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BIOWIND

Activity A3.3

Summary report

of the workshop on sustainable approaches to wind turbine decommissioning

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1. Background

1.1. The BIOWIND project

The Interreg Europe program was introduced by the EU in order to improve the cooperation across boundaries by sharing innovative and sustainable solutions to regional challenges. One of the projects supported by Interreg is the BIOWIND Project. This project aims to support project partners to set forward an integrated wind planning approach to enhance social acceptance and secure sustainable wind energy expansion.

BIOWIND brings together 11 partners from 8 EU countries, who will collaborate and exchange experiences throughout a 4-year implementation period. The BIOWIND project consists of the following partners:

1. Lead Partner: Region of Western Greece (Greece)
2. Regional Council of South Ostrobothnia (Finland)
3. Zemgale Planning Region (Latvia)
4. Northern and Western Regional Assembly (Ireland)
5. University of Patras (Greece)
6. Province of Flemish Brabant (Belgium)
7. Central Danube Development Agency Nonprofit Ltd. (Hungary)
8. Marshal Office of Świętokrzyskie Region (Poland)
9. Autonomous Community of the Region of Murcia - General Directorate of the Natural Environment (Spain)
10. Asturias Energy Foundation (Spain)
11. Advisory partner: The Hellenic Society for the Promotion of Research and Development Methodologies – (Greece)

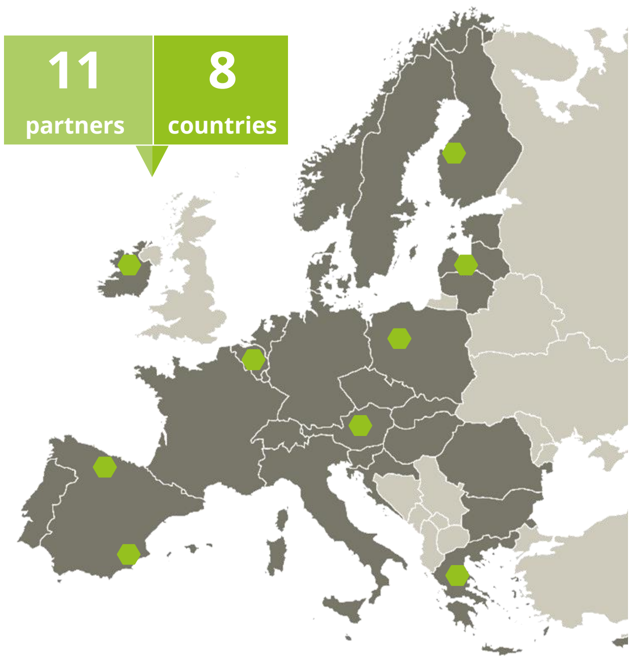

Figure 1: Partners of the BIOWIND project

The first of four interregional workshops was given in Sligo (Ireland) by the Northern and Western Regional Assembly (NWRA) on the 19th and 20th of September 2023. This workshop focused on developing measures to promote civic participation and engagement.

The second workshop was led by the Zemgale Planning Region (ZPR), and took place on the 20th and 21st of February 2024 in Jelgava, Latvia. The activity comprised a workshop on early warning systems in wind farms for biodiversity conservation, followed by a site visit to the Laflora wind farm project under development.

The third workshop concerns sustainable approaches to wind turbine decommissioning. The workshop was organized by the Belgian partner, Province of Flemish Brabant and was held on the 19th of June 2024 in the city of Leuven. This report will discuss the different topics covered during this workshop.

The fourth workshop will include a site visit to the Vöyrinkangas wind farm in Finland and will be led by the Regional Council of South Ostrobothnia. This workshop is scheduled on the 1st and 2nd of October 2024.

1.2. BIOWIND Project Activity A3.3

This report contains the summary of the third workshop where the decommissioning of wind turbines at the end of their lifetime was discussed. During the workshop, the background study linked to this subject was presented, different stakeholders and companies active in the decommissioning industry explained their work and view on the end-of-life of wind turbines. The complete schedule of the workshop can be found in **Appendix A**. The background study provided the partners a brief introduction to the different aspects of decommissioning. Informing them about the various options and possibilities, allowed them to provide relevant and useful input during the round table discussions. The background study, conducted and presented by Tractebel on behalf of the Province of Flemish Brabant, will be briefly summarized in **section 1.3**.

The presentations during the third workshop were given by POM West-Vlaanderen (Provincial Development Corporation of the province of West Flanders, Belgium), Blade-Made, Business in Wind, and the Institute of Natural Sciences. So, governments as well as private bodies and knowledge institutions were represented. The different presentations will be shortly summarized in **section 2.1** of this report.

These presentations were followed by some roundtable discussions on the topics presented in the background study. Each table consisted of about five people representing different partners and stakeholders. In order to grasp the challenges faced while talking about decommissioning, the following questions were discussed in each group:

- What does the evolution of the wind industry look like in your country (for the future)? What is the general trend across the entire EU and when can we expect a wave of decommissioning?

- What opportunities and difficulties seem decisive in wind turbine decommissioning?
- What possible aspects could be optimized to reduce the cost of decommissioning?
- What measures should be taken to optimize and possibly improve the restoration of the site compared to the original condition?
- What legislations or recommendations could contribute from your government in increasing the recyclability of the wind turbine (blades)?
- What measures could be taken to further reduce carbon emissions from wind energy?

The different conclusions and interesting insights drawn from these roundtable conversations are discussed in **section 2.2** of this report.

To end the workshop a small summary was made including some policy recommendations and good practices gathered from the background study and the round table discussions. These take-aways, which could be implemented by the partners and participants all over Europe, are summarized in **chapter 3**.

1.3. Decommisioning of wind turbines

1.3.1. End-Of-Life of a wind turbine

Once wind farms and turbines worldwide reach their end-of-life, there are some options that can be considered. The most favourable option, from an energy point of view, would be to repower the wind farm. Repowering consists of decommissioning and dismantling the existing turbines and replacing or redeveloping the area with newer, bigger, better performing wind turbines. Depending on the regulations and restrictions, it might be feasible to double or triple the production on site with the same or a smaller number of turbines. Although grid connections and capacity need to allow this increase in production.

If for some reason repowering is not a feasible option for a particular wind farm and the end-of-life of the current equipment is reached, the second option consists of refurbishing the existing turbines. This means replacing or repairing the components that are most vulnerable to wear and tear. These components often limit the lifetime of the turbines. By replacing them and keeping the components which could stand the loads for many more years, the lifetime of the turbine and windfarm can be prolonged to 30 years or even longer.

Whenever the end-of-life of most components is reached and repowering or refurbishing is not an option, a complete dismantling of the wind turbine and project zone will be required. In order to restore the zone and landscape to its original state, all components, including complete foundations and underground cables, should ideally be dismantled and removed.

Depending on the scenario chosen at the end-of-life of the particular wind farm, the decommissioned turbines and components will need to be processed. The most sustainable way of processing these components is by reselling them on a second-hand market. Otherwise recycling or repurposing the components, is a sustainable way of reusing the available resources.

1.3.2. Quantitative description of the market

To estimate the challenges ahead, a quantitative description of the wind industry in Belgium and Europe has been carried out. In Belgium there are 1234 onshore wind turbines installed in April 2024. These are divided over 345 wind farms all over the country. Two thirds of the installed turbines onshore in Belgium are less than 10 years old, one quarter is between 10 and 15 years old and only one tenth of the installed turbines are between 15 and 20 years old. In Belgium there are only a handful turbines with an age exceeding 20 years.

Wind turbine manufacturers estimate a lifetime of a turbine to be approximately 20 years. The profitability of repowering might bring forward the decommissioning. Taking this into account, it can be estimated that 10% of all the operational wind turbines today will need to be decommissioned in the following 5 years.

Some of the BIOWIND partners provided information on their local wind turbines, which was included in the thematic background as well. By combining the numbers of the partners, it is possible to have an overview of the European market and to estimate the flow of decommissioning in the following years. The information on the size and the age of the different wind farms from Finland, North and West Ireland (based on the amount of wind farms and an estimate of the average amount of wind turbines for each farm), Greece, Asturias (ES), Murcia (ES), Belgium and Latvia were combined.

In total, as visualized in **Figure 2**, about half of the turbines installed in the participating countries were younger than 10 years old. Approximately 20% was installed between 10 and 15 years back while ca. 15% is between 15 and 20 years old. Based on the information provided, 12% is between 20 and 25 years old while a few percent exceed the age of 25 years. Based on a lifetime of 20 years, almost 30% of the existing operational turbines will need to be decommissioned in the following years.

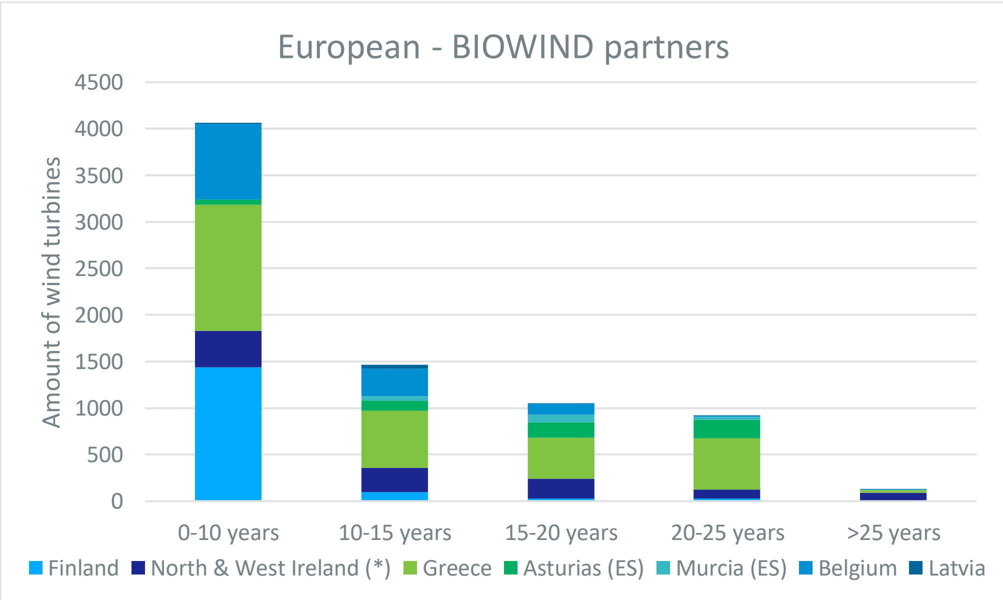

Figure 2: The age of wind turbines in the participating BIOWIND partners.

1.3.3. End of concession of the European wind farms

The actual end-of-life of a wind turbine is influenced by multiple varying factors. First of all, the lifetime of a turbine can be limited due to technical reasons. Some of the components of a wind turbine are vulnerable to wear and tear as they are constantly in motion and impacted by big loads. Maintenance and monitoring can prolong the lifetime. By monitoring the loads, wind climate and wind gusts on the turbines and its components and combining this information with the knowledge and know-how of the wind turbine manufacturers, it should be possible to predict and schedule the necessary maintenance and repairs to enlarge the lifetime. Wind turbine manufactures estimate a lifetime of 20 years with the possibility to prolong this period with the necessary repairs if needed (1).

Besides the technical reasons, some administrative reasons can lead to the premature end of a wind turbine. For example, some (older) environmental permits are limited in duration. Depending on the region and legislation it is possible that turbines need to stop operations after 20 or 25 years if they do not renew the permit.

If the asset owner already decided to repower the zone, the lifetime of the existing wind turbine might be subject to the duration of the permitting phase as well. The longer the permitting phase takes, the longer the existing turbine will be kept operational, if possible.

Once the wind farm reaches a certain age, some financial reasons can be decisive in the decommissioning phase. The investment cost of the existing turbine and the potential future turbine (CAPEX) should be considered. In combination with the maintenance and operational costs (OPEX), which will most likely increase with the age of the turbines. Administration and finance costs are part of the equation as well. These costs should be compared with the revenue mainly coming from the electricity prices and subsidies. Depending on the region and country, the subsidies might be limited in time as well.

Repowering a wind farm might be beneficial from a financial point of view. In order to estimate the profitability of a repowering project some factors need to be considered as well. The repowering cost, including the cost of dismantling and the investment cost of the new turbines will be significant, while future subsidies might be considerably lower than the subsidies currently received for the wind farm. The permitting and development of the new project might be costly as well. But a new wind farm will result in new and bigger installed capacity which will increase the revenue. The maintenance cost of newer turbines will be different in comparison with the older wind farm. At last, it might be possible as well to sell the turbine on a second-hand market or regain a profit from the material resources (2).

The background study included some figures to give a rough estimate of the **costs** of wind turbine operations:

- CAPEX/OPEX of a wind farm
  - CAPEX: ± 1 800 €/kW
  - OPEX (0-20y): ± 30 €/kW/year
  - OPEX (20-25y): ± 60 €/kW/year
- Decommissioning
  - Dismantling: ± 85 - 230 €/kW

While the **revenue** of a wind turbine can be roughly estimated using the following factors:

- Decommissioning
  - Scrap material: ± 30 - 50 €/kW
- Energy generation
  - Electricity price: ± 80 - 120 €/MWh
  - Subsidies: ± 65 - 107 €/MWh
- Benefits of repowering
  - Resale value of wind turbine in combination with the dismantling costs: ± 7.5 €/kW

Other costs will need to be included as well. For example, land lease can account for several tens of thousands of euros each year for the lot on which the turbine is situated.

Once the end-of-life is decided and the decommissioning can start, the following schedule can be expected for the dismantling of the existing turbines. This schedule might vary for each project and can only be considered as an indication of an ideal situation:

1. Wind turbine preparation: 3 days
2. Disconnection from the grid: 1 day
3. Assembling the main crane: 1-2 days
4. Dismantle wind turbine: 2 days
5. Load components and transport to port: 2 days
6. Demobilize or move the main crane: 1-2 days
7. Demolish the foundation: 7 days

Some of these steps can occur simultaneous while others might be delayed due to unforeseen circumstances or availability of material and machinery.

Decommissioning a wind turbine is a challenging process which includes some opportunities and some difficulties. Resource recovery, energy generation (in the case of a repowering), urban renewal and improved safety and environmental impacts can be considered as opportunities and improvements after decommissioning.

While a lack of clear instruction manuals, recyclability of the turbine blades, the costs and logistics, the environmental impact and health and safety risks during the works can be considered as difficulties in the process that will require special attention.

Once the turbine is dismantled, it is important to restore the terrain and landscape to its original state. A description of this original state can potentially be part of the permit or can be included in documentation of some sort. A discussion with the landowner can be held to know the needs of the location. The recovery itself is regulated on a national level and mostly includes restoring the local topsoil to erase the differences with the surroundings. This should be considered during the planning of the yard facilities (in an early phase of commissioning of the turbines) in order to minimize the disturbance during the work while still facilitating the dismantling.

1.3.4. Recyclability of Wind Turbine Components

The EU has some waste management directives which need to be considered while processing the decommissioning of a wind turbine. Taking the Waste Framework Directive (WFD) into consideration safeguards the environmental and human health. This directive indicates prevention as being the most preferred option in waste management. Followed by reuse, repurpose, recycle, recover and disposal in order of most preferred to least preferred.

Wind turbines are primarily composed of steel, concrete, copper and composite materials with small additional quantities of plastic and aluminium. The recyclability of these components varies significantly. Approximately 90% of a wind turbine's mass is recyclable, but the turbine blades, which are made from composite materials, pose a particular challenge. The different materials have different recycling methods (3):

1. **Metals:** These include steel, iron, copper, and aluminum. Metals can be recycled almost indefinitely. The process typically involves crushing, separating, and melting the metals for reuse.
2. **Concrete:** Used for turbine foundations, concrete can be recycled and reused for new turbine installations.
3. **Plastics:** Although a minor component, plastics can be recycled through standard plastic recycling processes.
4. **Composites:** The most challenging material to recycle due to the combination of resin and fibers (usually glass or carbon). Several methods are used for recycling composites:
    - Mechanical Recycling: Involves physically breaking down the materials into smaller parts. This process results in matrix powder and recycled fibers, which can be used as fillers or reinforcements, though they are typically of inferior quality compared to virgin materials.
    - Thermal Recycling: Includes incineration or pyrolysis to separate the fibers from the resin. This method has high energy demands and often results in weakened fibers especially with glass fiber.
    - Chemical Recycling: Utilizes solvents to break down the resins. This method maintains better fiber properties but also requires significant energy and solvent volume.

1.3.5. Carbon Emissions of Wind Power

To meet the ambitious targets set at the Paris climate agreement, more and greener energy sources will be necessary. Even though wind energy does not require fossil fuels to generate electricity, there are some carbon emissions linked to the lifetime of a wind turbine. In order to better understand the contribution of the end-of-life to the total emissions of a wind turbine, a Life Cycle Analysis (LCA) was discussed. The LCA was conducted by Vestas and independently reviewed. The LCA concerned a V136-4.2 MW turbine for which the lifecycle was divided in four stages (4):

1. **Manufacturing:** The extraction, processing, and transportation of raw materials, along with the production of all components, accounts for 8.8 gCO_{2e}/kWh.

2. **Transport and Installation:** Emissions from transporting turbine components and the installation process are relatively low, contributing 0.1 gCO_{2e}/kWh.
3. **Operation Phase:** This phase, which includes site servicing and operations, contributes 0.2 gCO_{2e}/kWh.
4. **End-of-Life Recycling:** The recycling process at the end of the turbine's life provides environmental credits, which can offset 3.4 gCO_{2e}/kWh of the emissions by preventing the production of new virgin material which require a higher energy demand.

In total the carbon footprint of wind energy is estimated to be around 5.7 gCO_{2e}/kWh for this particular turbine type, in average wind conditions and without taking the energy production into account.

Wind turbine manufacturers are trying to reduce these carbon emissions by reducing their energy consumption and reducing the waste along the production process. Attempts are being made to optimize the blade design to allow complete recyclability and to work together with the suppliers to reduce the emissions of the production process by 45% by 2030.

2. Workshop

2.1. Presentations

The following sections summarize the main takeaways from the four presentations given during the workshop.

2.1.1. Towards a Belgian decommissioning plan – *POM West-Vlaanderen*

The first presentation of the workshop titled "Towards a Belgian Decommissioning Plan" and was offered by the POM West-Vlaanderen (Provincial Development Corporation of the province of West Flanders, Belgium). The presentation explores the intricate process of decommissioning wind turbines, with a special emphasis on offshore installations. The province of West-Flanders is closely related to the offshore wind farms as this is the only province with direct access to the North Sea. Currently there are 9 wind farms with a total of 399 wind turbines in the Belgian part of the North Sea, with the first wind turbine operational since 2009 and the first decommissioning expected in 2039.

These offshore turbines are supported by various foundation types, including gravity-based (6 turbines), monopile (344 wind turbines), and jacket structures (49 turbines). These offshore turbines are constructed from the same materials as onshore turbines such as concrete, steel, and composites. In comparison with onshore turbines, offshore constellations use an additional scour protection layer made from gravel and rocks which prevents erosion of the ocean floor.

Depending on the type of foundations, the following steps are undertaken to decommission the offshore wind turbines:

- Decommissioning on sea
- Transport to port
- Further disassembly and processing into transportable parts
- Transport to recycling company
- Processed in recycling company
- Scrap and materials for reuse

It is possible that some transports are done using pontoons to water-based recycling companies or breaking yards.

A noteworthy aspect of the presentation is the synergy between onshore and offshore decommissioning efforts. Onshore decommissioning is relatively straightforward, involving direct transport to the destination without intermediate transfers. In contrast, offshore decommissioning necessitates intermediate transshipment in ports and the clustering of material flows for efficiency. While onshore decommissioning is more decentralized in comparison with offshore decommissioning, where wind farms have a larger amount of wind turbines.

A significant part of the effort is dedicated to informing the public about what happens to wind turbines once they reach the end of their operational life. In order to estimate the need for information concerning this topic, a public survey was held with 704 participants from all of Belgium (58% lived in the province of West Flanders). The following multiple-choice questions were included in the survey:

- What percent of the total electricity mix comes from offshore wind and what percent comes from onshore wind in 2023?
  - 10.5% offshore and 8.2 % onshore, totalling at 18.7% (70.9% of the participants answered correctly).
- On average, how long does a wind turbine last at sea and on land?
  - 20-25 years (81.4% of the participants answered correctly).
- At the end of their life, wind turbines are decommissioned. What happens to the parts?
  - Some components get recycled and certain parts are given a new purpose (61.2% of the participants had both answers right).
- How much of a wind turbine's material is recyclable?
  - 90% (68.5% of the participants answered correctly).
- Who pays for the complete decommissioning of wind turbines?
  - Wind farm owner (73.0% of the participants answered correctly).
- Under Belgian law, what must be done when a wind turbine is decommissioned at sea?
  - Everything needs to be removed (67.3% of the participants answered correctly)

The survey revealed that respondents had varying levels of awareness about the recycling processes and the costs associated with decommissioning. The average score of respondents was 7.36 out of 10, with coastal residents scoring lower on average. Results will be used to create targeted information campaigns to further increase knowledge about renewable energy.

Several questions from the participants of the survey remained unanswered, indicating areas where further education and information are needed. These questions covered a range of topics, including environmental impacts, technological developments, regulatory issues, operational details, industrial involvement, and economic comparisons. Concerns about the environmental impact of decommissioning, the future potential of offshore wind energy, and the specifics of European regulations were prominent among the responses.

2.1.2. The scalable repurposing strategy - *Blade-Made*

Blade-Made has developed an alternative approach to address the environmental challenge posed by wind turbine blade disposal. Instead of conventional methods like landfilling, incineration or recycling, which have negative or neutral environmental impacts, Blade-Made focuses on repurposing these blades into useful products for outdoor purposes. By repurposing the blades, a reduction of virgin material is possible, implementing a positive environmental impact.

This circular value chain, as shown in Figure 3, begins with decommissioning and transportation by third-party contractors to Blade-Made's storage facilities. Here, the blades are transformed into various items such as playgrounds, urban furniture, artwork, shelters, and sound barriers that are delivered to the customer. When cutting waste remains or blades cannot be refurbished by Blade–Made, a recycling facility will ensure responsible disposal of the material.

Their projects include installations like a playground, urban furniture and artworks in Rotterdam. Additionally, in Terneuzen Blade-Made installed a playground and urban furniture at the seaside, highlighting the durability and versatility of these repurposed materials, albeit with occasional maintenance needs in those coastal environments.

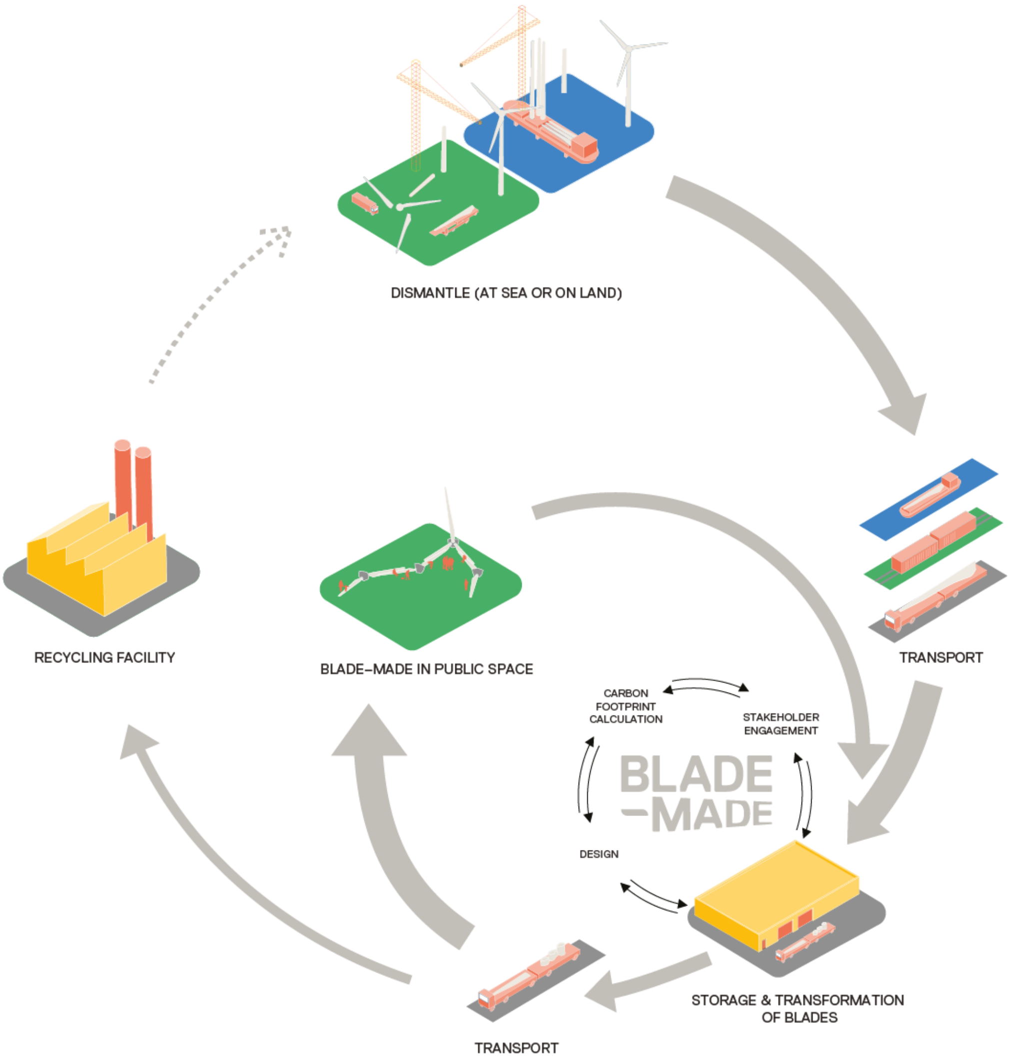

Figure 3: The Circular Value Chain for wind turbine blades from Blade-Made (5).

Blade-Made reports substantial environmental benefits, achieving up to a 90% reduction in carbon emissions compared to conventional materials. They have demonstrated economic feasibility, with costs for their products comparable to those made from traditional materials. However, challenges remain, particularly in securing funding for the eventual recycling of these products. Currently, the responsibility for recycling lies with wind asset owners when the turbines are operational, whenever the blades are sold to Blade-Made, this responsibility is transferred to Blade-Made as well.

Looking ahead, Blade-Made aims to diversify applications beyond their current range, addressing potential usage of wind turbine blades as sound barriers alongside highways in the Netherlands. Thereby representing a sustainable and impactful solution, turning potential waste into valuable public assets while promoting the principles of the circular economy.

2.1.3. Market for pre-owned wind turbines – Circular Wind Energy Business – *Business in Wind*

Business in Wind is a Dutch company specialized in acquiring, refurbishing, and installing second-hand wind turbines. Their track record includes working with Vestas and Enercon turbines from the Netherlands, Germany, Austria, and Belgium. The installations of the second-hand turbines span destinations such as the UK, Italy, Kazakhstan, Ukraine and Sweden. With processes involving inspection, budgeting, preparations, dismantling, civil works, installation, and commissioning combined with addressing foundations and cables during decommissioning.

Some projects require the use of used wind turbines for various reasons. There might be restrictions on the dimensions of the turbines due to permits, but there might be logistical limitations as well. Some mountainous regions or road infrastructure will not allow the installation of newer and bigger turbines. High interest rates and low CAPEX can be decisive as well. Combined with long lead times of OEM-turbines (Original Equipment Manufacturers) can result in the choice for used wind turbines.

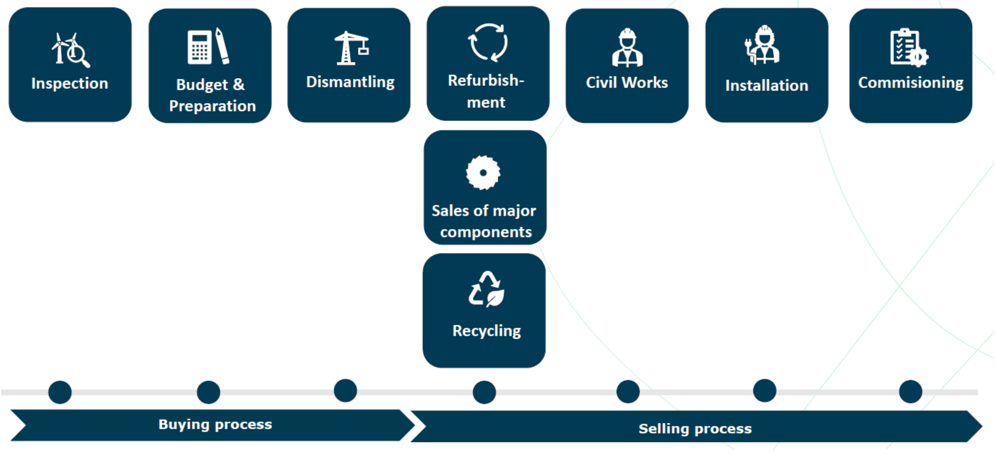

Figure 4: The process of the purchase and commissioning of second-hand turbines by Business in Wind.

In the first phase of these projects, as shown in Figure 4, third-party inspections are conducted as these significantly impact selling prices. Business in Wind plans for lifetime extensions and conducts route surveys. After these actions, budgeting and preparations need to be carried out. They consider four factors when deciding whether to re-use turbines: dimensions, logistics, capital expenditure and lead time. Second-life use depends on economic feasibility, remaining lifetime, refurbishment costs, operational expenses, spare parts availability and overall costs.

Business in Wind has experience with various turbine models, including V80, V90, V52, E48, and E70. Some components can be reused as spare parts, while others undergo refurbishment.

Concrete and reinforcement steel are recycled if needed. The concrete used in the decommissioned wind turbine can be repurposed for new foundations. A mobile mixing plant at site can produce new concrete from the dismantled foundations. Occasionally, the piles are removed as well. Depending on the local legislation, everything possibly needs to be removed in order to restore the nature to its original status without leaving anything behind.

Business in Wind has previously tackled some unique challenges as well, including dismantling turbines in the middle of the Atlantic and handling burned turbines in Germany. Currently they are exploring demolition robots to ease the task.

In general, Business in Wind estimates the duration from the request of a client for a second hand turbine until the actual commissioning of the turbine on the new location to take 6 to 9 months. The company does not expect the second-hand turbine market to explode, demand will stagnate, while the supply will increase hugely. This will eventually balance out and result in a more selective process while purchasing used turbines.

2.1.4. Taking into account biodiversity aspects of decommissioning of marine offshore wind farms – *Institute of Natural Sciences*

Offshore wind farms play a crucial role in the context of global climate agreements like the Paris Agreement. With ambitious targets aiming for 2000 GW of offshore wind capacity worldwide by 2050, impacting approximately 500,000 square kilometers of sea surface, comparable to 115% of the surface of the North Sea.

These developments, however, are not without environmental impact. Originally characterized by sandy sediment, offshore wind farms transform these areas into artificial hard substrates. This alteration creates a multitude of small islands in the sea, establishing vertical connections between the sea floor and surface. This change diversifies sediments, the water column, and introduces new habitats.

Remarkably, offshore wind turbines themselves support thriving ecosystems. Each square meter can host kilograms of mussels, illustrating the dynamic nature of these environments with constant changes. Factors like scour protection layers introduce new species to these regions.

A study conducted over eleven years after installation of an offshore wind farm showed the appearance of new species previously absent in these environments, prompting questions about how to approach decommissioning (6). Should diversity considerations guide these processes?

The impacts are significant. For instance, local fish production increases near offshore wind farms. Animals living on turbines act as biofilters as well, absorbing particles from the water. Remarkably, animals on a single turbine can filter an amount equivalent to 7.5 Olympic swimming pools daily. This process contributes to additional organic carbon uptake on the sea bottom, leading to a 10% increase in over 20 years.

Regarding decommissioning, full removal is often imposed by the environmental permit, involving cutting turbines two meters below the sea floor and returning areas to their original state, including removing scour protection layers. However, this poses challenges for biodiversity, as full decommissioning removes all associated species as well. There are some other alternatives which might be more beneficial for biodiversity, as visualized in Figure 5.

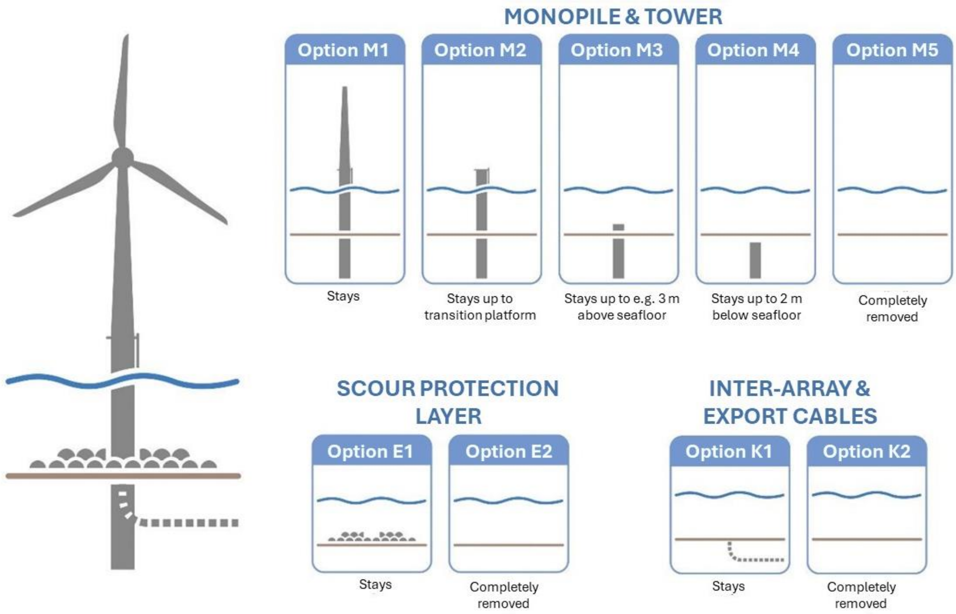

Figure 5: Different possibilities concerning the decommissioning of offshore wind turbines (7).

Research suggests that most of the species present on the scour protection layer are generally present elsewhere on the turbine. Leaving the scour protection layer, as visualized in option E1 on Figure 5, might keep biodiversity in place but that does not necessarily result in maintaining the ecosystem functioning rates (8).

A stakeholder process led by the Royal Belgian Institute of Natural Sciences and the Marine Environment Department of the Federal Public Service of Health, Food Chain Safety and Environment discussed the decommissioning. The decisions regarding complete or partial decommissioning should consider spatial context. If new habitats significantly differ from the original, full decommissioning might be less critical. A potential repowering might lead to new nature and functions disappearing locally but reappearing somewhere else.

However, when habitats resemble the original, alternatives to complete removal should be considered (7). A side note needs to be made concerning carbon accumulation as this was not fully considered in the report.

Looking forward, inclusive nature design is a key factor to take into account in future offshore wind projects as this could minimize the impacts during the decommissioning process. It needs to be noted as well that offshore wind farms might introduce new nature and biodiversity on the turbines itself, the original biodiversity on the seafloor might be influenced negatively by the installation of the foundations and the scour protection layer.

2.2. Roundtable discussions

The background study and the presentations from the experts provided the partners and stakeholders present at the workshop with some useful background information concerning the sustainable decommissioning of wind turbines. Thanks to the organization of roundtable discussions, the participants could share information and ideas around these topics. The Province of Flemish Brabant and Tractebel moderated and guided the discussions with detailed questions as summarized in the following section.

2.2.1. What does the evolution of the wind industry look like in your country (for the future)? What is the general trend across the entire EU and when can we expect a wave of decommissioning?

The evolution of the wind industry in the EU shows significant variability across different countries, with each nation experiencing unique trends and challenges:

- In Finland, the focus is on new turbine installations as their first turbine was installed in 2015.
- In Spain, there is a clear distinction between the north, where wind turbines are nearing decommissioning or repowering and some decommissioning projects have already taken place, and the south, which is more focused on solar energy due to its weather and geographical features.
- Hungary is not installing any new turbines but has a wind turbine fleet of around 172 turbines installed between 2000 and 2011. Some of these existing turbines are approaching the end of their lifetime. It is expected to see a wave of decommissioning by 2025 there.
- Belgium has already initiated decommissioning, and regulatory adaptations are necessary to keep pace. Belgium has around 10% of its turbines nearing 20 years of operation.
- Ireland’s oldest turbines date back to 1994, with many others installed in 1999.
- Greece is focusing on repowering, despite some abandoned projects. In Murcia (Spain), most turbines have been or will be decommissioned soon.
- Latvia has two wind farms, with the oldest turbines dating back to 2002, which will reach the decommissioning phase shortly as well.

Overall, the general trend across the EU suggests that decommissioning is becoming increasingly pertinent, with a significant wave expected in the following years.

2.2.2. What opportunities and difficulties seem decisive in wind turbine decommissioning?

Decommissioning wind turbines presents several significant **opportunities** that can benefit both the environment and local communities. One major opportunity lies in the reuse of materials. Many components of wind turbines, including metals and concrete, can be recycled or repurposed, reducing waste and conserving resources. This potential for material reuse aligns with broader sustainability goals and can create economic opportunities in the recycling sector. Additionally, transparency in the materials used for turbine blades can lead to better recycling practices and more efficient resource management.

Another opportunity is the enhancement of biodiversity. Once turbines are decommissioned, the land can be restored to its natural state, allowing local flora and fauna to thrive. This restoration effort does not only support biodiversity but also enhances the ecological value of the land.

Furthermore, repurposing decommissioned sites can in some situations provide new uses for the land, such as community projects or tourism initiatives, which can bring economic benefits to local communities. The involvement of local communities in these projects fosters a sense of ownership and can lead to more successful and sustainable outcomes.

Energy gain is another critical opportunity when repowering. Replacing the older existing turbines by newer, bigger and better performing turbines can increase the energy generation in the project zone by factor two or three. It is even possible to achieve this increase while decreasing the number of installed turbines.

Decommissioning wind turbines also presents several significant **difficulties** that need to be addressed. A primary challenge is the lack of expertise in decommissioning processes. As the industry is relatively young, there is limited experience and knowledge in safely and efficiently dismantling wind turbines. There is no clear instruction manual for decommissioning in comparison with commissioning. This expertise gap can lead to increased costs and potential safety risks.

The general public's knowledge of wind turbine decommissioning is currently limited which can impact the public opinion against wind energy projects and can also complicate (de)commissioning efforts. In order to increase the social acceptance and support, turbine blades can be repurposed into public furniture or infrastructure, bringing the wind turbine closer to the communities and informing them on the benefits. Acceptance issues may arise when communities are not adequately informed or involved in the planning stages.

Permits and regulatory requirements present another difficulty. The process of obtaining the necessary permits, although really different between countries, can be complex and time-consuming, with fast-moving environmental permits and requirements adding to the challenge. Additionally, geographical issues such as access and logistics difficulties can make the physical process of decommissioning turbines more complicated and costly.

Other difficulties might include protest groups, even against repowering efforts, grid problems, including capacity issues mainly impacting the repowering processes and negotiations for new contracts with landowners.

Finally, the fast-paced evolution of environmental permits and requirements can make it difficult for operators to stay compliant with current regulations, a consistent and long-lasting regulatory framework could simplify the process.

By addressing these difficulties and leveraging the available opportunities, the wind energy sector might be able to make further improvements on the decommissioning process and contribute to a more sustainable and efficient energy future.

2.2.3. What possible aspects could be optimized to reduce the cost of decommissioning?

Wind turbine project margins are typically limited, leading to streamlined construction processes that leave little room for further cost reductions, a reality that applies equally to the dismantling phase. Nonetheless, small actions can contribute to limited cost savings. Reusing as many components as possible during dismantling can be significantly more beneficial than recycling, as refurbished turbines are more valuable than their scrap materials. Efficient dismantling also involves careful planning to avoid high wind seasons, minimizing weather-related delays and additional costs.

Emphasizing local work and staying local can reduce costs, repurposing components in the direct area can reduce the costly and complex logistics. By increasing the longevity of turbines, the relative cost of decommissioning might be smaller in comparison with the generated energy.

A business model of a supplier of second-hand wind turbines can for example cover decommissioning costs as well, reducing the cost for the assets owner. Enhancements in (decommissioning) technology can also help reduce the cost of decommissioning.

Reducing the duration of the permit phase is another potential optimization. In Spain for example, no impact study is required for repowering projects if the increase in capacity is lower than 50%. If the tip height increases by less than 10% a new permit is no longer required. This will decrease the costs for new repowering projects.

Innovative tools are being developed as well to enhance cost-efficiency and circularity in decommissioning. Some tools help developers minimizing turbine waste by providing data on local material processing facilities, decommissioning providers, and cost models and thereby offering a comprehensive end-of-life management system for wind farms.

2.2.4. What measures should be taken to optimize and possibly improve the restoration of the site compared to the original condition?

To optimize and improve site restoration compared to the original condition, planning in advance is crucial. There is a significant difference between onshore and offshore restoration efforts. Offshore decommissioning has its own challenges as discussed in sections 2.1.1 and 2.1.4.

For onshore recovery, the restauration of the topsoil is essential, combined with clearing the site and removing the foundations completely if no new purpose can be found. Site repurposing, whether for tourism, such as creating poetry trails or observation posts, or for other uses might be options in order to upgrade the surroundings. Improving access roads and involving local communities can also be important measures.

Defining the virgin state of the site is necessary but not always easy. Regulations vary by country as well. For example, in Spain, concrete demolition must reach one meter below ground, whereas Belgium mandates complete removal of all structures. In Ireland or other mountainous regions, such as Norway or the Alps, a complete removal of the foundations can pose a danger due to instability. Restoration plans should be required and included from the start of the permit process.

2.2.5. What legislations or recommendations could contribute from your government in increasing the recyclability of the wind turbine (blades)?

Governments can help increase the recyclability of wind turbines by implementing obligations and support measures. It might be helpful as well to have a general top-down legislation from a centralized European point of view. Legislation could include financial motivations, support for the second-hand market and incentives for recycling. A clear legislation concerning the recycling of wind turbines blades and its composites can provide an additional guideline as well.

This all could contribute to the sustainability of wind turbine decommissioning but it needs to be considered as well that less bureaucracy might simplify the decommissioning process and decrease the permitting duration.

3. Policy recommendations

3.1. Comparison between EU regulation and national regulation

3.1.1. European regulations

Europe does not have regulations on waste management of wind turbines that must be followed by member states. They defined a framework, the EU Waste Framework Directive (2008/98/EC), containing basic concepts related to waste management. The aim of this framework is to demonstrate the finite nature of landfills and place more responsibility on producers with regards to recyclability.

In July 2018, the European Commission approved the Circular Economy Package, which contains revised legislative proposals that need to be transferred into national law by the Member States. These proposals are mainly focused on households as they aim to recycle 65% of municipal waste by 2030 and want to reduce the maximum proportion of municipal waste that ends up on a landfill to 10%. Concerning the recycling of wind turbines, the Circular Economy Package includes legislative proposals for a total ban on landfilling separately collected waste such as concrete, metal and plastic waste.

More specific legislation for separate waste streams will follow in the future as a result of these targets. Following regulations or standards are already in use today in relation to these specific waste streams:

- **Cement and concrete**: Under the EU Waste Framework Directive (2008/98/EC), at least 70% by weight of non-hazardous concrete and cement waste must be reused or recycled from 2020 onwards.
- **Metal**: article 10(2) of the EU Waste Framework Directive (2008/98/EC) states that paper, metal, plastics and glass shall be separate collected. This means that metals coming from wind turbine waste should be held separate from other waste streams. Article 11 of the same framework states that Member States need to act in order to meet the necessary quality standards for the relevant recycling sectors of these separate collected waste streams (9).
- **Composites**: To this day, there is not much regulation around the composite waste industry. However, the EU pushes towards more circularity, stressing that the private sector, together with national and regional authorities, will need to mobilise to fulfil this vision.

3.1.2. Regulations per country

Starting from the European directives, it is up to member states to build specific laws around them. The section below discusses the specific laws for some EU member states regarding waste streams from wind turbines. These countries were chosen because their regulations are easily accessible (10).

3.1.2.1. DENMARK

The operating permit includes the conditions for decommissioning which e.g. must start one year after the wind turbine has stopped operating at the latest (10).

Typically, the municipality sets the conditions for site restoration in the permit. A common requirement is to remove all equipment, including the foundation, as deep as 1 m below the surface and to rehabilitate the area.

3.1.2.2. FRANCE

France sets targets for the recycling of wind turbines, specifically for the composite rotor blades (11):

- From 1 July 2022, a minimum of 35% of the rotor mass must be reused or recycled (for existing wind turbines).
- After 1 January 2023, this is 45% (for wind turbines for which a planning application is submitted after this date).
- After 1 January 2025, this is 55% (for wind turbines for which a planning application is submitted after this date).

At the end-of-life, total excavation of foundations is required, unless an Environmental Impact Assessment (EIA) recommends not to do it. The excavated foundations are replaced by earth with characteristics comparable to the land in place near the installation.

France requires the owner of the wind farm to give a financial guarantee of up to €50,000 for each wind turbine installed at the beginning of the project in order to have the financial resources available for decommissioning (12). Other countries have similar legislations, in the United Kingdom for example a 'decommissioning bond' with the local planning authority needs to be agreed on at the point of planning in order to cover the costs of decommissioning (10).

3.1.2.3. GERMANY

A ban on directly landfilling waste with a total organic content higher than 3% came into force in 2009. Considering blades contain an organic part due to the resin that glues the glass fibers, they cannot be landfilled.

Germany's Building Code has the following provisions: "The operator has to issue a declaration of commitment to dismantle the installation and remove all soil sealing when permanently abandoning the site.". There are also implemented guidelines on soil protection measures to be observed when dismantling wind turbines.

3.1.2.4. THE NETHERLANDS

Landfilling of composites is banned. However, wind farm operators can use an exemption if the cost of treatment of alternative solutions is higher than the benchmark value of €200/ton and thereby deemed too expensive.

Any foundation removal requirements are set in the agreements between the landowner and the operation as no specific legislation is in place.

3.2. Good practices for handling wind turbine waste and recommendations

Based on the EU directives, national legislation of some countries, the background study and the discussions during the workshop, it is possible to list some good practices and useful tips for handling decommissioning of onshore wind turbines:

- Create **dedicated waste codes** for composite materials in all sectors and **identify the composition** of the composite materials.

  By creating dedicated waste codes, it will be possible to precisely track the composite materials throughout their lifecycle. This improved traceability helps in understanding the quantities and types of composites used and disposed of, which is essential for managing and optimizing recycling processes. Identifying the composition of the composite materials can help in choosing the most suitable recycling technique for that wind turbine blade. Overall dedicated waste codes will increase the recyclability and circularity of wind turbine blades.

  At the beginning of the project, the composition of the composite material in the blades must be known and an end-of-life roadmap for these materials must be specified. The waste codes and composition information should be available in other sectors such as boating and aviation as well as they allow the use of the most efficient recycling technique for each specific composite material. Including boating and aviation will enlarge the demand and thereby contribute to the development of new recycling technologies.

- Introduce **progressive targets** and support the **research** and development financially for **recycling of composite material waste**.

  By introducing targets, developers and manufacturers will be pushed towards innovative ways of recycling the composite blades. In order to achieve those targets, some financial incentives can be given to boost the recycling techniques.

- Include a **direct ban** on **landfilling** composite material waste as of 2025.

  Landfilling is the least favourable way of dealing with (composite material) waste. Wind turbine blades are not biodegradable and will persist in landfills for hundreds of years. In order to terminate this, there needs to be clear regulations. By banning landfilling other options will need to be considered by the wind turbine owners, this will encourage the development of recycling technologies and infrastructure and will promote the circularity.

- Ensure that the **waste shipment regulation** allows for **cross-border** transport of composite material waste in various stages of treatment.

  By allowing and regulating cross-border transport of waste flows, it is possible to prevent landfilling to be outsourced to non-EU countries and it allows for better centralization of recycling facilities.

  Since wind turbines are scattered all around the world, if composite recycling plants become viable at industrial scale, logistics and transportation will become challenging. Proper regulations will be needed.

- Require **total excavation** of foundations.

  In order to leave no marks behind and bring the whole project zone back to the original state, a complete demolition of the foundations is required. Often the resource gain from the foundations does not outweigh the cost of demolition of the foundation. A clear legislation will oblige the complete demolition of these components. The foundations should be replaced by earth with characteristics comparable to the land in place near the site.

- Secure **financial guarantees** from an early stage of the project.

  Securing a predefined sum of money from the asset owner at the time the (operational) permits are granted, should prevent financial restrictions from holding back the complete decommissioning of the wind turbine and the recovery of the project zone. A predefined sum for each turbine installed, as is already the case in France, should take the real decommissioning costs into account and should encourage full recycling of the wind turbine components.

- Include the **local community** and the **landowner**.

  Including local authorities and residents together with the landowner to see what the needs might be of the area in the future, might raise the general local support. By informing on the future use of the project zone, a complete and adequate recovery of the terrain can be accomplished.

4. Summary and conclusion

The BIOWIND project is aiming at improving the policies and establishing connections and support civilians concerning wind energy and technology. In order to increase the support and the understanding concerning wind energy, this workshop researched the sustainable approach towards wind turbine decommissioning and recycling. The current situation concerning wind turbine farms and ages in Belgium and Europe was discussed, resulting in a distribution by age category, which allows to predict the rate in which decommissioning will be needed in the following decades.

Once the end-of-life is in sight, the developer or project owner has some options to consider. Nowadays, most of the decommissioned turbines get replaced by repowering projects, in which new, bigger and better performing turbines replace the older turbines in order to produce more green energy for the same area. The different decisive factors in the process of the decommissioning influence the time of decommissioning and the desired outcome. Different opportunities and difficulties linked to this project need to be considered by future developers or stakeholders. As in most industrial processes, the economical aspects need to be considered together with some opportunities to reduce these costs. Whether or not repowering is chosen, the aim should be to restore the site to its original state. This needs to be implemented as soon as possible in the early stages of the project development.

If the turbines are decommissioned and do not end up serving a second life on another location, the different components need to be recycled. Most materials, like the concrete, steel and iron included in the turbine can easily be recycled. The biggest challenge is faced with the recycling of the wind turbines blades. Even though there are multiple technologies available, scaling up to cover the entire industry will be challenging while maintaining economic viability. The necessity of proper regulation needs to be considered in this industry. Currently most countries and regions in Europe lack the proper regulation with regards to handling the recycling of wind turbine blades.

For a complete image of the sustainability of the decommissioning phase, the carbon emissions need to be considered as well. In which it is clearly noticeable that the end-of-life could impact the overall life cycle assessment in a positive manner. This results in a smaller contribution to global warming.

To conclude the report, some policy recommendations and good practices were formulated in order to give an indication on the different paths (local) governments and developers can take towards a more sustainable decommissioning of wind turbines.

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Appendix A: Workshop Agenda

BIOWIND

INTERREGIONAL WORKSHOP ON SUSTAINABLE APPROACHES TO WIND TURBINE DECOMMISSIONING

WEDNESDAY 19 JUNE 2024
Location: (*Provincieplein 1, 3010 Leuven*)

TABLE 1: WORKSHOP AGENDA

09:00 - 09:20	Arrivals & registration	All
09:20 - 09:40	**Opening of the meeting by our deputy** Overview and objectives of the workshop	PFB
09:40 - 09:50	**Photoshoot**	All
09:50- 10:10	Brief introduction of all partners and stakeholders present	All
10:15 - 11:00	**Presentation on the thematic background study** • *Quantitative description of the market* • *End of concession: decisive factors* • *Timing and financial aspects of decommissioning* • *Recovery of the site and landscape* • *Carbon emissions of wind power*	Tractebel Engie Belgium
11:00 - 11:30	**COFFEE BREAK**	
11:30 - 12:30	**Guest speaker 1: Towards a Belgian decommissioning plan** • *Logistical and processing challenges* • *Informing the public about the fate of wind turbines at the end of their operational life*	POM West-Vlaanderen
12:30 - 13:00	**Guest speaker 2: Blade–Made, the scalable repurposing strategy** • *A design strategy to reuse end-of-life wind turbine blades*	Blade-Made
13:00 - 14:00	**LUNCH**	
14:00 - 14:30	**Guest speaker 3: The second-hand market of wind turbines** • *Circularity: giving wind turbines a second life elsewhere in the world in cases of repowering*	Business in Wind

14:30 - 15:00	**Guest speaker 4: Taking into account biodiversity aspects of decommissioning of marine offshore wind farms** • *Sustainable management of marine areas, impacted by (the decommissioning of) offshore wind farms*	Institute of Natural Sciences
15:00 - 15:45	**Roundtable discussions** • *What does the evolution of the wind industry look like in your country (for the future)? What is the general trend across the entire EU and when can we expect a wave of decommissioning?* • *What opportunities and difficulties seem decisive in wind turbine decommissioning?* • *What possible aspects could be optimised to reduce the cost of decommissioning?* • *What measures should be taken to optimise and possibly improve the restoration of the site compared to the original condition?* • *What legislations or recommendations could contribute from your government in increasing the recyclability of the wind turbine (blades)?*	All *(Supervision by PFB and Tractebel)*
15:45 - 16:15	**COFFEE BREAK**	
16:15 - 16:35	**Roundtable discussions** • *Sharing conclusions in large group (collective feedback on finds from the small groups)*	All *(Supervision by PFB and Tractebel)*
16:35 - 16:50	**Wrap up** • *Short recap of the day* • *Policy recommendations*	Tractebel Engie Belgium
16:50 - 17:00	**Concluding the workshop** • *Thank you & Next steps*	PFB