

Article

Current State and Future Prospective of Repowering Wind Turbines: An Economic Analysis

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Abstract: For over two decades, the construction of wind turbines in Germany has been supported by guaranteed feed-in tariffs determined by the Renewable Energy Sources Act (EEG), the primary goal of which is climate protection, in addition to reducing the country's dependence on the import of (finitely available) fossil fuels. After China and the United States, Germany ranks third worldwide in the production of wind energy. The number of onshore wind turbines in Germany has risen to approximately 30,000 plants, of which approximately 10,000 wind turbines will fall out of the guaranteed EEG funding window in the next one to two years. There are basically two alternatives for these wind turbines: either continuing operations, with the sale of electricity at relatively low and fluctuating electricity stock prices, or repowering, which opens access to the fixed feed-in tariffs for another 20 years. However, repowering has the disadvantages that an approval process must be carried out and the investor must participate in a tender. There is no guarantee for the granting of a building permit; economically feasible operations also depend on the fact that one can win a contract without the submitted price being set too low. This area of tension is illustrated by a wind farm in Mecklenburg-Western Pomerania and analysed economically. The investment in new, more efficient, and larger wind turbines currently promises a high return. The profitability of the investment in wind turbines is determined using the net present value (NPV) method. In addition, a risk analysis is carried out using stochastic simulation. As a result, the feed-in tariff contributes to over 95% of the variance in the net present value (NPV).

Keywords: wind energy; repowering; net present value; risk analysis

1. Introduction

Climate change and the associated energy turnaround towards renewable energies (RE) are currently hotly debated topics. Governments, parliaments, and the population worldwide have been pushing for measures to be implemented, in order to limit global warming—as per the agreement reached in Paris in December 2015—to well below 2 degrees below pre-industrial values [1]. For this purpose, energy production from fossil sources should be reduced and replaced by renewable energies (RE). In Germany, electricity from renewable energies is set to increase to 80% by 2050 [2] where the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz—EEG) has been promoting energy generation primarily from wind, sun, and biomass for over two decades. In 2018, wind energy was the leading RE, with a 17.1% share in total electricity production [3]. This article examines the economic viability of investments; in particular, the repowering of older wind turbines. First, the development of the wind industry is discussed.

The wind industry has experienced a rapid increase in development worldwide. In 2018, 591,549 MW were already installed (Figure 1). Of the worldwide installed onshore wind power, China has the highest share (36%), followed by the USA (17%), and then Germany, with a worldwide share of 9%

(Figure 2). Within Europe, the highest amounts of wind power were generated in Germany (111.6 TWh), the United Kingdom (55.8 TWh), Spain (50.8 TWh), and France (27.9 TWh) in 2018 (Figure 3). There are approximately 30,000 onshore wind turbines in Germany, of which approximately 10,000 will soon reach the age of 20 years (Figure 4). The latter have significant technical disadvantages (i.e., lower efficiency), as well as economic disadvantages (i.e., expiry of the guaranteed EEG feed-in tariff for electrical power), which are discussed in more detail below.

The German measures to support the investments in RE are briefly described here. The feed-in tariff is a guaranteed price for producers of renewable electricity, which is determined by the Renewable Energy Sources Act (EEG). These electricity revenues, which are in general above the market price, are financed through a levy on the electricity consumer. This EEG surcharge is part of the electricity price and amounts, in 2020, to 6.756 ct/kWh. The feed-in tariff has demonstrated a tendency to decline, due to economies of scale and technical progress in RE production, in order to avoid overcompensation to producers, while the EEG surcharge has increased due to growing investments in RE.

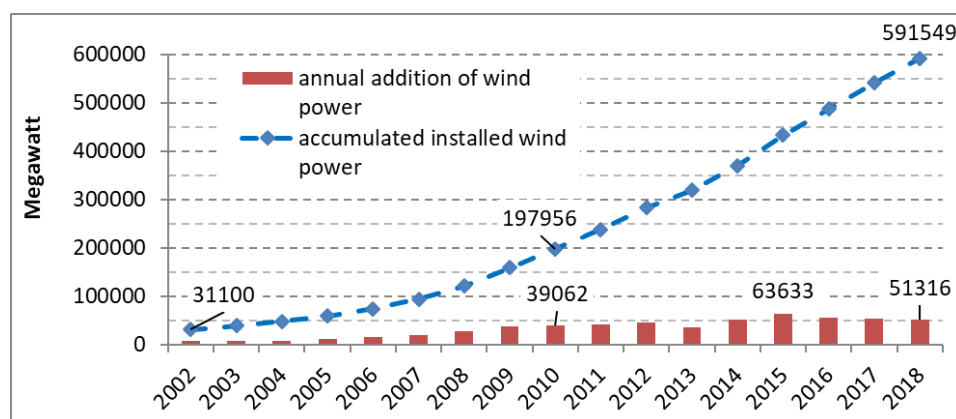


Figure 1. Worldwide cumulative installed wind energy output and annual output increase (in megawatts) from 2002–2018 [4], own illustration.

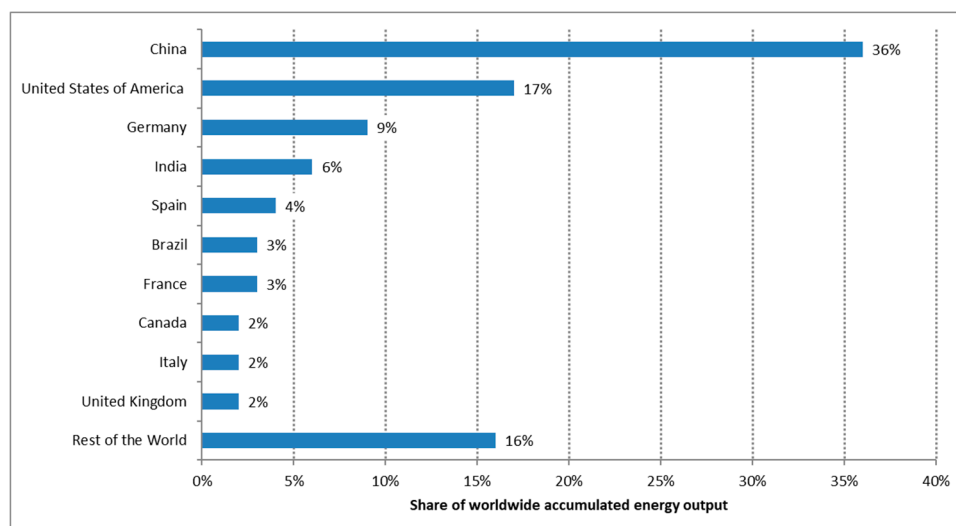


Figure 2. Most important countries by share of the worldwide installed onshore wind energy output (cumulative) in 2018 [4].

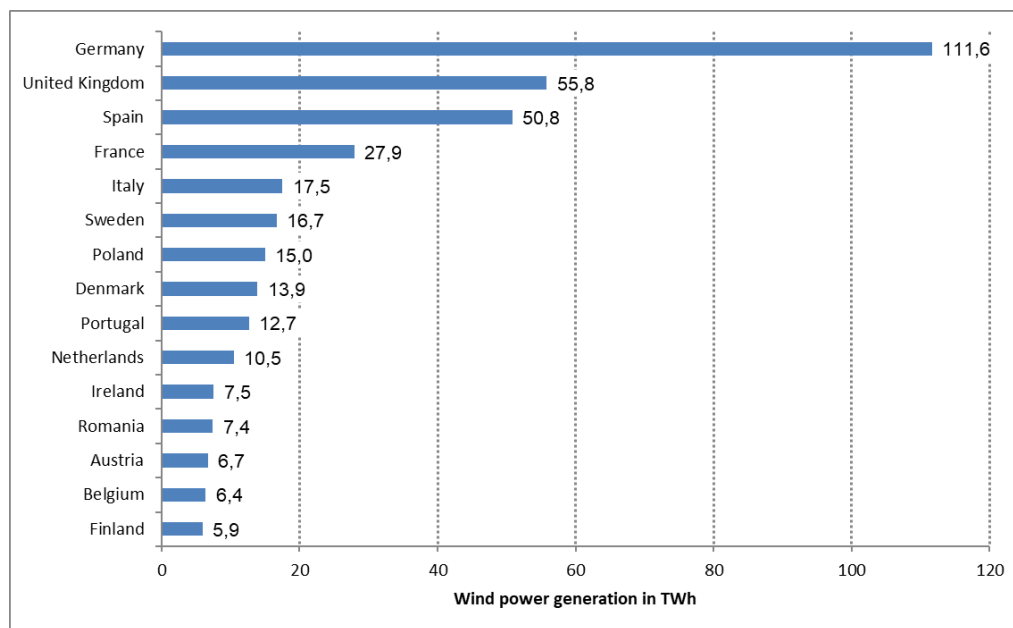


Figure 3. Most important countries in Europe, according to the amount of electricity generated from wind energy in 2018 (in terawatt hours) [5].

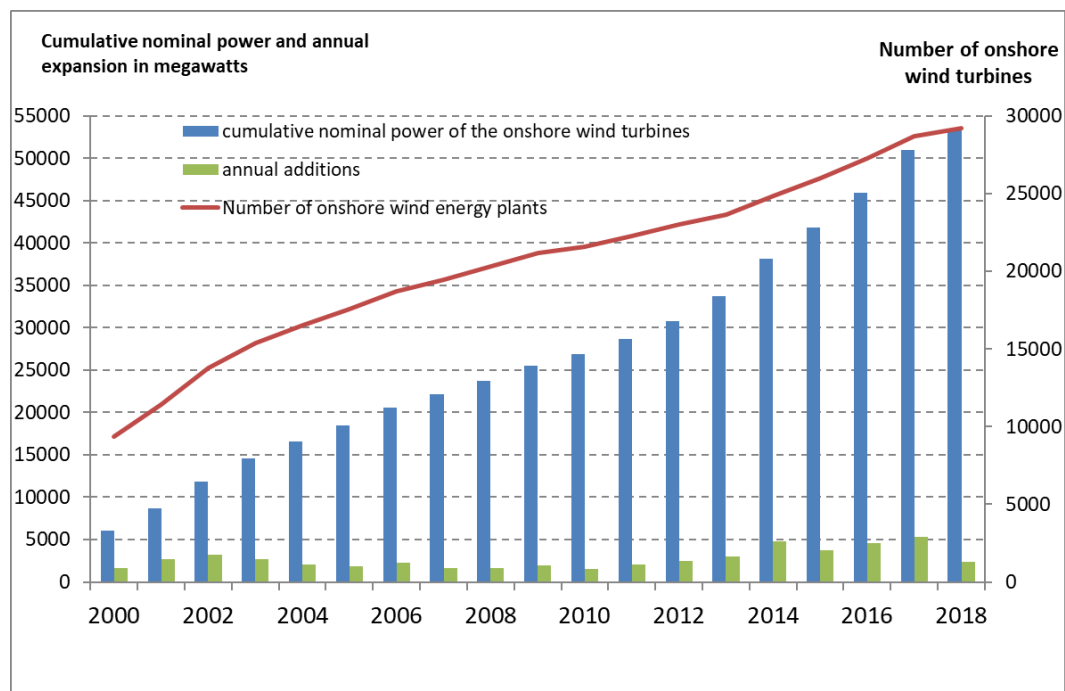


Figure 4. Number of onshore wind turbines, the cumulative nominal power, and annual additions of wind turbines in Germany from 2000 to 2018 [5], own illustration.

All in all, the prominent position that the wind industry has among REs and its importance are clear, particularly in Germany. Although the expansion of the wind turbines is currently stalling [6], wind energy is expected to continue to be a pillar of the energy transition in the future, both by designating new wind suitability areas and by replacing smaller, outdated plants with larger and more efficient new plants.

In the following, the beginning situation and the cost structure for the repowering of wind turbines (WKA) are shown using a wind farm in Mecklenburg-Western Pomerania, which went into

operation in 2001 and 2002. Their decision about replacement essentially depends on the outcome of the approval process, which is briefly described. The expected future profits (net present value, NPV) are determined, to a certain extent, by future events. The associated risks form the conclusion of their considerations.

2. Description of the Wind Farm Example and the Technical Innovations of Repowering

The wind turbines to be replaced are type V80 wind turbines from the Danish company Vestas Wind Systems. Based on recent reports, the wind farm operators at the location in Mecklenburg-Western Pomerania considered in this paper want to switch to new, larger, and more efficient wind turbines of types N133 and N149 from Nordex (Table 1). The use of two different types of turbine is necessary, in order to meet the different requirements for the optimal design of the wind farm area, with regards to height, distance, and performance. Thanks to more efficient turbines and the better usable volume at higher altitudes, the new wind turbines not only produce more power (and, thus, electricity), but are also—thanks to the low number of revolutions per minute—significantly less noisy and produce energy more consistently, contributing to grid compatibility. Another associated positive effect is the increase in full load hours [7]. To determine the average wind speed at scar height, data from wind reports and from the German Weather Service (Deutscher Wetterdienst, DWD [8]) were used. The Formula (1) of the Weibull distribution, modified according to Konstantin (2013), was used to calculate the wind speed distribution:

$$f(w) = 8760 * \pi/2 * w/w_m^2 * e^{-\pi/4 * (w/w_m)^2}; \text{ in h/a} \quad (1)$$

with w = wind speed in the time interval, w_m = annual wind speed on the scar.

For V80, with 2 MW, the wind speed w_m is assumed to be 6.2 m/s at 80 m hub height and 7.3 m/s for N133 at 125 m hub height. The distribution of the wind speed over a year has a maximum at 911 h for the N133 system; however, the old system, V80, has a maximum of 1074 h a year. The new system can use a wide range of wind speeds and convert it into power (Figure 5). This results in an overall higher gross annual energy yield, which differs significantly from the V80, due to the higher nominal output. Compared to the old system, the new N133, according to the model calculation, brings an increase of approximately 92 h/a [9]. By reducing the number of wind turbines and increasing their performance, the landscape is rectified, which can contribute to acceptance among the population. Furthermore, a new adjustment of the plants to the changed settlement structure can be made.

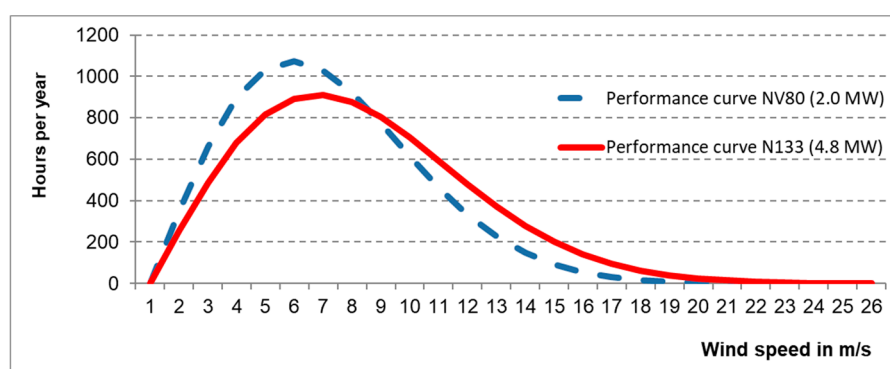


Figure 5. Performance curve as a Weibull distribution (according to [10]) of the old wind turbine (V80) and the new system (N133). Source: Own illustration.

Table 1. Technical data of the old wind turbine (commissioned in 2001) and the new wind turbines.

Key Figure	Unit	Old Wind Turbine	New Wind Turbines	
Type/kW	-	V80/2000	N149/4500	N133/4800
Manufacturer	-	Vestas	Nordex	
Installation	Jahr	2001	New	
Tower height	m	78	105/125/164	78/83/110
Performance Characteristics				
Rated capacity	kW	2000	4500	4800
Power regulation	-	Pitch	Pitch	Pitch
Switch-on speed	m/s	3.5	3	3
Nominal wind speed	m/s	14.5	11.5	
Shutdown speed	m/s	25	20	20
Power density	m ² /kW	2.52	3.9	2.9
Rotor				
Rotor diameter	m	80	149.1	133.2
Number of blades	-	3	3	3
Swept area	m ²	5027	17,460	13,935
Variable speed	U/min	9–19	6.4–12.3	6.9–13.9
Transmission				
Type	-	spur/planetary	planetary	planetary-spur gear
Generator				
Type	-	Asynchronous	Double Fed induction	Double Fed Asyn
Nominal voltage	V	690	660	690
Maximal generator speed	U/min	1909	1420	

Source: [10–15].

Repowering requires a new approval process. The technical part of the necessary planning documents includes a soil survey, the course of the cable routes, and proof of ownership and lease relationships in the building land. For this purpose, a description of the location (geographical location and land maps) is required, which contains information on crane access, crane parking spaces, construction documents for the wind turbines, and a map of the areas indicating the associated distance requirements [16]. The second component of the approval process is an environmental impact assessment, according to the Federal Immission Control Act (Bundesimmissionsschutzgesetz (BImSchG)) [17]. A large number of documents relating to the environment and emissions law must be obtained; in particular, relating to occupational safety, air traffic control, a wind report, turbulence, ice shedding, sound emissions, the construction materials used, waste treatment, visualization, plant safety, lightning and fire protection, and a landscape management plan, as well as (where applicable) the archaeological peculiarities, the termination of operations, species protection, the settlement structure, Flora–Fauna–Habitat Directive (FFH) compatibility, monument protection, classification of flora and fauna, biotope structure, soil management, natural characterization, water management, and soil sealing [16].

A study by the specialist wind energy agency on land in 2015 determined the duration and costs of the planning and approval process, specifically for all federal states in Germany. The studies for Mecklenburg–Western Pomerania showed average costs for planning and approval of €69 per kilowatt (kW) and an average duration of 78 months (6.5 years) until approval [18]. Project development, thus, corresponds to about 5% of the total investment costs. Initially, this poses a high investment risk for the operator; after all, the costs incurred from the planning and approval phases cannot be generated later by the project if approval is denied [7].

Although regional development programs have called for the further designation of wind suitability and priority areas [19], the expansion of wind energy in recent years has been locked in the approval process, due to stricter conditions and an annually restricted tender volume for the secure remuneration of fed electricity, making the process more difficult. If repowering is not approved, the old wind turbines can continue to operate. The old plants are able to continue to achieve good energy yields, especially in the wind conditions on the coast [7]. The balance between the continued use of old wind turbines and investment in new wind turbines should, therefore, also be considered here.

Since the amendment of the EEG in January 2017, the remuneration amount for fed-in electricity is no longer fixed by law; instead, investors must participate in a tendering procedure. The surcharge volume is limited, as is the remuneration rate. According to the Federal Network Agency, a total volume of 3675 MW in Germany was divided into six auction dates in 2019. Throughout 2019, 269 bids with a bid volume of 2111.25 MW were submitted, for which 236 bids were awarded. This corresponds to an additional quantity of 1846.71 MW. Therefore, the upper limit was not reached (Figure 6) and the remuneration for electricity could be granted at the highest permissible level (Figure 7). The permissible maximum bid for the remuneration of electricity for new wind turbines is currently 6.2 ct/kWh. The average quantity-weighted surcharge over the six cut-off dates was 6.1583 ct/kWh. The range of variation was 5.24–6.2 ct/kWh [20]. Under these conditions, the obstacle to investing in wind turbines at suitable locations is not the electricity revenues, but the lack of building permits. The current (i.e., as long as the investment backlog for wind turbines persists) relatively high remuneration rates for new wind turbines and repowering can, thus, be assumed.

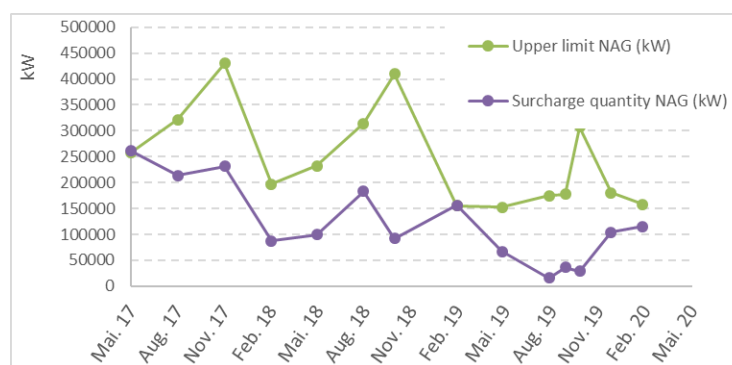


Figure 6. Upper limit and additional amount in the network expansion area in Germany at the bidding dates according to the Renewable Energy Sources Act (EEG) 2017 (in kW) [20], own presentation.

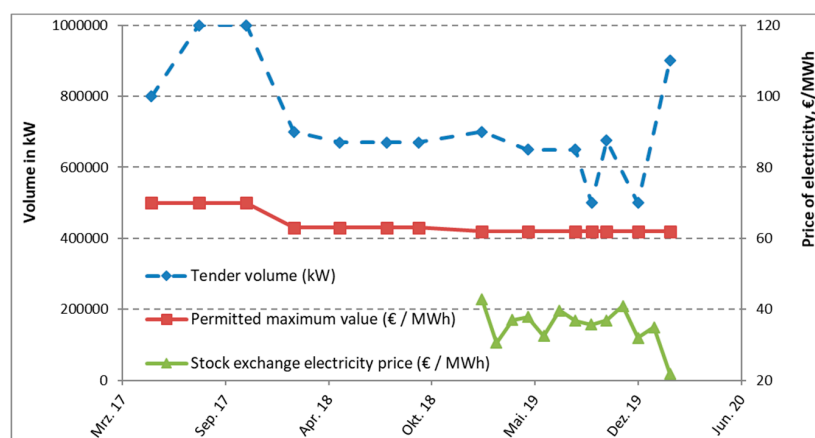


Figure 7. Tender volume (in kW, left Y-axis) and permissible maximum values for remuneration (in €/MWh, right y-axis) in Germany at the auction dates, according to the EEG 2017; as well as exchange price on the European Power Exchange (EPEX) spot market for Germany/Luxembourg from February 2019 to February 2020 [20], own illustration.

For more and more old wind turbines, which were built during the building boom in the early 2000s, the period of 20 years with secured remuneration will expire in the near future. This usually means lower remuneration rates for the electricity produced; for example, on the EPEX spot market for Germany/Luxembourg in the period from February 2019 to February 2020, an exchange electricity price between “only” 21.92–42.82 €/MWh could be achieved (Figure 7). If a wind turbine falls out of the EEG subsidy, its profitability drops considerably, due to the lower remuneration, and this situation confronts the operator with the decision to “continue operation” or “repowering”. Both scenarios are examined, in more detail, in the following chapter.

3. Investment Analysis

3.1. Static Analysis: Continued Operation or Investment at Currently High Remuneration Prices

The starting point for the economic assessment is the average gross annual energy yield of the wind turbines, which is calculated based on the technical key figures of the wind turbines (Table 1) and the Weibull distribution (Figure 5). The old plant, V80, has an annual energy yield of 4329 MWh. If flow-related shadowing effects (wake losses) of 11.3% are deducted, the net annual energy yield is 3840 MWh [10]. To minimise the shadowing effects in a wind farm, minimum clearances should be maintained. The rotor diameter is decisive when optimizing the distances [7,21]. The new 4.5 MW plants (4.8 MW plants) have an annual gross energy yield of 15,751 MWh (16,478 MWh) and net (i.e., minus wake losses of 11.3%) yield of 13,971 MWh (14,616 MWh). The new wind turbines, thus, yield as much output as three to four of the old wind turbines.

In the case of new wind turbines, an investment requirement including transport and construction of €1000 per kW is assumed (Table 2). In addition, the costs of the approval process must be considered, with an additional share of 10.38% of the technical investment costs, made up of acquisition costs for site rights (5.64%) and project development (5.19%) (Table 2). The investment costs of the new wind turbines, including their connection to the high-voltage network, thus, amount to around six million euro.

Table 2. Exemplary representation of the investment costs for the new wind turbines with connection to the high-voltage grid.

Key Figure	Cost Range in €/kW			Average Specific Costs in €/kW	in %	Costs in 000 € *	
Size/type						4.5 MW	4.8 MW
Acquisition costs of site rights	50	–	100	75	5.64	337.5	360
Project development	20	–	50	69	5.19	310.5	331.2
Wind turbine including transport and construction	900	–	1100	1000	75.24	4500	4800
Technical infrastructure							
Foundations	40	–	60	50	3.76	225	240
Paths and parking space	10	–	20	15	1.13	67.5	72
Internal wiring	10	–	20	15	1.13	67.5	72
Grid connection	40	–	60	50	3.76	225	240
Total technical infrastructure	100	–	160	130	9.78	585	624
Other costs							
Construction management	5	–	10	7.5	0.56	33.75	36
Compensatory measures	15	–	30	22.5	1.69	101.25	108
Reserve	20	–	30	25	1.88	112.5	120
Total other costs	40	–	70	55	4.14	247.5	264
Technical investment costs	1110	–	1480	1329	100%		
Total investment costs						5980.5	6379.2

* Source: [16], own illustration.

In addition, depending on the size of the wind turbine, there are annual operating costs of €160,000–170,000 (Table 3). On average, this corresponds to 3.55% of the ex-factory price. By using the existing infrastructure (e.g., access roads and power lines), repowering is cheaper than a completely new investment [22]. Although the wind turbines considered in the case example are located on the operator's own land, usual opportunity costs of 7% of the electricity revenue can also be expected here, as the location could alternatively be leased (Table 3).

Table 3. Annual operating costs of the old wind turbine and the alternative new wind turbines.

Key Figure	Percentage of the Ex-Factory Price *			Mean (%)	Proportional Costs (in €) for a 2.0 MW Operation	Proportional Costs (in €) for a 4.5 MW Operation	Proportional Costs (in €) for a 4.8 MW Operation
Maintenance contract	0.7	–	0.9	0.80	16,000	36,000	38,400
Repair reserves	0.5	–	1.0	0.75	15,000	33,750	36,000
Insurance	0.5	–	0.6	0.55	11,000	24,750	26,400
Technical supervision and management	0.5	–	0.6	0.55	11,000	24,750	26,400
Other (including electricity, maintenance)	0.8	–	1.0	0.9	18,000	40,500	43,200
Total annual operating costs	3	–	4.2	3.6	71,000 **	159,750	170,400
Opportunity costs for the lease of the location	Share of lease of electricity revenue				Annual lease (€ per location)		
	4%	–	10%	7%	10,752	48,899	51,154
Total					81,752	208,649	221,554

* The specified fluctuation ranges are used in the stochastic simulation (Section 3.2). ** Is changed by a factor of 1 to 3 in the risk analysis. Source: [16], own illustration.

With the old wind turbines, due to the high number of operating hours already reached, greater repair expenditure can occur, which can result in more frequent maintenance work and higher maintenance costs. This is taken into account in the next chapter (risk analysis), in which maintenance costs in multiple amounts (up to a factor of 3) are expected.

The net present value (NPV) method is used to estimate the profitability of repowering. For this purpose, all revenues and withdrawals were discounted and added up [23]:

$$NPV = \sum_{t=1}^n \frac{R_t}{(1+i)^t}, \quad (2)$$

with R_t = Net cash inflow-outflows during a single period t , i = Discount rate or return that could be earned in alternative investments, and n = Number of time periods.

The interest rate (i) is currently 0.4% [24]. The acquisition costs of the 4.8 MW plant are reduced from €6,379,200 to €6,159,200 by the estimated liquidation proceeds of the old plant (€220,000). The dismantling costs for the new plants after 20 years (n) are estimated, on average, at €300,000 [25]. Tax aspects and ways of financing the project are not considered further here.

The remuneration rate for the new system was only calculated based on the new legal requirements regarding the maximum values for remuneration rates. The results of the five tenders from 2019 were used for this purpose. The Federal Network Agency (BNetz-A), subsequently, broke down the bids, which resulted in an average volume-weighted bid value of 6.1583 ct/kWh [20]. The net present value (NPV) is, then, €6.2 million (new 4.5 MW plant) or €7.5 million (new 4.8 MW plant). This gives an economic advantage under the above-described average conditions; in particular, the relatively high remuneration for electricity of 61.583 €/MWh. The internal interest rate is 9.08% for the 4.5 MW system and 10.02% for the 4.8 MW system; therefore, the pay-off period is 9 to 10 years.

With the old system (V80 with 2 MW), with a net annual energy yield of 3,840 MWh, and at the current electricity price (October 2019) of 37 €/MWh [26], annual revenues of €142 thousand can be expected. The advantages and recommendations for continued operation depend heavily on the operating costs. With a remaining useful life of 10 years and operating costs of approximately €71,000 per year (p.a.), as well as the lease rate of approximately €10,000 per year, a net present value (discounted gross margin) of €587 thousand can only be expected. If the operating costs were twice as high (factor 2), this net present value (NPV) is already negative.

Comparing the two alternatives—(a) continued operation of the old wind turbines and (b) repowering—one can draw the interim conclusion that the profitability of the old wind turbines (with NVP €587 thousand) is much lower than replacement with new wind turbines (with NVP from approximately €6–7 million). Compared to repowering, the continued operation of the old wind turbines is not competitive. Under certain circumstances, this means that, in the case where the old wind turbines generate negative gross margins, they should be shut down immediately after the end of the operation period with fixed feed-in tariffs. If the gross margins of the old wind turbines are positive, then they should continue to be operated until a building permit(s) for the new wind turbine(s) has been obtained.

If more new wind turbines are approved again, it can be assumed that the guaranteed feed-in tariff for these new wind turbines would decrease in the long run, due to increasing completion in the tender. This has a significant impact on profitability, as the net present value (NPV) to be achieved also decreases. To what extent this could be the case is shown in the following risk analysis.

3.2. Results of the Risk Analysis: Future Development

As already stated, investments are currently (i.e., at the beginning of 2020), in terms of return expectations under average conditions, quite cheap, as the building permits are lacking. When investing in a wind turbine or in your own wind farm, essential parameters are contractually and thus firmly agreed upon for the entire term. In the future, however, the conditions assumed for the static analysis may change and, thus, involve risk. A risk analysis using stochastic simulation was carried out with 10,000 repetitions. In the following risk analysis, the fluctuation ranges for the risk parameters of the annual operating costs were assumed as in Table 3 and taken into account as triangular distributions. In addition, the dismantling costs of a new (4.5 MW or 4.8 MW) plant after 20 years are assumed to be between €100,000 and €500,000, with a median of €300,000 [25]. The variability of other influencing factors particularly affect the old systems. Here, a remaining useful life of between 5 and 10 years and operating costs multiplied by a factor of 1 to 3 are assumed. In addition, it is assumed that the wind turbines are insured against natural hazards, such that insurance would take over in the event of a total loss (e.g., fire). The usage costs for the location of a wind turbine are estimated with a possible range of 4%–10% of the electricity revenue (Table 4).

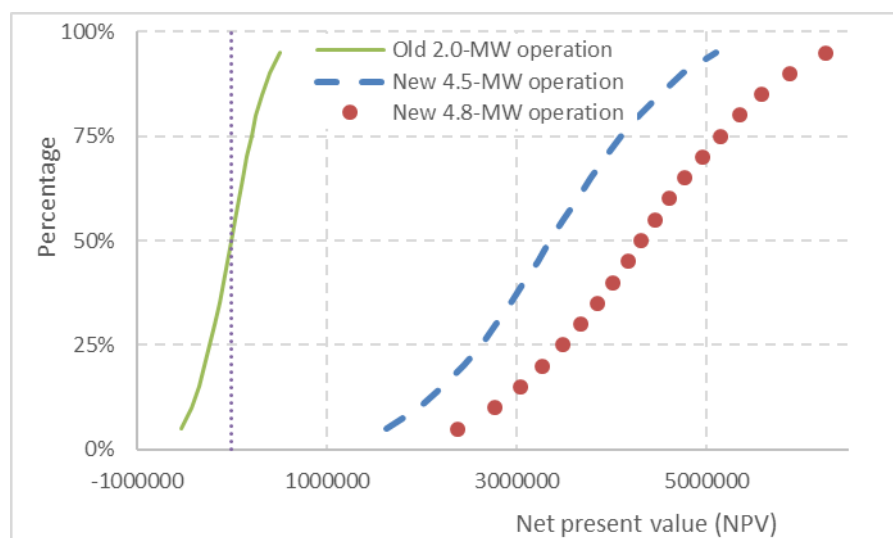
For this study, leasing of the repowered wind turbines was not an option for the owners of the old wind park, due to their sufficient access to capital for the new investment. In other cases, leasing may be considered as an option. If the latter is the case, how to deal with the question has already been discussed by the authors in another paper, also published in *Energies* [27] and the further literature listed there). The background to the analysis there was the question why very few landowners, especially farmers, lease their wind turbine sites and do not invest themselves. One of the reasons for this is that farmers have other opportunities or needs; for example, they can also invest their capital in buying land, such that there is usually not enough capital for both investment in wind turbines and land purchase. In addition to a lack of capital, personal risk attitudes also play a role. Risk-averse actors will not anticipate the high fees for planning if the outcome is uncertain. High lease payments also provide motivation to leave the construction of wind turbines to external investors. As part of the study, the authors [27] came to the conclusion that, if the investor is optimistic about wind energy, the existing (equity) capital, and the prospect of approval, leasing is not an option, but the farmer or landowners should invest themselves. These above-mentioned conditions also apply to the wind farm considered here, such that leasing to external investors was also out of the question, even from a risk perspective.

Table 4. Net present value (NPV) for three wind turbines with variable remuneration, operating costs, dismantling costs, and leasing rate; stochastic simulation with 10,000 repetitions.

Key Figure	Old Operation (2.0 MW)	New 4.5 MW Operation	New 4.8 MW Operation
Input: Risk Parameters (Triangular Distribution with Minimum—Median—Maximum Value)			
Feed-in tariffs	20—35—60 €/MWh	40—50—60 €/MWh	
Operating costs *	Factor 1—2—3	3%—3.6%—4.2% from factory price	
Remaining service life	5—7.5—10 years	20 years (fix)	
Dismantling costs	-	100 T€—300 T€—500 T€	
Lease rate	4%—7%—10% of yearly electricity revenues		
Result: Net Present Value (NPV)			
Minimum (5%-Limit)	−533,372 €	1,634,061 €	2,374,956 €
Average	−10,305 €	3,360,819 €	4,314,152 €
Maximum (95%-Limit)	505,066 €	5,103,302 €	6,247,754 €

* See Table 3 for fluctuations in operating costs; stochastic simulation with 10,000 repetitions with @RISK. Source: own calculations.

The analysis shows that the new wind turbines achieve a positive net present value (NPV) in all scenarios under the given general conditions and flow losses. Even under unfavourable conditions (i.e., high costs and low remuneration), minimum net present values (NPVs) of approximately €1.6 million and €2.3 million are achieved with the 4.5 MW and 4.8 MW wind turbines, respectively. On average, the net present value (NPV) is €3.3 million (4.5 MW) or €4.3 million (4.8 MW). This makes the new wind turbines comparatively lucrative. Meanwhile, the old wind turbines can still be operated economically. With low repair costs and high remuneration, positive gross margins are possible, which was achieved in approx. 50% of the simulations (Figure 8).

**Figure 8.** Distribution of the net present value (NPV) for three wind turbines with variable remuneration, operating costs, dismantling costs, and lease rate; stochastic simulation with 10,000 repetitions with @RISK; (Range 5%–95%). Source: own calculations.

A stochastic dominance can be determined for all three systems under consideration (Figure 8). It follows that, if a building permit were granted, the old wind turbines should be replaced for economic reasons.

The main influencing factor for profitability is the feed-in tariff. This becomes clear in the tornado analysis (Figure 9). The feed-in tariff contributes over 95% to the variance of the net present value

(NPV). Fluctuations in the annual operating costs, as well as in the dismantling costs, have only a minor influence on the end result.

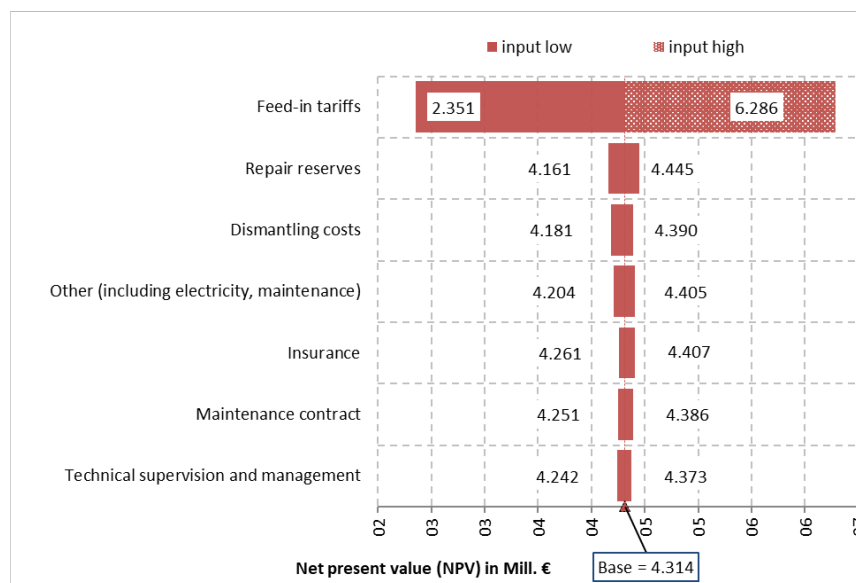


Figure 9. Tornado diagram with the relevance of the most important factors influencing the net present value (NPV) of a 4.8 MW wind turbine plant; stochastic simulation with 10,000 repetitions with @RISK. Source: own calculations.

The results of the stochastic simulation can also be analysed in terms of which bid value an investor should not fall below, if a minimum value for the net present value (NPV) is to be achieved (Figure 10). The recommendation is that old wind turbines (older than 20 years) should continue to be operated as long as there is no building permit for the repowering and as long as they still generate positive gross margins (i.e., if the repair costs do not increase sharply). Otherwise, repowering the existing system is the more advantageous alternative.

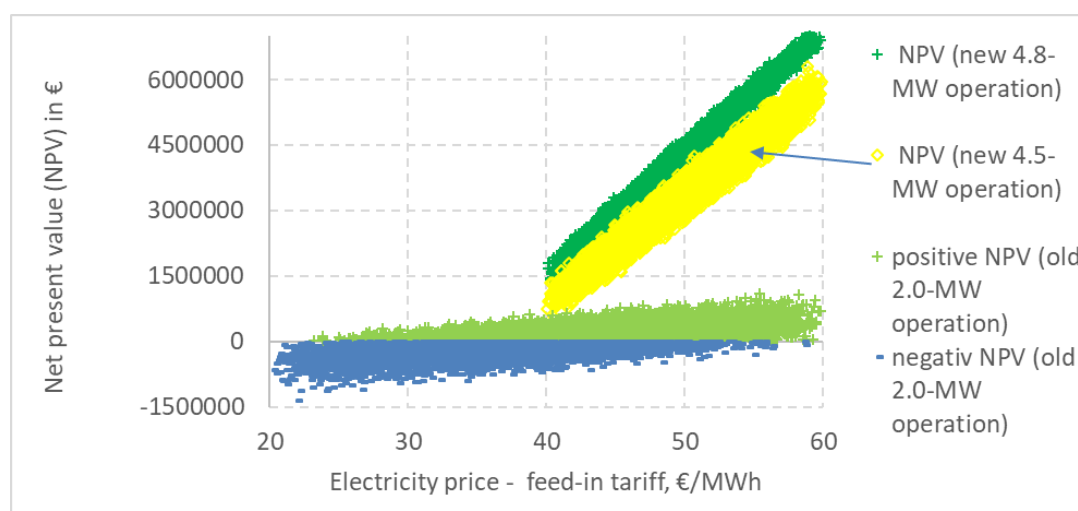


Figure 10. Net present value (NPV), depending on the feed-in tariff and other influencing parameters (see Table 4); stochastic simulation with 10,000 repetitions with @RISK. Source: own calculations.

4. Conclusions

Worldwide, wind farms play a major role in the energy transition away from fossil fuels and towards renewable energies. Germany ranks third, worldwide, in terms of cumulative electrical output

from wind farms. This high level of around 30,000 wind turbines has been achieved primarily through a subsidy with high feed-in tariffs, which are stable for each plant over a period of 20 years. Of the approximately 30,000 onshore wind turbines in Germany, approximately 10,000 of them will fall out of the window of guaranteed high feed-in tariffs in the next one to two years.

There are basically two alternatives for these wind turbines: either continued operations with the sale of electricity at relatively low and fluctuating electricity stock prices, or repowering. Repowering, in turn, opens access to the fixed EEG feed-in tariffs for another 20 years. However, repowering has the disadvantage that a new approval process must be carried out and that the investor has to participate in a tender. There is no guarantee that a building permit will be granted and an economic operation also depends on the fact that one can win a contract without the submitted price being set too low.

The illustrated example is a wind farm in Mecklenburg-Western Pomerania, which was analysed economically. An investment into new, more efficient, and larger wind turbines currently promises a high return. The profitability of the investment in the wind turbines was determined using the net present value (NPV) method. In addition, a risk analysis was carried out by using stochastic simulation. At the beginning of the 2020s, the further expansion of wind energy in Germany stalled, due to a lack of building permits. Therefore, the guaranteed feed-in tariff—62 €/MWh of electricity—is relatively high. From this point of view, the continued operation of the old wind turbines would only be necessary if no planning permission was granted for the new wind turbines and as long as positive gross margins can be achieved. The risk of negative gross margins, even for old wind turbines with no further depreciation, could exist if high maintenance and repair costs occur along with low electricity revenues. The economic viability of repowering depends, to a large extent, on the feed-in tariff; although the investment would still be profitable even if the minimum price was assumed to be 40 €/MWh.

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