Geographic Information System Analysis of the Repowering Potential of Wind Turbines in Germany

Masterarbeit

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1 Introduction

While there is consensus that global warming poses a serious threat to society, the debate on the contemporary topic is far from over. In December 2015, 195 countries agreed for the first time at the Paris Climate Change Conference (COP21) on a general, legally binding global climate agreement. This concession to the urgency of the energy turnaround was last clouded by the political turnaround in the United States and its withdrawal from the agreement. Despite the withdrawal, US President Donald Trump recently affirmed in a statement that the US nevertheless considered climate protection important and that a return to the Paris Agreement was conceivable [Der Tagesspiegel (2017)]. So even supposed opponents of the Parisian efforts are giving in and the necessity of the energy turn is generally undisputed. But the question remains: how should the energy revolution be implemented? Within the framework of the Paris Agreement, the States agreed on a long-term goal to limit the rise in the global average temperature to well below 2 °C compared to pre-industrial levels, or to ensure that global emissions exceed their peak as soon as possible, with more time for developing countries to do so (European Union, 2018). Participating states commit themselves to define projects in order to achieve the corresponding goals. The structure of the pro rata contributions remains undefined. Of course, the ambition of the efforts increases with the level of development of the countries and regions. Whereas the EU presented its intended contribution to the new agreement in March 2015 and is already taking steps to achieve its target of at least a 40% reduction in emissions by 2030 (European Union, 2018), Germany has set its own targets with the decision of the "Erneuerbare Energien Gesetz 2017" (EEG 2017). Accordingly, the Federal Republic's mandatory target is to increase the share of electricity generated from renewable energies in gross electricity consumption to:

1. 40 to 45 percent by 2025,
2. 55 to 60 percent by 2035 and
3. at least 80 percent by 2050 (see EEG 2017).

Only recently, the coalition agreement of March 2018 of the new federal government defined even more offensive targets and increased the required share of renewable energies to 65% of gross electricity generation by 2030, acknowledging that the expansion of renewable energies must be significantly increased (see Koalitionsvertrag 2018). The figures are already well approaching the target and the share of renewable energies in gross electricity production rose sharply from 31.6% (2016) to 36.2% (2017) due, among other things, to an extensive expansion of wind energy [BMWi (2017)]. Nonetheless at first glance, the figures seem high, but in view of the fact that Germany is not only facing the reduction of CO_2 emissions, but also the nuclear phase-out in 2022, the switch to renewable energies remains the only sensible strategy. A look at Scandinavian regions also shows the potential. Iceland, on the one hand, already covered about 95% of its electricity demand with renewable energies in 2016 and Norway, on the other hand, produced about 104% of its electricity demand with renewable energies in 2016 (see [Eurostat (2018)]). According to a report of the Energi Norge of 2018, Norway wants to become the first country in the world with a 100% supply of renewable energies of total demand (see [sonnenseite.de (2017)]). The legal claims are therefore justified. However, the expansion in Germany is increasingly reaching various limits. Although wind energy yields from a given area will increase as technology improves, the area that is economically and technologically feasible for wind energy development will decrease as existing areas are almost exploited. In addition, there is increasing competition from social, economic and political interests for the use of inland areas. A recent study about the future of Wind energy expansion in Germany of 2018 indicates increasing disputes in the communities where the turbines are planned [Agora Energiewende (2018)]. There are increasing conflicts of interest in which landscape conservation and protection of residents from negative influences through the construction of wind turbines are offset against the positive effects of wind energy on climate change. For some years now, policymakers have been reacting with spatial restrictions on the construction of wind energy turbines. Correspondingly increasing restrictions have a negative effect on the potential area of wind energy. In addition, there is the fact that large potential areas with suitable wind conditions have already been exhausted. A 2013 study by the Umweltbundesamt (Federal Environment Agency) indicates that the potential areas are already largely covered by wind turbines in 2010 [Lütkehus et al. (2013)]. The continuing importance of wind energy in contrast to the stronger restrictions of the potential area and in connection with expiring EEG tariffs for old turbines, repowering as an effective solution is moving further and further into the foreground. However, these conflicting circumstances also raise the question of the potential of repowering for wind energy in Germany.

In this context, an association is already obvious, namely to link the deconstruction and a possible repowering to the point in time of the EEG tariff expiration time of a wind turbine.

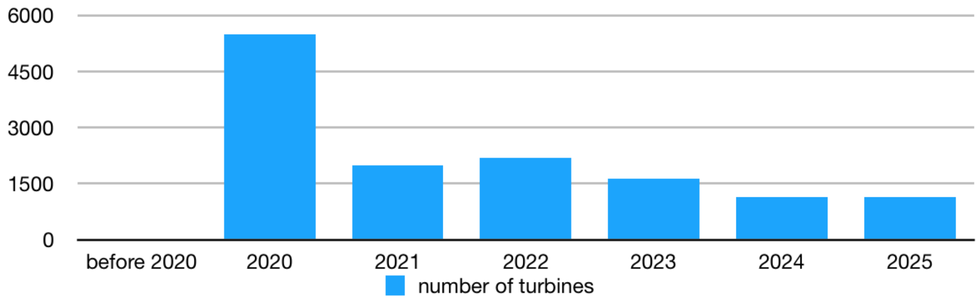

Figure 1 Absolute number of turbines based on expiration date before 2026, source: own illustration, based on wind turbines in Germany with status of 2017)

However, a distortion of the resulting relationship is also conceivable. If it makes sense to

continue operating a plant even after the EEG remuneration has expired, the turbine lifetimes could also be extended beyond the duration of the EEG remuneration. Or, however, the continued operation of a plant is so disadvantageous compared to a possible repowering that deconstruction and repowering dates are to be settled noticeably earlier than indicated by the expiration dates. So there are the elementary questions, is a repowering project technically possible under consideration of possible exclusion criteria? and is repowering economically sensible and at what point in time? Depending on the wind turbines already installed and their operating strategies, the present thesis aims to demonstrate the full potential of onshore wind energy in Germany, which is available from a technical and economic point of view. In line with this objective a spatial GIS-based analysis is carried out to account for prevailing restrictions and a model is developed which allows the analytical identification of the repowering potential under consideration of the optimal strategies of the operators and their possibility to choose for an option.
In order to carry out a well-founded analysis to answer the research question of repowering potential adequately, a literature review was carried out. Thereby a Webster and Watson based approach of a literature matrix was used to categorize relevant literature and to elaborate the current state of research to identify possible research gaps with regard to the topic covered. Furthermore, important factors to be considered can be found in this way.
Subsequently, as a first step of the techno economic analysis, a spatial GIS-based location analysis will be carried out for Germany, Lower Saxony, North Rhine-Westphalia and Hanover Region, taking into account regulatory restrictions and spatial factors in different scales, in order to obtain information about the theoretical site potential for repowering. For this purpose, relevant spatial restrictions and factors are identified and the tool-based procedure is explained. The chapter thereafter then deals with the economic potential analysis carried out as part of the overall work. In a first step, the applied method is derived and adapted from the approach of a Net Present Value of difference investment (NPV_{diff}), in the context of wind energy investments presented by the authors [Madlener and Schumacher (2011)]. The resulting approach of an Adjusted Present Value of difference investment (APV_{diff}) is explained and its implementation in an analysis supporting tool is presented. In order to obtain information about the actual potential in Germany, a scenario analysis was carried out in different stages (Lower Saxony, North Rhine-Westphalia, Hanover Region) which is presented in a separate chapter. The results of the analysis are then presented and evaluated. The corresponding results are discussed and in a sensitivity analysis used factors are tested for their influence potential. At the same time, the sensitivity and robustness of the model is tested. This is followed by a discussion of the present work, within the framework of which possible limits in modelling and spatial analysis are discussed and recommendations for future research are presented. The work concludes with a summary of the insights gained and an outlook

for future research needs.

2 Current State of Research

2.1 Narrowing the Scope of Relevant Literature

The following chapter outlines the performed approach to analyze and categorize relevant literature with the aim of best possible and profound research. To appropriately and sensible analyze literature according to planned research of this thesis, it is strictly necessary to spot relevant literature out of, in most cases, a large quantity of accessible literature. In order to provide insight into the prominence of this papers topic "Google Scholar" is used to visualize the temporal change of publications with different relations to the topic. Moreover the actual search for literature is done using databases of "Google Scholar", "SpringerLink", the "International Association of Energy Economics" (IAEE) and the "Association for Information Systems electronic Library" (AISeL). All used databases are one of the most established web search engines that index scholarly literature, whereas the IAEE solely indexes literature related to energy economic and AISeL solely indexes information and communications technology related topics. The following graph 2 shows the temporal development of publications containing the exact phrase "wind energy potential" and therefore a minimal limitation to this papers subject over a period of the last 20 years from 1998 until 2017. The graph unmistakable illustrates the continuous growth and high amount of literature concerning the potential of wind energy since 1998, which might be closely related to the widespread launch of wind turbines in the early 1990's. Since 1998 the number of publications per year was constantly growing every year except 2016, which lead to a total number of publications of around 1340 in 2017, indexed by Google Scholar. To narrow down the number of publications to a comprehensible and most of all relevant set of literature keywords were established that fit best to the requirements of the search. To establish appropriate keywords possible words were compared among each other by its number of publications. In respect of "potential", "wind energy" turned out to be more suitable than "wind power" since the number of publications of "wind power" over last 20 years with an amount of about 6280 publications is much lower than wind energy with about 12300. Resulting keywords used for the literature search finally were variations of: "wind energy", repowering, optimal, timing, gis, techno, economic, potential, germany. Whereas the explicit phrase "wind energy" was part of the search in every case.

work can be recommended from the point of view of this work.

7 Conclusion

This thesis was dedicated to the potential analysis of repowering in Germany under consideration of spatial restrictions and economic options. One focus was the spatial differentiation of regulatory restrictions on the basis of federal states. A further focus was on the annual consideration of economically reasonable options from the operator's point of view for a realistic assessment of the actual technically possible and economically reasonable potential. The requirements for action were first derived from a comprehensive literature search and incorporated into the development of the models and analysis. In summary, the research revealed a research gap in the field of techno-economic analyses for a differentiated potential study in Germany. According to this, the studies considered have primarily relied on average values in the determination of area potentials and have disregarded economic options of the operators. In order to counteract the backlog, restrictions specific to the federal states were applied in the following, from which the actual area potential and suitable locations were derived. The economic analysis was then carried out for the federal states of Lower Saxony and North Rhine-Westphalia and the Hanover region, taking into account the suitable locations. Corresponding results were calculated for the estimation of the potential and broken down by annual potential. The results were then placed in the context of the German energy market and tested for validity in a sensitivity analysis.

The results clearly indicate a distortion of the actual potential due to the generally valid assessment of the EEG phase-out points as a valid repowering time. The comparison of Figure 2 presented at the beginning of the paper and the following Figure 46, based on the results of the analysis, illustrates the extent of the shift. The graph shows the accumulated share of turbines after their repowering date in the total number of turbines considered with EEG expiration date up to 2025 in Lower Saxony and NRW. The illustration clearly shows the significantly higher number of repowering projects in 2019. the data set under consideration includes turbines with eeg expiration dates up to and including the year 2025, which may lead to the extremely early dates, among other things. The early phase-out data are accompanied by a rather homogeneous picture of the turbine capacities and are mostly limited to turbines of about 2000 kW with a few higher outliers. The relatively old turbines have to be replaced accordingly early, as the current market is probably profitable enough to compensate for the higher subsidies of the old turbines.

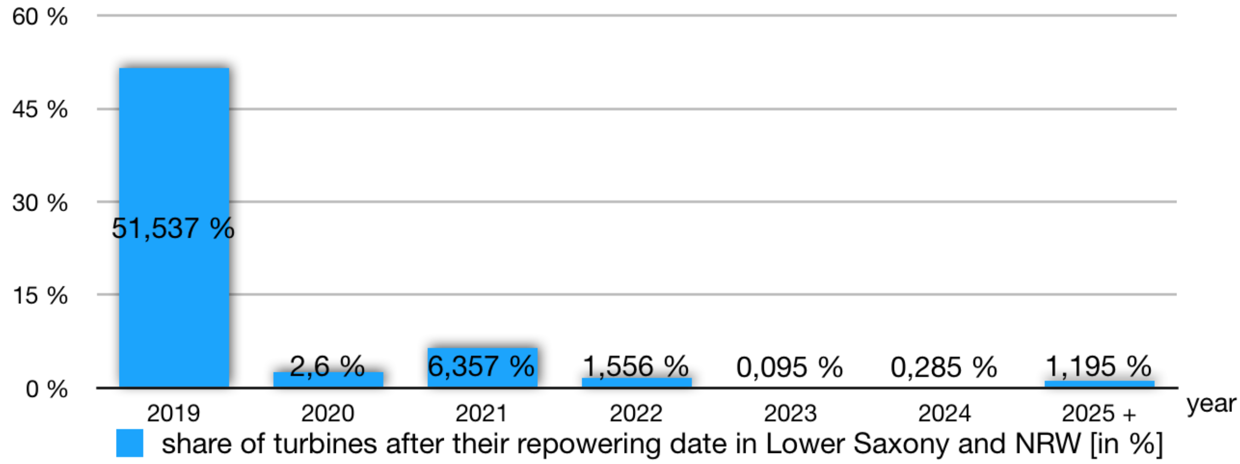

Figure 46 share of turbines after their repowering date in Lower Saxony and NRW, source: own illustration

In accordance with the prevailing opinion of current studies, the present study has revealed a surface potential in Germany of around 11%. In comparison with corresponding studies, this surface potential is regarded as sufficient to bring the share of renewable energies through wind energy to 100 percent of gross electricity generation in the long term (see [UBA (2013)]). The results of the study suggest that the greater limitation of the potentials is based on the currently valid tender volume. The potential theoretically possible in 2019, taking into account the necessary dismantling of the plants to be repowered, clearly exceeds the tender volume and possible repowering projects would have to be divided over the following three years. The resulting potential over the following three years by repowering the plants under consideration with EEG phase-out until 2025 amounts to a capacity of about 9.5 GW. Nonetheless, a comparison of the comparative results with the Hanover region has shown that the potential areas have to be estimated lower due to regional planning and existing hard and soft criteria of restrictions. The calculated potential could therefore be lower in reality according to the circumstances explained in more detail in the limitations in subsection 6.1. Nevertheless, the calculation provides a well-founded indication of the repowering potential and the premature postponement of the implementation of repowering projects for old plants. Furthermore, the results of the present study and its evaluation have led to certain meaningful recommendations for future research. Therefore, if possible, the increasingly detailed priority areas should be taken into account in the future. An incentive was created to also include spatial cost drivers in the techno-economic analysis for the evaluation of onshore projects and a corresponding approach was presented. The results have also indicated that the greatest influence on the repowering timing comes from the remuneration of the repowering project and also the initial project. Accordingly, future research should deal with an exact and realistic modelling of auction and market prices.