DECOM TOOLS 2022

BUSINESS MODEL REPOWERING

Interreg
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Decom Tools
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project Partners

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1 Introduction

Wind energy has made an enormous progress in development. MW's per windmill have increased considerably over the past years.
Technical innovations have grown accordantly.
As on land the wind parks offshore are reaching the end of their operational live, being meant for a restricted amount of years the licenses are running near to the end.

At the end of the life span of wind turbines, 20-25 years offshore, the stakeholders are consulted and must make a choice: either the project is permanently dismantled, or it is possible to work on repowering, or the wind farm can continue to be operated, but this can lead to rising costs and a reduction in benefits.
Although the life span is a calculated effort the real end of life experience can be much longer due to less deterioration of the material or components.
Studies have shown that full repowering will be attractive after 20 years of operation, while before this time the benefits of repowering are insignificant.

The timeframe required for a repowering project is shorter than the installation of a new park, especially thanks to the permit already licensed on basis of the existing windfarm.
Choices must be made how to go on as the use of renewable sources like wind and sun gain in importance and will be key important in the near future.

At the same time the space for wind parks on land is limited and problems occur due to noise, wing shadow disturbance in the vicinity of urban settlements
Therefore options to at one hand limit the disturbance and at the other hand being able to use the energy to the full have to be discussed. The North Sea countries are putting more effort in using the sea as part of their ongoing strategy to increase durable energy. Making use of existing and new wind parks in the North Sea means also increasing the capacity of the wind parks already operational.

Due to the increasing demand for renewable energy, the installed capacity needs to be enhanced. In line with these prospects, governments and companies need to make decisions how to enlarge the output to meet demands. Although new parks still are being developed, we have to look at the existing stock also.

A large number of offshore wind parks will have to make critical end-of-life decisions the coming years. Two end of life strategies have to be considered.
These are:

- Lifetime extension
- Repowering

Lifetime extension means an overhaul, which affects not only the power generation but also the capital and operational expenditures of an overhauled wind turbine.
A determination is needed of the most sensitive factors that affect the economic results.
These factors have effect on the economic viability and their most critical variables, namely the energy tariff, capacity factor, and capital and operational expenditures.
Lifetime extension can be a low-risk alternative for the short run because of its highly stable effects, even though it has less number of positive economic indexes in the long run.

Repowering as we know it is the complete renewal of the wind park with bigger, stronger high capacity wind mills.
Repowering gives improved feasibility in terms of economic indicators in the long run. For the short run it can give undesirable results for the critical variables.

In this research we will address the possibilities of full repowering.

2 Impact of the overall repowering of existing wind turbines

2-1 Introduction

Originally wind-farm developers planned decommissioning at the planned end of a wind-farm's lifecycle. However, the availability of more efficient turbines means that trend is changing. Repowering is now an important option for some aging wind farms, but it is a process and there are many policy decisions, permits availability, and cost factors to consider first.

Essentially, repowering updates an aging wind park. This means replacing several wind-turbine components and turbines, or the full fleet of turbines and towers at a site. Additionally, repowering modernizes interconnection of the infrastructure, or add more turbines to the park. The aim is a wind farm with a greater and more efficient generating capacity than before.

Factors that influence the impact of an overall repowering of existing wind mills are:

- Changes in laws and regulations.
- New wind turbine technology
- Contract structure of real property agreements
- Environmental and permitting considerations
- Integration of hybrid technologies

2-2 Changes in laws and regulations.

Built in a period that experiments were the leading projects in offshore wind we come to the acknowledgement that it has grown up to become an industry. The wind parks have had a bigger impact on the availability of space in the North Sea. The crowding of the North Sea due to development of new parks has had its influence on the traditional users such as fishing. Also the use of ship lanes across the sea in comparison to highways have got in the way of free available space. Limitation of areas to build have to be tackled in regulations to prevent accidents occurring. European safety and environmental laws should be considered.

Borders are no longer preventing or limiting full size wind parks to be developed. We see projects emerging overlapping the territory of the different countries. International consortia are building and maintaining the wind parks. The way this will be executed must be supervised and that can only be with a European watch organization to secure rules to be coherent out through the Nord Sea area

2-3 New wind turbine technology

New wind parks are built with new technology. Materials differ, are more sustainable and can make a large impact on the park as a whole.

Replacing the existing ones with new ones is to simple. The change in size and the growing capacity of the wind mills make it necessary to recalculate the parameters which were leading when building the original park.
New wind calculations must be made to measure the influence between mills in the park when placed. This can lead to another way of positioning. Even the placement of less wind mills can be the outcome. Although this is compensated due to the increase of MW's it is an important issue when calculating the benefits of repowering in an existing park.
Lower costs and increased efficiency are providing developers important incentives for monetizing repowered projects.

2-4 Contract structure of property agreements

The owner of a park is not the owner of the ground below. The ground is mostly owned by governments. Sometimes this is forgotten but it can be a very important issue when repowering is at hand.
Contracts are made upon the realization of the existing park. Exploitation licenses are limited in time, mostly 20 to 25 years. The repowering acquires a new agreement, indicating a prolonging of the exploitation time or a whole new lease. This can complicate admission as new rules and regulations have to be administrated and followed. This also makes contracts less certain of acquiring a lease if tenders have to be enforced according to new regulations.

Additionally, redevelopment of the wind farm, which may require a new design of the project and decommissioning of the existing wind turbines, also means new negotiations or agreements.

2-5 Environmental and permitting considerations

Depending upon the location and ownership of the project property, authorities have the right to exercise jurisdiction over the project. For example agencies that oversee and enforce environmental and permitting regulations throughout their continental area.

Turbine size may also affect the permitting regimes. Larger wind turbines, for instance, use more space and may require additional compliance steps and approvals.
It is important to prepare a pre-submittal of the proposed turbine locations prior to (or concurrently with) permitting and environmental review of the project. Similarly, the Defense Department may impose jurisdictional requirements over wind projects so a preliminary discussion is recommended in the initial review of the wind project and turbine locations.

Higher wind mills can impose serious problems for birds. An environmental survey can be part of the permitting procedure. The location can interfere with fishing grounds and noise can be hazardous for sea wildlife.
As full repowering means new piling will be needed, the chance sea life will be effected has to be taken in consideration. Noise and other disturbances can affect the natural habitat and has to be taken in consideration.
An Environmental Impact Report (EIR) is necessary.

2-6 Integration of hybrid technologies

Hybrid renewable projects are now an option for many developers. Pairing wind with hydrogen or battery storage may enhance and improve the economics and reliability of such projects, while providing greater energy generation efficiency.

Although hydrogen or battery storage is still being researched, it can reduce concerns relating to the variability of wind power. Storing energy when winds are strong and providing power to balance the grid when winds are low is to become a key consideration for developers looking to maximize revenues and generation flexibility when repowering wind farms.

2-7 Effects of wind power due to expansion of offshore wind parks

A new phenomenon being examined is the effect the wind parks have on the weather conditions at sea. Especially the strength of the wind is being influenced by the wind parks. Measurement show a downfall of wind power in the vicinity of a park that could influence the total capacity of wind power throughout the region. Further research on the matter is important to get more knowledge of the effects on the environment. Even so this could have an impact on the output of the projected wind parks.

3 Overall business model for the repowering process

3-1 Introduction

For total repowering, the replacement of a wind turbine Haliade-X 14 is chosen. This is a new kind of wind mill and it is taken in consideration because it will be repowered in the future, but is has still a good working life into the near future.
Seen the strong build is likely the construction will be able to carry new turbines when repowering is at hand.

The worldwide average capacity factor has increased considerably in the last thirty years. and it is not unusual for a country to have capacity above 30%. This will still be a reliable factor for the near future although the repowering will be more of a refurbishing and updating of the turbine and other moving parts.
We don’t take in consideration the most available windmills operating in the North Sea at the moment due to the fact that already a lot of research has been done on these wind parks.

The Capex (Capital Expenditure) of turbines has fallen by 50% in the last ten years. Current O&M estimates vary depending on the source, but most references recognize that there has been a substantial decrease due to more mature wind technology and improvements in O&M practices, resulting in improvements in Opex (Operating Expenditure).
When determining the future Decex (Decommissioning Expenditure) for the Haliade X13 we assume that there is no variation in costs in the next twenty years. In the repowering option we take into account the Decex for both the old and new wind farms.

The switch from old to new turbines is done in a staggered manner and according to a properly designed schedule. It can take as little as two months. During that time the turbines are not producing electricity and these costs should be incorporated in the overall business model.

3-2 Business model on repowering

In order to create a suitable business model for repowering offshore wind farms, we used the Business Model Canvas from Osterwalder and Pigneur as a support tool. With the Business Model Canvas, the two authors have created an opportunity to present entire business models in a uniform, simple and understandable way for everyone. The canvas uses nine "building blocks" to show how organizations can make money. These blocks covers the four most important areas of a company: the customers, the supply and infrastructure of the organization as well as the financial activities (Osterwalder, A. & Pigneur Y. (2011), p.19 etseqq).

The following illustration shows the business model canvas with all nine “building blocks” in detail.

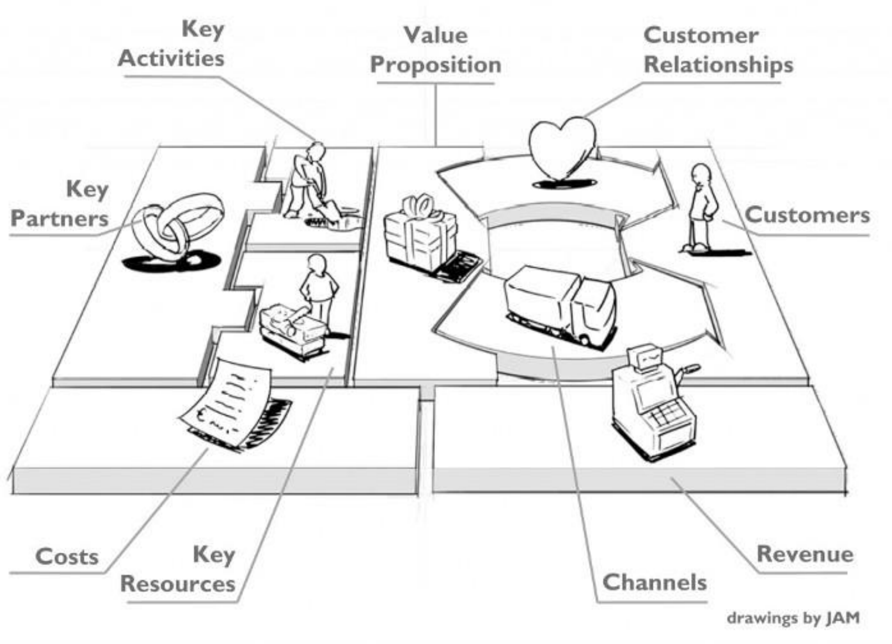

Illustration 1: Business Model Canvas (Sammer, W. Der Business Model Canvas: Dein Geschäftsmodell kompakt (online))

We have made a business model based on these nine "building blocks", which is described in more detail in the following. In addition a cost estimation was put forward.

Value proportions

In the business model canvas the "value proposition" tries to describe the customer needs (Osterwalder, A. & Pigneur Y. (2011), p.21). This customer needs for our business model of repowering would these be older wind turbines are replaced by modern and more powerful ones. Resulting in holistic project management for dismantling of existing offshore wind turbines.

An important issue has to be the positive value propositions connected to the reason for repowering a wind park.
Most viewed are:

- Facilitating work
- The recycling process is aimed at diminishing disposal material
- Waste becomes resource
- The higher revenues after repowering on sold energy
- The wind park aera can host less wind mills without loss of productivity
- The efficiency after repowering is of a higher degree
- Profit of a lower-maintenance due to upgrade by repowering
- More reliable equipment installed due to evolution of components
- Lesser mills give an improved landscape.
- Cost reduction possibilities by selling parts of the "old" plant
- Repowering can also be trigger to hybrid development such as hydrogen converters

Customer segments

The customer segments in business model canvas defines the various groups of people and organizations that a company want to reach and serve (Osterwalder, A. & Pigneur Y. (2011), p. 24 et. seqq). During the process of repowering the work will be done by contractors. They operate in service of the wind energy plant owners. Furthermore the whole process is being designed and monitored by developing companies.

The assignments are done by investors and wind park owners in the region. These investors and owners need to be convinced from the repowering of their wind parks by the contractors, developing companies and organizations that specialize in holistic project management and the implementation of offshore wind farm projects. Due to the increase of importance to become less reliant of external power sources, business models have been established to make this sustainable in a changing market.
Therefor parties are giving possibilities develop this market develop.

They main customer segments which need to be convinced of repowering there old Offshore Wind farms are:

- Energy companies (often the owner of the wind parks)
- Banks (Which invested in the old offshore wind parks, who now need to be convinced of the benefits of repowering in order to initiate the repowering process)
- Investment groups (Which invested in the old offshore wind parks, who now need to be convinced of the benefits of repowering in order to initiate the repowering process)
- Investment funds (Which invested in the old offshore wind parks, who now need to be convinced of the benefits of repowering in order to initiate the repowering process)
- Pension funds (Which invested in the old offshore wind parks, who now need to be convinced of the benefits of repowering in order to initiate the repowering process)
- Oil & Gas companies (Which invested in the old offshore wind parks, who now need to be convinced of the benefits of repowering in order to initiate the repowering process)
- Insurance companies

Channels

The “channel block” of the business model canvas describes how organizations reaches and appeals to the customer segments in order to convey value proposition (Osterwalder, A. & Pigneur Y. (2011), p. 31 et. seqq). Although not directly influencing the repowering process good communications, beyond the project, is of utmost importance to involve the public and the customer segments and to convince them from repowering must be addressed.
This can be done by having the following:

- Industrial fairs
    - Fairs based on wind energy, renewable energy and offshore
- Events, conferences and networking
    - Events and conferences based decommissioning offshore
    - Events and conferences based on repowering offshore
    - Events and conferences based on transition of energy in general

- Webpage
    - Presentation of services
    - Contact forms
- Social media
    - Linked-in
    - Facebook
    - Instagram
    - Twitter
- An information centre

Customer Relationship Management

The "customer relationships" module describes the relationship between a company and the customer segments (Osterwalder, A. & Pigneur Y. (2011), p. 32 et. seqq). For the repowering the companies have to find different ways to get in better relations with the customer segments. We suggest the following relationship activities to get in touch with the customer segments and convince them from repowering.

- Steering Committee
    - Emphasize the benefits of repowering
    - Presentation of different business cases

- Shareholder Meetings
    - Clarification
    - Emphasize the benefits of repowering
    - Presentation of different business cases

- Bilateral meetings

- Vision processes meetings

Key partners

The module "key partners" of the business model canvas describes all partnerships and networks with suppliers and partners, who contribute to be successful as a company (Osterwalder, A. & Pigneur Y. (2011), p. 42 et. seqq). We define different partners in the wind industry important to successfully execute the repowering process.

The key partners are:

- Partners without the "value proposition" cannot be maintained
    - Licensing governments
    - Power companies
    - Grit proprietors
- Partners who provide the value chain and transport of material
    - Recycle companies
    - Ports
    - Shipping companies

- Partners who provide access to new personnel, technologies and innovation
    - Personnel agencies
    - Schooling companies and universities
    - Engineering partners
    - Research organizations
- Partners who provide access to new markets and customers
    - Energy cluster organizations
    - Professional trade organizations (e.g. Wind Europe)

In addition we define partners that provide access to new technologies and innovation
For repowering we have the focus on recycling of components to prevent unnecessary waste. The redundant components need to be dismantled in an experienced and sustained manner. The materials that are recovered have some value for the second hand market. Waste becomes resource.

The commitment and the long term operation is depending on the approval of the governments as the license authority. Their admission cannot be missed if an upgraded wind park wants to continue to produces electricity.

Delivering electricity contracts with the power companies are needed to be sure that the delivered electricity will be transported to house owners and industry. These companies are mostly in a double role as park owner and transporter or delivery responsible for the electricity.

The energy from wind farms goes to land via electricity cables: the grid at sea. Grid operators manage the transport of energy. The grid operator is therefore responsible for connecting the wind farms via the offshore grid to the onshore electricity grid. This way, the energy ends up to the consumers.

Target group for the electricity are the consumers. But the grid operator is the receiver of the electricity and therefor the direct target group of the wind park owner.
The electricity is bought by the electricity companies to be sold to the end consumer.
This is regulated through government rules and contracts made before the actual repowering or new build is executed.
Special attention should be given to the fact that when repowering is at hand the net can take the rise in electricity delivery. Overload to the net is always a no go area.

Reasons for repowering are always cost driven.
These are:

- The end of cost effective life (maintenance material and components)
- The innovation due to new high performance wind turbines
- Price market electricity security for longer period
- Demands from market to deliver more electricity than cannot be delivered by the existing park.

At the moment with the current demand due to the transition effort and unstable conditions on the electricity market there is a drive to let the existing wind turbines have a longer life due to the fact that repowering gives a dip in delivery. Even so the margins are very large for the grid operator.

Key activities

The key activities describes the most important tasks a company must to keep its business, regarding the business model canvas (Osterwalder, A. & Pigneur Y. (2011), p. 40 et. seqq). In the repowering process as it was presented full replacement of a whole wind park was being issued.

This involves:

- Planning of the replacement process
- The replacement activities
- The recycling of the materials

Important for a good manageable repowering process is the way the preparation has been organized. The planning is essential. When what has to start or has to be done calls for a differentiated planning aimed at a minima loss of production in line with available finances. The logistics have to be in line with the planning and the use of equipment has to be adjusted to the same goals.
Licenses have to be issued in time before the start of the repowering process.

The recycling of the materials is an important item in the whole process when decommissioning a wind turbine. It is also part of the business model.

Much of the materials used in the old turbines can be recycled according to the rules and regulations.

The materials in full or after they have been treated and upgraded to new use.
These are:

- The concrete (scour protection) as part of new concrete mixes
- The ferrous metals to be used fully after melting
- The non-ferrous metals to be used after melting.
- The batteries to be brought back in the process
- The magnets to be brought back in het process
- The collection of different fluid materials (oils) to be upgraded and reused
- The utilization of CFC (chlorofluorocarbon) if present
- The utilization of GRP (glass fiber reinforced plastic) for the cement industry
- The recycling of cables components for reuse as electricity transport material

Key recourses

With the “key resources” are the most important assets of the company in the business model canvas meant (Osterwalder, A. & Pigneur Y. (2011), p. 38 et. seqq). Key recourses can be described as being crucial for the different aspects involving an organization of decommissioning. There is distinction between the different sorts of assets that benefit this. There are the following resources involved:

- Physical assets
    - Suitable vessels
    - Cutting tools and technologies for efficient decommissioning
    - IT-systems
    - Logistical infrastructure
    - Recycling facilities
    - Buildings/offices
- Intellectual property resources
    - Proprietary know how
    - Patents and copy rights
    - Partnership and customer databases
- Human resources
    - Trained repower and decommissioning personnel
    - Trained technicians and engineers
- Financial resources
    - Credit facilities
    - Cash flow

Cost structure

In the business model canvas the "cost structure" describes all the costs arise during the work on the new business model (Osterwalder, A. & Pigneur Y. (2011), p. 44 et. seqq). Of most importance, when realization of a repowering activity is planned, are the costs involved. These are not alone based on the construction costs.
The following have to be considered:

- Administration
- Decommissioning of the existing energy park
- Construction of a new park
- Planning and infrastructure costs
- Waste management
- Gate fees
- Taxes
- Interest rates
- Insurance
- Lost revenues
- New wind calculations due to wind flow interference
- New wind engineering of the park
- New license acquirements for exploitation (old one mostly max. 20-25 years)
- Calculating hybrid possibilities (hydrogen fabrication and pipelines)

Revenue streams

The revenue streams represent income that a company makes in the business model canvas (Osterwalder, A. & Pigneur Y. (2011), p. 34 et. seqq). The basic revenues as a result of the decommissioning of existing wind mills could be established by selling recycling components and waste material. Generally they are recognized as resource material instead of waste. These are for example material streams such as:

- Concrete material
- metals

- Cable material
- Generator parts
- Possible sale of old wind mills on second hand market

When established the most revenues can be expected to come from the higher yields due to the increased energy output.

4 Optimalization of the repowering layout

4-1 Introduction

In analyzing the way the repowering strategy will be able to meet its goals a process of optimalization is being carried out. There is more to it then removing old windmills and replace them with new ones at some time. As mentioned above a lot of considerations have to put in the model to establish the right strategy.

Therefore the process must be visualized to get all the components accountable. The correct moment of repowering depends on decisions made to find the optimal moment.

It is possible to add new wind farms, but above all it is necessary to renew existing offshore wind farms, not only to avoid losing production capacity, but to significantly increase their production by capitalizing on the wind resources with more powerful machines, reducing the number of turbines. Repowering also allows a reduction in operating costs related to maintenance due to more modern and reliable machines.

4-2 Optimization

Repowering actively participates in the energy transition by significantly increasing the connected capacities without contributing to the saturation of exploitable sites.
In practice, a repowering is a long-term project, which begins with the monitoring phase of the operational status of the existing wind farm, the market conditions at the end of the remuneration supplement and on the applicable regulatory framework for a possible renewal with an eligibility for a X-year purchase contract (remuneration supplement).

In order to make best use of the existing facilities, repowering seems to be a better choice. However, the conditions in each wind farm (wind condition, original WT type, WT layout, etc.) are different.

In general repowered sites are:
- More productive with fewer machines.
- Less difficult to integrate into the grid.
- Easier on the ear and eye.

4-3 Model for evaluation of profitability

A method is required to evaluate the profitability of repowering. An optimized repowering strategy is there to help the wind farm owner make the decision. This model that is developed to make the strategy viable is based on the “Levelized Cost of Electricity” (LCoE).

LCoE

The “Levelized Cost of Electricity” (LCoE) refers to the estimated revenue required to build and operate a generator over a specified cost recovery period.

Given this we can also state that:

- The maintenance costs for generators with over ten years of service will increase significantly.

- The first wind farms used the highest wind measurements; nowadays production can be greater.
-

Experiences elsewhere show that the overall estimated costs for decommissioning are 1.6% of the total levelized cost of energy (LCoE) and around 12% of the total capital cost.

Wake effect

When repowering is an issue higher wind mills and larger wings can have an effect on the output capacity of the wind park as a whole. In general this is called wake effect.
In large wind farms, wakes may cause 10 to 20% power losses of the total energy output. By developing the layout of a wind farm, much power losses can be avoided by taking wake effect into account.

Flow chart of the optimization process

To get a good overview of the quality of the existing wind park a comparison is made on the costs versus the total energy revenue. Therefore a flow chart can be used to illustrate the process.

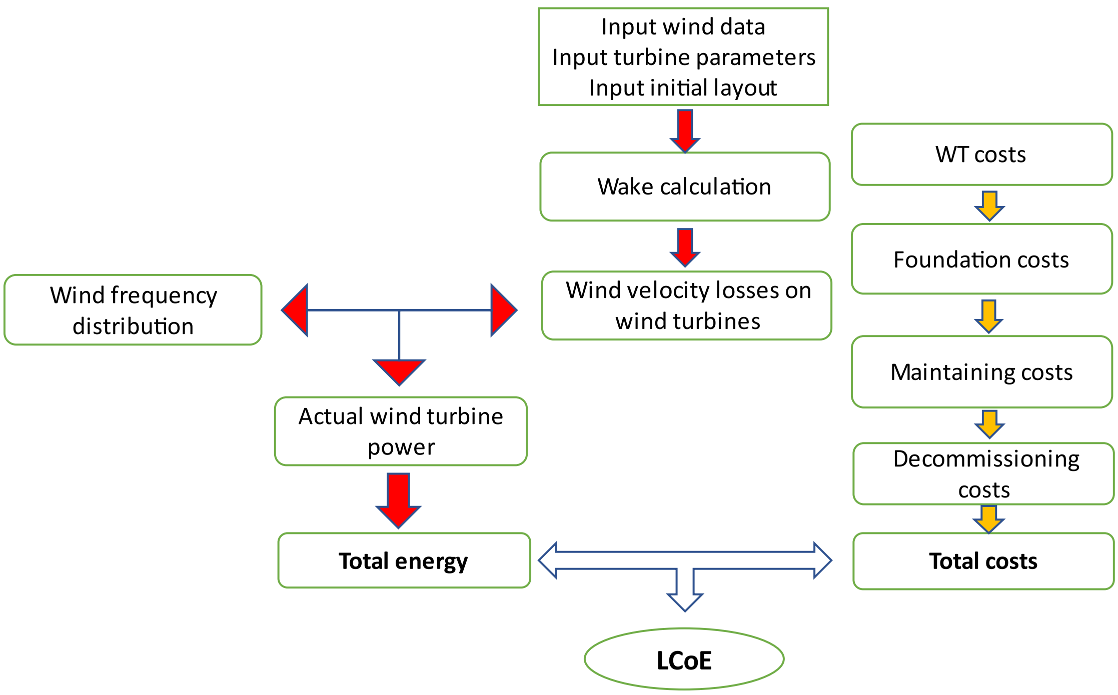

Illustration 2 the flow chart of optimization process

The flow chart shows the relation between the wind energy revenue and the costs to build, maintain and decommission. The LCoE is the equation between total energy and total costs.

$$LCoE = \frac{Total\ Costs}{Total\ Enery\ Revenue}$$

The moment of repowering is the established outcome of the LCoE when an existing wind park is being calculated in line with the flow chart over the existing lifespan and in line with the permitted licensed time.
When repowering is the issue the flow chart is being calculated with higher windmills, more wind, more output due to stronger generators and larger wings. This can give an even more increasing output of revenue when a new lease is commissioned of 20 to 30 years. Notwithstanding the lesser numbers of wind turbines.

5 Business model in practice

5-1 Introduction

Stakeholders in the wind industry need to precast investment opportunities. This can be done by changing the wind farm layout when repowering. Better use of the existing wind power, new technology, higher output and stronger WT's can culminate in less turbines with more power and higher output. This will result in an increase on the return of investment in the operating years of a wind farm.

Financial benefits are at the heart of repowering projects.
There is no need to make an acquisition, as it is a reinvestment in an existing asset for the owner operators.
The value of the assets increases, due to the significant increase in production through the installation of larger turbines with a greater efficiency.
Operating times of new turbines are longer due to less maintenance
More and better automation systems reduce man costs visiting the turbines
Fewer turbines are needed due to higher output.

Repowering generally involves substantial modifications on the site. The redesign of the wind farm therefore mobilizes all the traditional professions involved in developing a wind farm on a greenfield site.

The dismantling of existing wind turbines, their recovery and the installation of new wind turbines generate jobs in the traditional wind farm development and waste management professions. Repowering also allows local jobs to be sustained (maintenance in particular) by prolonging the activity of the farm.

Dismantling activities are usually carried out by the same type of service providers as those involved during installation (marine vessels, lifting, crane and transport companies, civil engineering, electrical engineering, etc.)
A total removal of the foundation piles is generally necessary in case of relocation of a new wind turbines on the same site: a higher wind turbine of a different model systematically requires a new foundation.

Groups of companies work together to develop recycling chains and work the material according to the sort to be recovered (concrete, scrap metal, composite materials, obsolete cable networks, etc.). The different companies form a value chain for the structured and identified collection, sorting, reuse of materials .

5-2 Successful issues

Full repowering means removing the old wind turbines and replace them with new stronger ones. This can be a big investment in comparison with refurbishing the existing WT's, but can bring more profit in the long run. Due to higher output. Eventually lowering the costs per MW in the LCoE.

Repowering offshore wind farms gives an opportunity to optimalization and maximizing of the value of a wind farm.
The strategy used depends on the situation on site, the state of the WT's and the price developments to be able to sell the acquired energy to the market.

5-3 Conclusions

Repowering business models need to be successful on the following issues:

- The existing park should have one office to represent the owner/investor. No problem if there is one owner, more owners should be prepared to delegate to one office.
- Contracts between the contractor and design partners should be made in advance. Design partners such as developers, manufacturers, wind scientists should be the base of the repowering design.
- The existing assets must be precured included turbines and use of the sea area.
- PPA (Power Purchase Agreement) of the existing wind park must be protected and serve as basis for repowering.
- The enhanced power supply must give a positive result in the long run based on higher output and lower prices.
- A feasibility plan must be made in advance of the realization of repowering.
- Contract with recycling companies should be made in advance of the repowering of an existing wind park making certain the redundant material and components will we be processed according to rules and regulations by the governing administration of the area. In the contract the recycling companies should guarantee ownership of the redundant material or components.
- An EIR is (Environmental Impact Report) is obligatory.

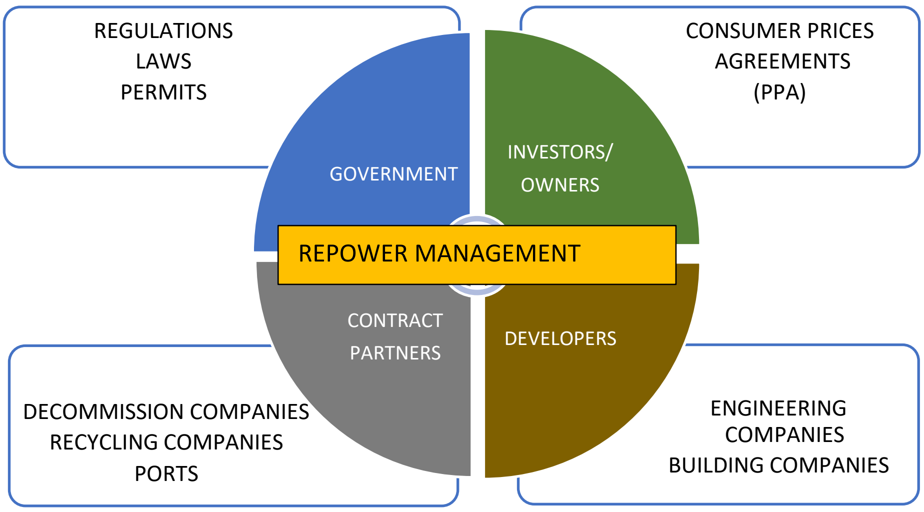

Illustration 3 Repowering Partners Business Model

6 Calculation on repowering of a wind turbine.

6-1 Introduction

For the calculation of a repowering process a new wind turbine Haliade X 14 has been chosen. Although not yet full operative it will give some idea how decommissioning and repowering can be estimated.

6-2 Parameters decommissioning of old wind park

In this example, the assumption is made, that an offshore wind farm has reached its lifetime and must be decommissioned. In particular, the parameters of the Horns Rev 1 wind farm were used as a guide. The initial parameters include 80 x 2MW turbines. This results in 160MW of total installed power. Another assumption to financially buffer the decommissioning are the reserves/accruals, which are counted with 40-50 Mio. € over the total lifetime of the old turbines.

Power WT	2	MW
Amount of turbines	80	turbines
Hub height	70	meters
Total power	160	MW
Reserve/Accruals	€ 40.000.000-€ 50.000.000[a]	euros
[a]: Source: Köpke, R. (2015) Den Schrott nicht auf dem Meer lassen (Online) https://www.energie-und-management.de/fileadmin/sonderdruck/108360.Den.Schrott.nicht.auf.dem.Meer.lassen.pdf, retrieved on: 26.01.2023		

Table 1 parameters of old wind park

6-3 Parameters repowering with Haliade X 14

The Haliade X14 was chosen as the new offshore wind turbine in this exemplary calculation. Already 12 of these turbines exceed the 160 MW of the 80 previous turbines. It can therefore be assumed that the area used can be reduced or that even more power could be installed on the area.

Power WT	14	MW
Amount of turbines	12	turbines
Hub height	220	meters
Yearly per turbine	74	GWH/a
Total power	168	MW
Source: Kramper, G. (2021) Größte Windturbine der Welt nimmt Betrieb in Rotterdam auf (Online) https://www.stern.de/digital/technik/haliade-x-14--weltweit-groesste-windturbine-nimmt-betrieb-in-rotterdam-auf-30811276.html, retrieved on: 26.01.2023		

Table 2 parameters repowering with Haliade X 14

Looking at the prospects when using the Haliade X14 to be profitable different scenarios have to considered based on the different prices for the electricity. The model is based on the German rules and regulations under EEG. The prices of electricity can be changed to country.

price first 8 years, wind park installed in 2018/2019 (Feed-in tariffs)	18,4	Ct/KWH
profit for 12 turbines per year with Feed-in subsidies	€ 163.392.000,00	
price for the last 12 years, wind park installed in 2018/2019 (Base model)	3,9	Ct/KWH
profit for 12 turbines per year with Base model	€ 34.632.000,00	
Price for the first 12 years	14,9	Ct/KWH
profit for 12 turbines per year with base model	€ 132.312.000,00	
Bundesministerium für Wirtschaft und Klimaschutz (2022) EEG Vergütung und Kapazitätszuweisung (Online) https://www.erneuerbare-energien.de/EE/Navigation/DE/Technologien/Windenergie-auf-See/Finanzierung/EEG-Verguetung/eeg-verguetung.html, retrieved on 26.01.2023		

Table 3 price of electricity in Germany

Illustration 4 Haliade X-14 General Electrics

6-4 Vessels needed for decommissioning

For decommissioning an existing wind farm different vessels are needed to be able to make it successful. As seen below based on a simulation analysis in the Decom Tools project the following vessels are used with an estimate of the time and costs involved. It is assumed that the ships that built the wind farm will also dismantle it in terms of "reverse installation".

Vessel	Amount vessels	Amount days	Charter rate/ship/day	Costs/vessel
"Pre Decom Vessel"	1	60	€ 100.000,00	€ 6.000.000,00
WTIV (OWT-Topside)	2	170	€ 200.000,00	€ 68.000.000,00
CLV/ cable laying vessel	1	106	€ 150.000,00	€ 15.900.000,00
Installation Vessel (Substructure)	1	270	€ 200.000,00	€ 54.000.000,00
Feeder Vessel (Substructure)	1	270	€ 50.000,00	€ 13.500.000,00
Installation Vessel (Offshore High Voltage Substation)	1	15	€ 200.000,00	€ 3.000.000,00
Feder Vessel (Offshore High Voltage Substation)	1	15	€ 50.000,00	€ 750.000,00
Total	**8**	**621**		**€ 161.150.000,00**

Table 4 Vessels needed for decommissioning

6-5 Recycling income old wind park

The total removal of the old park is part of the decommissioning plan. The work itself is already taken in concern with the decommissioning by the different vessels on to the port. Prices can differ, not knowing what the current rates are, and monitored as previous revenues from experiences elsewhere. Also taken into account are the different recycling rates to be expected when decommissioning the materials.

		Materials	Mass (to) per owt	mass (to) 80 owt	Monetary Value (€/to)[h]	Monetary value (total)	Recycling Rate (%)[i]	Monetary Value incl. Recycling rate
OWT	Topside	Steel	162[a]	12960	€ 430	€ 5.572.800	0,92	€ 5.126.976
		Cast Iron	18[b]	1440	€ 132	€ 190.080	0,98	€ 186.278,40
		Copper	1,5[c]	120	€ 6000	€ 720.000	0,98	€ 705.600
		Others[1]	9	720	€ 6500	€ 4.680.000	0,325[j]	€ 1.521.000
	Sub struct.	Steel	250[d]		€ 430	€ 107.500	0,50	€ 53.750
Cables		Copper	2500[e]		€ 3000	€ 7.500.000	0,98	€ 7.350.000
OHVS	Topside	steel	4700[f]		€ 430	€ 2.021.000	0,92	€ 1.859.320

[1] fibreglass, epoxy, aluminium, magnet, electrical devices, transformers, batteries

	Sub struct.	steel	1500[g]		€ 430	€ 645.000	0,50	€ 322.500
							Total:	**€17.125.424,40**

a, b, c: Topham E. (2019) Recycling offshore wind farms at decommissioning stage, in: Energy Policy No. 129, DOI: 10.1016/j.enpol.2019.01.072
d: Assumption
e: Assumption 40 kg copper per 1m, approx. 60 km total cable length
f: Semco Maritime (2022) Horn Rev 1 Offshore Substation (Online) https://www.semcomaritime.com/cases/hornsrev1 retrieved on: 27.01.2023
g: ISC Consulting Engineers A/S (2022) ISC and Offshore Substation Design (Online) https://isc.dk/wp-content/uploads/2021/11/Vind_brochure_November-2021_k04.pdf retrieved on: 27.01.2023
h: Scrap Metal Buyers (2022) Scrap Metal Prices (Online) https://www.scrapmetalbuyers.com/current-prices retrieved on: 16.11.2022
i: Amogh U. G. (2020) Assessment of recycling potential and circularity in decommissioning of offshore wind farms, DTU Wind Energy-M-0402402, Roskilde, Denmark
j: Assumptions average based on Amogh U. G. (2020)

Table 5 recycling income old wind park

6-6 Acquisition costs of the Haliade X 14, substation and cables

The costs of the Haliade X 14 and the substation are dependent of the current market. Therefor it is estimated that the costs will be in line with benefit calculated by the manufacturer. Also taken in consideration are the additional costs because of the cables that have to connect the wind turbines with the substation and the cable that will be the connection to the grid. In most situations the substation that is in place will be sufficient for the repowered wind farm, but in this case the calculation has been done as if everything had to be renewed.

Acquisition costs	Amount of costs	Source
1 turbine Haliade X-14	€ 11.000.000,00	Ridden, P. (2021) World's largest offshore wind turbine starts operating at 14 MW (Online) https://newatlas.com/energy/haliade-x-14-prototype-offshore-wind-turbine-operational/, retrieved on 26.01.2023
12 turbines	€ 132.000.000,00	
Cables	€ 87.500.000,00	Nieradzinska, P. (2021) Price for Cables (Online) https://www.researchgate.net/figure/Cables-costs-breakdown-in-M_tbl1_291554198, retrieved on 26.01.2023
Substation for 160	€ 23.000.000,00	BVG Associates (2022) Wind farm costs (Online) https://guidetoanoffshorewindfarm.com/wind-farm-costs, retrieved on 26.01.2023
Total	€ 242.500.000,00	

Table 6 Acquisition costs of the Haliade X 14, substation and cables

6-7 Vessels needed for installation

The installation vessels needed for buildup of the Haliade X13 wind park can be the same machines.

Sort	Amount of vessels	Amount of days	Charter rates vessel/day	Costs per vessel
Installation Vessels (Offshore High Voltage Substation)	1	28	€ 200.000,00	€5.600.000,00
Installation Vessels (OWT)	1	106	€ 150.000,00	€15.900.000,00
Installation vessels for monopiles (Substructure) Jack Up Vessel Feder vessel (Transport)	1 1	56 56	€ 200.000,00 € 50.000,00	€11.200.000,00 € 2.800.000,00
Installation Vessels (Offshore High Voltage Substation) Heavy Lift Vessel Feder vessel (Transport)	1 1	15 15	€ 200.000,00 € 50.000,00	€3.000.000,00 €750.000,00
Total	6	205		**€39.250.000,00**

Table 7 Vessels needed for installation

6-8 Calculation example

The example calculation seen below gives an estimated idea of the costs and revenues when fully repowering a wind park.
Calculated are:

- The cost of decommissioning the old wind park
- The cost of repowering the new wind park
- The revenues of the old wind turbines/ parts being removed and resold

Decommissioning old park	Costs	Source
Execution decommissioning	€ 161.150.000,00	
Preparation (Planning, Engineering and Project Management (40%)	€ 64.460.000,00	Topham, E. & Macmillan D. (2016) Sustainable Decommissioning of Offshore Wind Farm, in: Renewable Energy, No. 102, DOI: 10.1016/j.renene.2016.10.066
Subtotal for decomm.	€ 225.610.000,00	
Acquisition and installation costs of Haliade X-14		
Acquisition costs for the turbine incl. cable	€ 219.500.000,00	
Vessel Installation costs	€ 39.250.000,00	
Substation costs	€ 23.000.000,00	
Preparation (Planning, Engineering and Project Management (40%)	€ 112.700.000,00	Topham, E. & Macmillan D. (2016) Sustainable Decommissioning of Offshore Wind Farm, in: Renewable Energy, No. 102, DOI: 10.1016/j.renene.2016.10.066
Subtotal for installation costs	€ 394.450.000,00	
Total costs	**€ 620.060.000,00**	

Yields, reserve/ accruals that decrease the total costs		
Reserve/ Accruals for Decommissioning	€ 50.000.000,00	
Income from Recycling Materials	€ 17.125.424,40	
Total revenue	€ 67.125.424,40	

Total costs minus revenues	**€ -552.934.575,60**	Negative figure Costs higher than the revenues

Table 8 calculation example

6-9 Year to year revenue calculation

Based on all the information gathered in the different tables above two cost/venue tables have been made based on this information an estimate can be derived when the wind park can be profitable. The calculation is based on the German ruling (EEG). Therefor the price of electricity is guaranteed. In other countries different or similar stimulation measures are available. Some countries have no subsidies included at all.

The German Bundestag and the German Bundesrat passed the amendments to the Renewable Energy Sources Act (EEG) and the Energy Industry Act (EnWG) in 2014.
The EEG 2014 provides a choice between two different remuneration models for offshore wind farms commissioned before January 1st, 2020:

- *Optional feed-in model: Claim an initial payment of 19.4 ct/kWh (or 18.4 ct/kWh in 2018/2019) for a total of 8 years.*
- *Basic model: Use of the initial tariff of 15.4 ct/kWh (or 14.9 ct/kWh in 2018/2019 and 13.9 ct/kWh in 2020) over a period of at least 12 years, or*

At the end of the respective period, the basic fee is a flat rate of 3.9 ct/kWh.

For comparison the tables are based on the two assumptions:

- A model based on the feed-in system
- A model based on the basic system

Model based on the feed-in system

year	1	2	3	4	5
revenue	Decommissioning and Installation			163.392.000,00 €	163.392.000,00 €
Remaining initial costs		-43.494.500,00 €	-86.989.000,00 €	-683.418.075,60 €	-565.620.575,60 €
costs operating systems					
Maintenance costs				-2.100.000,00 €	-2.100.000,00 €
Insurance	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €
Operational Management	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €
Land allocation (Rent)	-588.000,00 €	-588.000,00 €	-588.000,00 €	-588.000,00 €	-588.000,00 €
Tax consultancy	-168.000,00 €	-168.000,00 €	-168.000,00 €	-168.000,00 €	-168.000,00 €
Administration	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €
Occupational tax	-672.000,00 €	-672.000,00 €	-672.000,00 €	-672.000,00 €	-672.000,00 €
Dues	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €
Allowance for depreciation	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €
Interest rate	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €
Fixed costs	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €
Reserve/Accurals	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €
Profit	-43.494.500,00 €	-86.989.000,00 €	-130.483.500,00 €	-565.620.575,60 €	-447.823.075,60 €

year	6	7	8	9	10
revenue	163.392.000,00 €	163.392.000,00 €	163.392.000,00 €	163.392.000,00 €	163.392.000,00 €
Remaining initial costs	-447.823.075,60 €	-330.025.575,60 €	-212.228.075,60 €	-94.430.575,60 €	23.366.924,40 €
costs operating systems					
Maintenance costs	-2.100.000,00 €	-2.100.000,00 €	-2.100.000,00 €	-2.100.000,00 €	-2.100.000,00 €
Insurance	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €
Operational Management	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €
Land allocation (Rent)	-588.000,00 €	-588.000,00 €	-588.000,00 €	-588.000,00 €	-588.000,00 €
Tax consultancy	-168.000,00 €	-168.000,00 €	-168.000,00 €	-168.000,00 €	-168.000,00 €
Administration	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €
Occupational tax	-672.000,00 €	-672.000,00 €	-672.000,00 €	-672.000,00 €	-672.000,00 €
Dues	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €
Allowance for depreciation	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €
Interest rate	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €
Fixed costs	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €
Reserve/Accurals	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €
Profit	-330.025.575,60 €	-212.228.075,60 €	-94.430.575,60 €	23.366.924,40 €	141.164.424,40 €

year	11	12	13	14	15
revenue	163.392.000,00 €	34.632.000,00 €	34.632.000,00 €	34.632.000,00 €	34.632.000,00 €
Remaining initial costs	141.164.424,40 €	258.961.924,40 €	247.999.424,40 €	237.036.924,40 €	226.074.424,40 €
costs operating systems					
Maintenance costs	-2.100.000,00 €	-2.100.000,00 €	-2.100.000,00 €	-2.100.000,00 €	-2.100.000,00 €
Insurance	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €
Operational Management	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €
Land allocation (Rent)	-588.000,00 €	-588.000,00 €	-588.000,00 €	-588.000,00 €	-588.000,00 €
Tax consultancy	-168.000,00 €	-168.000,00 €	-168.000,00 €	-168.000,00 €	-168.000,00 €
Administration	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €
Occupational tax	-672.000,00 €	-672.000,00 €	-672.000,00 €	-672.000,00 €	-672.000,00 €
Dues	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €
Allowance for depreciation	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €
Interest rate	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €
Fixed costs	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €
Reserve/Accurals	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €
Profit	258.961.924,40 €	247.999.424,40 €	237.036.924,40 €	226.074.424,40 €	215.111.924,40 €

year	16	17	18	19	20
revenue	34.632.000,00 €	34.632.000,00 €	34.632.000,00 €	34.632.000,00 €	34.632.000,00 €
Remaining initial costs	215.111.924,40 €	204.149.424,40 €	193.186.924,40 €	182.224.424,40 €	171.261.924,40 €
costs operating systems					
Maintenance costs	-2.100.000,00 €	-2.100.000,00 €	-2.100.000,00 €	-2.100.000,00 €	-2.100.000,00 €
Insurance	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €
Operational Management	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €
Land allocation (Rent)	-588.000,00 €	-588.000,00 €	-588.000,00 €	-588.000,00 €	-588.000,00 €
Tax consultancy	-168.000,00 €	-168.000,00 €	-168.000,00 €	-168.000,00 €	-168.000,00 €
Administration	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €
Occupational tax	-672.000,00 €	-672.000,00 €	-672.000,00 €	-672.000,00 €	-672.000,00 €
Dues	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €
Allowance for depreciation	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €
Interest rate	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €
Fixed costs	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €
Reserve/Accurals	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €
Profit	204.149.424,40 €	193.186.924,40 €	182.224.424,40 €	171.261.924,40 €	160.299.424,40 €

Table 9 model based on feeding system

In the first three years, decommissioning and repowering must be dealt with. Nevertheless, various operational costs are already incurring in this phase. We adapted these costs from LW-Heute (2022) to our case. The costs incurred in the first three years must then be added to the remaining costs from chapters 6-8. In year four, the higher feed-in remuneration rate is calculated over eight years for the first time. This can be used up to year 11 of the term. In year 9 of the term, profit can then be made for the first time. In this model, profit increases to 258 million by year 11. From year 12, according to German law, a low remuneration must be expected for the feed-in model. From this year until the end of the term in year 20, the costs are higher than the profit. It must therefore be drawn from the surplus generated in year 9 to 11 to cover all operational costs. After 20 years, a surplus of 160 million will be generated with the feed-in model in our case.

Model based on the basic system

year	1	2	3	4	5
revenue	Decommissioning and Installation			132.312.000,00 €	132.312.000,00 €
Remaining initial costs		-43.494.500,00 €	-86.989.000,00 €	-683.418.075,60 €	-596.700.575,60 €
Costs operating systems					
Maintenance costs				-2.100.000,00 €	-2.100.000,00 €
Insurance	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €
Operational Management	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €
Land allocation (Rent)	-588.000,00 €	-588.000,00 €	-588.000,00 €	-588.000,00 €	-588.000,00 €
Tax consultancy	-168.000,00 €	-168.000,00 €	-168.000,00 €	-168.000,00 €	-168.000,00 €
Administration	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €
Occupational tax	-672.000,00 €	-672.000,00 €	-672.000,00 €	-672.000,00 €	-672.000,00 €
Dues	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €
Allowance for depreciatio	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €
Interest rate	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €
Fixed costs	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €
Reserve/Accurals	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €
Profit	-43.494.500,00 €	-86.989.000,00 €	-130.483.500,00 €	-596.700.575,60 €	-509.983.075,60 €

year	6	7	8	9	10
revenue	132.312.000,00 €	132.312.000,00 €	132.312.000,00 €	132.312.000,00 €	132.312.000,00 €
Remaining initial costs	-509.983.075,60 €	-423.265.575,60 €	-336.548.075,60 €	-249.830.575,60 €	-163.113.075,60 €
Costs operating the systems					
Maintenance costs	-2.100.000,00 €	-2.100.000,00 €	-2.100.000,00 €	-2.100.000,00 €	-2.100.000,00 €
Insurance	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €
Operational Management	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €
Land allocation (Rent)	-588.000,00 €	-588.000,00 €	-588.000,00 €	-588.000,00 €	-588.000,00 €
Tax consultancy	-168.000,00 €	-168.000,00 €	-168.000,00 €	-168.000,00 €	-168.000,00 €
Administration	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €
Occupational tax	-672.000,00 €	-672.000,00 €	-672.000,00 €	-672.000,00 €	-672.000,00 €
Dues	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €
Allowance for depreciation	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €
Interest rate	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €
Fixed costs	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €
Reserve/Accurals	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €
Profit	-423.265.575,60 €	-336.548.075,60 €	-249.830.575,60 €	-163.113.075,60 €	-76.395.575,60 €

year	11	12	13	14	15
revenue	132.312.000,00 €	132.312.000,00 €	132.312.000,00 €	132.312.000,00 €	132.312.000,00 €
Remaining initial costs					
Costs operating systems					
Maintenance costs	-2.100.000,00 €	-2.100.000,00 €	-2.100.000,00 €	-2.100.000,00 €	-2.100.000,00 €
Insurance	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €
Operational Management	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €
Land allocation (Rent)	-588.000,00 €	-588.000,00 €	-588.000,00 €	-588.000,00 €	-588.000,00 €
Tax consultancy	-168.000,00 €	-168.000,00 €	-168.000,00 €	-168.000,00 €	-168.000,00 €
Administration	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €
Occupational tax	-672.000,00 €	-672.000,00 €	-672.000,00 €	-672.000,00 €	-672.000,00 €
Dues	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €
Allowance for depreciatio	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €
Interest rate	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €
Fixed costs	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €
Reserve/Accurals	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €
Profit	86.717.500,00 €	86.717.500,00 €	86.717.500,00 €	86.717.500,00 €	86.717.500,00 €

year	16	17	18	19	20
revenue	132.312.000,00 €	34.632.000,00 €	34.632.000,00 €	34.632.000,00 €	34.632.000,00 €
Remaining initial costs		443.909.424,40 €	432.946.924,40 €	421.984.424,40 €	411.021.924,40 €
Costs operating systems					
Maintenance costs	-2.100.000,00 €	-2.100.000,00 €	-2.100.000,00 €	-2.100.000,00 €	-2.100.000,00 €
Insurance	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €
Operational Management	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €	-420.000,00 €
Land allocation (Rent)	-588.000,00 €	-588.000,00 €	-588.000,00 €	-588.000,00 €	-588.000,00 €
Tax consultancy	-168.000,00 €	-168.000,00 €	-168.000,00 €	-168.000,00 €	-168.000,00 €
Administration	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €
Occupational tax	-672.000,00 €	-672.000,00 €	-672.000,00 €	-672.000,00 €	-672.000,00 €
Dues	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €	-252.000,00 €
Allowance for depreciatio	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €	-10.080.000,00 €
Interest rate	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €	-6.048.000,00 €
Fixed costs	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €	-4.872.000,00 €
Reserve/Accurals	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €	-19.722.500,00 €
Profit	86.717.500,00 €	432.946.924,40 €	421.984.424,40 €	411.021.924,40 €	400.059.424,40 €

Table 10 model based on basic system

Even in the model based on the basic remuneration system, there are initially costs for the operating system. Decommissioning and repowering will take place in the first three years. The costs incurred for operating in the first three years must also be added to the costs listed in Chapters 6-8. From year 11 until 17 positive numbers are generated for the first time. From year 4 to year 16, a remuneration of 132 million per year is generated. From year 17, a smaller price must be taken for the sale of the energy. As a result, from year 17 the profit is less than the costs incurred. From this point onwards, the remaining costs with the profits generated from years 11 to 17 must be used to cover the costs in the years 17 to 20. In total of 400 million would be generated in this case. This means that the base model should be preferred to the feed-in model.

7 Conclusions

The research by Decom Tools has shown that repowering is going to be a huge part of wind power developers work in the next years. The volume of wind farms to handle is going to increase fast, and wind developers need to anticipate if they do not want to become overwhelmed and see their wind farms stopped waiting for their repowering.

From an administrative point of view, the regulation is not yet set primarily due to the lack of experience of authorities. Guidelines have emerged that provide a starting point, which the studies can be based on. In this case the German regulation was used to make a comparison. Other countries have their own set of rules making it more difficult to get an overall policy for the North Sea. To have a European approach would bring a “one fits all” situation closer. An European authority assigned to harmonize rules and regulations could make this possible. Investors would get a level playing field to operate. This would be healthy for the costumer prices in the long run.

Technically, repowering is almost like a classic wind power project with a few differences. End-of-life strategies for maintenance are very important in the decision process. However, it is important to consider the timing of the dismantling activity in order to minimize its impact on the energy yield.

Wind projects are a business and with several viable scenarios, the differentiation will come from financial profitability. Therefore, a financial decision help tool is needed to set up to perform a sensitivity analysis on the repowering scenario.

The tariff, the date of repowering, the turbine prices and many other factors are input variables, leaving multiple choices for the user. The results are presented showing the profitability of the project depending on tariff and repowering date, which are the two factors that have the most influence on the results.
The health condition of offshore WTs provides a basis for the repowering strategy.

8 Research register

8-1 List of research documents

Offshore Wind Farm Repowering Optimization
Peng Hou*, Peter Enevoldsen, Weihao Hu*, 3ong Chen, Zhe Chen*
Department of Energy Technology, Aalborg University

Levelized Costs of New Generation Resources in the Annual Energy Outlook 2022
U.S. Energy Information Administration (EIA)

Repowering existing Wind farms will help reach Renewable electricity targets faster
SIA partners

Reborn and upgrading: Optimum repowering planning for offshore wind farms
Yang Liu, Yang Fu, Ling-ling Huang, Kaihua Zhang

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Isabel C. Gil-García 1 , Ana Fernández-Guillamón 2 , M. Socorro García-Cascales

End-of-life planning in offshore wind
Angeliki Spyroudi ore.catapult.org.uk

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Decommissioning vs. Repowering of offshore wind farms – a techno-economic assessment
A.M. Jadali, A. Ioannou, K. Salonitis, A. Kolios
Department of Naval Architecture, Ocean & Marine Engineering, University of Strathclyde, Glasgow, United Kingdom

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Haiying Sun , Xiaoxia Gao and Hongxing Yang
Hong Kong Polytechnic University

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Marko Bezbradica
Uppsala University Department of Earth Sciences, Campus Gotland

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Ontario Ministry of the Environment and Climate Chang

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Laura Castro-Santos Almudena Filgueira

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Katherine Ortegon, Loring F. Nies , John W. Sutherland

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Mr. Marjan NIKOLOV, M.Sc. Mr. Risto NAUMOV

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Marko Bezbradica Uppsala University

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Decommissioning vs. Repowering of offshore wind farms – a techno-economic assessment
A.M. Jadali1 A. Ioannou, K. Salonitis, A. Kolios

Repowering of old wind turbines in India
Mr.Balwant Mr. Krishnajith

Lifecycle and decommissioning offshore wind
Bernard Bulder Martijn van Roermund ECN

A Review of Life Extension Strategies for Offshore Wind Farms Using Techno-Economic Assessments
Benjamin Pakenham, Anna Ermakova Ali Mehmanparast

Advanced maintenance, lifetime extension and repowering of wind farms supported by advanced digital tools
Windext

Understanding decommissioning of offshore infrastructures
Ergiomstilling Vest

Business Model Generation – Ein Handbuch für Visionäre, Spielveränderer und Herausforderer Alexander Osterwalder, Yves Pigneur

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8-2 List of illustrations

8-3 List of Tables