Development of a Decision Support System for Probabilistic Scenario Analyses of Offshore Wind Park Projects

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1 Introduction

In 2014 the global primary energy supply of 12,928.4 Mtoe (or 155,141 TWh) was mainly based on fossil energy sources. Although hydroelectric and other renewables have both reached record shares of 6.8% and 2.5%, the shares of oil (32.6%), natural gas (23.7%), coal (30.0%) and nuclear energy (4.4%) are still far too high. This unilateral mix of energy supply causes diverse externalities, as for example great greenhouse gas emissions or destruction of the nature and livelihoods as a consequence of surface mining, which have devastating effects on humanity, nature and the environment. Especially the pollution of air, soil, surface- and groundwater leads to a massive environmental damage that results in an ongoing climate change. Furthermore, the combination of the growing global primary energy demand (3,728 Mtoe in 1965 to 12,928 Mtoe in 2014) and the shortage of fossil sources leads to increasing energy prices (13.5 $/bbl. in 1965 to 98.9 $/bbl. in 2014).[1] As a sequel to these heavy problems, many social as well as political institutions force extensive changes concerning the global energy supply. Therefore, in the *2015 Paris Climate Conference* the United Nations (UN) target a commitment to low-carbon economies and a legally binding and universal agreement on climate matters with aiming at keeping global warming below 2°C. Thus, as "*today, renewable energy technologies are seen not only as a tool for improving energy security, but also as a way to mitigate greenhouse gas emissions and to provide direct and indirect social benefits*"[2], the share of renewables in global primary energy supply inevitably needs to grow more rapidly in order to reach the UN aims.

Hence, various transformations within energy supply systems must be realized. Large-scale and central fossil-fueled as well as nuclear power plants have to be gradually replaced by smaller, decentralized units that are based on renewable energy sources. The result should be an implementation of a mix of energy supply from different renewables. Although these transformations are already taking place in several highly industrialized as well as some developing countries, further research needs to be done to optimize the transformation processes continually.[3] In this regard, the European Union (EU) defines within their climate and energy policy that all further actions must be consistent with the goals that constitute their goal triangle: sustainability, security and cost-competitiveness.[4]

Due to global economic and political crises, not only the member states of the EU but also a lot of further states are facing budgetary constraints. "*Competitiveness and affordability of energy costs are thus of increasing concern*,"[5] resulting in the goal of cost-competitiveness

[1] Cp. Dudley (2015), p. 40ff.
[2] Sawin and Sverrisson (2014), p. 5.
[3] Cp. Schäfer (2012), p. 1.
[4] Cp. D'Oultremont (2014), p. 1f.
[5] D'Oultremont (2014), p. 2.

being brought to the top of the triangle.[6] Therefore, in order to ensure the progression of the expansion of renewables, any future renewable energy project should primarily face the goal of cost-competitiveness. But, as potential investors as well as lenders focus especially on profitability and financial feasibility key figures, not only costs, but also benefits must be taken into account. Only if both, profitability and financial feasibility of future renewable energy projects are adequate, these projects are realizable, as these are necessary conditions for potential sponsors to be willing to invest or lend.

By considering the EU goal triangle it becomes apparent that besides solar and onshore wind energy, especially the offshore wind energy is likely to play an important role within the future mix of energy supply. It is a maturing low-carbon technology that can be deployed at scale.[7] In comparison to onshore wind farms (1,500-2,000 FLH), current offshore wind farms are operating for more full load hours (FLH) (4,000-4,500 FLH).[8] Therefore, they are operating much closer to the base load and are thus helping to ensure grid stability and security of supply.[9] Hence, the achievement of sustainability as well as security can be supported via an increasing effort in developing the offshore wind energy.

Currently Great-Britain and Denmark are exemplary going ahead concerning the usage of offshore wind energy. Nevertheless, many other countries also recognized the advantages of this technology. Within the next decades especially Germany, France, Belgium, Japan, China and the Netherlands strive great expansions of their installed offshore wind power capacity. By summing up the expansion targets across all EU member states, a common installed capacity target of 40.0 GW until 2020 is calculated.[10] At the moment, the German government strives for the greatest expansion. It claims to increase the installed capacity to 6.5 GW in 2020 and 15.0 GW in 2030.[11] But, at the end of 2014 only 0.6 GW of offshore wind power capacity were installed in the German parts of the North and Baltic Seas.[12] Hence, this indicates that Germany currently targets great average expansion rates of approximately 26% per year until 2030. In order to promote the expansion of the installed offshore wind power capacity, especially the techonolgy's profitability and financial feasibility have to be adequate, both at macroeconomic as well as project level. Therefore the governments have to offer incentives for private as well as institutional investments to guarantee the realization of further projects. As long as there is an insufficient access to debt and equity capital, the governments are not able to reach their ambitious expansion targets. For instance, by having a look on its targeted expansion rates, it becomes clear that the European offshore wind

[6] Cp. D'Oultremont (2014), p. 2.
[7] Cp. Smith (2014), p. 122ff.
[8] Cp. Kunz (2013), p. 13f.
[9] Cp. Bilgili et al. (2011), p. 907f.
[10] Cp. Arapogianni (2013), p. 9.
[11] Cp. Gesetz fuer den Ausbau erneuerbarer Energien (Renewable Energies Act), EEG §3(5).
[12] Cp. Corbetta (2015), p. 15.

energy industry needs between 90 € billion and 123 € billion of investments until 2020.[13] Therefore, a lot of further equity investors as well as lenders need to be attracted in order to cover this financing gap.

In this regard, equity investors are especially interested in an adequate return on investment (ROI), whereas lenders demand an appropriate debt coverage to be willing to provide the necessary credits. Both, equity investors as well as lenders typically simulate and estimate these financial key figures via probabilistic scenario analyses. Their investment decisions are made upon cost-benefit and total risk analyses, taking into account the probabilistic costs and revenues of planning, construction, operation and renaturation phases. But, unless the average ROI of offshore wind farm projects is quite attractive, many potential investors avoid investments due to a difficult, inaccurate Value-at-Risk simulation and estimation.[14] Today, the major technical, regulatory as well as economic/market risks and their correlations are not well understood. Therefore, further research has to be done to evaluate the impact of specific risks on the financial key figures. Taking the most important risks into account, it has to be shown whether potential debt as well as equity investments in offshore wind farm projects are currently reasonable.

Unfortunately, only little methodological support exists that is based on a probabilistic approach and considers various important risks along with their correlations. On this account, an own financial decision support system (FDSS) is developed within this thesis. The resulting application is dedicated to the research field of Green information systems. This research field focuses on the development of information systems (IS) that are geared to the investigation of environmental challenges and research questions. Therefore, Green IS are developed in particular for giving decision support on potential future actions that concern the environmental sustainability and social responsibility.[15] The application is intended to provide relevant information for investment and lending decisions regarding offshore wind farm projects. By means of the FDSS, potential investors and lenders are able to evaluate important financial key figures within probabilistic scenario analyses, including for instance the adjusted present value (APV), the annual return on investment (ROI) and the debt service cover ratio (DSCR). On this account, giving decision support for potential investors and lenders the FDSS shall support the future expansion of offshore wind energy and is therefore characterized as a Green IS.

For the developing of the FDSS the programming language MATLAB is used. In order to allow for calculations of important financial key figures, it is based on a comprehensive cash flow model. Furthermore, in order to consider the important risks of offshore wind

[13] Cp. Arapogianni (2013), p. 9.
[14] Cp. Montes et al. (2011), p. 4746.
[15] Cp. Dedrick (2010), p. 173.

farm projects within the analyses, risky parameters are specified via implementations of probability distributions. The scenario analyses are performed via Monte Carlo simulations (MCS), which allow Value-at-Risk (VaR) analyses on the resulting frequency distributions of the financial key figures. Within the MCS the Iman-Conover method is implemented in combination with a Cholesky-decomposed correlation matrix for the purpose of taking risk correlations into account. On behalf of improving the handling of the FDSS, a graphical user interface (GUI) is programmed.

The development of the FDSS is performed in accordance with the Design Science Research (DSR) method. For that reason, the goals of this thesis are the demonstration, evaluation and communication of the FDSS within this research method. Based on a fictive offshore wind farm project, which is assumed to be situated in the German Bight, the capabilities of the FDSS are highlighted. In this regard, the profitability and financial feasibility of this fictive project is estimated and assessed. In addition, sensitivity analyses are performed in order to evaluate the robustness of the cash flow model and the resulting key figure distributions. Moreover, these sensitivity analyses allow for investigations of the impacts of each specific risk on the financial key figures. All in all it can be concluded that this thesis aims an investigation of how to give adequate financial decision support on investments in offshore wind farm projects, taking risks as well as risk correlations into account.

In order to comprehensibly assort the following argumentation, this thesis is organized as follows: at first summarizing major contributions as well as characterizing the selected research design helps to get an overview of the research background. This initially ensures a transparent and rigorous research approach. In the following section, special emphasis is placed on the theoretical framework of financing offshore wind farm projects. Current financial structures and sources of finance are discussed with a special focus on project finance and the most important key figures for equity investors as well as lenders are demonstrated. Afterwards the complex financial structure of offshore wind farm projects is modeled within a cash flow model. Furthermore, the impacts of the most important risks of these projects on financial key figures are identified and implemented in a business risk model. In this context, it is especially focused on correlations between risks or risky parameters. Following this, the programming of the FDSS is explained extensively, including the implementation of the cash flow and business risk model via MCS and ICM, a representation of the system architecture and a discussion on implemented parallelization tools. Then the FDSS is applied to a case study of a fictive offshore wind farm project. By performing scenario and sensitivity analyses its capabilities are demonstrated and evaluated. The results of the analyses are discussed, requirements of decision support on offshore wind farm projects are defined and limitations of the FDSS are identified. Finally, recommendations for researchers, potential investors and lenders are provided and a conclusion in combination with an outlook is made.

method in combination with a Cholesky-decomposed correlation matrix is an advisable approach to implement correlations between vectors of random numbers.

- As MCS require the performance of a large number of random experiments to generate accurate results, this solution approach might become very computing time consuming. On this account, the minimum number of iterations that guarantees a sufficient accuracy of results should always be calculated. In this context, using the approach of Vose (2008) might be reasonable.
- Moreover, it is recommended to implement parallelization methods. If, for instance, MATLAB is selected as development environment, especially the "parfor" function should be implemented in order to reduce the required computing time significantly.

9 Conclusion and outlook

Within the IS research an increasing focus on research activities on the future energy supply, including in particular renewable energies research, can be observed. On the one hand, this can be especially traced back to the current ecological and environmental issues that emerge due to the diverse externalities caused by the unilateral mix of energy supply. On the other hand, the arising pressure for change and transformation in the energy supply systems exerted by these issues enhance the attractiveness and importance of renewable energies research significantly. Ever since the publications of Dedrick (2010) and Watson et. al (2010) on Green IS, the renewable energies research is an inherent part of the IS research. In accordance with Dedrick (2010), Green IS are developed in particular for giving decision support on potential future actions that concern the environmental sustainability and social responsibility. As the FDSS focuses on decision support for potential investors and lenders of future offshore wind farm projects, it might support the expansion of the offshore wind energy and thus automatically meets the requirements to be characterized as a Green IS.

In order to generate relevant information for potential investors and lenders of offshore wind farm projects, probabilistic scenario and sensitivity analyses of individual projects can be performed by means of the FDSS. Investors obtain decision support by Value-at-Risk analyses of APV and ROI distributions, whereas different distributions of debt coverage key figures, including the DSCR, PLCR and LLCR, are generated in order to improve the information basis of the decision-making of potential lenders. Therefore, the FDSS represents a methodological support that allows for summarizing and consolidating the complex financial structure of an offshore wind farm project in a convincing system of key figures.

Although various investigations on the profitability of offshore wind farm projects conclude that the average ROI is likely to be quite attractive, many potential investors avoid participating in these projects due to an inaccurate understanding of the complex risk structures. The same applies to a significant number of potential lenders. Therefore, considering the specific risks of offshore wind farms within the simulation of financial key figures is of particular importance. Rather than performing deterministic analyses, implementing a probabilistic approach is necessary to ensure a sufficient accuracy of the results. Only if accurate Value-at-Risk simulations and estimations are performed, the understanding of the complex risk structure of offshore wind farm projects will be improved significantly, which finally might result in an increasing willingness to invest or lend.

The presented FDSS is developed due to the fact that a lack in the methodological support for accurate Value-at-Risk analyses of offshore wind farm projects is identified within the literature review. In order to model the complex financial structure and to allow for the calculation of financial key figures a comprehensive cash flow model is derived and implemented in MATLAB. Furthermore, a business risk model is set up that takes major risks as well as their impacts on various parameters into account. The complex risk structure is implemented by defining a BetaPERT probability distribution for each risky parameter. Moreover, a risk correlation matrix is specified and implemented via Iman-Conover method. By finally applying a MCS on the probabilistic cash flow model, the probability distributions of the risky parameters are simulated numerically resulting in frequency distributions of the financial key figures. In order to enable a faster comprehension as well as simpler handling and to allow for the visualization of results, a MATLAB based GUI is developed in the end.

In order to demonstrate and evaluate its capabilities, the FDSS is applied to a case study of a fictive German offshore wind farm project. For the purpose of elaborating the case study, a comprehensive literature research is initially performed. Based on this necessary input data the parameters as well as their risks and correlations are specified. Afterwards, scenario and sensitivity analyses of the profitability and financial feasibility of this fictive project are performed by means of the FDSS.

At first, the analysis of the results shows that giving generally valid recommendations regarding investment or lending decisions is typically not expedient. As each decision depends on various individual factors, as for example the individual risk aversion or alternative investment opportunities, assessments of the attractiveness of a participation in a specific offshore wind farm project need to be always performed from the perspective of an individual investor or lender. However, the results also show that the fictive project is likely to provide a ROI that is slightly greater than the returns of a comparable investment in the capital market. Hence, the majority of potential investors is likely to assess an investment in the fictive project as highly reasonable. The same applies to the majority of potential lenders, as the likeliness of an insufficient coverage of the contractual debt service is on a low level. Therefore, it is very likely that negotiations on the financing of the fictive project would result in a successful financial close due to a sufficient access to debt and equity capital.

Although, general statements on the profitability of offshore wind farm investments are not expedient, the results of the analyses allow for defining general requirements of decision support on offshore wind farm projects. A sufficient accuracy of decision support information for potential investors and lenders is only received if major risks and their correlations are taken into account. Rather than using deterministic analyses, the decision support should be based on a probabilistic analysis approach. In order to implement the major risks, performing MCS based on probability distributions of risky parameters is recommended. When using a MCS, the correlations should be implemented via Iman-Conover method. However, as generating a large amount of random numbers as well as resorting the random numbers in order to simulate the specified correlations are both highly time consuming computations, calculating the sufficiently large number of iterations is very advisable. In addition, it is reasonable to implement efficient parallelization methods that reduce the number of sequentially computations and thus the required computing time, too.

Even though parallelization is already implemented in the FDSS, the possibilities for parallelization are still far from being exhausted. Currently only fine-grained parallelization is possible as long as a multiprocessor computer is used. But in order to improve the performance of the FDSS in future research activities, it is striven for an implementation of coarse-grained parallelization by using homogeneous and/or heterogeneous computer clusters. Furthermore, various tools for fine-grained parallelization that are not yet implemented should also be tested. For instance, a large pool of tools for both fine- and coarse-grained parallelization is provided by the MATLAB add-on "Parallel Computing Toolbox".

Moreover, in order to enhance the access to the FDSS, it must be provided as a standalone executable file. Although the underlying source code fulfills all requirements to be packed in an executable, the final creation step still needs to be performed in further research activities. Furthermore, the FDSS is intended to be provided as a web application, as this improves its platform independence. Using the open-source web framework Ruby on Rails (RoR) for this purpose seems recommendable as RoR has an implemented interface that allows for a comprehensive MATLAB code integration. Further research activities should also focus on an implementation of the contribution to variance sensitivity analysis method as it improves the quality of results on the one hand and enables the parallel performance of scenario and sensitivity analyses on the other hand.

In order to reach a greater accuracy and reliability, further research activities should also focus on an improvement of the data base used to specify the characteristics of the fictive project. On the one hand, the quantification of risks and thus the estimations of probability distributions of risky parameters need to be enhanced in terms of accuracy. On the other hand, as dependencies between risky parameters have significant impacts researchers should pay greater attention to measurements of the direction and strength of correlations.

Although, the FDSS and thus its results are still limited to a significant extent, the performed analyses show that investments in as well as lendings to German offshore wind farm projects can be highly reasonable. Nevertheless, due to their complex risk and financial structures the profitability and financial feasibility of these projects should definitely be assessed using comprehensive DSS that rely on a probabilistic approach considering risks and their correlations. This lowers the risk of misinvestments on the one hand and might increase the willingness to lend or invest on the other hand. On this account, it can be concluded that the FDSS represents a methodological support that might make a relevant contribution to the efforts of covering the current funding gap in the offshore wind energy market.