, p. 6); in a worldwide ranking, China (91,424 MW) and the US (61,091 MW) are the countries with the most capacity installed by the end of 2013, followed by Germany (34,250 MW), Spain (22,959 MW) and the UK (10,531 MW) (GWEC, 2014).

6 Turner et al. (2013, p. 5), Markard and Petersen (2009, p. 3547).

7 Markard and Petersen (2009, p. 3548).

8 Jin et al. (2014, p. 1071).

9 Note that we use the terms policy and regulatory risks as synonyms.

offshore wind, our work is also intended to inform emerging (and potentially much larger) markets with respect to risks and risk management solutions.

Our analysis shows that policy and regulatory risks, in particular, are among the most significant risks from the industry experts' viewpoint with only limited risk transfer opportunities. Furthermore, apart from insurance, diversification is currently one of the most important risk mitigation techniques and is used in various dimensions, also in part, due to a lack of alternative coverages. In addition, in regard to political, policy and regulatory risks, insurance coverage is still limited due to several challenges. Private political risk insurance mainly covers risks such as expropriate breaches of investor's rights, while public policy risk insurance may become a vital alternative instrument for risk mitigation.

In the literature, various papers deal with the risks and risk management of renewable energy projects, thereby mainly focusing on individual or specifically relevant aspects. For instance, Montes and Martín (2007) study the profitability of wind energy in Spain and discuss major short-term risk factors, while Jin et al. (2014) focus on the current status and challenges for the wind insurance market in China. In addition, other works focus on the impact of policy support schemes on the attractiveness of wind park investments (e.g., Boomsma et al., 2012; Brandstätt et al., 2011; Campoccia et al., 2009; Holburn, 2012; Kitzing, 2014; Yang et al., 2010), resource risks resulting from wind volatility (e.g., Liu et al., 2011) or curtailment risk (e.g., Jacobsen and Schröder, 2012). With focus on renewable energy technology in developing countries, Waissbein et al. (2013) provide a comprehensive framework for policymakers to select the most cost-effective portfolio of public instruments (intended to reduce investor risk) based on a quantitative comparison of the different instruments using various performance metrics. Industry studies include Watts (2011), who conducts a survey regarding the management of risks associated with renewable energy projects and finds that insurance plays a major role as a part of the risk mitigation strategies of senior executives. Turner et al. (2013) focus on risk management approaches for solar and wind energy projects in six different markets and find that managing these risks will become increasingly important, as market risks, and also construction and operation risks, will generally increase. A detailed overview of technical risks and the technological status quo of renewable energies, including onshore and offshore wind energy, are provided by the German Insurance Association (GDV, 2013). In addition, EWEA (2013) discusses key construction and operation risks for offshore wind parks including some risk mitigation strategies. Thus, our paper contributes to this literature by comprehensively presenting current risks and risk management solutions in mature markets (Europe) along with gaps in coverages and best practices with explicit focus on onshore and offshore wind parks from the investors' perspective, which allows insight also for emerging wind markets.

In what follows, Section 2 first describes the methodology and procedure and lays out the classification of risks associated with onshore and offshore wind park projects. The results regarding these risks are then discussed in detail in Section 3 along with available risk management (response) approaches, including risk transfer (insurance, service contracts, alternative risk transfer), risk mitigation, and risk avoidance. Risks include strategic and business risks, transport, construction, and completion risks, operation and maintenance risks, liability and legal risks, market and sales risks, counterparty risks, and political, policy and regulatory risks. In Section 4, we first use industry surveys to obtain an insight regarding which of the risks presented in Section 3 are most relevant for the industry, and then discuss the results and challenges associated with current risk management instruments for these specific risks. Section 5 summarizes and provides implications.

2. Methodology and Procedure

To assess risks and risk management solutions associated with onshore and offshore wind parks and to identify potential critical gaps in risk management instruments, we proceed as follows. We first derive a classification of risks, which forms the basis of the following review, whereby focus is mainly laid on the investor's perspective as well as the European market. As the literature currently does not provide a standardized classification of risks associated with renewable energy and wind parks in particular (see Appendix A.1 for a comparison of risk classifications in different academic and practitioner-oriented publications), we propose the categorization laid out in Table 1 along with a description of each risk category, which entity/actor caused or produced the risk, and how in some cases risk categories relate to each other.[10] Concrete examples and detailed discussions for each risk category listed in Table 1 are provided in the following section.

Table 1: Risks associated with onshore and offshore wind parks[11]

Risk type	Description	Entity/actor (cause of risk)
1. Strategic / business risks		
a) Financing risks / insufficient expertise / insufficient management know-how	Risk arising from scarcity of capital (e.g. debt) and/or investors' insufficient expertise and/or insufficient management know-how resulting in potential revenue losses	Debt providers / investors / project developers
b) Technology and innovation risk	Risk arising from inaccuracies in early planning regarding resource assessment and supply of renewable energy technology (see also risks 2 and	Project developers / supplier / general public (see also risks 1c, 2, 3a, 7)

[10] A comprehensive and very detailed technical discussion of risks and loss potentials from the insurers' perspective associated with wind parks is also provided in GDV (2013).

[11] For an overview of risk categorization among literature, see Appendix A.1. The presentation of the columns "Description" and "Cause of risk" is mostly aligned with the presentation in Waissbein et al. (2013, pp. 50-51).

	3a) and innovations inducing a lower technological efficiency / obsolete technology along with insufficient public (and political) acceptance causing a potential adverse change in policy support schemes (see also risks 1c and 7) resulting in lower than expected revenues	
c) Insufficient public acceptance	Risk arising from potential adverse changes in public acceptance and/or resistance of end-users to renewable energy resulting in resistance to construction and /or adverse changes in policy support schemes (see also risk 7)	General public / end-users / national level (see also risk 7)
d) Complex approval processes	Risk arising from inefficient or intransparent administration regarding licensing and permits of renewable energy projects resulting in delays and/or higher than expected payments	Public sector's administrators
2. Transport / construction / completion	Risk arising from various types of disruptions during the transport and construction phase and/or damages or theft resulting in start-up delays and thus revenue losses	People / supplier / grid operator / natural hazards / project developer
3. Operation / maintenance		
a) General operation and maintenance risks	Risk arising from damages to physical assets due to negligence, accident, wear and tear, and/or possible unplanned closure due to unavailable resources/replacements and/or unreliable/ inefficient renewable energy technology resulting in revenue losses (see also risk 1b)	People / supplier / project developers
b) Damage due to natural hazards (severe weather)	Risk arising from damages of wind park due to natural hazards resulting in revenue losses	Natural hazards
c) Damage due to serial losses	Risk arising from defective components/turbines (serial losses) resulting in lost revenues	Supplier
d) Revenue loss due to business interruption	Risk arising due to potential business interruptions (see risks 3a, b, c) resulting in revenue losses	See risks 3a), b), c)
4. Liability / legal risk	Risk arising from liabilities to third parties due to potential environmental damages and/or uncertainty regarding resulting legal disputes and/or contracting risks due to complex legislation or processes resulting in revenue losses	Nature (see also risk 3b) / supplier (see risks 3a and 3c) / national level and public sector's administrators (see risk 1d)
5. Market / sales risks		
a) Variability of revenue due to weather / resource risk	Risk arising from uncertainty regarding future renewable energy resources (wind) due to inaccurate resource or capacity assessment resulting in lower than expected revenues	Project developers / nature
b) Variability of revenue due to grid availability / curtailment risk	Risk arising from limitations in grid management / infrastructure resulting in lower than expected revenues	Utility / transmission company / grid operator
c) Variability of revenue due to price volatility	Risk arising from uncertainty regarding future energy prices resulting in lower than expected revenues	Energy market environment (supply and demand)

6. Counterparty risk		
a) Supplier of O&M services	Risk arising from a counterparty's poor credit quality resulting in revenue losses	Supplier
b) Counterparty risk Power Purchase Agreement (PPA)	Risk arising from a counterparty's poor credit quality resulting in revenue losses	Power purchaser
7. Political, policy, regulatory risks	Risk arising from uncertainty regarding potential adverse changes in country-specific policy support schemes or regulations in regard to renewable energy investments resulting in lower than expected revenues	National level / legislators, policymakers

The description of the respective risk as well as the cause in Table 1 follows the risk framework developed in Waissbein et al. (2013, pp. 50-51), which includes key stakeholder groups, barriers, risk categories, and risk definitions. In addition to the categorization in Table 1, one can generally distinguish between endogenous and exogenous risks,[12] where exogenous risks include policy and regulatory risk, innovation risk, natural hazards, and weather / resource risk, for instance. In addition, some categories (2, 3, 5, 6) mainly refer to the particular life-cycle phase of the wind park project.[13] Furthermore, the relevance of the risks depends on the situation in the respective country as is also addressed in the following individual presentation of each risk. Offshore wind power generation is thereby generally considerably more complex than the already better-established and more common onshore power generation sector.[14] This technical complexity, amongst other issues, is accompanied by increased risks, which demand more sophisticated risk management and insurance solutions.[15]

Based on the classification in Table 1, a literature review is conducted based on which each risk is discussed in detail with a focus on onshore and offshore wind parks, as well as currently available risk management solutions. This is done based on a traditional narrative approach, as we include current academic as well as practitioner-oriented literature which are not necessarily listed in standard databases, but which are intended to ensure a broad perspective on the relevant risks. With respect to risk management solutions, we divide the respective instruments in risk avoidance, risk mitigation, and risk transfer, whereby regarding the latter we further distinguish between insurance, guarantees, and other risk transfer solutions.

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[12] E.g., Balks and Breloh (2014, p. 30).

[13] Following Liebreich (2005), for instance, the project life-cycle can be decomposed in the phases "planning and permitting", "construction", "operating", and "decommissioning / repowering".

[14] EWEA (2013, p. 33, 36), Markard and Petersen (2009, p. 3548).

[15] GDV (2013, pp. 98-100).

We complement the study by evaluating selected recent industry surveys among industry experts to gain insight regarding the relevance and potential impact of each risk category and thus the importance of risk management instruments, whereby the industry surveys were also selected based on a narrative approach as they are generally not listed in academic databases.

3. Results: Risks and Current Risk Management Solutions of Renewable Energy Projects for the Case of Wind Parks

3.1 Strategic and business risks

The first risk category comprises strategic and business risks associated with the project as shown in Table 2, including, for instance, insufficient management know-how,[16] insufficient access to capital or a lack of cooperating partners to share technical expertise, financing and market access, as well as the diversification of risks and the exploitation of economies of scale to reduce costs.[17] Technological and innovation risk on the one hand refers to inaccuracies in early planning regarding resource assessment and supply of renewable energy technology (also impacting construction and operations, see 3.2 and 3.3),[18] and to obsolete technology in the future on the other hand, which may imply a lower efficiency as compared to newer plants, as well as also potentially induce a diminishment of public (and political) acceptance,[19] thus also potentially causing an adverse change in policy support schemes (see also Section 3.7 on “political, policy, and regulatory risk”). Complex and long approval procedures are especially relevant for offshore wind parks. In Germany, for instance, the approval period can take more than two years due to an assessment of the environmental sustainability by the authorities.[20] Risk mitigation techniques include effective project management and careful contracting, the reliance on proven technology and suppliers to reduce the risk of technological inefficiencies and/or supply chain shortages, as well as the establishment of contingency plans and the consideration of “lessons learned” and industry information, in order to improve the understanding and identification of risks.[21]

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16 Bader and Krüger (2013, p. 21).

17 Bader and Krüger (2013, pp. 23-25), Blanco (2009, pp. 1374-1375), Watts (2011, p. 9).

18 Waissbein et al. (2013, p. 50).

19 Balks and Breloh (2014, p. 30), Hitzeroth and Megerle (2013, p. 577),,Liebreich (2005, p. 19), Montes and Martín (2007, p. 2194).

20 Bader and Krüger (2013, p. 21).

21 Turner et al. (2013, p. 9).

Table 2: Strategic and business risks

<table>
<tr><th>Relevance for wind parks</th><th>Risk management</th></tr>
<tr><td>a) Financing risks / insufficient expertise / insufficient management know-how</td><td rowspan="8">Risk mitigation:
• Establish contingency plans for relevant “what if” scenarios (EWEA, 2013, p. 49) (see also “transport”)
• Identify and better understand the risks based on prior lessons learned in the market and meaningful industry data / information (EWEA, 2013, p. 49)
• Prior to construction: monitor weather to evaluate suitability of a location (EWEA, 2013, p. 47)
• Risk retention by captive insurance subsidiaries due to information asymmetry regarding risks (insurer estimates risks higher) or in case of hard markets (high insurance prices) (Watts, 2011, p. 22)
• Rely on proven technology / suppliers (Watts, 2011, p. 18)
• Adequate communication of project plans / communication strategy to gain social acceptance (Hitzeroth and Megerle, 2013, p. 582)
• Effective project management and planning of the project, due diligence, careful contracting (Turner et al., 2013, p. 9) (see also “transport”)</td></tr>
<tr><td>• Risk of insufficient access to capital (financial risk, Watts, 2011, p. 9; Waissbein et al., 2013, p. 51)
• Insufficient management know-how / management track record (Bader and Krüger, 2013, p. 21; Waissbein et al., 2013, p. 51)
• Insufficient cooperation to share technical expertise, market access, risk diversification, economies of scale (costs), and financing (Bader and Krüger, 2013, pp. 23-25)</td></tr>
<tr><td>b) Technology and innovation risk</td></tr>
<tr><td>• Technology and innovation risk: obsolete technology implies lower efficiency compared to newer, more efficient plants; public acceptance of obsolete technology diminishes (Balks and Breloh, 2014, p. 30), potentially causing adverse policy support changes; inaccuracies in early planning regarding resource assessment and supply of renewable energy technology (Waissbein et al., 2013, p. 50)
• Decommissioning / repowering the wind turbine (Watts, 2011, p. 9)</td></tr>
<tr><td>c) Insufficient public acceptance</td></tr>
<tr><td>• Insufficient acceptance in general public (Bader and Krüger, 2013, p. 21; Hitzeroth and Megerle, 2013, p. 577)</td></tr>
<tr><td>d) Complex approval processes</td></tr>
<tr><td>• Complex and long approval procedures (Bader and Krüger, 2013, p. 21)

Specific considerations for offshore wind parks:
• Approval periods especially long in Germany with 2-2.5 years (assessment of environmental sustainability, BMU, 2013, p. 11)</td></tr>
</table>

3.2 Transport, construction, and completion risks

Transport, construction, and completion risks (see Table 3) mainly focus on the first phase of the life-cycle of the wind park and the construction period is generally considered as the most risky project phase.[22] Risks particularly include the loss of revenue due to start-up delays, as well as the risk of damage during transportation or construction of the wind park,[23] which, due to the high capital intensity of these projects, can become very costly.[24] In addition, completion risk can arise from potential problems associated with the connection to the grid.

[22] EWEA (2013, pp. 47, 49), Turner et al. (2013, p. 9).

[23] Balks and Breloh (2014, p. 30), Liebreich (2005, p. 19).

[24] Blanco (2009, pp. 1373, 1376), Turner et al. (2013, p. 9).

Completion risk and grid connection problems (a “bottleneck” risk[25]) are especially relevant for offshore wind parks, as the transportation and construction processes are considerably more complex than in the case of onshore wind parks.[26] In Germany, for instance, the grid infrastructure supplier was not responsible for grid connection until 2012, which implied a serious timing mismatch and major delays in completion.[27] After severe problems with the offshore grid connection, the grid operator has been obligated to compensate the infrastructure provider (wind park constructor) in case of a delayed grid connection since 2012 (see § 17e Energiewirtschaftsgesetz). In addition, transportation risk is increased by the necessary usage of several means of specialized transportation (road vehicles, cranes, pontoons, “jack up” vessels), including the handling of goods and components at different storage locations. These highly specialized construction vessels can also induce a bottleneck risk due to limited availability, as they may be booked out for years in advance.[28] In addition, weather monitoring is critical when transporting the components and material to the building lot at sea.[29] Furthermore, although other countries such as Denmark or the United Kingdom are more experienced with the construction of offshore wind farms, know-how cannot be easily transferred to other countries. In the case of Germany, for instance, the Wadden Sea requires wind energy projects to be erected with a minimum distance to the shore, thus also implying a different water depth.[30] In general, one also needs to take into account the soil condition, as well as foundation design risk, when planning the construction of offshore wind parks.[31]

Table 3: Transport, construction, and completion risks

Relevance for wind parks	Risk management
• Construction period and completion most risky (Turner et al., 2013, p. 9) • Risk of start-up delays / advanced loss of profits (Turner et al., 2013, p. 9) • Damage or theft during transport or construction highly costly (capital-intensive products, Turner et al., 2013, p. 9) • Grid connection risk (EWEA, 2013, p. 42)	**Risk transfer - Insurance:** • Available for delay in start-up, advanced loss of profit, construction and transportation risks • Offshore logistics insurance solutions by Munich Re, e.g., covers weather-related delays • Coverage for accidental damage (e.g., power cable damage on sea bed) (Turner et al., 2013, p. 9)

[25] “Bottleneck” here generally refers to shortages, congestions or limited availability of resources that are necessary to continue an operation / a project (e.g. supply bottlenecks).

[26] EWEA (2013, pp. 42-43), Markard and Petersen (2009, p. 3548).

[27] EWEA (2013, p. 42).

[28] Turner et al. (2013, p. 6); the latter expect the availability and cost issues of special transportation to be overcome by 2020.

[29] GDV (2013, pp. 108-111).

[30] GDV (2013, p. 37), Markard and Petersen (2009, p. 3553); water depth ranges between 17m and 42m with a distance to the shore of 25 to 100 km (in UK: water depth 6-26 m, distance to shore 0-34 km), see EWEA (2014b, p. 9). Note that this specific example can also be considered a regulatory barrier as well as a strategic / business risk due to the decision to invest in an offshore wind park in this region as well as the potentially unavailable know-how transfer.

[31] EWEA (2013, p. 43).

Specific considerations for offshore wind parks: • Completion risk particularly relevant: Construction delays due to wind turbine parts (e.g., lower capacity than contractually defined, larger components than onshore) and complex transportation, exceeding the construction budget (Balks and Breloh, 2014, p.30) • Special construction vessels required ("jack up" vessels etc.: bottleneck risk): limited availability, possibly booked out for years (Turner et al., 2013, p. 6: expect availability and cost issues to be overcome by 2020) • Experiences from other countries not easily transferable to other countries (e.g., German offshore situation requires minimum distance to coast (protected Wadden Sea), also implies different water depth (GDV, 2013, p. 37)) • Requires good weather conditions for foundation and construction • Need to take into account soil condition, foundation design risk (EWEA, 2013, p. 43) • Grid connection risk especially relevant in case of offshore wind parks (bottleneck risk) (since 2012, in Germany grid operator obligated to compensate in case of a delayed grid connection) (debt providers reluctant to invest during construction period)	**Risk transfer - Operation & Maintenance (O&M) contracts (service provider guarantees):** • Negotiation of joint contingency funds to cover cost of weather impact during construction and installation, e.g., in context of full service agreement (EWEA, 2013, p. 47) • Full service agreements cover various risks associated with transportation and construction (EWEA, 2013, p. 47) **Risk mitigation:** • Effective project management, due diligence, careful contracting (Turner et al., 2013, p. 9), effective contingency planning (plans for relevant "what if" scenarios) (EWEA, 2013, p. 49) • Prior to construction: monitor weather and measure wind availability to evaluate suitability of a location and timing of construction (EWEA, 2013, p. 47) • Rely on proven construction technology and ensure reliable recovery plans (Watts, 2011, p. 18) • Risk mitigation regarding grid connection: Well-defined responsibilities, project responsible managers should harmonize intentions with offshore transmission contractor (EWEA, 2013, p. 49) **Risk avoidance:** • Risks associated with construction may be avoided by directly investing in already built wind parks (Brownfield investment in case of onshore, Gatzert and Kosub, 2014)

Insurance solutions are available for losses in revenues due to construction delays, as well as construction risk in general, including various damages. For offshore risk coverage, insurers often require marine warranty surveyors to survey the transportation and construction process at sea.[32] In addition, *operation & maintenance (O&M) contracts* by service providers (full service agreement) may offer joint contingency funds to cover the cost of weather effects during construction and installation resulting in start-up delays and losses of revenue, as well as various risks of damages associated with transportation and construction.[33] Further *risk mitigation* includes effective project management and careful contracting (see also strategic and business risks), as well as contingency planning and recovery plans for relevant "what if" scenarios.[34] In addition, prior to construction, weather monitoring is vital to evaluate the suitability of a location and the best timing for construction.[35] Regarding the grid connection risk, EWEA (2013, p. 49) recommends well-defined responsibilities for grid development and that responsible project managers harmonize their intentions with responsible offshore

[32] Munich Re (2009, p. 27).

[33] EWEA (2013, p. 47).

[34] EWEA (2013, p. 49), Watts (2011, p. 18).

[35] EWEA (2013, p. 47).

transmission contractors. After completion of the wind park, this risk category becomes irrelevant for further risk considerations and can thus be avoided in case of investing after the construction phase (Brownfield in case of onshore).

3.3 Operation and maintenance risks

After completion of the wind park, various risks may arise during operation, such as general operational and maintenance risks, business interruption due to damages or grid availability risks, and natural hazards, as well as serial losses (see Table 4).

Table 4: Operation and maintenance risks

Relevance for wind parks	**Risk management**
a) General operation and maintenance risks	
• Risk of damage to physical assets (accident, negligence, wear and tear, design flaws, component failure, Turner et al., 2013, p. 9) • Unavailable resources / replacement risk can cause delays and possible unplanned closure (Watts, 2011, p. 9) • Technology risk (technical limitations imply lower capacity than planned, design flaws, Balks and Breloh, 2014, p. 30; uncertainty regarding operational use, Waissbein et al., 2013, p. 50) **Specific considerations for offshore wind parks:** • Particularly high maintenance risk due to special transportation requirements to repair damages; limited availability of transportation (see "transportation risk") • Weather risks in regard to maintenance and repair: access only possible in case of sufficiently good maritime weather conditions (Turner et al., 2013, p. 11) • Accumulation risk due to concentration on one relay station and risk of damages to (bundled) submarine cables and exposure to natural hazards • Maritime environment (e.g., salt water, humidity) increases risk of wear and tear • Technological risk especially relevant in case of offshore due to new and unproven technology, can imply unreliable performance (blade, bearings and gearbox risks, EWEA, 2013, p. 46)	**Risk transfer - Insurance**: • Coverage for damage due to various reasons; losses due to damages in case of offshore sites is generally only partially covered due to high costs of transport and larger turbines etc. (Turner et al., 2013, p. 9); coverage also limited due to use of new and unproven technologies (EWEA, 2013, p. 46) **Risk transfer - Manufacturer warranties / O&M contracts (guarantees by service providers):** • Partial coverage of wear and tear effects of weather for an agreed period by O&M services in service contracts (full service agreement, EWEA, 2013, p. 47) • Onshore turbine warranties are typically 2-5 years (potentially extendable), partly including availability guarantees (i.e., wind park able to operate); O&M contracts with service, maintenance, replacement of parts; offshore: turbine warranties limited, in general no cost of replacement cover; maintenance limited by maritime weather conditions (Turner et al., 2013, p. 10) • Note: General problem with replacement guarantees of turbines by O&M contracts: if wind manufacturer is insolvent, sourcing a replacement may be very difficult (e.g., insolvency of Clipper Wind power used in the case of a US wind park owned by BP, which implied lower sales price, see Turner et al., 2013, p. 10) (see also Section 3.6 on counterparty risk) **Risk mitigation:** • Highly relevant for offshore in particular: implement conditional monitoring system (CMS) and structural health monitoring (SHM) to continuously measure status of components: allows precise identification of cause of changes and respective component parts, as well as estimates regarding the length of time of further operation, allowing better maintenance planning (e.g., in times of better weather conditions) and thus optimizing cost planning for maintenance (GDV, 2013, pp. 62-66) • Rely on proven technologies to avoid technology risks (in the sense of e.g. inefficient or unreliable); technology should have been established for at least five years, preferably from Germany and Switzerland (Watts, 2011, p. 18; EWEA, 2013, p.

	49) • In case new technologies are unavoidable (offshore), use hardware from well-established suppliers (Watts, 2011, p. 19); gather information from suppliers on testing and operational data; include suppliers in ownership structure of project (e.g., minority shareholding) (EWEA, 2013, p. 46) • Diversification with regards to the supplier of wind turbines to reduce technical risk (deficiencies) and replacement risks (available resources) • Ensure adequate equipment and plant maintenance (see first point), establish reliable recovery plans in case of failure (Watts, 2011, p. 18) • Use newly built vessels better equipped to cope with adverse weather conditions (EWEA, 2013, p. 49)
b) Damage due to natural hazards (severe weather)	
• Risk of damage due to natural hazards **Specific considerations for offshore wind parks:** • Natural hazards such as strong winds, waves, tides, hail, formation of ice, lightening, and earthquakes affect wind turbine efficiency and cause damages, they also delay repair / maintenance activities (thus causing losses in revenues, see d))	**Risk transfer - Insurance**: • In case of natural catastrophes rely on large globally diversified insurers (Turner et al., 2013, p. 9) **Risk transfer - Other:** • Weather derivatives (potentially high basis risk, availability difficult) • Catastrophe bonds for natural hazards (in case of index-based structures, potentially high basis risk, see Gatzert and Kellner, 2011)
c) Damage due to serial losses	
Specific considerations for offshore wind parks: • High costs due to cost-intensive repair / replacement at sea (see issues above regarding transportation, weather etc.)	**Risk transfer - Insurance**: • Serial loss cover (e.g. Munich Re) **Risk mitigation**: • Diversification of manufacturer (for multiple wind parks)
d) Revenue loss due to business interruption	
• Revenue losses due to business interruption due to damages (see a)), natural hazards (see b)) or grid availability risk / curtailment risk (see also market risk b)) • High wind speed may require onshore wind park to shut down turbines for security reasons (Turner et al., 2013, p. 10) **Specific considerations for offshore wind parks:** • High costs due to cost-intensive repair / replacement on the sea (see issues in a) regarding transportation, weather, accumulation risk, unavailability of replacements etc.)	**Risk transfer - Insurance / O&M contracts:** • Cover for unscheduled downtime, triggered by wind speed and/or wave height (Turner et al., 2013, p. 10) • Business interruption cover: Insure lost revenues (if not covered by O&M contracts) (in contrast to physical damage; does not include policy risk or PPA counterparty risk) (Turner et al., 2013, p. 10) • Despite higher relevance for offshore due to high loss potential in revenue (exceeds component costs; e.g., faults in offshore substation transformers can shut down entire wind parks) (Turner et al., 2013, p. 10), according to EWEA (2013, p. 48) offshore wind parks lack an adequate insurance product; instead, risks are partially mitigated by O&M / contractual guarantees and warranties (coverage depends on the provider's balance sheet; the counterparty is typically a major utility, e.g., DONG incentivizes institutional investors by offering guarantees of project earnings) **Risk mitigation**: • Reduce risk of delays / time of interruption by design, preventive maintenance, replacement parts on standby (Turner et al., 2013, p. 10), conditional monitoring system (see a)) • Use of newly built vessels that are better equipped to cope with adverse weather conditions (EWEA, 2013, p. 49) (see also a))

a) General operation and maintenance risks

General operation and maintenance risks refer to damages to physical assets due to, e.g., accident, negligence, or wear and tear,[36] and possible unplanned closure (e.g., due to unavailable resources or replacements, which can cause considerable delays).[37] In addition, design flaws and component failure may result from technology risk thus negatively impacting operations (see also “strategic and business risk” in Section 3.1).[38] Technology risk is especially relevant in the case of offshore wind parks due to the installation of new and partly unproven technologies and design, thus leading to the risk of unreliable performance (blade, bearings and gearbox risks).[39] Offshore wind parks also face major challenges during operation in regard to maintenance risks due to the distance to the coast and the special transportation (ship) requirements and their limited availability when damage repairs are necessary (see “transportation risk” in Section 3.2). In addition, the maritime environment (e.g., salt water, humidity) increases the risk of wear and tear. Weather risks further imply that maintenance or repair is not always possible, as offshore wind plants are not easily accessible and access is dependent on maritime weather conditions. During the winter months with high winds and thus potentially high power output, severe weather may prevent access, which can imply severe revenue losses.[40] Finally, one major problem is accumulation risk, which arises as several wind turbines typically concentrate on one single relay station; in case of damage the power output of an entire wind park may be cut off. Such accumulation risks are also present in cases of damage to submarine cables, transmitting energy from offshore wind parks to the mainland grid.[41] Along the German North Sea Coast, for instance, sea cables must be aggregated when connecting the offshore wind parks with the main land (nature-compatible grid connection), which can cause major accumulation risks. Wind park owners, investors, as well as insurance companies, should therefore identify potential accumulation risks due to an increased risk exposure of several wind parks across areas exposed to, e.g., natural hazards.[42] Overall, this also emphasizes the need for sophisticated insurance and risk management solutions for offshore wind parks.

While *insurance* coverage for damage due to accident, negligence, wear and tear, design flaws and natural catastrophes is generally available for onshore wind parks, coverage for

36 Turner et al. (2013, p. 9).

37 Watts (2011, p. 9).

38 Balks and Breloh (2014, p. 30), Hitzeroth and Megerle (2013, p. 577),,Liebreich (2005, p. 19), Montes and Martín (2007, p. 2194).

39 EWEA (2013, p. 46).

40 Turner et al. (2013, pp. 9-11).

41 GDV (2013, pp. 104-105).

42 GDV (2013, p. 111).

offshore wind parks is partly limited due to the use of new and unproven technology (and may only cover a partial loss in case of damage due to the high costs of transport and larger turbines etc.).[43] In addition, insurers often include revision clauses (e.g., regarding serial losses) in their wind park insurance contracts and wind turbine manufacturers (suppliers) therefore offer long-term supplier guarantees of certain wind turbine components (e.g., up to five years).[44] Insurers may also force wind park owners to maintain certain wind turbine components regularly (e.g., by O&M service contracts) or to install a monitoring system measuring the condition of the wind park.[45]

In addition, *manufacturer warranties* as well as *O&M service contracts* partially mitigate wear and tear effects of weather for an agreed period of time.[46] Warranties regarding onshore turbines are provided for between two to five years and partly include availability guarantees (wind park remains operating for a certain time period), while O&M contracts include service, maintenance, and replacement of parts, for instance.[47] In the case of offshore turbines, warranties are limited and there may not be a cost of replacement cover; in addition, maintenance services are limited by maritime weather conditions (see also transportation risk).[48] A general problem with replacement guarantees of wind turbines by O&M contracts arises if the manufacturer is insolvent (see also Section 3.6 “counterparty risk”), implying that replacement may not be easily possible. BP, for instance, faced lower sales prices when trying to sell their US wind park, which used components of the insolvent manufacturer Clipper Windpower.[49]

Further risk mitigation techniques for the operation phase, which are particularly relevant for offshore wind parks, comprise the implementation of a conditional monitoring system (CMS) and structural health monitoring (SHM) to continuously measure the status of the components, as well as wear and tear effects. This allows a precise identification of the cause of changes and respective component parts, as well as estimates regarding the length of time of further operation, allowing better planning regarding maintenance (e.g., in times of better weather conditions) and thus optimizing cost planning for maintenance.[50] Overall, effective maintenance is vital to ensure an efficient use of onshore and offshore wind parks. In addition, one should rely on proven technologies to avoid technology risks (in the sense of

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[43] EWEA (2013, p. 46), Turner et al. (2013, p. 9).
[44] Munich Re (2004, pp. 40-41).
[45] Dalhoff et al. (2007, p. 13), Munich Re (2004, p. 40).
[46] EWEA (2013, p. 47).
[47] Turner et al. (2013, p. 10).
[48] Turner et al. (2013, p. 10).
[49] Turner et al. (2013, p. 10).
[50] GDV (2013a, pp. 63-65).

inefficient or unreliable technology impacting operations) (if possible), where technology should have been established for at least five years, preferably from Germany and Switzerland according to Watts (2011, p. 18), for instance. In case new technologies are unavoidable as is generally the case for offshore wind parks, hardware from well-established suppliers should be used[51] and information from suppliers regarding testing and operational data should be gathered.[52] Furthermore, the weather should be monitored to assess the future impact of adverse weather conditions during operation, and newly built vessels should be used with better equipment to cope with adverse weather conditions.[53] In addition, *diversification* in regard to the manufacturer of wind turbines can reduce technical risk (deficiencies) and replacement / resource risk.

b) Damage due to natural hazards (severe weather)

Natural hazards represent a special risk for onshore wind parks and can cause severe losses due to damage of wind turbines.[54] This is especially relevant for offshore wind parks at sea, where strong winds, waves and tides can cause damage. In addition, hail or formation of ice can occur (e.g., through spray) and affect the wind turbine functionality. As the offshore wind turbine is the highest point at sea, lightning can strike wind energy plants. Additionally, earthquakes due to tectonic plate movements and possible tsunamis can be a substantial risk factor for a wind park.[55]

As laid out in the previous subsection, *insurers* provide coverage against natural catastrophes, whereby Turner et al. (2013, p. 9) point out that large and globally diversified insurers are needed to cover these risks. The KLIMArisk policy by HDI-Gerling in Germany, for instance, pays a fixed sum insured in the case of a contractually defined parametric weather index (e.g., wind, rainfall, temperature, sun, waves) exceeds or falls below a certain threshold. Alternatively, *weather derivatives* based on parametric indices can directly be purchased or *catastrophe bonds* may possibly be used to provide a counter-position against losses resulting from natural hazards. However, in the case of risk transfer instruments based on industry loss or parametric indices, high basis risk[56] may arise (given that they are available for the required location in the first place).

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[51] Watts (2011, p. 19).
[52] EWEA (2013, p. 46).
[53] EWEA (2013, p. 49).
[54] GDV (2013, pp. 101-103).
[55] GDV (2013, pp. 101-103), Leblanc (2008, p. 148).
[56] E.g., Gatzert and Kellner (2011).

c) Damage due to serial losses

A further important single risk associated with wind parks is the serial loss of defective turbines or components,[57] which is particularly severe in the case of offshore wind parks, due to the cost-intensive nature of repair and replacement operations at sea (see also issues above regarding transportation, weather etc.). Munich Re, for instance, offers a specific serial loss *insurance* cover. Alternatively, as before, diversification regarding the manufacturer may help to mitigate risk in the case of multiple wind parks. Serial risks particularly arise from the early application of unproven technological innovations, which has been the case in the early phase of wind park turbines. In 2002, for instance, various losses from damages to wind turbines occurred, resulting in increased premiums for wind park insurance and the exit of several insurers from the wind energy insurance market.[58] With the evolution of wind parks worldwide, especially less mature and rapidly growing wind park markets such as China need to assess the risks of unproven technology carefully to avoid serial risk exposures due to imperfect technologies and concepts.[59]

d) Revenue loss due to business interruption

Business interruption due to damages (see a)), grid availability risk / curtailment risk (see also market risk b)) as well as natural hazards (high wind speed and shut down of turbines for security reasons, see b)) or serial losses (see c)) may imply considerable losses of revenue, which may even be enhanced by accumulation risks as described above.[60] As discussed before, business interruptions are particularly severe for offshore wind parks.

Insurance and *O&M contracts* can offer coverage for unscheduled downtime triggered by wind speed and/or wave height.[61] Business interruption covers insure lost revenues in case these are not covered by O&M contracts. Even though this cover is much more relevant for offshore wind parks due to the high loss potential, which can considerably exceed the component costs,[62] according to EWEA (2013, p. 48) offshore wind parks lack insurance products that directly cover earnings losses. Instead, the risk is partially transferred by O&M contracts or contractual guarantees and warranties, whereby the coverage depends on the provider's balance sheet with a utility typically being the counterparty instead of the state

[57] GDV (2013, pp. 69, 72), Montes and Martín (2007, p. 2194).
[58] Munich Re (2004, p. 40).
[59] Jin et al. (2014, pp. 1073-1074).
[60] Turner et al. (2013, p. 10).
[61] Turner et al. (2013, p. 10).
[62] Turner et al. (2013, p. 10).

(e.g., DONG Energy incentivizes institutional investments by offering guarantees for project earnings).[63]

To reduce the risk of delays and the time of interruption, further *risk mitigation* should focus on technology and design, preventive maintenance and effective monitoring systems (see also a)), and replacement parts on standby.[64]

3.4 Liability and legal risks

Liability risk to third parties and law costs are further major single risks associated with wind parks (see Table 5),[65] including damage to the environment and the liability arising from the damage.[66] Available *insurances* include various liability coverages, also for environmental risks, and various coverages for legal and law costs. However, risks associated with offshore wind projects strongly differ from onshore wind parks. In particular the increased traffic volume at sea and the complexity of the construction, operation and maintenance phases (heavy parts, installation at sea) imply new loss patterns and volumes, e.g., a higher risk of liability from property damages and bodily injuries of persons. As offshore wind is a new technology, underwriting of possible losses is thus challenging for insurers.[67] In addition, legal contracts for offshore wind parks are mostly international contracts[68], aligned to cope with all parties involved in the construction and erection of wind parks.

Table 5: Liability and legal risks

Relevance for wind parks	Risk management
• Damage to the environment and liability arising from damage (Watts, 2011, p. 9) **Specific considerations for offshore wind parks** (GDV, 2013, pp. 106-107)**:** • Increasing traffic volume on the sea increases liability risk • Due to more difficult construction (heavy parts, installation on the sea), higher risk of liability from property damage and bodily injuries of persons • Legal contracts often international; need to comply with national law	**Risk transfer - Insurance**: • Various liability coverages, also for environmental risks • Various coverages for law / legal costs (e.g., in Germany special defense insurance policy for renewable energy by LVM) **Risk mitigation**: • Assure applicability of contracts under national law; extensive due diligence prior to contracting

63 EWEA (2013, p. 48). One example for such an incentive is the transaction with PensionDenmark: „DONG Energy will provide an operating guarantee to PensionDanmark, and in return DONG Energy receives a larger share of the operating profit if the power price increases over the current power price level.“ (www.dongenergy.com/en/investors/company-announcements/company-announcement-detail?omxid=503928).

64 Turner et al. (2013, p. 10).

65 Balks and Breloh (2014, p. 30), GDV (2013, pp. 106-107), Montes and Martín (2007, p. 2194).

66 Watts (2011, p. 9).

67 GDV (2013, pp. 106-107).

68 E.g., Construction All-Risk and Erection All-Risk (CAR/EAR) contracts; often multi-contracts covering all involved parties (e.g., Elleser and Smith, 2013, pp. 469-470).

3.5 Market and sales risks

Market and sales risks (see Table 6) refer to the variability of financial income due to, e.g., deviations of power prices, or the inability to sell electricity due to regional grid oversupply (curtailment risk).[69] While these risks are not relevant in countries where grid operators are obliged to purchase electricity from renewable energy sources (e.g., in the case of feed-in tariffs in Germany), the default of counterparties (e.g., grid operators) can occur, leading to losses from power purchase agreements (see next subsection). In addition, weather and resource risks are of high relevance due to fluctuations in wind during the year, which also substantially influences the profitability of wind parks.[70]

Table 6: Market and sales risks

Relevance for wind parks	Risk management
a) Variability of revenue due to weather/resource risk	
• Revenues vary due to different wind speeds (in the US around 15-20% year-to-year variability for wind projects depending on region, only 5% in the case of solar), while debt has to be paid regularly: need a minimum debt service coverage ratio (Turner et al., 2013, p. 11) • Actual wind park capacity differs from prediction, implying a shortfall in production and revenue, in the future possibly more relevant due to climate change (Watts, 2011, p. 13) • Resource risk is more relevant for onshore than offshore due to higher inter-year variation (Turner et al., 2013, p. 11)	**Risk transfer - Insurance**: • Coverage of minimum income in case output falls below a critical threshold (Turner et al., 2013, p. 11) • Insurance against climate and weather risks: fixed sum in case insured event occurs, very flexible, based on index **Risk transfer - Guarantees by service providers (full service agreement):** • Cover effects of weather conditions, insure against insufficient wind: Recent shift in type of guarantee from availability guarantees (for wind park operation) to guaranteeing output targets (EWEA, 2013, p. 47) **Risk transfer - Other:** • Energy derivatives (weather-contingent): reduce volatility risks of prices arising due to volatile output, but electricity price behavior may change when the share of renewable energy increases (becoming more complex) (Turner et al., 2013, p. 13) (Watts, 2011, pp. 21-22). **Risk mitigation:** • Geographic diversification • Diversification in regard to different technologies to reduce resource (volume) risk (reduce volatility from a portfolio perspective by investing in wind (highly volatile) and solar (less volatile) parks) (Watts, 2011, p. 17) • Add storage to increase flexibility (Lew et al., 2013, p. 5) • Use technology in pre-construction period for weather assessments to predict future impact of adverse weather conditions or poor wind yields; advanced site investigation techniques (as done by service providers, see EWEA, 2013, p. 47, with focus on offshore) • Use alternative mezzanine debt structures with debt fluctuating in line with outputs to reduce default risk on debt (more expensive than fixed coupon loans, Turner et al., 2013, p. 11)

69 Balks and Breloh (2014, p. 30), Jin et al. (2014, p. 1070), Turner et al. (2013, p. 9).

70 EWEA (2013, p. 40), Montes and Martín (2007, p. 2194).

b) Variability of revenue due to grid availability / curtailment risk	
• Curtailment risk / grid availability (bottleneck risk): excess generation of wind energy (strong fluctuation over time) in combination with insufficient network capacities (transmission / distribution congestion) and insufficient regional demand (regional grid oversupply) can imply that power output cannot be sold (Jacobsen and Schröder, 2012, pp. 663-664) • Current capacities, e.g., in Germany, are not sufficient, unable to balance power output peaks on windy days and to transport power from the north (high production) to the south (high demand); increase in capacities may take decades, whereas wind park is constructed in around three years (Bader and Krüger, p. 7, Turner et al., 2013, p. 8) • In Germany (FiT), costs of curtailments / insufficient capacity are transferred to the consumer, whereas in China, costs remain with the project owner even though they cannot control the risk (Turner et al., 2013, p. 12)	**Risk transfer - Other:** • Sign power purchase agreements (PPAs; in the UK and US): lower price reflects costs of balancing that arises for the grid operator (Turner et al., 2013, p. 11; Watts, 2011, pp. 17-18) **Risk mitigation** (Turner et al., 2013, p. 12): • Improve forecasting techniques • Diversify power generation portfolios (technologies (wind, solar) and geographically, e.g., distribute wind parks over a larger region (combine potential undersupply in one region with oversupply in another, reduce net balancing costs)) • Sell reserve capacity on the spot market at another time (given storage capacity) • Bid less power (storage) • Measures to be taken by state: invest in power grids to improve grid infrastructure, increase bandwidth of grid (Turner et al., 2013, p. 8, recommendation by EWEA, 2013, p. 54f)
c) Variability of revenue due to price volatility	
• Markets without support schemes are exposed to general fluctuations of energy prices • In case of the market premium model instead of FiT (e.g., in Germany after guaranteed FiT period or in the case of switching to a market premium model), fluctuations or a fall in energy prices imply revenue risk[71] (especially relevant in the case of insufficient storage opportunities, which implies "mandatory" sale)	**Risk transfer - Other**: • Energy derivatives (forwards) (see a), Turner et al., 2013, p. 13; Watts, 2011, p. 22) • Sign long-term power purchase agreement (often with a utility company instead of the state) or private contracts (Dinica, 2006, p. 470) to secure a fixed rate for power output, e.g., for 10-20 years (in the UK and US) (Turner et al., 2013, pp. 7, 13; Waissbein et al., 2013, p. 57)

a) Variability of revenue due to weather / resource risk

As described above, revenues of wind parks can vary considerably due to different wind speeds with a year-to-year variability of 15-20% (in the US) depending on the region (only 5% in the case of solar)[72], where onshore wind parks exhibit a higher inter-year variation than

[71] This becomes relevant if energy is sold at a lower price than the reference value used for the market premium model.

[72] These numbers refer to the yearly variability of wind generation in the US, while the standard deviation is lower at 8-13% for the US (in the case of solar approx. 3-7%; expected 2% in the long run, see Jenkin et al., 2013, p. 26). In Europe, the standard deviation for wind energy is estimated to approx. 6% (Thomas et al., 2009, p. 4).

offshore wind parks.[73] As debt has to be paid regularly, a minimum debt service coverage ratio (multiple of annual debt payment) is needed in case the financing involves debt.[74] This is especially relevant due to the high capital intensity of renewable energy projects and the often high leverage ratio (up to 70%-80%).[75] A further risk arises if the actual wind park capacity (generation) differs from the one predicted based on pre-construction wind assessments, implying a shortfall in production and thus revenue, a risk which in the future may even increase due to climate change.[76]

Regarding risk management instruments, *insurance* can be used to cover a minimum income in case the power output falls below a critical threshold due to insufficient wind[77] as provided by the “lack of wind cover” by Munich Re. Alternatively, contracts like the KLIMArisk policy by HDI-Gerling in Germany, for instance, can be purchased to obtain a fixed sum insured in case of specific weather conditions (see 3.3 b)). Similarly, *energy derivatives* can be used to reduce volatility risks arising from weather variability (weather-contingent electricity price hedging); however, the electricity price behavior may become more complex and change when the share of renewable energy increases.[78]

In addition, *service providers* to some extent cover certain effects of weather conditions and insufficient wind. In particular, according to EWEA (2013, p. 47), one could observe a recent shift from availability guarantees (guaranteeing wind park operation) to directly guaranteeing output targets. For instance, Vestas offers an Active Output Management service contract, which uses an extensive service and maintenance program to ensure the highest achievable output to help stabilize revenues.[79]

Most relevant alternative *risk mitigation* techniques from a portfolio perspective comprise diversification in regard to the geographic location of different wind parks, as well as in regard to technologies (e.g., investing in both wind (high volatility) and solar (low volatility) parks), which can contribute to a reduction of the overall weather-induced volatility in the portfolio.[80] In addition, storage capacity would allow an increase in flexibility[81] (if available and efficient) and prior to construction, a weather assessment should be conducted to predict the future impact of poor wind yields using advanced site investigation techniques as

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73 Turner et al. (2013, p. 11).
74 Turner et al. (2013, p. 11).
75 Turner et al. (2013, pp. 7-11).
76 Watts (2011, p. 13).
77 Watts (2011, p. 11).
78 Turner et al. (2013, p. 13), Watts (2011, pp. 21-22).
79 EWEA (2013, p. 47), www.vestas.com.
80 Turner et al. (2013, p. 12), Watts (2011, p. 17).
81 Lew et al. (2013, p. 5).

undertaken by service providers.[82] Finally, regarding the financing structure, to reduce the probability of default on debt one can use alternative mezzanine debt structures with debt fluctuating in line with outputs, but this is more expensive than fixed coupon loans.[83]

b) Variability of revenue due to grid availability / curtailment risk

The revenue also depends on the grid availability and thus curtailment risk, which represents another bottleneck risk and implies that power output cannot be sold, leading to losses in revenue in countries without fixed support schemes, such as the feed-in tariff. Curtailment risk arises in the case of an excess generation of wind energy in combination with insufficient network capacities, i.e., transmission and / or distribution congestion, and insufficient regional demand, i.e., regional grid oversupply.[84] Excess energy output in times of windy days can cause an imbalance in the energy system, which must be remedied by short-term balancing by the transmission grid operator (e.g., redispatch/dispatch-down, i.e., restrict project output or countertrading, selling energy to other countries, partly even negative spot prices).[85] In Germany, for instance, grid capacities are currently unable to balance power output peaks on windy days by transporting the excess power from the north (high production) to the south (high demand). An increase in capacities may take decades, whereas a wind farm can be constructed in around three years.[86] In Germany (feed-in tariff system), the costs of curtailments are transferred to the consumer, while in China, for instance, the costs remain with the project owners even though they cannot control the risk.[87]

Risk mitigation techniques include an improvement in forecasting techniques, selling reserve capacity on the spot market at another time (given the storage capacity) or bidding less power (given storage).[88] In addition, power purchase agreements (PPAs) can be signed (typically in the UK and US), whereby a lower price reflects the costs of balancing that arise for the grid operator.[89] Furthermore, diversification again plays a relevant role as in the previous subsection, as the diversification of power generation portfolios across technologies (wind, solar) and geographically larger regions can contribute to reducing revenue risk due to curtailment by combining potential undersupply in one region with oversupply in another,

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[82] EWEA (2013, p. 47) with a focus on offshore wind parks.
[83] Turner et al. (2013, p. 11).
[84] Jacobsen and Schröder (2012, pp. 663-664).
[85] Turner et al. (2013, p. 11).
[86] Bader and Krüger (2013, p. 7), Turner et al. (2013, p. 8).
[87] Turner et al. (2013, p. 12); in Northeast of China with many wind parks, the average capacity factor amounts to only 21.6%, one of the lowest values for onshore wind worldwide.
[88] Turner et al. (2013, p. 12).
[89] Turner et al. (2013, p. 11).

thus reducing the net balancing costs.[90] As a form of *risk transfer*, PPAs with a term of ten to twenty years during which the buyer agrees to purchase energy from the producer can help to reduce policy risks for the investor in case governmental support schemes are reduced.[91] Finally, to reduce curtailment risk and the considerable costs associated with it, the state should further invest in power grids by improving the grid infrastructure and by increasing the bandwidth of the grid, which however may take decades.[92]

c) Variability of revenue due to price volatility

Markets without support schemes are directly exposed to market risks, as sales fully depend on energy prices.[93] In case a market-based mechanism is used in addition or instead of a policy support scheme (e.g., in Germany after the guaranteed feed-in tariff period of 20 years or in case of switching from the feed-in tariff to the market premium model, where switching back and forth must be declared one month in advance), fluctuations or a fall in energy prices can imply a considerable revenue risk if output is sold at a lower price than the reference value. This is especially relevant in the case of insufficient storage opportunities, which implies "mandatory" sales independent of current prices. As a *risk transfer* mechanism, energy derivatives (e.g., forwards) can be purchased, whereby as discussed before, the electricity price behavior may change in the case of an increasing share of renewable energy.[94] With respect to *risk transfer*, again long-term power purchase agreements or private contracts can be used to secure a fixed rate for power output,[95] whereby Waissbein et al. (2013, p. 57) point out possible limitations that may arise with respect to "the design of standard PPAs and/or PPA tendering procedures," which is why key clauses should be transparent and well-designed, including, e.g., termination, curtailment, and currency denomination.

3.6 Counterparty risks

a) Supplier of O&M services

To ensure that contract fulfillment, as well as guarantees and warranties, can be met (along with replacement parts), the financial stability of the supplier of operation and maintenance (O&M) services (typically the manufacturer of wind turbines) is critical (see also operation risk in 3.3 a) and Table 7). This is also a particular issue for offshore wind parks that have

[90] Turner et al. (2013, p. 12).
[91] Watts (2011, pp. 17-18).
[92] EWEA (2013, p. 54f), Jacobsen and Schröder (2012), Turner et al. (2013, p. 8).
[93] Dinica (2006, p. 467), Saidur et al. (2010, p. 1749).
[94] Turner et al. (2013, p. 13), Watts (2011, pp. 21-22).
[95] Dinica (2006, p. 470), Turner et al. (2013, pp. 7, 13).

experienced numerous contractor insolvencies in the past.[96] For *risk transfer*, counter-guarantees against the default of loans can be acquired by public banks, which is a condition often required by institutional investors as a prerequisite to invest in offshore wind parks (e.g., Northwind project in 2012 with PensionDenmark).[97] In terms of *risk mitigation*, reputable contractors and long-term contracting should be chosen, e.g., experienced developers and suppliers with strong financial strength ratings and a solid performance track record, especially in the case of offshore wind parks with high entry barriers to the supply chain.[98] In addition, reserve contracts with other suppliers can be signed in case of a financially unstable O&M supplier.[99]

b) Counterparty risk power purchase agreement (PPA)

In case a power purchase agreement is signed (see risk transfer in case of market risk in 3.5), where the buyer agrees to purchase power from the provider for a fixed long-term price along with a guaranteed access to the electricity grid,[100] counterparty risk should be taken into account as well. In addition to the risk of a power purchaser's poor credit quality and the power producer's dependence on these payments, further barriers include problems regarding the corporate governance, management, or operational track-record of the power purchaser.[101] To mitigate this risk, reputable contractors should be chosen as discussed in the previous subsection.[102] In addition, in case of developing countries, partial risk guarantees by a development bank or guarantees by local governments that ensure that payments of a utility's PPA are met can be used as a risk transfer instrument.[103] Note that further risks may arise as well from PPAs in terms of market and sales risks as described in Section 3.5.

Table 7: Counterparty risks

Relevance for wind parks	Risk management
a) Supplier of O&M services	
• Financial stability of supplier of operation and maintenance (O&M) services is critical **Specific considerations for offshore wind parks:** • Counterparty risk of major suppliers / contractors considerable issue for offshore	**Risk transfer - Other:** • Counter-guarantee against default of loan by public bank (required by institutional investors to invest in offshore wind parks, e.g., Northwind project in 2012 with Pension Denmark) (Turner et al., 2013, p. 8) **Risk mitigation** (EWEA, 2013, p. 48,49): • Use experienced developers and suppliers with strong credit rating and performance track record (reputable contractors), especially relevant for offshore wind parks (high entry barriers to supply chain), as well as

96 EWEA (2013, p. 43).
97 Turner et al. (2013, p. 8).
98 EWEA (2013, pp. 48-49).
99 Turner et al. (2013, p. 9).
100 Waissbein et al. (2013, p. 38).
101 Waissbein et al. (2013, p. 51).
102 EWEA (2013, p. 49).
103 Waissbein et al. (2013, p. 57).

wind parks, where financial strength concerns contract fulfillment, as well as guarantees / warranties (EWEA, 2013, p. 43)	long-term contracting • Sign reserve contract with other suppliers in case of a financially unstable O&M supplier (Turner et al., 2013, p. 9)
b) Counterparty risk PPA	
• Counterparty risk of buyer in case of a power purchase agreement (US, UK, developing countries)	**Risk transfer - Other** • Partial risk guarantee by a development bank or local government to ensure payments by PPA (in case of developing countries) (Waissbein et al., 2013, p. 57) **Risk mitigation** (EWEA, 2013, p. 49): • Use reputable contractors

3.7 Political, policy and regulatory risks

Of special relevance for investments in renewable energy are political, policy and regulatory risks.[104] These include, for instance, changes in governmental priorities, resulting in reversed, modified or abandoned renewable energy support schemes (e.g., feed-in tariffs, tax benefits).[105] One can thereby distinguish between the risk of retrospective adjustment of support (see, e.g., case of Czech Republic, Spain)[106] and the future uncertainty regarding prospective policy support or regulatory requirements concerning, e.g., solvency capital requirements (Solvency II, Basel III).[107] Further political risks in developing countries may include, e.g., expropriation or war. According to Lew et al. (2013, p. 6), the risk of adjustment may also concern curtailment risk in the sense that wind park owners are no longer (fully) compensated in cases of curtailments. Policy risk may even increase in the future, as, e.g., Turner et al. (2013, p. 7) see a trend towards combining regulatory certainty with market-based components, as states change their support schemes to achieve cost reduction and a fair distribution of risks (e.g., US Production Tax Credit: subsidy + market competition). In addition, based on a survey and interviews among industry experts, Watts (2011, p. 11) finds that one relevant factor contributing to an increase in policy risk appears to be the strong fall in hardware prices (e.g., 60% fall of solar module costs since mid-2008 until 2011). This has resulted in considerably increased investments in renewable energy projects, thus increasing the governments' liabilities regarding support schemes in times of difficult macroeconomic outlooks.

Risk mitigation and transfer is highly challenging, especially when considering policy risk in the sense of adverse changes of support schemes. *Private insurance* is currently only available

[104] E.g., Balks and Breloh (2014, p. 30), Jin et al. (2014, p. 1070).

[105] Dinica (2006, p. 461), Holburn (2012, p. 654). See Saidur et al. (2010) for a review of wind energy policy schemes across different countries (e.g. US, Denmark, Germany, China, Egypt).

[106] Turner et al. (2013, p. 13).

[107] Bader and Krüger (2013, p. 22), Gatzert and Kosub (2014), Micale et al. (2013).

for political risks, which may provide partial coverage, but only in the case that the policy change can be considered as an expropriate breach of investor's rights, for instance.[108] Furthermore, according to Turner et al. (2013, p. 13), all-inclusive covers apparently include coverage for policy changes, but charge high premiums due to the difficult prediction of losses.

In addition, *public insurance* is available for political and policy risk with limitations regarding the country (developing, emerging markets etc.) and the type of financing (debt / equity).[109] MIGA (Multilateral Investment Guarantee Agency; World Bank Group agency) offers *political risk insurance* to small and medium size investors, companies, and banks from developing countries by insuring against governmental failures, which negatively affect the public or private project.[110] In addition, *feed-in tariff insurance* is offered by OPIC (Overseas Private Investment Corporation), but only for US equity holders according to a specific scheme and with a scope limited to specific projects (in developing economies). As there is apparently uncertainty regarding the timing, transaction costs, and compliance, the cover is not fully acknowledged by rating agencies.[111] Finally, the World Bank offers *partial risk guarantees*, which covers commercial debt against policy risk if included in the contract. The guarantee requires a three-party agreement, where a guarantee is issued by the World Bank to the commercial lender. At the same time, the World Bank signs an indemnity agreement (a counter-guarantee) with the host country.[112] Any project with private participation that depends on governmental decisions (PPP, Build-Operate-Transfer, privatizations) is eligible for this guarantee. The partial risk guarantee may cover several risks such as, e.g., changes in law, no adherence of contractual payments, expropriation and nationalization.[113]

Further *risk mitigation* regarding policy and regulatory risks include due diligence practices, by aiming to ex-ante assess potential future changes in legislation.[114] For instance, Holburn (2012) advises potential investors to consider the autonomy of the regulatory agency (low, high) and the policy-making process (flexible, rigid) as relevant political risk indicators. Using the US and Canada as an example, the author finds that regulatory risks are lower in jurisdictions where regulatory agencies have greater autonomy and where energy policies are executed more rigidly, as both factors stabilize regulatory policies over time, which is advantageous for long-term renewable energy investors.

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108 Frisari et al. (2013a, p. 27), Micale et al. (2013, p. 6).
109 Frisari et al. (2013a), Micale et al. (2013).
110 Frisari et al. (2013a, p. 27).
111 Micale et al. (2013, pp. 6, 8).
112 Micale et al. (2013, p. 7).
113 World Bank (2014).
114 Holburn (2012), Micale et al. (2013, p. 4).

The likelihood of a change in government support schemes could further be reduced by engaging in social activities, involving local communities, co-financing projects with host governments, and joint ventures and alliances with local companies.[115] In addition, communications with policymakers, regulators and industry bodies could be intensified, but according to a survey and interviews by Watts (2011, p. 17), even with well-developed communications, mitigation of political and regulatory risks remains difficult.

Finally, as found in all previous risk categories, geographical and thus regulatory diversification across countries with different support schemes and different exposure to regulatory risk can help to reduce the overall political, regulatory, and policy risk in a portfolio (benefits of scale in risk management).[116] Moreover, as mentioned in the previous subsections, signing PPAs can help to reduce policy and regulatory risk,[117] in case a counterparty is available.

Table 8: Political, policy and regulatory risks

Relevance for wind parks	Risk management
• Risk of retroactive adjustment of support (EWEA, 2013, p. 45) • Future uncertainty regarding prospective policy support or regulatory requirements regarding solvency capital requirements (Gatzert and Kosub, 2014) • Risk of expropriation or war, e.g., developing countries • Risk of adjustment can also concern curtailment risk (e.g., curtailments no longer compensated) (Lew et al., 2013, p. 6) - Combining regulatory certainty with market-based components possible future trend; support changes by state driven by cost reduction and fair distribution of risks (e.g., US Production Tax Credit: subsidy + market competition) (Turner, 2013, p. 7); also driven due to fall in hardware prices, resulting in increases in renewable energy investments and thus an increasing burden for governments regarding	**Risk transfer – (Private) Insurance**: • All-inclusive covers typically include cover for policy changes, but are expensive due to the difficultly of prediction (Turner et al., 2013, p. 13) • Political risk insurance may provide partial cover in case policy change is an expropriate breach of the investor's rights (Frisari et al., 2013a, p. 27; Micale et al., 2013, p. 6) (see political risk insurance by Zurich) • General problem of private insurance of policy risk: moral hazard and incentives of the state in case private insurance is available (Frisari et al., 2013: use, e.g., PPPs) **Risk transfer – (Public) Insurance** (Frisari et al., 2013a; Micale et al., 2013): • Political risk insurance by MIGA (Multilateral Investment Guarantee Agency; World Bank Group agency): covers only developing economies and emerging markets • FiT insurance by OPIC (Overseas Private Investment Corporation; only for US equity holders); scope limited to large projects, uncertainty regarding timing (expropriation claims approval process), transaction costs, compliance => not fully acknowledged by rating agencies (Frisari et al., 2013b,p. 2; Micale et al., 2013, pp. 6, 8) • Partial risk guarantees by the World Bank: can cover commercial debt against retroactive policy risk if clearly included in the contract, requires three-party agreement: World Bank issues a guarantee to commercial lender and signs an indemnity agreement (counter-guarantee) with host country (Micale et al., 2013, p. 7) **Risk mitigation**: • Due diligence practices including an assessment of potential future changes in legislation, e.g., by identifying political risk indicators (Holburn, 2012; Micale et al., 2013, p. 4) • To reduce the likelihood of governments' breach of contract: engage in

[115] Micale et al. (2013, p. 4).

[116] Watts (2011, p. 18).

[117] Watts (2011, p. 17).

support schemes (Watts, 2011, p. 11) - Predictable future policy support for renewable energy projects highly relevant for investors (Watts, 2011, p. 11)	social activities to involve local communities, co-financing projects with host governments, joint ventures and alliances with local companies (Micale et al., 2013, p. 4) • Intensify communications with policymakers, regulators and industry bodies, but: even with well-developed communications, mitigation of political and regulatory risks remains difficult (Watts, 2011, p. 17) • Geographical and regulatory diversification (benefits of scale in risk management) (Watts, 2011, p. 17) • PPAs may help reduce political and regulatory risk (Watts, 2011, p. 18)

4. Discussion: Evaluation of Available Risk Management Instruments

4.1 Assessment of risks associated with renewable energy – insights from industry surveys

To obtain an insight regarding the relevance of the respective risk categories displayed in Table 1 and the importance of the availability of risk management instruments (or the lack thereof) as presented in Tables 2-8, we evaluate several industry surveys that asked industry experts to rank these risks as laid out in Section 2. Table 9 indicates that even though the scope of the studies may differ to some extent, they all specifically emphasize policy and regulatory risks as major barriers and risks associated with renewable energy projects. Among the listed top risks are weather-related volume risks and financing risks (during the financing stage). In the case of offshore wind parks, we further find construction risk (including grid connection risk), as well as operation risks (and technological) and supplier counterparty risk to be of high relevance.

Table 9: Selected industry surveys on risks of renewable energy projects

Survey and participants	Major risks and barriers
Bader and Krüger (Deloitte and Norton Rose) (2013): • Investment situation regarding renewable energy projects in the German market • More than 100 participants (German-based companies or investors in German renewable energy: major utilities, insurers, institutional funds, representatives from the wind and solar industry)	1. General uncertainties regarding political and regulatory changes (~70%) (feed-in tariff development, adjustment of Basel III and Solvency II) 2. Complex approval procedures (~40%), complex regulation of subsidies (~30%) 3. Grid connection risk (bottleneck risk) (~30%) 4. Technological risks (~20%)
European Wind Energy Association (EWEA) (2013) • More than 40 lenders, institutional investors, power producers, sponsors, service providers, wind turbine manufacturers across Europe; majority were banks, followed by private equity and power producers • Focus on offshore wind parks	1. Regulatory changes represent the major operating risk (p. 9) 2. Grid availability among construction risks for offshore wind energy (p. 39). 3. Counterparty risk of suppliers and contractors
International Renewable Energy Agency (IRENA) (2013) • Approximately 100 potential Global Atlas end-users • Including about 30 project developers	Amongst most important risk indicators for solar and wind energy projects (pp. 13, 37): 1. Financial risk (e.g., country credit rating) 2. Governance risk (e.g., political stability) 3. Security risk (e.g., terrorism)

Rieder and Kreuter (Palladio Partners) (2014): • 105 institutional investors in renewable energy in Germany (especially insurers, pension funds)	1. Political and regulatory risk (97%) 2. Increasing prices caused by increasing capital inflow (66%) 3. Little expertise of market participants (58%) 4. Greenfield construction risks (58%) 5. Uncertainty about future solvency capital requirements (42%)
Watts (The Economist and Swiss Re) (2011) • Risks and risk management solutions regarding renewable energy projects, worldwide perspective • 280 senior executives in the renewable energy industry in Germany, the UK, Denmark, Spain and Italy, North America and Australia • 15 interviews with renewable energy executives and other experts on the risks	1. Financing stage of renewable energy is the most relevant "high risk" 2. Political and regulatory risk named as one of the most significant risks (rated as "high" risk by 15% after financial risk, as "medium" risk by 46%) 3. Weather-related volume risk, especially for wind projects 4. Operational / technological risk (business interruption due to resource / replacement unavailability, damage, component failure)
Wiegand and Nillesen (pwc) (2011) • 57 interviews with offshore wind power executives in 12 countries • Focus on offshore wind parks	1. Technology / O&M risk (73%) 2. Uncertainty due to political changes of government subsidies (64%) 3. Uncertainty due to high investments (55%) 4. Construction risk (36%) (p. 18)

4.2 Discussion of current challenges in risk transfer and mitigation, and the need for innovation

Based on the major risk categories indicated by industry surveys as discussed in the previous subsection, we next discuss the availability of risk management instruments for these specific risks, as well as challenges and current gaps in coverage.

Insurance coverage

Tables 2 to 8 show that in the case of onshore wind parks, insurers generally offer fairly comprehensive coverage for the *construction* and *operation* stages, including risks from construction, transportation, property damages, start-up delays, general and third party liabilities, as well as machinery breakdown and business interruption. This finding is also consistent with previous observations in the literature.[118] In the case of offshore wind parks, however, coverage is more limited for these stages (see also discussions in 3.2 and 3.3), even though they represent major risks from the investors' perspective, as indicated in the previous subsection (this perception also arises due to the limited coverage). In particular, more sophisticated and capacious insurance solutions are needed to cover higher asset values and risk exposures (due to higher complexity, new technology), as well as the generally considerably increased construction and operating costs. Offshore projects are often so called multi-contract projects, involving several project partners and thus making insurance

[118] E.g., Leblanc (2008), Montes and Martín (2007).

solutions more complex.[119] Furthermore, required coverages are generally much larger than in the case of onshore sites, which can require a pool solution with several insurers to provide coverage for offshore wind farms[120] that, according to industry experts, may easily exceed project volumes of USD 1.5 billion. The coverage for offshore wind turbines mainly comprises property damages, start-up delays, contractor's risk, as well as third party liabilities, leaving construction, machinery breakdown, business interruption and technology risks with only limited coverage (see Montes and Martín, 2007, p. 2194, and 3.2 and 3.3). The limited coverage is a particular problem, as especially the construction stage is the most risky period with the majority of losses according to historical experience occurring during this phase,[121] as also illustrated by the survey results in the previous subsection.

Major challenges for insurers – especially regarding offshore coverage and the high risks identified in the previous subsection – still include the lack of sufficient loss data[122] as well as new loss patterns due to the high complexity and new technology, which complicate the underwriting and pricing of contracts (see also Section 3.4, liability and legal risk). In addition, in the case of low numbers of insured offshore wind parks, balancing risks within a portfolio and over time is difficult, especially if insurance portfolios first need to grow over time in order to allow portfolio diversification effects. Additionally, risks with high loss potential, such as natural hazards, typically require large and globally diversified insurers to offer coverage (see also 3.3 b)).

In addition, *operation and maintenance (O&M) service contracts* by hardware suppliers (manufacturers) of wind parks typically offer full service agreements (FSA), for instance guaranteeing the wind park operator a certain amount of wind turbine availability and covering various risks involving the construction, erection and transportation process (see also Sections 3.2 and 3.3).[123] Also, insurers implement revision clauses, forcing wind park owners to either maintain certain wind park components regularly (e.g., by O&M service contracts) or to install a condition monitoring system as a prerequisite for coverage. These requirements were introduced after numerous component failures during the first years after introducing wind energy.[124] However, many FSAs do not offer complete risk coverage, excluding losses due to force majeure, vandalism or theft.[125]

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[119] Elleser and Smith (2013, p. 456).
[120] Elleser and Smith (2013, p. 469).
[121] Elleser and Smith (2013, p. 457), Turner et al. (2013, p. 9).
[122] GDV (2013, p. 99), Leblanc (2008, p. 149), Liebreich (2005, p. 19).
[123] EWEA (2013, p. 47).
[124] Dalhoff et al. (2007, p. 13), Munich Re (2004, p. 40),
[125] Windkraft Journal (2012).

Apart from construction, operation, and liability risks, insurance companies have also started to offer coverage for certain market and sales risks in regard to *weather-related volume (resource) risk* (see Sections 3.5 and 3.1), e.g., Munich Re with their “lack of wind” cover.

Particularly for the most relevant source of concern from the industry perspective, as consistently named by experts in all industry surveys as shown in Table 9, *policy and regulatory* risks, private insurance is currently only available in the form of political risk insurance. However, this typically requires an expropriate breach of investor’s rights, for instance, and is intended for emerging markets or developing countries. The problems of private policy risk insurance (e.g., moral hazard or opportunistic behavior by the government) is also addressed in Micale et al. (2013, p. 10). Public insurance for policy risks is available to some extent (partial risk guarantees by the World Bank, feed-in tariff insurance by OPIC), but comes with limitations as well (see Section 3.7). In general, against the background of an increasing relevance of renewable energy and the role of policy support schemes, new risk transfer instruments are needed to mitigate policy risk. Amongst other aspects to be taken into account when designing new policy risk insurance coverages, Micale et al. (2013) recommend an alignment of interest by including the government, for instance, in order to limit moral hazard behavior (as is done by MIGA and OPIC, see Table 8).

Further risk transfer and risk mitigation solutions

Overall, many risks associated with renewable energy can thus be covered (partly with limitations, especially in regard to new technologies) with conventional insurance solutions. However, risks such as policy and regulatory risks, market risks, or transportation, construction and completion risks in the context of offshore wind parks cannot easily be insured. These risks demand adequate alternative risk management instruments.

Regarding *market and sales risks*, for instance, *weather-based derivatives* and *energy derivatives* appear to be particularly promising, even though they can become complex and may involve severe basis risk. In the case of the latter, the owner of the wind park can sell its future produced energy upfront via energy forwards, thus lowering the risk of changing market prices for energy. In addition, acquiring *catastrophe bonds* further enables investors to mitigate losses from potential *natural hazards* that might affect onshore and offshore wind parks in general.[126]

Furthermore, when studying the available risk management solutions for the different risks presented in Tables 2 to 8, we find that in addition to insurance solutions, *diversification* plays

[126] UNEP (2004, pp. 29-31).

a major role in various dimensions in particular (manufacturer, geographically, technologies, countries/regulations), which is often also due to a lack of alternative risk mitigation or risk transfer techniques. This is also one main result of the survey by Watts (2011). Investors should thus diversify in various dimensions, including the manufacturer of wind turbines, therefore lowering wind park portfolio risks of *operation risks* (particularly business interruptions, resource / replacement risk) and *serial losses*, as well as *technological* and *innovation risks*. In addition, *weather* / *resource risks* can be reduced within a portfolio by geographic diversification across a larger area. Geographic diversification across various countries also contributes to reducing *policy* and *regulatory risks*. The benefit of geographic diversification is also analyzed in Drake and Hubacek (2007), for instance. The authors compare two scenarios, where a 3.6 gigawatts wind farm in the UK is located at i) a single location and ii) sharing the capacity amongst four different locations in the UK For case ii), the portfolio theory is applied by minimizing the standard deviation of the four wind park outputs and by deriving the most efficient frontier. Findings show that widespread dispersion of wind parks leads to reduced wind power variability up to -36%. Chaves-Schwinteck (2011) also applied modern portfolio theory to wind farm investments; two case studies showed that unsystematic risks can be diversified, thus reducing the risks of wind availability in the portfolio overall.

In addition, the risk mitigation approaches presented in Tables 2 to 8 are highly relevant to reducing the gross risks in the first place, before acquiring alternative risk transfer or insurance instruments to reduce net risks.

5. Summary and Implications

This paper provides a comprehensive discussion of risks associated with onshore and offshore wind park projects from the investor's perspective, as well as current risk management solutions with focus on the European market. In addition, the relevance of the risks is indicated based on a comparison of several industry surveys, and available risk transfer instruments and gaps in coverage are discussed. Our results show that current insurance products typically cover the majority of technical onshore and offshore wind park risks. However, insurance coverage for major risks from the investors' perspective, including construction and operation risks (especially for offshore wind parks), as well as policy and regulatory risks, is still limited due to several challenges. Alternative risk management approaches are typically necessary to provide a holistic risk management of onshore and offshore wind park risks, and diversification plays a major role in various dimensions in particular, including the manufacturer, technology (wind and solar), geographic region (reduce weather / resource risk) and country (political and regulatory diversification).

In the long-run, construction risks may certainly decrease with technological progress; political and regulatory risks, however, will remain relevant for investors if policy makers do not adequately address these risks. To ensure a sustainable growth in renewable energy, the policy and regulatory stability is of high relevance and risk transfer solutions need be discussed and developed, possibly together with international institutions such as the World Bank, which already offers partial risk guarantees to some extent for certain policy risks.

Furthermore, new technologies will generally remain a challenge for insurance companies regarding an adequate underwriting and pricing. However, insurance plays a major role in regard to technical innovation, and insurability can serve as a link between sustainable development and technological innovations.[127] Thus, developing new coverages and innovative insurance and risk management solutions as already observed in recent years in certain cases[128] is vital for allowing further sustainable growth in renewable energy as a financially attractive and technologically innovative source for nearly emission-free power generation with manageable risks.[129]

There are several limitations of the study which can be addressed in future research, including its focus on Europe as a mature market, the focus on wind parks as well as taking the investor's perspective when assessing risks instead of studying other stakeholder groups. While many of the identified risks and risk management solutions should generally be transferrable to other renewable energy technologies such as photovoltaic (PV), for instance, concrete types of risks and cases will differ and the specificities of the respective technology must be taken into account. For instance, policy risk in case PV should be considerably higher (and has already materialized in several European countries) due to the strongly decreasing hardware prices, among other reasons, as described in Section 3.7. Future research could also expand the perspective to other (e.g. emerging) markets and different stakeholder groups (e.g. project developers, end customers, public sector, see Waissbein et al., 2013). In addition, given that the present description of risks and risk management solutions uses various academic and practitioner-oriented case studies as instances to gain a comprehensive view, future research could use the presented results as a starting point and focus on one specific case study only, where the various risk management approaches can be illustrated and addressed in detail in terms of application to the specific case. Furthermore, while the present paper focuses on the presentation of risk management instruments and discusses associated challenges, future work could conduct an in-depth analysis of the costs of the presented risk management solutions and their implications on profits and cost competitiveness for specific

[127] Stahel (2003, p. 374).

[128] E.g., in regard to serial loss coverage or insurance of weather / resource risk.

[129] Balks and Breloh (2014, pp. 32-33).

wind park projects.[130] This could be done, e.g., by considering relative changes in the cost of capital for specific case studies, which will be impacted by the portfolio choice of risk management instruments that change the perception of investors regarding the respective risks.

130 In this context, we also refer to Waissbein et al. (2013) for a framework and case studies regarding renewable energy projects in developing countries that explicitly include the costs for financing (Waissbein et al. 2013, pp. 17-18, 22).

APPENDIX

Table A.1: Risk classification

Practitioner-oriented literature				Academic literature			
EWEA (2013): only offshore	GDV (2013)	Turner et al. (2013)	Watts (2011)	Balks and Breloh (2014)	Jin et al. (2014)	Liebreich (2005)	Montes and Martín (2007)
• Construction risks ○ Grid availability and connection risk ○ Contract and sub-contract interface risk ○ Credit risk of major suppliers ○ Weather risk ○ Financing availability ○ Harbor bottleneck risks ○ Generic supply chain bottlenecks ○ Foundation design and quality risk (certification) ○ Soil conditions / ground risk ○ Turbine design risk (certification) • Operating risk ○ Regulatory change risk ○ Bearings risk ○ Cable reliability ○ Warranties and liquidated damages availability risk ○ Gearbox risk ○ Cable availability ○ Wind risk ○ Blade risk	• Natural hazards • Business interruption • Interior damages • Liability risk • Transportation risk	• Construction ○ Loss or damage ○ Start-up delays • Operation ○ Loss, damage & failure ○ Business interruption • Market ○ Weather ○ Curtailment ○ Power price ○ Counterparty • Policy	• Building and testing risk • Business / strategic risk • Environmental risk • Financial risk • Market risk • Operational risk • Political / regulatory risk • Weather-related volume risk	• Completion risk • Operation and management risk • Technological risk • Market and Sales risk • Liability risk • Resource risk • Innovation risk • Political and regulatory risk	• Policy risk • Investment risk • Design risk • Marketing risk • Operation risk • Ecological risk	• Planning and permitting ○ Delays ○ Ownership disputes ○ Legal and consulting costs • Construction ○ Construction delays ○ Cost overruns ○ Availability of interconnect • Operating ○ Raw material volume and price variations ○ Technology risk, maintenance costs ○ Electricity price / volume ○ Renewable premiums or incentives ○ Counter-party risk • Decommissioning / repowering ○ Ability to re-power ○ Renewal of permits ○ Land remediation costs	• Construction all risk • Resource supply / exploration • Property damage • Machinery breakdown • Business interruption • Delay in start up • Defective part / technology risk • Constructors overall risk • General / third party liabilities

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