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Life Cycle Inventories of Wind Energy

Electricity generation from onshore and offshore wind farms for the Swiss and European context

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Summary

This report provides a comprehensive update of the Life Cycle Inventories (LCIs) for electricity generation from wind power, focussing on the Swiss and European context. Commissioned by the Swiss Federal Office for the Environment (FOEN) and the Swiss Federal Office of Energy (SFOE) and conducted by the Zurich University of Applied Sciences (ZHAW), this study addresses the growing demand up-to-date environmental data in national LCI databases.

The updated LCIs cover onshore and offshore wind farms with modern turbine capacities from 2.3 MW to 15 MW. A total of 39 datasets were created, including infrastructure datasets and electricity production datasets at the wind farm level, as well as aggregated wind electricity mixes for Switzerland and Europe. These inventories are compliant with the FOEN database protocol and are based on the reference year 2024.

The modelled system covers all life cycle stages: manufacturing, transport, installation, operation and maintenance (O&M), decommissioning and end-of-life (EoL) treatment. For each turbine size, separate LCIs were created for moving parts (blades, hub, nacelle), tower, foundation, and electrical components (substations, cables). The models account for realistic transport routes, vessel activities, replacement rates over 25 years, and SF_6 leakage emissions.

The Swiss wind electricity mix was modelled using 2.3 MW and 3.4 MW onshore turbines with the national capacity factor from Swiss wind energy statistics. For the European context, the wind electricity mix includes both onshore and offshore installations. Onshore turbine sizes include 2.3 MW, 3.4 MW, 4.5 MW, and 6.2 MW, while offshore turbines include 5 MW, 10 MW, and 15 MW units. The selected configurations reflect actual market shares and future trends (e.g. growing role of 10–15 MW turbines offshore).

Environmental impacts were assessed based on the global warming potential (GWP, IPCC 2021), cumulative energy demand (CED), and the total environmental impact according to the Ecological Scarcity Method. GHG emissions range from 10.4 to 22.7 g CO_2-eq/kWh. Offshore wind generally has higher impacts due to vessel activities than onshore wind, despite higher capacity factors (~34% for offshore vs. ~23% for onshore in Europe and ~19% in Switzerland).

The Swiss wind mix yields 18.1 g CO_2-eq/kWh, higher than the European average of 14.9 g CO_2-eq, due to lower capacity factors and smaller turbines. The total environmental impact and CED for the Swiss mix are also 13–16% higher than for the European mix.

This study enhances the quality and representativeness of wind power data for LCA studies, supporting more accurate environmental impact assessments and policy decisions in the context of climate goals and energy transition strategies. It also ensures alignment of the Swiss FOEN database with current wind technology.

Main conclusions

Updated inventories enable accurate assessments

The new datasets reflect current wind power technologies and replace outdated models in the Swiss LCI database ensuring representativeness for current and future installations. The study models wind electricity mixes using real deployment data, enabling assessments for policy and industry.

Capacity factor and vessel activity drive environmental performance

Higher electricity output per installed MW (i.e., capacity factor) significantly reduces impacts per kWh. Vessel operations for installation and maintenance significantly increase the environmental footprint of offshore wind.

Wind energy has a comparably low climate impact

With life cycle GHG emissions from 10.4 g of CO_2-eq to 22.7 g of CO_2-eq/kWh, wind energy remains among the power generation technologies with the lowest impact on climate change. If replacing power generation from fossil energy, further expansion of wind energy in Switzerland and Europe can contribute to reducing the environmental intensity of grid electricity.

Zusammenfassung

Dieser Bericht enthält eine umfassende Aktualisierung der Lebenszyklusinventare (LCI) für die Stromerzeugung aus Windkraft im Schweizer und europäischen Kontext. Im Auftrag des Bundesamtes für Umwelt (BAFU) und des Bundesamtes für Energie (BFE) wurde diese Studie von der Zürcher Hochschule für Angewandte Wissenschaften (ZHAW) durchgeführt.

Die aktualisierten LCIs umfassen Onshore- und Offshore-Windparks mit modernen Turbinenkapazitäten von 2.3 MW bis 15 MW. Insgesamt wurden 39 Datensätze erstellt, darunter Infrastrukturdatensätze und Stromproduktionsdatensätze auf Windparkebene sowie aggregierte Strommixe für die Schweiz und Europa. Diese Inventare entsprechen dem Datenbankprotokoll des BAFU und basieren auf dem Referenzjahr 2024.

Das modellierte Inventar deckt alle Lebenszyklusphasen über Herstellung, Transport, Installation, Betrieb und Wartung (O&M), Rückbau und Abfallbehandlung ab. Für jede Turbinengrösse wurden separate LCI für bewegliche Teile (Rotor, Nabe, Gondel), Turm und Fundament sowie elektrische Komponenten wie Umspannwerke und Kabel erstellt. Die Modelle berücksichtigen realistische Transportwege, Schiffsaktivitäten, Austauschraten über 25 Jahre und SF_6-Leckage.

Der Schweizer Windkraftmix wurde anhand von 2.3-MW- und 3.4-MW-Onshore-Turbinen mit dem nationalen Kapazitätsfaktor aus der Schweizer Windenergie-Statistik modelliert. Für den europäischen Kontext umfasst der Strommix sowohl Onshore- als auch Offshore-Anlagen. Die Onshore-Turbinen haben eine Leistung von 2.3 MW, 3.4 MW, 4.5 MW und 6.2 MW, während die Offshore-Turbinen eine Leistung von 5 MW, 10 MW und 15 MW haben. Mit dieser Auswahl werden tatsächliche Marktanteile sowie zukünftige Trends abgedeckt (z. B. die wachsende Bedeutung von 10–15-MW offshore Turbinen).

Die Umweltauswirkungen wurden auf der Grundlage des Treibhauspotenzials (GWP, IPCC 2021), des kumulativen Energiebedarfs (CED) und der Gesamtumweltbelastung gemäss der Methode der ökologischen Knappheit bewertet. Die Treibhausgasemissionen liegen zwischen 10.4 und 22.7 g CO_2-eq/kWh. Offshore-Windenergie führt aufgrund der Schiffsaktivitäten zu höheren Resultaten, trotzt höheren Kapazitätsfaktoren (~34% für offshore gegenüber ~23% für onshore in Europa und ~19 % in der Schweiz). Der Schweizer Windmix ergibt 18.1 g CO_2-eq/kWh und liegt damit über dem europäischen Durchschnitt von 14.9 g CO_2-eq/kWh, was auf niedrigere Kapazitätsfaktoren und kleinere Turbinen zurückzuführen ist. Die gesamten Umweltauswirkungen und die CED für den Schweizer Mix sind ebenfalls 13–16% höher als für den europäischen Mix.

Diese Studie verbessert die Qualität und Repräsentativität der Windkraftdaten für Ökobilanzstudien und unterstützt so genauere Berechnungen von Umweltauswirkungen und politische Entscheidungen im Zusammenhang mit Klimazielen und Strategien zur Energiewende. Ausserdem gewährleistet sie die Angleichung der Schweizer BAFU-Datenbank an den aktuellen Stand der Windtechnologie.

Résumé

Ce rapport contient une mise à jour complète des inventaires du cycle de vie pour la production d'électricité à partir d'énergie éolienne dans le contexte suisse et européen. Cette étude a été réalisée par la ZHAW Université des sciences appliquées de Zurich sur mandat de l'Office fédéral de l'environnement (OFEV) et de l'Office fédéral de l'énergie (OFEN).

Les Inventaires de Cycle de Vie (ICV) actualisés couvrent les parcs éoliens terrestres et en mer avec des capacités de turbines modernes allant de 2.3 MW à 15 MW. Au total, 39 jeux de données ont été créés, dont des jeux de données d'infrastructure et des jeux de données de production d'électricité au niveau des parcs éoliens, ainsi que des mix électriques éoliens agrégés pour la Suisse et l'Europe. Ces inventaires sont conformes au protocole de base de données de l'OFEV et se basent sur l'année de référence 2024.

L'inventaire modélisé couvre toutes les phases du cycle de vie couvrant la fabrication, le transport, l'installation, l'exploitation et la maintenance (O&M), le démantèlement et le traitement des déchets. Pour chaque taille de turbine, des ICV distincts ont été établis pour les parties mobiles (rotor, moyeu, nacelle), la tour, les fondations ainsi que les composants électriques tels que les sous-stations et les câbles. Les modèles tiennent compte de trajets de transport réalistes, de l'activité des navires, des taux de remplacement sur 25 ans et des fuites SF_6.

Le mix éolien suisse a été modélisé à l'aide de turbines terrestres de 2.3 MW et 3.4 MW avec le facteur de capacité national issu des statistiques suisses sur l'énergie éolienne. Pour le contexte européen, le mix électrique éolien comprend à la fois des installations terrestres et en mer. Les turbines terrestres ont une puissance de 2.3 MW, 3.4 MW, 4.5 MW et 6.2 MW, tandis que les turbines offshore ont une puissance de 5 MW, 10 MW et 15 MW. Cette sélection permet de couvrir les parts de marché réelles ainsi que les tendances futures (par exemple, l'importance croissante des turbines offshore de 10-15 MW).

L'impact environnemental a été évalué sur la base du potentiel de réchauffement global (GWP, IPCC 2021), de la demande d'énergie cumulée (CED) et de l'impact environnemental total selon la méthode de la rareté écologique. Les émissions de gaz à effet de serre se situent entre 10.4 et 22.7 g CO_2-eq/kWh. L'énergie éolienne offshore donne des résultats plus élevés que l’énergie éolienne terrestre en raison de l'activité des navires, et malgré des facteurs de capacité plus élevés (~34% pour l'offshore contre ~23% pour l'onshore en Europe et ~19% en Suisse). L’impact du mix éolien suisse vaut 18.1 g CO_2-eq/kWh, ce qui est supérieur à la moyenne européenne qui vaut de 14.9 g CO_2-eq/kWh, en raison de facteurs de capacité plus faibles et de turbines plus petites. L'impact environnemental total et la CED pour le mix suisse sont également 13 à 16% plus élevés que pour le mix européen.

Cette étude améliore la qualité et la représentativité des données sur l'énergie éolienne pour les études d'écobilan et soutient ainsi des calculs plus précis des impacts environnementaux et des décisions politiques en rapport avec les objectifs climatiques et les stratégies de transition énergétique. En outre, elle garantit l'adaptation de la base de données suisse de l'OFEV à l'état actuel de la technologie éolienne.

ABBREVIATIONS

EBoP	Electrical Balance of Plant
ENTSO-E	European Network of Transmission System Operators for Electricity
FOEN	Federal Office for the Environment (CH)
GHG	Greenhouse gas
GWP	Global warming potential
HFO	Heavy fuel oil
MGO	Marine gas oil
NREL	National Renewable Energy Laboratory (USA)
O&M	Operation and maintenance
REMPD	Renewable Energy Materials Properties Database (USA)
SF_6	Sulphur hexafluoride
SFOE	Swiss Federal Office of Energy (CH)
TUM	Technical University of Munich (GER)
ZHAW	Zurich University of Applied Sciences (CH)

TABLE OF CONTENTS

1 INTRODUCTION

Wind energy plays an increasing role in the electricity mixes worldwide. In Europe, the installed capacity doubled from 148 GW to 285 GW in the last decade, covering 19% of the electricity demand in 2024. This trend is expected to continue, with projections of 190 GW newly installed wind power capacity until 2030, according to estimations by WindEurope (Costanzo et al., 2025).

Along with new wind park projects, the technology of wind turbines has also advanced. The average nominal capacity of newly installed onshore wind turbines in Europe increased from 2.5 MW to 4.6 MW in the last decade. At the same time, the average nominal capacity of offshore wind turbines increased from 4.2 MW to 10.1 MW. Projected offshore farms consider turbines of 15 MW and higher (Costanzo et al., 2025).

Despite these advancements, recent environmental assessments of wind energy still largely relied on outdated inventory data, with corresponding background databases dating back to the early 2000s. These models covered only wind turbines with nominal capacities of up to 2 MW and no longer reflected current technologies.

This study provides up-to-date inventories for wind energy for the Swiss Life Cycle Inventories database (FOEN database), focusing on the Swiss and the European context. The inventories cover current technologies and nominal capacities of onshore and offshore wind turbines from 2 MW to 15 MW. Furthermore, the inventories for electricity production from wind energy were updated, considering representative European wind farms and actual capacity factors.

The overall objective of the study is to provide up-to-date inventory for European electricity mix from wind energy and the Swiss electricity from wind energy. These electricity datasets will serve to update national European electricity mixes in the FOEN database and can be used for reliable comparisons within different energy technologies as well as for reliable background data for supply chain inventory.

2 GOAL AND SCOPE

Goal of the present study is to provide up-to-date Life Cycle Inventory (LCI) data of onshore and offshore wind power in the FOEN database (BAFU DQRv2, 2024) for the Swiss and European context. The provided LCI encompasses a total of 39 datasets, including infrastructure datasets on wind turbine level, electricity datasets on wind farm level and datasets for wind electricity mixes. The datasets were compiled according to the FOEN database protocol (Frischknecht et al., 2023). The reference year of this study is 2024.

An overview of the considered turbines, wind farms and electricity mixes is given in section 2.1. The system boundaries of the LCI models are described in section 2.2, followed by a summary of created datasets and corresponding data sources in section 2.3. Section 2.4 describes the impact assessment methods which were used to assess the environmental impact related to the newly created datasets as well as the end-of-life approach used.

The updated inventory is shown in detail in chapters 3 and 4, while the results of the impact assessment are shown in chapter 5. Discussion of the data quality and comprehensiveness and general conclusions is found in chapter 6.

2.1 Overview of turbine types, wind farms and wind electricity mixes

To provide LCI data which was representative for the electricity production from wind power in Switzerland and in Europe, four sizes of onshore wind turbines and three sizes of offshore wind turbines were modelled, covering nominal capacities from 2.3 MW to 15 MW. For each modelled wind turbine size, a corresponding electricity dataset on wind farm level was created. For example, in the case of the 3.4 MW onshore turbines, it was considered that the electricity is produced by a 200 MW wind farm, consisting of 3.4 MW turbines exclusively (see Table 1). The Swiss electricity mix from wind power was modelled as one wind farm consisting of 2.3 MW and 3.4 MW turbines. For the European electricity mix from wind power, all the modelled datasets at wind farm level were used in the respective shares as inputs to create the electricity mix for Europe. Table 1 gives an overview on the considered wind turbine sizes, wind farm sizes, and electricity mixes from wind power.

Table 1 Overview of wind turbine sizes, wind farm sizes and electricity mixes from wind power, which were considered in the derived inventory for wind energy.

	Wind turbine size	Electricity at wind farm level	Electricity mix
Onshore	2.3 / 3.4 MW, onshore, CH		Electricity, at wind farm, CH
	2.3 MW, onshore, RER	Electricity, at 100 MW onshore wind farm, RER	Electricity, at wind farm, RER
	3.4 MW, onshore, RER	Electricity, at 200 MW onshore wind farm, RER	
	4.5 MW, onshore, RER	Electricity, at 100 MW onshore wind farm, RER	
	6.2 MW, onshore, RER	Electricity, at 100 MW onshore wind farm, RER	
Offshore	5 MW, offshore, RER	Electricity, at 150 MW offshore wind farm, RER	
	10 MW, offshore, RER	Electricity, at 740 MW offshore wind farm, RER	
	15 MW, offshore, RER	Electricity, at 1’005 MW offshore wind farm, RER	

The selection of considered wind turbines and wind farm sizes was made based on statistics of installed wind turbines, which are shown in the following paragraphs, as well as based on data availability.

Wind turbine sizes in Switzerland

Onshore wind turbines with nominal capacities of 2.3 MW and 3.4 MW were considered for the electricity mix from wind power in Switzerland.

Being a landlocked country without sea, Switzerland only has onshore wind turbines. As of 2025, the number of installed wind turbines in Switzerland was 47 with a total installed wind power capacity of 100.45 MW (Suisse Eole, 2025). The Swiss wind turbine fleet was modelled as one wind farm, and the wind farm level directly represents the wind electricity mix for Switzerland.

The nominal capacities of installed wind turbines in Switzerland’s 13 wind farms ranged from 0.6 MW to 3.3 MW in 2024. The contributions to the electricity production from wind power per turbine size is shown in Figure 1. About 70% of the electricity from wind power was produced by wind turbines with nominal capacities from 2 MW to 2.35 MW, while about 25% was produced by wind turbines of 3 MW and higher. Consequently, the modelled wind turbines of 2.3 MW and 3.4 MW were used as representative turbine sizes in the Swiss context. Section 4.2.1 describes how the wind turbines with smaller nominal capacities were modelled, in order to account for 100% of the Swiss fleet.

Considering the high share of electricity produced by 2-2.35 MW turbines, the tower materials of the turbines in this size range was investigated. Of the 41 turbines with a capacity of up to 2.35 MW, 21 turbines consist of concrete towers, while 20 turbines consist of steel towers (Bauer & Matysik, 2025; Eymann et al., 2015).

Due to these equally relevant shares, both tower materials were considered for the Swiss electricity mix, as further described in section 4.2.1.

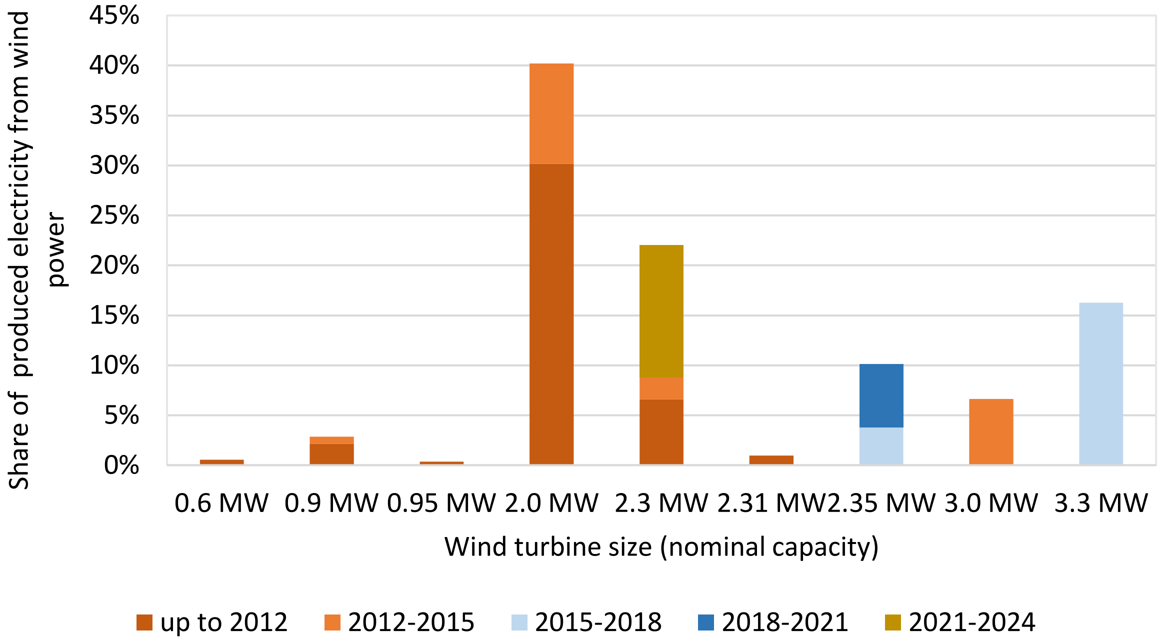

Figure 1 Share of produced electricity in 2024 from wind power per turbine size in Switzerland; given years refer to the year of commissioning; source: (BFE, 2025).

Onshore wind turbine sizes in Europe

To model the electricity production from onshore wind turbines in the European context, four onshore wind turbine sizes with nominal capacities of 2.3 MW, 3.4 MW, 4.5 MW and 6.2 MW were considered.

The distribution of onshore wind turbine sizes installed in Europe between 2000 and 2024, according to their share of total installed onshore capacity is shown in Figure 2. The two modelled turbine sizes of 2.3 MW and 3.4 MW are representative for the most relevant turbine sizes in Europe, together covering a share of installed onshore capacity of about 67% (corresponding to the ranges 2-3 MW and 3-4 MW in Figure 2). The modelled turbine sizes of 4.5 MW and 6.2 MW do not yet play a significant role in the European onshore fleet, considering the share of installed capacity of turbines between 4-7 MW. However, considering that about two thirds of recently installed wind turbines have nominal capacities of 4 MW and higher, these wind turbine sizes are expected to play an increasingly relevant role in the upcoming decade. In contrast, wind turbines with nominal capacities of 1 MW and below were not considered in this study, due to their low share of the installed capacity (<10%), which is expected to further decrease. Section 4.2.2 shows an overview of the modelling choice per range of nominal capacity, in order to account for 100% of the European onshore fleet.

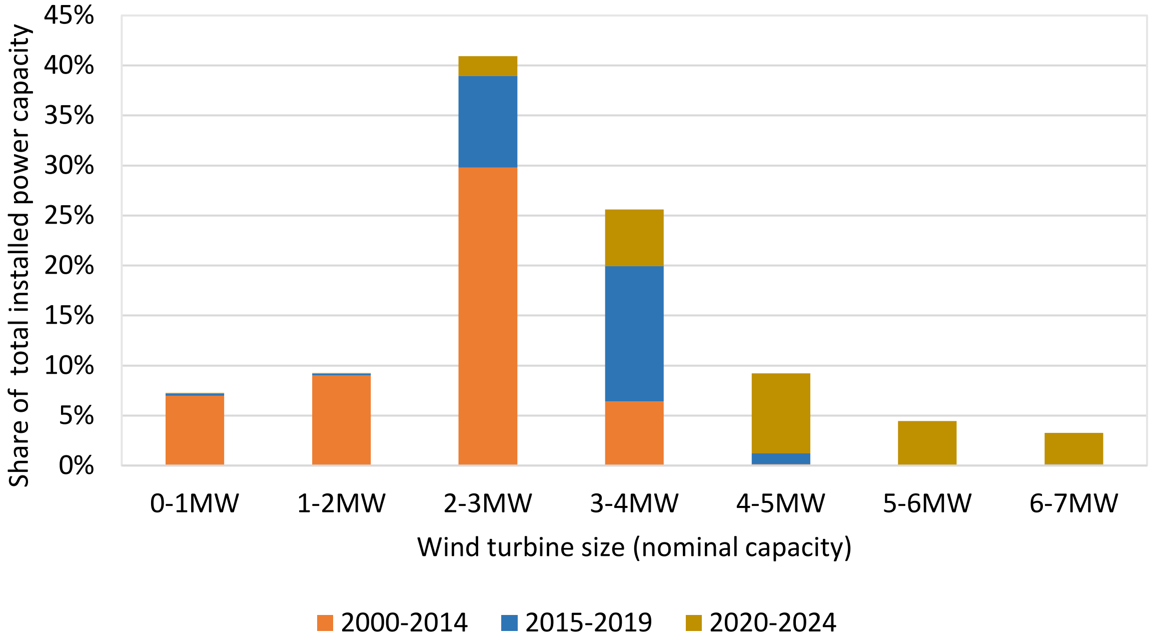

Figure 2 Share of onshore wind power capacity per turbine size in Europe in 2024 (ranges exclude the lower value and include the upper one; i.e. the 2-3MW range refers to wind turbines of >2 MW and <=3 MW); given years refer to the year of commissioning; data source: WindEurope[1].

Offshore wind turbine sizes in Europe

Regarding electricity production from offshore wind turbines in the European context, three offshore wind turbine sizes with nominal capacities of 5 MW, 10 MW and 15 MW were considered.

The distribution of offshore wind turbine sizes installed in Europe, according to their share of total installed offshore capacity, is shown in Figure 3.

Wind turbines with nominal capacities below 4 MW were only installed until 2015 and play a decreasing role in European offshore wind energy. Since 2015, all newly installed turbines had capacities of 4 MW or greater. As of 2024, the nominal capacities between 4 MW and 12 MW accounted for approximately 75% of the European offshore fleet, making the modelled 5 MW and 10 MW turbines representative of the most common current installations. The 15 MW turbine was included to reflect the emerging generation of large-

[1] Statistics on installed wind turbines per commissioning year provided by WindEurope via personal communication.

scale offshore turbines. Turbines with capacities of 12 MW and above represented about 10% of installed capacity in 2024. However, this share is expected to increase in the coming years.

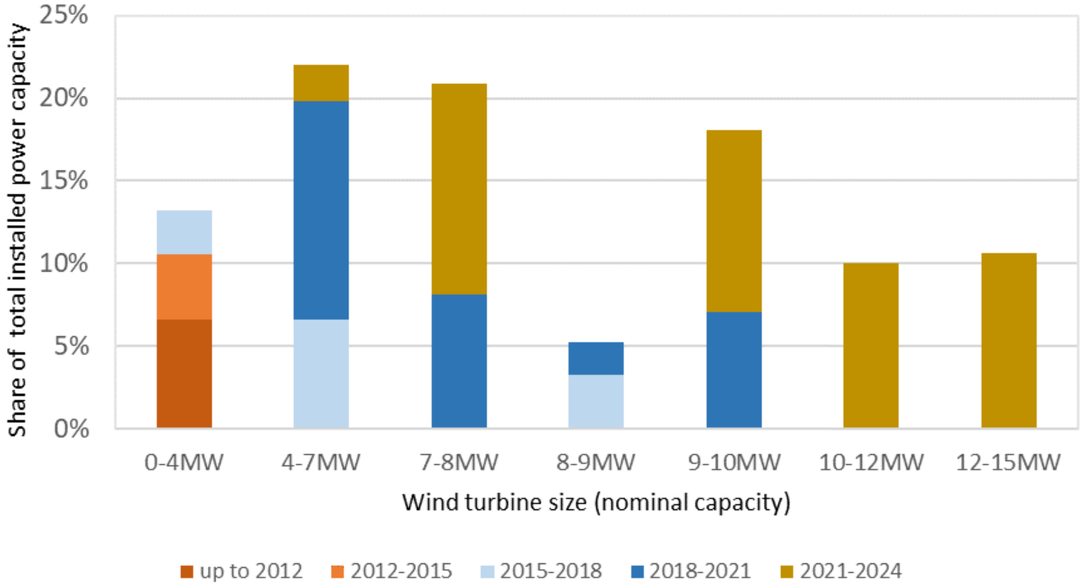

Figure 3 Share of offshore wind power capacity per turbine size in Europe in 2024 (given ranges for nominal capacity and years exclude the lower value and include the upper one; i.e. the 4-7MW range refers to wind turbines of >4MW and <=7MW); given years refer to the year of commissioning; data source: values are derived based on the data compilation of European offshore wind farms by Grothe et al. (2022).

2.2 System boundaries and dataset structure

The established LCI data includes all life cycle stages of electricity produced from wind energy. As depicted in Figure 4, the entire life cycle can be divided into four major stages being:

1. component manufacturing
2. installation
3. operation and maintenance (O&M) and
4. decommissioning & waste treatment.

Separate infrastructure datasets were created for the wind turbines and the Electrical Balance of Plant (EBoP). Infrastructure datasets for wind turbines consist of a dataset for the moving parts (including blades, hub and nacelle), a dataset for the tower and a dataset for the foundation/substructure. The EBoP is divided into four separate infrastructure datasets in the case of offshore wind power, being array cable, export cable, land-based substation and offshore substation. In the case of onshore wind power, the EBoP consists of two infrastructure datasets being array and export cable combined and the substation. Each infrastructure dataset includes manufacturing transportation, installation, decommissioning and waste treatments for original and replaced components, according to their relative shares.

The infrastructure datasets are used as inputs to the electricity dataset, which describes the electricity production at wind farm, expressed in the functional unit of *1 kWh of electricity at wind farm*. O&M of the wind farm and, in the case of onshore wind power road construction, are modelled as direct inputs into the electricity dataset and include e.g. oil exchange and service vessel activities. The electricity datasets at wind farm are then used as inputs to the European electricity mix, while for the Swiss electricity mix, the wind farm level simultaneously represents the electricity mix. Finally, sulphur hexafluoride (SF_6), of which leakages occur from the switchgear used in wind turbines and substations, is modelled as a direct emission from the electricity dataset.

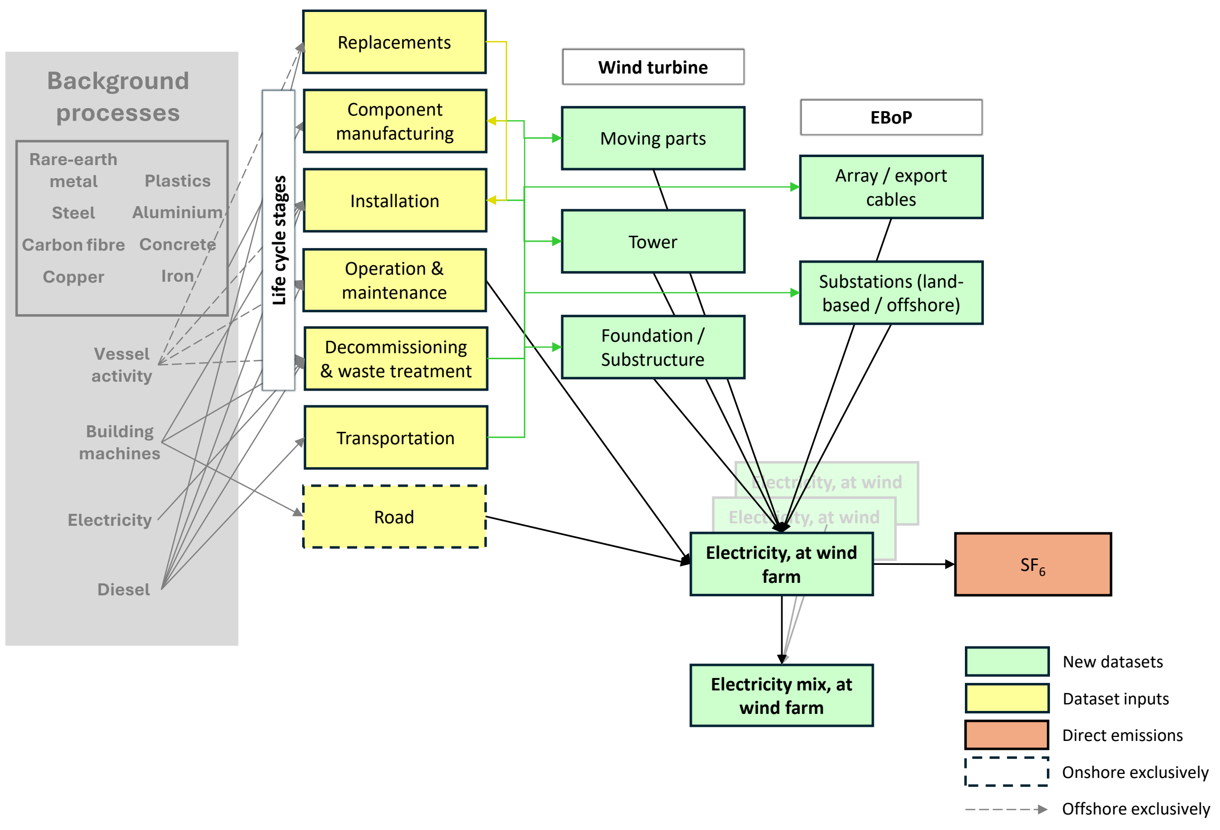

Figure 4 System boundary and structure of the datasets for the electricity production from wind power. Green boxes are created datasets, yellow boxes reflect inputs to these datasets and red boxes are direct emissions. The dashed box indicates inputs only present in electricity production from onshore wind power, while the dashed arrows represent inputs only present in electricity production from offshore wind power.

2.3 Datasets and data sources

The background data used in this study is an unpublished pre-version of the 2025 FOEN database (pre-version from August 2024).

The new datasets created in this study and the primary data sources are listed in Table 2.

The 2.3 MW turbine from Enercon was modelled based on published data from Enercon (2011) and Eymann et al. (2015). This specific model was selected because the E-82 turbine accounts for a majority of wind turbines currently installed in Switzerland, making it a representative choice for national-scale assessments. As the wind turbines installed in Switzerland have a close to equal share of concrete and steel towers, an additional dataset for a steel tower was created, based on the Vestas V90-2.0 MW turbine (Eymann et al., 2015; Garrett & Rønde, 2011).

The modelled 3.4 MW onshore wind turbine represents a reference wind turbine developed within IEA Wind Task 37 (Bortolotti et al., 2019). The main data source for this wind turbine is the *Renewable Energy Material Property Database* (REMPD), compiled by the National Renewable Energy Laboratory (NREL) (Cooperman et al., 2023). This data source further includes data for a substation, which was used for all onshore wind farms.

The 4.5 MW and 6.2 MW onshore wind turbines were modelled based on published LCA studies by Vestas (Mali & Garrett, 2023; Martinez Aguado & Garrett, 2025). The data for the cabling of the wind farms was extracted from the study of the 4.5 MW wind turbine and used for all onshore wind farms.

Regarding offshore wind power, the modelled 5 MW wind turbine is based on the REpower 5M turbine using a jacket foundation (REpower, 2025). The corresponding modelled 150 MW wind farm represents the Ormonde offshore wind farm in the Irish Sea, approximately 10 km off the coast of Barrow-in-Furness, Cumbria, UK (Ormiston, 2012). The REpower 5M turbine served as basis for the 5 MW offshore reference wind turbine defined by the IEA (Jonkman et al., 2009). Inventories of materials of the 5 MW offshore wind turbine and the 150 MW wind farm were mainly drawn from the publication by Kouloumpis and Azapagic (2022).

The offshore wind turbines of 10 MW and 15 MW also represent the IEA reference wind turbines, defined in the IEA Wind Task 37 (Bortolotti et al., 2019; Gaertner et al., 2020). The considered offshore wind farm using 10 MW wind turbines represents the IEA reference wind farm *IEA Wind 740-10 MW Reference Offshore Wind Plant*, derived in the IEA Wind Task 55 (Kainz, Quick, et al., 2024).

For the IEA Wind 740-10 MW Reference Offshore Wind Plant, detailed LCI was provided by the Wind Energy Institute of the Technical University of Munich - hereinafter abbreviated as TUM (Kainz, 2025). The LCI had been calculated specifically for this project with TUM's *Design and Evaluation Toolchain with Eco-Conscious Targets,* DETECT, and included material quantities, replacements, fuel consumptions for vessel activities and end-of-life treatment rates. To calculate the mass-per-material specific inventory of turbine and balance-of-plants components, DETECT relies on common scaling models from literature. Descriptions regarding the DETECT toolchain can be found in Kainz, Guilloré, et al. (2024), and a detailed Wind Energy Science (WES) research article about DETECT is currently under preparation. ANNEX VII (page 72) provides detailed information regarding data sources and assumptions used by TUM for the model of the 740 MW wind farm using 10 MW wind turbines. The DETECT toolchain was also used to derive life cycle vessel activities of the Ormonde offshore wind farm using 5 MW offshore wind turbines. Furthermore, the results for life cycle vessel activities for the 740 MW offshore wind farm were used to estimate life cycle vessel activities for the 1005 MW wind farm using 15 MW offshore wind turbines.

The REMPD was used as main data source for IEA 15 MW offshore wind turbine, as well as for the offshore substation of the corresponding 1005 MW wind farm (Cooperman et al., 2023).

Electricity mixes from wind energy on Swiss and European level were compiled using the created electricity datasets on wind farm level and applying capacity factors based on published statistics by the Swiss Federal Office for Energy and the European Network of Transmission System Operators for Electricity (ENTSO-E).

Table 2 Overview of created datasets for wind turbines, electric infrastructure, electricity at wind farm level and electricity mixes from wind power, as well as primary data sources used. In blue, datasets are shown which are modelled based on one data source and scaled to the other wind farms.

	New datasets	Main data sources
Onshore wind power 2.3 MW wind turbine	wind turbine 2.3 MW, onshore, moving parts {RER} wind turbine 2.3 MW, onshore, tower, concrete {CH} wind turbine 2.3 MW, onshore, tower, steel {CH} wind turbine 2.3 MW, onshore, foundation {RER} electricity, at 100 MW wind farm, onshore, 2.3MW turbines {RER}	**Enercon** (Eymann et al., 2015)**,** based on (Enercon, 2011)
Onshore wind power 3.4 MW wind turbine	wind turbine 3.4 MW, onshore, moving parts {RER} wind turbine 3.4 MW, onshore, tower {RER} wind turbine 3.4 MW, onshore, foundation {RER} substation, 200MW onshore wind farm {RER} electricity, at 200MW wind farm, onshore, 3.4MW turbines {RER}	**NREL, REMPD** (Cooperman et al., 2023), based on IEA reference wind turbine (Bortolotti et al., 2019)
Onshore wind power 4.5 MW wind turbine	wind turbine 4.5 MW, onshore, moving parts {RER} wind turbine 4.5 MW, onshore, tower {RER} wind turbine 4.5 MW, onshore, foundation {RER} array and export cables, 33kV/110kV, onshore wind farm {RER} electricity, at 100MW wind farm, onshore, 4.5 MW turbines {RER}	**Vestas** (Martinez Aguado & Garrett, 2025)
Onshore wind power 6.2 MW wind turbine	wind turbine 6.2 MW, onshore, moving parts {RER} wind turbine 6.2 MW, onshore, tower {RER} wind turbine 6.2 MW, onshore, foundation {RER} electricity, at 100MW wind farm, onshore, 6.2MW turbines {RER}	**Vestas** (Mali & Garrett, 2023)
Offshore wind power 5 MW wind turbine	wind turbine 5 MW, offshore, moving parts {RER} wind turbine 5 MW, offshore, tower {RER} wind turbine 5 MW, offshore, jacket substructure {RER} substation, offshore 150MW offshore wind farm {RER} electricity, at 150MW wind farm, offshore, 5MW turbines {RER}	**(Kouloumpis & Azapagic, 2022**); **TUM** (Kainz, 2025)
Offshore wind power 10 MW wind turbine	wind turbine 10 MW, offshore, moving parts {RER} wind turbine 10 MW, offshore, tower {RER} wind turbine 10 MW, offshore, monopile substructure {RER} array cable, 66kV, offshore wind farm {RER} export cable, 220 kV, offshore wind farm {RER} substation, offshore, 740MW offshore wind farm {RER} substation, land-base, 740MW offshore wind farm {RER} electricity, at 740MW wind farm, offshore, 10MW turbines {RER}	**TUM** (Kainz, 2025); **IEA** (Bortolotti et al., 2019); **IEA** (Kainz, Quick, et al., 2024)
Offshore wind power 15 MW wind turbine	wind turbine 15 MW, offshore, moving parts {RER} wind turbine 15 MW, offshore, tower {RER} wind turbine 15 MW, offshore, monopile substructure substation, offshore, 1005MW offshore wind farm {RER} electricity, at 1005MW wind farm, offshore, 15MW turbines {RER}	**NREL, REMPD** (Cooperman et al., 2023), **IEA** (Gaertner et al., 2020)
Electricity mix, CH	electricity, at wind farm {CH}	(BFE, 2025)
Electricity mix, Europe	electricity, at wind farm {RER}	Own statistics based on ENTSO-E (ENTSO-E, 2017, 2018, 2019, 2023a, 2023b, 2024c, 2024a, 2024b, 2025), WindEurope, and Grothe et al. (2022)

2.4 Impact assessment methods and end-of-life allocation

To evaluate the LCI models established in the present study, the impact assessment methods listed in Table 3 were applied. The choice of the assessment methods was based on the required impact categories to be assessed, according to the FOEN database protocol (Frischknecht et al., 2023).

Regarding the end-of-life modelling, the cut-off approach was used, where environmental burdens are assigned to the production and disposal phases of a product, excluding any benefits from recycling at end-of-life. Recycled materials entering the system are considered burden-free, while materials leaving the system for recycling carry no credits.

Table 3 Environmental indicators and impact assessment methods applied in the present study, according to the FOEN database protocol (Frischknecht et al., 2023).

Environmental indicator	Assessment method	Description
Global warming potential	IPCC (2021)	The assessment climate change according to IPCC 2021 takes into account all emissions that contribute to climate change. The potential climate impact of a greenhouse gas is compared with the climate impact of CO_2 and expressed in CO_2 equivalents.
Total environmental impact	Ecological scarcity method (Frischknecht et al., 2021)	The total environmental impact is assessed using the ecological scarcity method, which weights emissions and resource consumption based on current flows and target values. The result is expressed in eco-points.
Cumulative energy demand	Frischknecht et al. (2007)	The cumulative energy demand (CED) indicates the consumption of renewable and non-renewable energy resources over the entire life cycle of a product. Both direct and indirect energy consumption are taken into account. Results are expressed in MJ equivalents.

3 LIFE CYCLE INVENTORIES OF WIND TURBINES AND ELECTRICAL BALANCE OF PLANT

This chapter describes the inventory of the new datasets for wind turbines and EBoP of wind farms. An overview of the key parameters is given in section 3.1.

Section 3.2 describes the inventory of the component manufacturing, giving materials quantities (including replacement) and materials processing.

The inventory of all transportation processes is described in section 3.3. This includes the transportation of raw materials to the sites of component manufacturing, the transportation of components to the sites of installation as well as the transportation at end-of-life to the waste treatment sites.

Section 3.4 covers the inventory needed for the installation of components, including replacements, while section 3.5 summarises the modelled end-of-life treatment of materials.

The full life cycle inventory of wind turbines and the electrical balance of plant is included in Annex I (wind turbines, page 61) and Annex II (EBoP, page 63)

3.1 Key parameters

The lifetime of all modelled wind turbines and EBoP was set to 25 years. Further key parameters of the modelled wind turbines are listed in Table 4. The main data sources of each turbine are listed in Table 2.

The average water depth and distances to installation port and service port for the offshore 5 MW wind turbine were defined based on data and location of the existing Ormonde wind farm. For the 10 MW wind turbine average water depth and distances to ports represents the IEA reference wind farm. For the 15 MW offshore wind farm, the REMPD did not include specific data regarding distances to ports. As these distances were needed to estimate the fuel consumption for vessel activities during installation, maintenance and decommissioning, the same distances were assumed as for the 10 MW wind turbine, which allowed to estimate reliable fuel consumptions for the 15 MW turbine based on the values derived by TUM for the 10 MW turbine, by upscaling based on component weight (see section 3.4.2).

Table 4 Key parameters of the onshore and offshore wind turbines. Inputs marked in *italic* represent data which were not extracted from the primary data sources, but which are based on assumptions.

		onshore				offshore		
Parameter	Unit	Wind turbine, 2.3 MW	Wind turbine, 3.4 MW	Wind turbine, 4.5 MW	Wind turbine, 6.2 MW	Wind turbine, 5 MW	Wind turbine, 10 MW	Wind turbine, 15 MW
Lifetime	a	25	25	25	25	25	25	25
Hub height	m	107 / 95 [a]	110	98	149	90	119	150
Rotor diameter	m	82	130	163	162	126	198	240
Tower type	-	Concrete / steel	Steel	Steel	Steel	Steel	Steel	Steel
Foundation type	-	-	-	-	-	Jacket	Monopile	Monopile
Water depth	m	-	-	-	-	19	34	18
Distance to installation port	km	-	-	-	-	*187* [b]	80	*80* [c]
Distance to service port	km	-	-	-	-	*10* [b]	50	*50* [c]

[a] the 107 m refer to the concrete tower, the 95 m refer to the steel tower.
[b] assumption: Belfast as installation port and Barrow-in-Furness as service port
[c] own assumption

3.2 Component manufacturing

An overview of the main materials used in each wind turbine is given in Table 5. The total masses per component and wind turbine, along with the masses per MW are indicated in Table 6. No additional cut-off regarding material masses was applied in the present study. Information on cut-off criteria in the original data sources is only indicated for the 4.5 MW and 6.2 MW onshore turbine, where cut-off criteria of 0.1% was applied regarding masses and 1% regarding energy flows. For the 5 MW offshore wind turbine, the material quantities included a 1% cut-off regarding material mass and an increase of all other material masses to compensate the cut-off (Kouloumpis & Azapagic, 2022). Not specified materials, which were summarised as “others” in the original data sources by NREL in the REMPD (Cooperman et al., 2023), were accounted for by increasing the quantities of known materials proportionally, i.e. according to their share of the total mass.

All material quantities given in Table 5 and Table 6 include replacements over the lifetime of 25 years, according to the replacement rates given in Table 8. The recycled contents of materials are defined in the used background datasets. These are, e.g., 43% in low-alloyed steel, 37% in chromium steel, 30% in copper, 49% in aluminium and 35% in cast iron (version 2022 of the FOEN database (UVEK DQRv2, 2022)).

For the 4.5 MW and 6.2 MW Vestas turbines, the material masses on turbine level were only available for moving parts as a total, and the tower and foundation separately. For means of consistency, the moving parts were divided into blades, nacelle and hub according to the ratio of these components of the 3.4 MW turbine.

For the 15 MW offshore wind turbine, total masses for hub, nacelle and monopile substructure given in the REMPD (Cooperman et al., 2023) were not consistent with the values included in the IEA description of the 15 MW reference wind turbine (Gaertner et al., 2020). Consequently, the materials quantities as given in the REMPD were scaled to reach the masses of 190’000 kg for the hub, 630’888 kg for the nacelle and 1’318’000 kg for the monopile substructure without scour protection (values without replacements), as given in Gaertner et al. (2020).

Regarding lubrication oil, the value of 111 kg per MW was extracted from Mali and Garrett (2023) and was applied to all onshore and offshore wind turbines for means of consistency.

ANNEX V (page 67) includes a complete list of all used background datasets for materials. In general, material datasets for the region Europe were used (RER), which is for most materials the only region available. The RER datasets represent the average of the world and European production mix, which is assumed to correspond to the consumption mix in Europe (BAFU DQRv2, 2024). In cases where the material datasets did not already include processing of raw materials, additional processing background datasets were used, which are also included in Annex V. This mainly concerned steel, cooper, aluminium and plastic materials.

Table 5 Overview of the main materials of each wind turbine. The given quantities refer to a lifetime of 25 years and include replacements. The materials are divided into the different wind turbine components. Inputs marked in *italic* represent data derived by extrapolation based on values for other turbines.

				onshore				offshore		
Dataset	Component	Material	Unit	**Wind turbine, 2.3 MW**	**Wind turbine, 3.4 MW**	**Wind turbine, 4.5 MW [b]**	**Wind turbine, 6.2 MW [b]**	**Wind turbine, 5 MW**	**Wind turbine, 10 MW**	**Wind turbine, 15 MW**
Moving parts	Blades	Fiberglass	t	30	32	*34*	*46*	45	88	146
		Epoxy	t	-	11	-	-	18	48	29
		Polyester, PCV, other polymers	t	-	6.2	*26*	*36*	1.3	22	43
		Steel	t	1.2	0.88	*1.0*	*0.95*	-	5.1	6.1
		Wood	t	-	1.9	-	-	3.3	-	17
		Carbon fibre	t	-	1.9	-	-	-	-	13
	Nacelle	Steel	t	98	62	*80*	*117*	169	236	347
		Iron	t	78	25	*58*	*75*	138	-	235
		Copper	t	13	3.6	*3.1*	*5.0*	14	61	46
		Aluminium	t	1.3	1.1	*1.9*	*3.0*	6.0	15	13
		Glass-reinforced plastic	t	-	1.6	-	-	-	-	6.0
	Hub	Steel	t	-	15	*18*	*18*	33.0	137	154
		Iron	t	-	8.0	*21*	*27*	29.0	-	47
		Aluminium	t	-	0.03	*0.06*	*0.09*	-	14	0.14
Tower		Steel	t	103 / 139 [a]	302	247	478	217	552	636
		Aluminium	t	- / 2.9 [a]	1.7	2.7	5.8	4.0	-	4.9
		Concrete	t	791 / - [a]	-	-	-	-	-	-
Foundation / Substructure		Concrete	t	1’091	1’339	1’445	2’454	-	-	-
		Steel	t	52	70	79	127	729	1’047	1’275
		Manganese	t	-	1.3	-	-	-	-	24
		Nickel	t	-	1.3	-	-	-	-	18
		Scour protection/crushed rock	t					*2’006* [c]	2’006	*2’477* [c]

[a] first value refers to concrete tower, second value to steel tower

[b] values for moving parts derived from material distribution of 3.4 MW onshore turbine

[c] values for scour protection derived by scaling the value for 10 MW offshore turbine according to assumed occupied areas on seabed: 127 m² (5 MW), 127 m² (10 MW), 157 m² (15 MW)

Table 6 Total masses and masses per MW for component of considered wind turbines.

			onshore				offshore		
	Component	Unit	Wind turbine, 2.3 MW	Wind turbine, 3.4 MW	Wind turbine, 4.5 MW	Wind turbine, 6.2 MW	Wind turbine, 5 MW	Wind turbine, 10 MW	Wind turbine, 15 MW
Moving parts	Blades	t	31	54	61	83	67.0	170	254
	Nacelle	t	190	96	152	211	336	485	672
	Hub	t	- [a]	24	39	46	64	151	202
	Total	t	221	173	251	340	467	805	1’129
	Total per MW	t/MW	96	51.0	56	55	93	81	75
Tower	Total	t	894 / 146 [b]	305	250	484	221	552	645
	Total per MW	t/MW	389 / 63 [b]	90	56	78	44	55	43
Foundation / Substructure	Total	t	1’143	1’412	1’524	2’580	750 [c]	1’066 [c]	1’318 [c]
	Total per MW	t/MW	497	415	339	416	150 [c]	106 [c]	88 [c]
Total per turbine		**t**	**2’258 / 1’510 [b]**	**1’890**	**2’026**	**3’404**	**1’438 [c]**	**2’423 [c]**	**3’092 [c]**
Total per turbine, per MW		**t/MW**	**982 / 656 [b]**	**556**	**450**	**549**	**288 [c]**	**242 [c]**	**206 [c]**
Total turbine (without substructure), per MW		**t/MW**	**485 / 159 [b]**	**141**	**111**	**133**	**138**	**136**	**118**

[a] weight of the hub is included in the nacelle
[b] first value refers to the turbine with a concrete tower, the second value refers to the turbine with a steel tower
[c] without crushed rock for scour protection

An overview of the main materials used in the modelled EBoP is given in Table 7.

For the onshore wind farms, the array and export cables were modelled in one dataset, per km of cable length. The data for the cabling was taken from the Vestas study of the 100 MW wind farm consisting of 4.5 MW turbines and consists of 33 kV array cables combined with 110 kV export cables (Martinez Aguado & Garrett, 2025). The data for the substation of the onshore wind farms was based on the 200 MW wind farm by NREL (Cooperman et al., 2023).

In the case of offshore wind, a 66 kV array cable and a 220 kV export cable were modelled in separate datasets and per km. The size of array cables depends on how many wind turbines are connected to transmit the generator electricity from the wind turbines to the offshore substation. The model by TUM for the 740 MW offshore wind farms considered five different sizes of array cables, with copper conductor cross-sectional areas between 95 mm^2 and 500 $mm^{2.}$ In this study, only one dataset for an average 66 kV array cable was created based on the material quantities given in the TUM data compilation. Export cables transmit the electricity from the offshore substation to shore. Their size depends on the power capacity of the wind farm. The inventory used for the 220 kV export cable was taken directly from the TUM data of the 740 MW offshore wind farm which assumed three parallel export cables of a conductor cross-sectional area of 1’000 mm^2. The new datasets for array and export cables were also used as approximation for the cabling of the 150 MW and the 1’005 MW offshore wind farms.

Offshore substations were modelled specifically for each considered wind farm. The dataset for the land-based substation was modelled specifically for the 740 MW offshore wind farm. This dataset was also used for the 1’005 MW offshore wind farm, by upscaling the inventory based on the installed capacity.

The EBoP components which were used for each onshore and offshore wind farm and details on the applied scaling factors are described in section 4.1.

Table 7 Main materials of the EBoP components. The given quantities refer to a lifetime of 25 years and include replacements.

		Onshore wind farms		**Offshore wind farms**					
		Array and export cables	Sub-station 200 MW	Array cable, 66 kV	Export cable, 220 kV	substation, offshore, 150MW wind farm	substation, land-based, 740 MW wind farm	substation, offshore, 740MW wind farm	substation, offshore, 1005MW wind farm
Material	Unit	**[km]**	**[p]**	**[km]**	**[km]**	**[p]**	**[p]**	**[p]**	**[p]**
Steel	t	-	223	9.7	19	1'325	391	5'837	7'460
Copper	t	0.93	41	6.8	25	54	83	84	82
Aluminium	t	3.7	0.91	-	-	90	40	41	-
Lead	t	-	0.012	7.1	29	-	-	-	-
Manganese	t	-	-	-	-	-	-	-	139
Nickel	t	-	-	-	-	-	-	-	104
PP/PE	t	8.1	0.34	6.0	25	-	-	-	-
Transformer oil	t	-	-	-	-	151	163	163	-
Concrete	t	-	125	-	-	-	-	-	-
Wood	t	-	-	-	-	-	18	18	-
Fiberglass	t	-	2.6	-	-	-	3.8	3.8	-
Total mass	**t**	**13**	**418**	**32**	**104**	**1'620**	**721**	**6'174**	**7'795**
Total mass, per MW	**t/MW** [a]	**-**	**2.1**	**-**	**0.42** [b]	**11**	**0.98**	**8.3**	**7.8**

[a] referred to the power capacity of the wind farm

[b] value per MW and km; three parallel exports cables are assumed for the 740 MW offshore wind farm**,** i.e. the total mass of export cable was divided by (740/3) to derive mass per MW

Based on Burger and Bauer (2007), an electricity consumption of 0.5 kWh/kg was assumed for the assembly of the rotor and nacelle. This electricity input was added to the moving parts dataset of each wind turbine.

SF_6, an insulation gas with unique dielectric properties, is used in wind turbines within the switchgear, where it is responsible for voltage electrical insulation, current interruption and arc quenching (Pan et al., 2020). Regarding the inputs of SF_6, the value for onshore and offshore wind turbines was extracted from Martinez Aguado & Garrett (2025). According to the study, 1.8 kg of SF_6/MW were used over the lifetime of each wind turbine. This resulted in SF_6 inputs between 4.2 kg for the 2.3 MW onshore wind turbine and 27.3 kg for the 15 MW offshore wind turbine.

For the 150 MW offshore wind farm, an input of 42 kg of SF_6 was used for the offshore substation (Kouloumpis & Azapagic, 2022). For 740 MW offshore wind farm, the SF_6 input was provided by TUM (Kainz, 2025), with 83 kg of SF_6 in the offshore substation. For the 1'005 MW offshore wind farm, no SF_6 input was considered according to the REMPD (Cooperman et al., 2023). Leakage was not modelled as part of infrastructure datasets, but as part of electricity datasets at wind farm level (see section 4.1.3).

Land occupation was considered as the surface area of the foundation occupying industrial area and seabed for onshore and offshore wind turbines respectively. For the onshore wind turbines, the required surface for the foundation was calculated so that the average pressure is 2 kg/cm2 (Treyer & Bauer, 2024). For the offshore wind turbines, the required surface for the foundation was calculated based on the outer diameter of the monopile. E.g. for the 2.3 MW onshore turbine, the land occupation is 111 m2, while for the 15 MW offshore turbine, the seabed occupation is 157 m2. For the 5 MW offshore wind turbine, which uses a jacket foundation, the same seabed area of 127 m2 as for the 10 MW wind turbine (using a monopile foundation) was assumed.

Yearly replacement rates for the moving parts were provided by TUM (Kainz, 2025) for the 10 MW offshore wind turbine and are adopted for all wind turbines. TUM estimated the following yearly replacement rates for components of the wind turbine: blades (0.08%), hub/pitch/nose (0.50%), generator (0.64%), electronics (0.05%), and nacelle (0.05%)[2]. As the used data sources for different wind turbines are not homogenous regarding granularity of single turbine components, these specific material replacement rates of hub/pitch/nose, generator and nacelle were transformed into average replacement rates per material in the total moving parts (excl. blades). The resulting material replacement rates are summarized in Table 8.

Apart from the replacements of moving parts of wind turbines, no other replacements are considered.

Table 8 Summary of yearly replacement rates for blades and different materials of the moving parts of wind turbines.

Component	Material	Yearly replacement rate [%/a]	Total replacement rate over 25 years [%]
Blades	All materials	0.08	2.08
Moving parts (excl. blades)	Chromium steel	0.42	10.6
	Copper	0.55	13.7
	Plastics, pastes and paintings	0.05	1.30
	Electronics	0.05	1.30
	Remaining materials	0.24	6.11

3.3 TRANSPORTATION

Transportation was modelled in the datasets for wind turbine components and EBoP as a sum of all transportation activities over the entire life cycle of the components. This includes three steps of transportation which are described in the following separate sections. The first step represents the transportation of all materials to the manufacturing site of the wind turbine and EBoP components, while

[2] Material replacement rates are significantly lower than the correspondingly considered component failure rates as for the considered replacement activities only parts of the original component are being replaced.

the second step includes the transportation of the components to the onshore wind farm site or to the offshore wind farm port of installation. The third step includes transporting the components to the respective waste treatment site at the end of life. All details of the modelled transportations can be found in Annex I and Annex II.

3.3.1 Transportation of materials to manufacturing site of components

The transport distances of the materials to the component manufacturing sites were based on the standard distances described in the FOEN database protocol (Frischknecht et al., 2023). The protocol describes transport distances to be used for train and lorry, differing between consumption of materials in Europe and in Switzerland. As all components modelled in this work were assumed to be manufactured outside Switzerland, European distances were used for all materials. The materials were summarised according to the needs of this study and consist of the material groups mineral products, metals, plastics, wood and basic chemicals, as depicted in Table 9. The detailed allocation of all used materials to the specific transportation group are included in Annex V (page 67).

Table 9 Transport distances to the manufacturing sites used for all materials of the wind turbine and EBoP components, based on the FOEN database protocol (Frischknecht et al., 2023).

		consumption in Europe	
Material group	**Material**	Train [km]	Lorry 32 t [km]
Mineral products	gravel / sand	-	50
	cement	100	100
	concrete	-	50
	float glass	600	100
Metals	aluminium	200	100
	other metals	200	100
Plastics	plastics	200	100
Wood (from Swiss forests):	sawn timber	100	50
	structural timber (softwood)	-	100
	particle board	200	50
Basic chemicals, inorganic and organic	other chemicals	600	100
	hydrochloric acid	200	100

3.3.2 Transportation of components to wind farm site

The transportation of the components to the wind farm site were based on different sources for onshore and offshore wind farms and are summarised in Table 10. Regarding the transportation of components to onshore wind farm sites, the transport distances were extracted from the Vestas study of the 100 MW wind farm consisting of 6.2 MW turbines, as it is assumed to be located in Germany, Europe (Mali & Garrett, 2023).

For the offshore 10 MW turbine, the transportation distances for the components to the wind farm site were obtained from the data compilation by TUM (Kainz, 2025). Transport distances for the components of the 5 MW offshore turbine were available specifically for the modelled Ormonde (Ireland) wind farm from Kouloumpis & Azapagic (2022). Transportation distances for the components of the 15 MW offshore turbine were assumed to be the same as for the 5 MW turbine, as the corresponding wind farm was a fictitious case for which no specific distances were available.

Regarding offshore wind farms, the transportation distances given in Table 10 refer to the transportation of components to the port of installation. The transportation via ship from the port to the actual installation site at sea was taken into account as part of the installation phase (see section 3.4).

Table 10 Transport distances used for components to the wind farm site; sources: Razdan & Garrett (2017) for onshore, Kainz (2025) for 10 MW offshore, Kouloumpis & Azapagic (2022) for 5 MW and 10 MW offshore.

		Onshore All turbines		**Offshore 10 MW turbine**		**Offshore 5/15 MW turbine**	
	Component	Lorry [km]	Ship [km]	Lorry [km]	Ship [km]	Lorry [km]	Ship [km]
Turbine	Blades	1’450	5’100	900	1’900	0	800
	Nacelle	600	9’000	800	-	0	800
	Hub, Pitch and Nose	600	8’600	300	3’100	0	800
	Tower	425	-	500	4’500	0	800
	Foundation / substructure	50	-	500	4’500	200	0
EBoP	Cables	600	-	600	-	200	0
	Substation, land-based	600	-	500	4’500	200	0
	Substation, offshore	-	-	500	4’500	200	0

3.3.3 Transportation of components to waste treatment site

At the end of the service life, all components were assumed to be transported to a respective waste treatment site. One exception are the recycling materials, where the cut-off is applied before their transportation to the recycling site, according to the FOEN database protocol. Another exception is the crushed rock which is used as scour protection for offshore wind turbines, and which was assumed to be left in the sea. The assumed distances for the transportation to the waste treatment site were based on the average distances for wastes as described in the FOEN database protocol and are summarised in Table 11 (Frischknecht et al., 2023). Information on the waste treatment process per material can be found in section 3.5.

Table 11 Transport distances used for all components to the waste treatment site, based on the FOEN database protocol (Frischknecht et al., 2023).

Waste treatment process	Distance
	Lorry [km]
municipal waste incineration	10
sanitary landfill	10
residual material landfill	50
inert material landfill	15

3.4 Installation

3.4.1 Installation of onshore wind turbine

The energy needed for the erection the onshore wind turbine was estimated based on the potential energy:

$$E_{pot} = m*g*h,$$

where m is the mass of the object, g is the acceleration due to gravity and h is the height of the object to be erected. For the erection of the tower, half the hub height is used (Burger & Bauer, 2007; Eymann et al., 2015). In addition to the energy needed for assembly and erection of the wind turbine, the excavation of the installation site was considered. Excavation volumes were calculated by considering the volume of the concrete of the foundation plus an additional 50% to account for over-excavation. This allowance reflects the practical requirement to excavate beyond the exact dimensions of the foundation to facilitate proper placement and compaction. The assumed energy consumption for the installation of each onshore wind turbine is summarised in Table 12 and can be seen per component in Annex I on page 61.

Table 12 Assumed energy consumption and material excavation for the installation of each onshore wind turbine.

	Unit	2.3 MW turbine, onshore	3.4 MW turbine, onshore	4.5 MW turbine, onshore	6.2 MW turbine, onshore
Hub height	m	107 / 95 [a]	110	98	149
Mass, moving parts and tower	t	1’074 / 327 [a]	478	497	817
Mass, total wind turbine	t	2’217 / 1’470 [a]	1’890	2’021	3’398
E_{pot}	MJ	658 / 257 [a]	351	347	856
Excavation	m^3	688	844	910	1’546

[a] the first value refers to the turbine with a concrete tower, the second value refers to the turbine with a steel tower.

3.4.2 Installation of offshore wind turbines and EBoP

Data regarding the installation processes for the 10 MW offshore wind turbine and electrical offshore infrastructure (cables and offshore substation) was provided by TUM (Kainz, 2025), which used the DETEC toolchain to derive heavy fuel oil (HFO) and marine gas oil (MGO) consumptions of employed vessels during installation as well as port crane operation hours. TUM also used the DETECT toolchain to provide corresponding data for the installation process of the 5 MW offshore wind turbine and the corresponding offshore substation of the 150 MW wind farm, considering the specific distance to the installation port and the jacket substructure type. Fuel consumption and crane operation hours for the 10 MW turbine and the offshore substation of the 1005 MW wind farm were assumed by scaling the values for the 10 MW offshore turbine based on the weight of components.

HFO and MGO consumptions were both modelled as *Transport, transoceanic freight ship {OCE}*, using the conversion factor of 649 tkm/kg fuel based on the amount of fuel per tkm in the dataset.

Regarding port crane operation, a diesel consumption of 16 kg/h was assumed (CranesToday, 2020). The crane operation was modelled as *Diesel, burned in building machine, average {CH},* which considers a specific energy density of diesel of 42.8 MJ/kg.

The fuel consumptions and port crane hours for the components of the 10 MW offshore wind turbine and electrical offshore infrastructure are summarized in Table 13 and Table 14, together with the resulting input values for *Transport, transoceanic freight ship {OCE}* and *Diesel, burned in building machine, average {CH},*

Table 13 Vessel and port crane activities for the installation of offshore wind turbines, as well as resulting input used to model the installation. Inputs marked in *italic* represent data derived by extrapolation based on values for other turbines.

Component		Unit	5 WM turbine	10 WM turbine	15 WM turbine
Moving parts	HFO consumption	t	48	38	*54* [a]
	MGO consumption	t	-	-	-
	Port crane operation	h	8.3	7.2	*10* [b]
Tower	HFO consumption	t	16	16	19 [a]
	MGO consumption	t	-	-	-
	Port crane operation	h	4.2	5.3	*6.2* [b]
Foundation/Substructure	HFO consumption	t	156	58	*72* [a]
	MGO consumption	t	-	-	-
	Port crane operation	h	24	24	*30* [b]
Resulting inputs (total wind turbine)	***Transport, trans-oceanic freight ship***	**tkm**	**142’646’000**	**73’255’000**	**93’942’000**
	Diesel, burned in building machine	**MJ**	**25’000**	**25’000**	**32’000**

a values for 15 MW turbine derived by scaling the value for 10 MW turbine according to (mass of components · distance to installation port),
b values for 15 MW turbine derived by scaling the value for 10 MW turbine according to mass of components

Table 14 Vessel and port crane activities for the installation of EBoP of offshore wind farms, as well as resulting input used to model the installation. Inputs marked in *italic* represent data derived by extrapolation based on values for other wind farms.

	Unit	Array cable, 66 kV	Export cable, 220 kV	Substation, offshore, 150MW wind farm	substation, offshore 740MW wind farm	Substation, offshore, 1005MW wind farm
	Unit	[km]	[km]	[p]	[p]	[p]
HFO consumption	t	-	-	180	134	*170* [a]
MGO consumption	t	14	6.5	187	127	*161* [a]
Port crane operation	h	0.21	0.04	24	24	*30* [a]
Transport, transoceanic freight ship	**tkm**	**9’117’000**	**4’200’000**	**238’133’000**	**169’679’000**	**214’208’000**
Diesel, burned in building machine	**MJ**	**147**	**29.4**	**40’541**	**16’436**	**20’749**

[a] values for substation of 1005 MW wind farm derived by scaling values for substation of 740 MW wind farm according to mass of substations

The inventory of offshore wind turbines also includes the vessel activity for replacements, as shown in Table 15. Analogously to the installation of the wind turbines, the vessel fuel consumption was modelled as *Transport, transoceanic freight ship {OCE}*, using the conversion factor of 649 tkm/kg fuel. Again, vessel activities for the 5 MW and 10 MW turbines were derived by TUM using the DETECT toolchain, while the fuel consumption for the 15 MW turbine was derived by upscaling the values for the 10 MW turbine by the weight of the components times the distance to installation port.

Table 15 Vessel fuel consumption for replacement activities of offshore wind turbines over the lifetime of 25 years, as well as resulting input used to model replacement activities. Inputs marked in *italic* represent data derived by extrapolation based on values for other wind turbines.

Component		Unit	5 WM turbine	10 WM turbine	15 WM turbine
Moving parts	HFO consumption	t	178	165	*231* [a]
Tower	HFO consumption	t	0.008	0.033	*0.046* [a]
Substructure	HFO consumption	t	0.028	0.064	*0.090* [a]
Resulting inputs (total wind turbine)	***Transport, transoceanic freight ship***	**tkm**	**115’238’000**	**106’822’000**	**149’703’000**

[a] values for 15 MW turbine derived by scaling the value for 10 MW turbine according to (mass of components · distance to installation port)

3.5 Decommissioning and end-of-life treatment

For all wind turbine and EBoP components, it was assumed that decommissioning requires the same logistics as the installation described in section 3.4, but in reverse order and with the exception of scour protection material which is not recovered at end-of-life. This assumption is common in LCA studies of wind power and was also considered in the DETECT toolchain (Kainz, 2025; Milne et al., 2021). The scour protection was assumed to be left in the sea without any decommissioning effort.

The transportation of components to the corresponding waste treatment sites was considered as part of the transportation over the entire life cycle (see section 3.3.3).

Regarding the waste treatment, all materials were assigned to end-of-life material categories with corresponding recycling, incineration and landfill rates. Crushed rock used for scour protection of offshore wind turbines was considered to not be treated at end-of-life but left in place on the seabed.

The assumed recycling, incineration and landfill rates are summarised in Table 16 and were based on TUM data for the 10 MW IEA reference offshore wind turbine (Kainz, 2025). Reuse was included in recycling with a cut-off approach applied. No credit was granted for recycling or reuse. Transportation to the recycling and reuse sites, recycling processes and preparation processes for reuse were not included in the inventory of wind energy, following the cut-off approach and the FOEN database protocol (Frischknecht et al., 2023).

The allocation of all materials to the specific end-of-life material groups is included in Annex V (page 67).

Table 16 Recycling rates (including reuse), landfill rates and incineration rates used for the waste treatment of wind turbine and EBoP components.

	Waste treatment rates		
End-of-Life material group	Recycling	Incineration	Landfill
Blades Steel and iron	95%	0%	5%
Aluminium	95%	0%	5%
Copper	95%	0%	5%
Plastics	0%	50%	50%
Blades (carbon fibre and glass fibre)	0%	50%	50%
Other materials	0%	0%	100%

4 LIFE CYCLE INVENTORIES OF ELECTRICITY FROM WIND POWER

This chapter describes the life cycle inventory of the new electricity datasets. Electricity datasets on farm level are described in section 4.1, while section 4.2 describes the datasets for electricity mixes from wind power in Switzerland and in Europe.

4.1 ELECTRICITY AT WIND FARM LEVEL

Key parameters of the wind farms used for modelling the electricity datasets are presented in Table 17.

For Switzerland, an onshore wind farm was modelled to represent the total installed capacity of 100 MW. For the wind farm, 2.3 MW and 3.4 MW wind turbines were used (see also section 4.2.1). Length of the export cables were extracted from Eymann et al. (2015) and were based on the actual export cable lengths of Switzerland's wind farms. For the array cables, the length was scaled linearly based on the farm's nominal power. The capacity factor was based on the total wind energy production in Switzerland between 2020 and 2024 and results in 19.7% (Kaufmann, 2024; Prime et al., 2025).

The 100 MW onshore wind farm consisting of 2.3 MW turbines was modelled to account for the 0-3 MW range of installed turbines in Europe. The size of 100 MW was chosen as an average and in consistency with the wind farms from the Vestas studies. Cable lengths and the substation were scaled linearly based on the farm's nominal power.

The 200 MW onshore wind farm consisting of 3.4 MW turbines represents a virtual wind farm, which is defined as representative onshore wind farm in the REMPD by NREL (Cooperman et al., 2023). The REMPD does not contain values for energy production.

The two 100 MW onshore wind farms consisting of 4.5 MW and 6.2 MW turbines were modelled according to the LCA studies by Vestas (Mali & Garrett, 2023; Martinez Aguado & Garrett, 2025). Cable lengths were extracted from the studies, while the substation was scaled linearly based on the farm's nominal power.

The modelled 150 MW offshore wind farm is based on the existing Ormonde wind farm, UK, consisting of 30 5 MW wind turbines using jacket substructures (Ormiston, 2012). The wind farm has a regular layout, with a total of 27 km of 33 kV array cables connecting the wind turbines to the offshore substation, from where the power is transferred to shore via a 132 kV export cable of 43 km (Kouloumpis & Azapagic, 2022). The dataset for the average 66 kV array cable based on TUM was used as proxy for the 33 kV array cables, as both cable types showed comparable densities of 36 kg/m (33 kV) and 30 kg/m (66 kV). The dataset of the 220 kV export cable based on TUM data for the 740 MW wind farm was used to model the 132 kV export cable, by downscaling the input per km according to the power capacity of the wind farms and by considering 3 parallel export cables (i.e. the length of the export cable was multiplied with the factor 3).

The modelled 740 MW offshore wind farm represents the IEA Wind 740-10 MW reference wind farm with irregular layout. The reference wind farm is a virtual fixed-bottom offshore wind farm, located approximately 50 km off the Dutch coast in the North Sea. It consists of 74 IEA 10 MW offshore reference wind turbines. At an offshore substation, the 66 kV array cable system is transformed to 220 kV, the power is then transferred to shore via 3 export cables (total length of 203 km). The inventory of the 740 MW offshore wind farm was taken from Kainz (2025).

The modelled 1'005 MW offshore wind farm is based on the fictitious wind farm defined in the REMPD, using 67 IEA reference wind turbines of 15 MW (Cooperman et al., 2023). The REMPD does not include assumption regarding wind farm layout, cable lengths and cable types. For this study, a regular layout was assumed, with 133 km of array cables and 70 km of export route[3]. Analogously to the 150 MW wind farm, array and export cables were modelled using the datasets for the 66 kV and 220 kV cables based on TUM data.

To be representative for the European fleet, average capacity factors were used for all European onshore and all offshore wind farms, respectively, based on ENTSO-E data for the years 2016 to 2024 (ENTSO-E, 2017, 2018, 2019, 2023b, 2023a, 2024b, 2024a, 2024c, 2025). The capacity factors were derived as the ratio of total amount of electricity generated to the total nominal power capacity installed. This resulted in average European capacity factors of 23.5% for onshore wind farms and 34.1% for offshore wind farms.

The full inventory of all electricity datasets at wind farm level is included in Annex III on page 65 Annex III.

[3] Personal communication with NREL

Table 17 Key parameters of the wind farms used for electricity datasets. Inputs marked in *italic* represent data derived by extrapolation based on values for other wind farms.

		Onshore wind farms					Offshore wind farms		
Parameter	Unit	**100 MW** 2.3 / 3.4 MW turbines CH	**100 MW** 2.3 MW turbines RER	**200 MW** 3.4 MW turbines RER	**100 MW** 4.5 MW turbines RER	**100 MW** 6.2 MW turbines RER	**150 MW** 5 MW turbines RER	**740 MW** 10 MW turbines RER	**1'005 MW** 15 MW turbines RER
Number of turbines	p	41	43	59	22	16	30	74	67
Number of land-based substations	p	1	1	1	1	1	-	1	1
Number of offshore substations	p	-	-	-	-	-	1	1	1
Length of array cables, total	km	-	-	-	-	-	27	140	133
Length of export route	km	-	-	-	-	-	43	66	70
Number of export cables	-						*3* [a]	3	*3* [a]
Length export cables, total	km						*129* [a]	203	*210* [a]
Length of cables, total	km	51	42	126	42	45	-	-	-
Distance to service port	km	-	-	-	-	-	10	50	*50* [c]
Capacity factor	-	19.7%	*23.5%* [b]	*23.5%* [b]	*23.5%* [b]	*23.5%* [b]	*34.1%* [b]	*34.1%* [b]	*34.1%* [b]
Predicted energy production, annual	GWh	173	206	413	204	204	448	2'212	3'004
Predicted energy production, total	GWh	4'330	5'150	10'300	5'100	5'100	11'200	55'300	75'100

[a] three parallel export cables were assumed for the 150 MW and the 1005 MW wind farms, to be consistent with the 740 MW wind farm.
[b] average capacities factors for European onshore and offshore windfarms based on ENTSO-E statistics for 2016-2024
[c] own assumption

4.1.1 Operation and maintenance

For the O&M activities regarding onshore and offshore wind farms, it was assumed that the lubrication oil is exchanged every two years, according to Burger and Bauer (2007). For onshore wind farms, it was further assumed that for each oil change, the transportation distance of the lubrication oil is 100 km by a light commercial vehicle.

The maintenance activities for the 740 MW offshore wind farm were modelled based on MGO consumption from vessel activities, as derived by TUM, taking into account component-specific failure rates for repair activities and corresponding vessel type usage for unscheduled maintenance , regular scheduled annual service, and the distance to the service port (Kainz, 2025). The maintenance activities for the 150 MW and the 1'005 MW wind farm were estimated by scaling the MGO consumptions for the 740 MW wind farm based on distance to service port and number of wind turbines, with the factor 6.4 t MGO/km per wind turbine. Over the entire lifetime, the inputs total MGO consumptions due to maintenance resulted in 1'920 t, 23'700 t and 21'500 t for the 150 MW, the 740 MW and the 1005 MW wind farm, respectively. These fuel consumptions were modelled as $1.6 \cdot 10^9$ tkm, $15 \cdot 10^9$ tkm and $14 \cdot 10^9$ tkm of *Transport, transoceanic freight ship {OCE}*, using the conversion factor of 649 tkm/kg fuel.

4.1.2 Road construction

For the onshore wind farms, it was assumed that the construction of new access roads is required. Based on Eberle et al. (2019), the road length was estimated based on the number of turbines and the average turbine spacing:

$$L_r = (N_t - 1) * D_r * S_t + l_{adder}$$

where N_t is the number of turbines, D_r is the diameter of the rotor, S_t is the spacing of the turbines relative to the rotor diameter (unitless), and l_{adder} is the excess roads for access to road strings from existing public roads and/or highway. A default value of 4 was taken for S_t and a default value of 5 km for the l_{adder}.[4] The values for the road construction can be found in Annex III on page 65.

4.1.3 Sulphur hexafluoride (SF_6) leakage

Following the data compilation by TUM (Kainz, 2025), it was assumed that 5% of the total amount of SF_6 is lost over the lifetime of the wind farm. This value was adopted for all wind farms considered. In the case of the onshore wind farms, the SF_6 leakage over the entire life cycle ranges from 9-18 kg, while the SF_6 leakage

[4] Personal communication, Annika Eberle, 13.03.2025

of the offshore wind farms ranges from 15-97 kg over the entire life cycle of the wind farms (see also inventory in Annex III on page 65).

4.2 ELECTRICITY MIXES FROM WIND POWER

4.2.1 Wind electricity mix Switzerland

For the Swiss wind electricity mix, a 100 MW onshore wind farm was modelled, which represents the total installed wind power capacity in Switzerland in 2025 (Suisse Eole, 2025). The wind farm was modelled to consist of 2.3 MW and 3.4 MW wind turbines. From the total electricity produced in 2024, 77% was produced by wind turbines of 2.35 MW or smaller. This share of the 100 MW wind farm was modelled using the 2.3 MW turbine. Of this share, 46% of the 2.3 MW turbines were modelled with a concrete tower, while the remaining 54% were modelled with a steel tower, according to the distribution described in section 2.1. This represents the shares of electricity produced in 2024 from wind turbines of 2.35 MW or smaller with concrete and steel towers respectively.

The remaining 23% of the electricity in 2024 was produced by wind turbines between 3-3.3 MW and was modelled using the 3.4 MW turbine.

4.2.2 Wind electricity mix Europe

For the European wind electricity mix, the ratio of electricity production from onshore and offshore wind farms was considered, as well as the contributions from different wind turbines sizes.

As of 2024, a total of 420 TWh electricity from onshore wind farms and 61.8 TWh from offshore wind farms was generated from ENTSO-E member states in Europe (ENTSO-E, 2025). Based on these values, the European wind electricity production mix for 2024 was set to 87% from onshore and 13% from offshore wind farms.

The electricity mix was modelled using the RER electricity datasets at wind farm level, as shown in Table 18. The contributions from different wind farm datasets were calculated based on the share of installed capacity for onshore wind turbines (see Figure 2) and for offshore wind turbines (Figure 3) separately.

Table 18 Share of electricity from offshore and onshore wind power, as well as from different wind turbines sizes which were used to model the European electricity mix from wind power.

Electricity dataset	Share of onshore and offshore	Share of turbine sizes		Used dataset
electricity, at wind farm {RER}	87% onshore	50%	< 3 MW	2.3 MW wind turbines
		22%	≥ 3 MW < 4 MW	3.4 MW wind turbines
		10%	≥ 4 MW < 5.5 MW	4.5 MW wind turbines
		5%	≥ 5.5 MW	6.4 MW wind turbines
	13% offshore	5%	< 7 MW	5 MW wind turbines
		7%	≥ 7 MW < 12 MW	10 MW wind turbines
		1%	≥ 12 MW	15 MW wind turbines

5 LIFE CYCLE IMPACT ASSESSMENT RESULTS

This chapter describes the impact assessment results of the established inventories for Swiss and European onshore and offshore wind power. Section 5.1 gives a summary of the results for the analysed environmental impacts, while sections 5.2 to 5.4 give a more detailed insight into the greenhouse gas emissions, cumulative energy demand and total environmental impact, respectively.

5.1 SUMMARY OF LCIA RESULTS

An overview of the environmental impacts of electricity at wind farm for the different wind farms modelled, as well as the wind electricity mixes for Switzerland and Europe is presented in Table 19. The greenhouse gas (GHG) emissions range from 10.4 to 22.7 g CO_2-eq/kWh of electricity at wind farm. In most cases analysed, the electricity produced by onshore wind farms causes lower GHG emissions per kWh than electricity produced by offshore wind farms. This finding is equally true for the total environmental impact as well as the CED.

The wind electricity mixes for Switzerland and Europe cause life cycle GHG emissions of 18.1 g of CO_2-eq and 14.9 g of CO_2-eq/kWh of electricity at wind farm, respectively. Similarly to the GHG emissions, the total environmental impact and the CED are between 13-16% higher in the Swiss electricity mix compared to the European electricity mix.

The higher environmental impacts of electricity produced by offshore wind farms can primarily be explained by the impacts from vessel activities. These vessel activities have a significant contribution to the overall environmental impacts on all three offshore wind farms. For the 740 MW and 1'005 MW wind farms, the vessel activity is responsible for 29% and 28%, respectively, of the overall GHG emissions. For the 150 MW wind farm, the contribution of the vessel activity to the overall GHG emissions reaches 43%, due to the considerably larger distance to the installation port, compared to the other two offshore reference wind farms, as well as longer operation time of vessels for the installation of the jacket foundations compared to monopile foundations. In turn, the energy production of the offshore wind farms is significantly higher compared to the onshore wind farms, with capacity factors being almost 1.5 times higher.

The environmental impacts of the Swiss wind electricity mix are slightly higher compared to the European wind electricity mix, with a GWP of 18.1 g CO_2-eq compared to 14.9 g of CO_2-eq/kWh. The higher impacts of the Swiss electricity mix can primarily be explained by the onshore capacity factor of 19.7%, which is lower compared to the 23.5% onshore capacity factor in Europe.

Table 19 Environmental impacts of the production of 1 kWh of electricity at wind farm for each modelled wind farm as well as the Swiss and European wind electricity mixes.

			Wind farms							Electricity mixes	
Environmental impacts per kWh of electricity at wind farm		Unit	electricity, at 100MW wind farm, onshore, 2.3MW turbines {RER} U	electricity, at 200MW wind farm, onshore, 3.4MW turbines {RER}	electricity, at 100MW wind farm, onshore, 4.5 MW turbines {RER}	electricity, at 100MW wind farm, onshore, 6.2MW turbines {RER}	electricity, at 150MW wind farm, offshore, 5MW turbines {RER}	electricity, at 740MW wind farm, offshore, 10MW turbines {RER}	electricity, at 1005MW wind farm, offshore, 15MW Turbines {RER}	electricity, at wind farm {CH}	electricity, at wind farm {RER}
GHG emissions		g CO_2-eq	15.7	13.1	10.4	12.2	22.7	18.9	15.6	18.1	14.9
Total environmental impact (Ecological Scarcity Method)		eco-points	43.3	36.2	31.8	35.4	61.3	54.3	46.1	47.8	41.8
Cumulative energy demand	non-renewable	MJ	0.19	0.16	0.13	0.15	0.29	0.25	0.20	0.22	0.19
	renewable	MJ	3.89	3.89	3.88	3.88	3.89	3.89	3.89	3.89	3.89

5.2 Greenhouse gas emissions

The life cycle greenhouse gas (GHG) emissions of 1 kWh of electricity from the different wind farms are shown in Figure 5. The overall GHG emissions are divided into contributions from the different wind farm components, including wind turbine, foundation, cabling, substations, road construction and O&M of the wind farm.

The GHG emissions of the electricity from all wind farms are dominated by the infrastructure of the wind turbine, being moving parts, tower and foundation, with a contribution of between 77-93% to the overall GHG emissions. This high contribution is largely due to the energy-intensive production of steel contained in the wind turbines (moving parts, tower and foundation). As for the offshore wind farms, the high contribution of the wind turbine is due to the fuel consumption of the vessels used for installation, replacement of components and decommissioning, which is included in these infrastructure datasets.

Another relevant contribution to the GHG emissions is the O&M of offshore wind farms caused by vessels used for maintenance activities. The contribution of the O&M activities is between 4-11% in offshore wind power, depending on the farm's distance to the service port. In comparison, the O&M activities have a contribution of <1% to the GHG emissions for onshore wind power.

The impact of the cabling has an additional contribution of 4-11%, while the substations contribute below 3% to the overall GHG emissions. A similarly low contribution in onshore wind power stems from the road construction, explaining between 1-3% of the total impact.

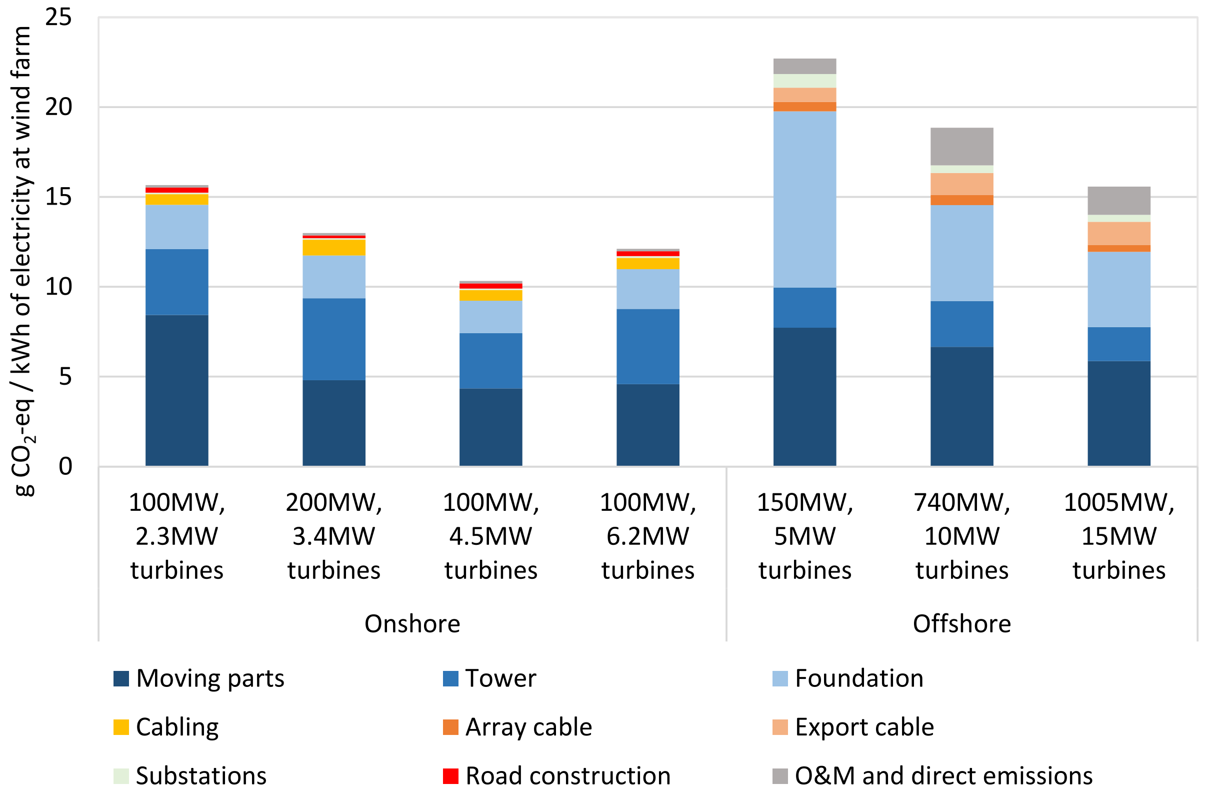

Figure 5 Life cycle greenhouse gas emissions of 1 kWh of electricity at the different onshore and offshore wind farms, assessed with IPCC (2021). The impacts per wind farm are divided into the different turbine and farm components; the impacts of moving parts, tower, foundation, cables and substations include all life cycle stages of the corresponding components (manufacturing, transportation, installation, replacements, decommissioning and waste treatment, as shown in Figure 4).

5.3 Primary energy demand

The non-renewable energy demand of 1 kWh of electricity from the different wind farms is shown in Figure 6. In line with the GHG emissions, the non-renewable energy demand primarily arises during the production and installation of the wind turbine infrastructure. The moving parts, tower and foundation contribute between 74-89% to the overall non-renewable energy demand. The energy-intensive steel manufacturing primarily contained in the moving parts and tower of the turbines largely explains the high contribution of the infrastructure in terms of onshore wind power, and partly in terms of offshore wind power. Aside from the steel production, the vessel activity is responsible for the majority of the non-renewable energy demand within offshore wind power, explaining between 32-50% of the overall consumption, due to the production of the fuel.

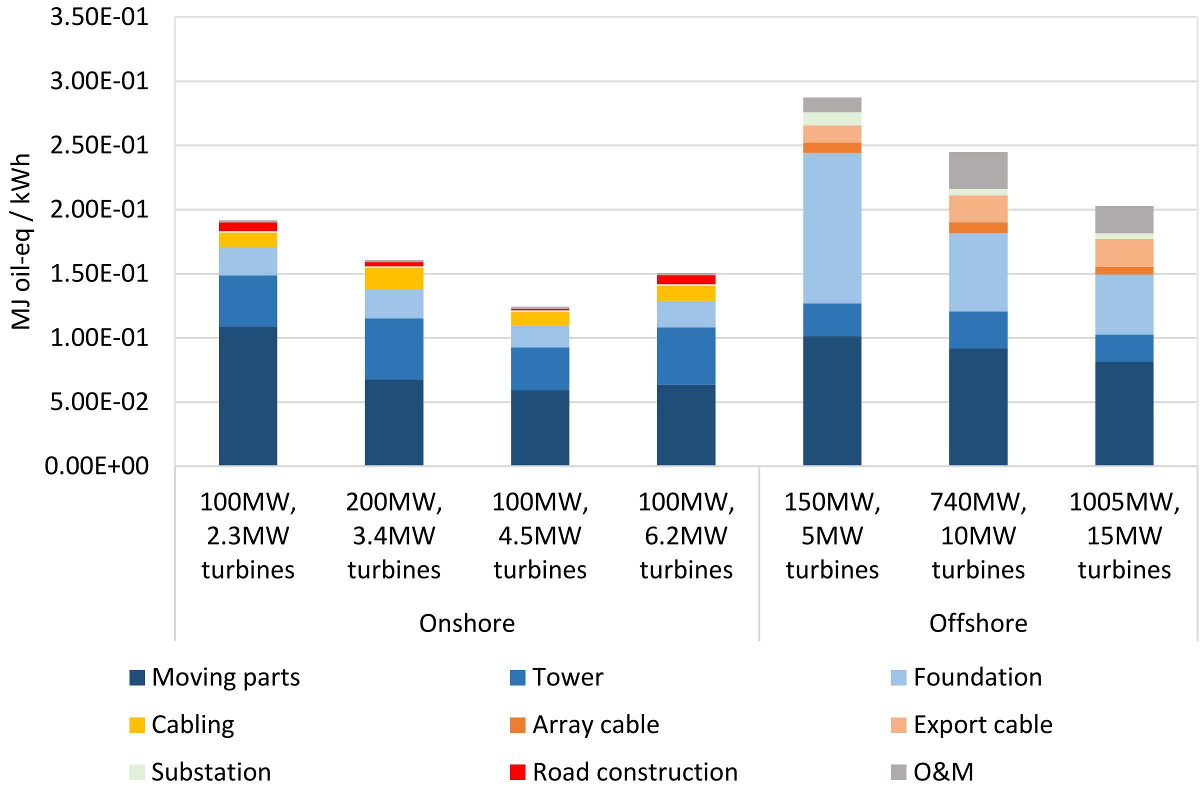

Figure 6 Non-renewable energy demand for 1 kWh of electricity at the different onshore and offshore wind farms, assessed with the CED method (Frischknecht et al., 2007). The impacts per wind farm are divided into the different turbine and farm components; the impacts of moving parts, tower, foundation, cables and substations include all life cycle stages of the corresponding components (manufacturing, transportation, installation, replacements, decommissioning and waste treatment, as shown in Figure 4).

Considering aside from the non-renewable energy demand also the renewable energy demand shifts the highest contribution to renewable energy from wind. In order to produce of 1 kWh of electricity from a wind farm, 3.87 MJ of wind energy are required. From the overall cumulative energy demand, the wind energy demand makes up 94% within the Swiss electricity mix and 95% within the European electricity mix. The non-renewable energy demand makes up 5% of the cumulative energy demand in the Swiss and European mix.

5.4 Total environmental impacts assessed with the Ecological Scarcity Method

The total environmental impact per kWh of electricity produced at the different wind farms and for the electricity mixes is depicted in Figure 7. Between 58-68% of the total environmental impact is caused by the GHG emissions and energy sources, which are explained in sections 5.1-5.3.

Aside from the mentioned environmental impacts, main air pollutants and emissions of particulate matter further contribute to the total environmental impact. The contribution of these emissions to the total environmental impact is between 11-14% in terms of onshore wind power as well as the electricity mixes, and between 20-25% within offshore wind power. The main air pollutants and particulate matter emissions arise primarily during the steel manufacturing as well as, in terms of offshore wind power, as direct emissions during the operation of the vessels.

Heavy metals emitted into the air contribute a further 7-11% to the total environmental impact. These emissions arise primarily during copper manufacturing, as well as the manufacturing of iron and steel.

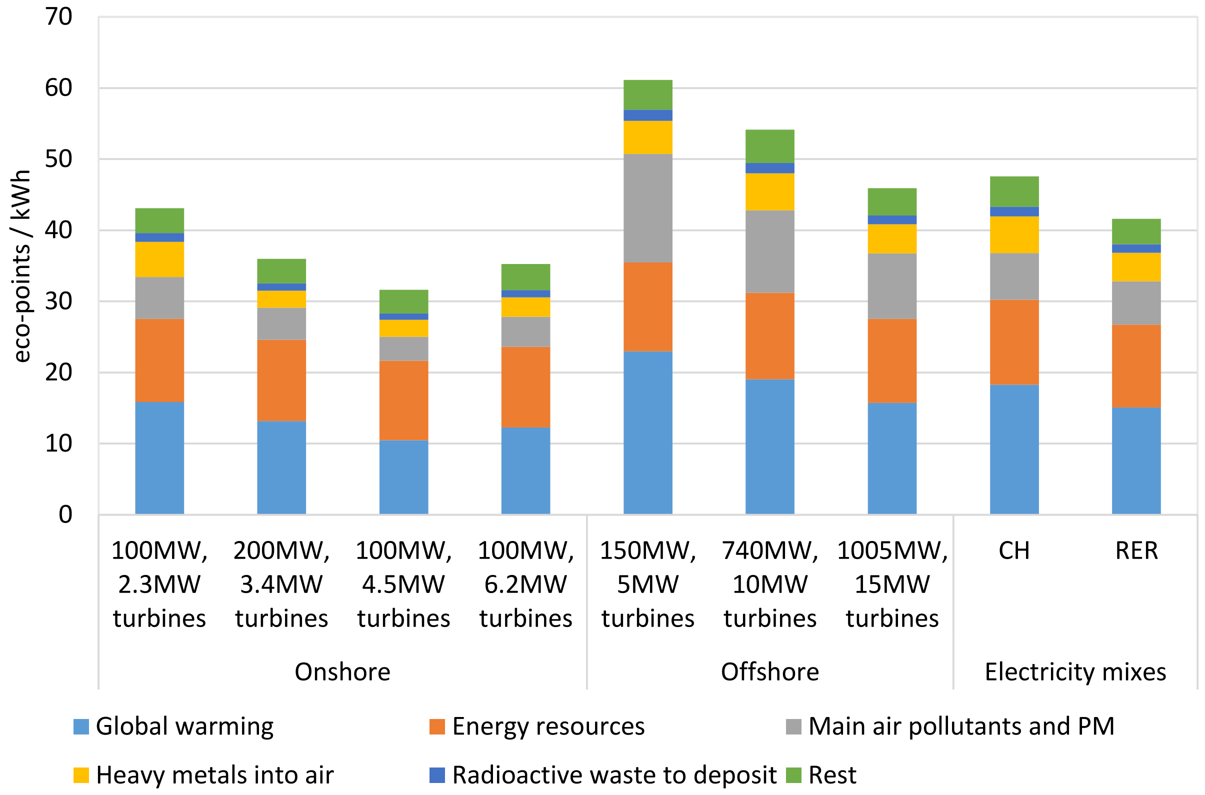

Figure 7 Total environmental impact of 1 kWh of electricity at the different onshore and offshore wind farms and for the wind electricity mixes, according to the Ecological Scarcity Method (Frischknecht et al., 2021). The impacts are divided into the different environmental impact categories.

6 DISCUSSION AND OUTLOOK

This report describes a comprehensive extension of the LCI models for electricity from wind farms, as well as updated electricity mixes for Swiss and European wind power in the FOEN database. The update includes new models for onshore and offshore wind turbines, electricity from specific wind farms as well as wind electricity mixes.

A list of all new datasets is given in ANNEX VI on page 70, which also lists the datasets to be replaced within the FOEN database and the datasets which become obsolete. The latter concern the LCI for 30-800 kW onshore wind turbines and a 2 MW offshore wind turbine, which were included in the previous version of the FOEN database, and which do not have the comprehensiveness of the new datasets (e.g. in terms of considered EBoP and vessel activities).

This chapter discusses the new LCI models for wind energy and puts them into perspective. A comparison of the new and the previous datasets is given in chapter 6.1. The data quality and the comprehensiveness of the new datasets is discussed in chapter 0, while chapter 6.3 summarises aspects for further studies. Overall conclusions are given in chapter 6.4.

6.1 Comparison with previous database version and other electricity generation technologies

Compared to the previous wind electricity mixes in the FOEN database, the results for GHG emissions remain in a similar range. The previous wind electricity mix for Switzerland, consisting of 30-800 kW wind turbines, showed a GWP of 19.2 g CO_2-eq per kWh. For the updated Swiss wind electricity mix, modelled with larger turbines reflecting the actual situation more accurately, a decrease in the GHG emissions of 6% is found. The previous wind electricity mix for Europe, consisting of a 98% share of onshore wind electricity from 800 kW turbines and a 2% share of offshore wind electricity from 2 MW turbines, showed a GWP of 12.6 g CO_2-eq per kWh. The updated European wind electricity mix therefore shows an increase of the GWP of 15%. This increase can be explained by the higher share of offshore wind electricity in the updated electricity mix, which increased from 2% to 13%. Additionally, the models for electricity from offshore wind have so far not accounted for all vessel activities, as they for example did not account for activities during O&M. Consequently, the environmental impacts of the updated models for offshore wind electricity increased, as they now consider the vessel activities more comprehensively.

The total environmental impact of the Swiss and European wind electricity mix is 48 eco-points and 42-ecopoints per kWh, respectively, as depicted in Figure 8. The total environmental impacts of Swiss wind power are thereby 8.8 times lower compared to the average consumer mix in Switzerland, while the total environmental impacts of European wind power are 19 times lower compared to the ENTSO-E mix.

Compared to solar power from Swiss photovoltaic systems (Stucki et al., 2024), wind power has a total environmental impact 2 and 2.3 times lower, for Switzerland and Europe respectively. The GWP for Swiss wind power amounts to 18.1 g CO_2-eq and to 14.9 g CO_2-eq for European wind power, per kWh. In comparison to the Swiss production mix, the GWP of Swiss wind power is 5.8 times lower, while the GWP of European wind power is 31 times lower than the GWP of the ENTSO-E mix. This makes wind power, along with hydropower, one of the electricity products with the lowest environmental impact.

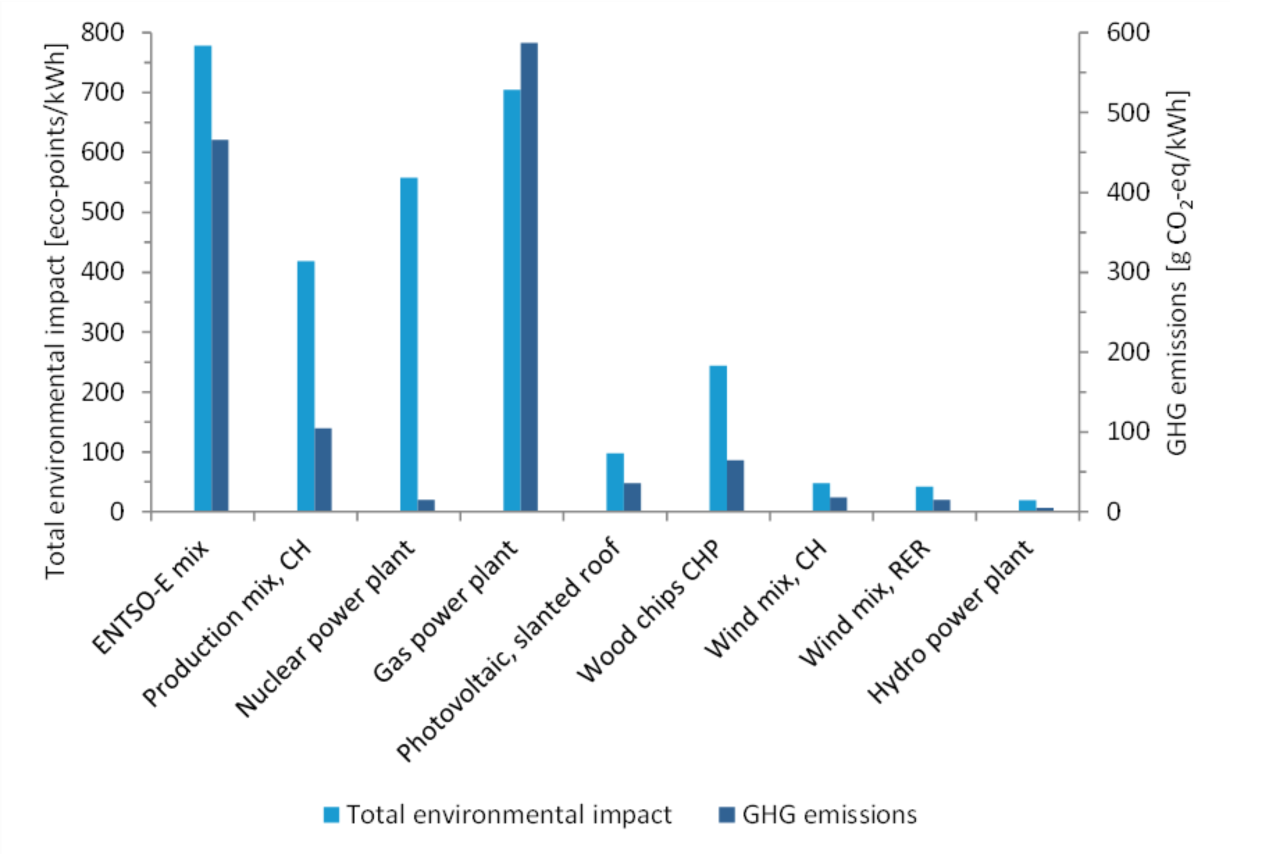

Figure 8 Total environmental impact (eco-points/kWh) and GHG emissions (g CO2-eq/kWh) of electricity at power plant, from different technologies. All data stem from the FOEN database 2025 (unpublished pre-version from August 2024), with exception of the photovoltaic data, which stems from PVPS Task 12 (Stucki et al., 2024).

6.2 Data quality and comprehensiveness

The updated LCI for wind energy covers the most relevant turbine sizes used for onshore and offshore wind power in Switzerland and Europe. Furthermore, all life cycle stages, and relevant processes were considered, including transportation, installation, replacements, O&M, decommissioning and end of life treatment. The updated LCI thus represents a comprehensive model of Swiss and European wind energy.

The data quality of relevant parameters as well as uncertainties related to data quality and modelling choices are discussed here.

6.2.1 Material compositions and quantities

Material composition and material quantities in the updated LCI are mainly based on published manufacturer data, (Mali & Garrett, 2023; Martinez Aguado & Garrett, 2025) as well as published data for IEA reference turbines and wind farms (e.g. Cooperman et al., 2023; Gaertner et al., 2020; Kainz, Quick, et al., 2024; Kouloumpis & Azapagic, 2022). These sources show generally a high reliability and quality data with high granularity, allowing for a detailed modelling of the established LCI.

6.2.2 Capacity factor

The assumed electricity production over the lifetime of the wind farm and the corresponding capacity factor have a significant impact on the results, as the results for the environmental impact per kWh fed into the grid decrease when the total electricity produced increases, the latter behaving linearly with the capacity factor..

Capacity factors were derived for onshore and offshore wind farms as average values for the entire Swiss and European fleet, respectively, without differentiation of wind turbines and wind farms sizes. This approach is justified, as capacity factors do not primarily depend on wind turbine sizes, but rather on the regional wind regime as well as on shut down times. Nonetheless, the representativeness of the average capacity factors for different turbine sizes remains an open aspect which could be investigated in future studies.

Annual wind speeds can show a considerable variability which has an impact on the annual electricity production of wind turbines and consequently also on the capacity factor. Capacity factors in this study were therefore derived as average over several years instead of only for the reference year 2024, to smooth out the effect of the variability of wind speeds.For the Swiss wind electricity mix, the used capacity factor is based on actual electricity production data from Switzerland between 2020 to 2024. Since this data reflects real measured performance, the derived capacity factor for the Swiss mix is considered to have low uncertainty.

Regarding the European wind electricity production, average capacity factors for onshore and offshore wind farms, respectively, were calculated using annual data published by ENTSO-E for installed nominal capacities and electricity production for the years 2016 to 2024 (ENTSO-E, 2017, 2018, 2019, 2023b, 2023a, 2024b, 2024a, 2024c, 2025). These average capacity factors are considered as accurate and with low uncertainty.

6.2.3 Representativeness of modelled wind turbines and wind farms

For the Swiss electricity mix, the modelled wind turbine sizes represent 95% of the wind turbine fleet in Switzerland. The specific wind turbines modelled reflect one of the most installed turbine models (2.3 MW), as well as a reference turbine (3.4 MW) and are therefore assumed to be representative for the Swiss context. The onshore wind farms modelled for the European context are based on a reference wind farm, as well as wind farms from a specific wind turbine manufacturer (Vestas). The Vestas wind farms may be less representative compared to a reference wind farm, however, they do rely on average data and general assumptions, making them a justifiable choice for this study. The wind turbine sizes modelled to represent the European situation cover 83% of the European fleet and are therefore assumed to be representative.

The offshore wind farms modelled in this study fall well within the range in the European context. Monopile and jacket foundations modelled in this study represented the most common substructure types in European offshore wind farms in 2024, with shares of about 73% and 24%, respectively (according to own statistic based on nominal power of offshore wind turbines as published by Grothe et al. (2022)). Furthermore, the water depths of European offshore wind farms ranged from 6 m to about 65 m, with an average of 33 m based on installed power (own statistic based on Grothe et al. (2022), compared to 18 to 34 m assumed in this study. Distances to shore ranged from 12 km to 130 km. Consequently, especially the distances to installation port (80 km) and service port (50 km) assumed for the 740 MW and 1005 MW offshore wind farms appear to be typical values in the European context.

A limitation of this study is based on the approach that the electricity production from a certain range of wind turbine size was modelled using the electricity data set of a specific reference wind farm, instead of deriving representative wind turbines and wind farms for each wind turbine size. The IEA reference wind turbines and reference wind farms used in this study are meant to reflect common technologies. However, the representativeness of the modelled wind turbines was primarily determined based on turbine size distributions (i.e. nominal power distribution) in the Swiss and in the European wind turbine fleet. Further studies could be conducted to better assess the representativeness of other relevant parameters, especially for offshore wind energy, such as water depth, substructure type and distance to port, as the choice of these parameters affects the inventory of the manufacturing phase and especially of the installation, maintenance and decommissioning phases.

6.2.4 Installation of onshore wind turbines

The data sources used for the onshore wind turbines did not include any data for the installation effort of the turbines. For means of completeness, the installation effort was therefore accounted for using other sources and own assumptions. The installation was approximated through the assembly of the moving parts calculated by the potential energy, and an excavation effort based on the concrete volume of the foundation. The uncertainty of the installation is therefore estimated as high. However, the installation efforts have a contribution of <0.1% to the environmental impacts in the present study. The potential uncertainty of the installation therefore affects the results only minimally.

6.2.5 Vessel activities related to offshore wind energy

Vessel activities, more specifically the fuel consumption of vessels, emerged as one of the most relevant parameters regarding offshore wind power, which is related to high uncertainties. Fuel consumption of vessels used in this study are not based on measurements but were derived based on the DETEC tool chain by TUM for the IEA 740 MW reference offshore wind farm using 10 MW wind turbines and for the installation of the 5 MW wind turbine. Furthermore, the results from TUM were scaled based on component weights and distances to ports to apply to the 150 MW and the 1’005 MW offshore wind farms. Actual fuel consumptions for existing individual European wind farms might differ significantly from the values used in this study.

In addition, the fuel consumption for vessel activities was modelled based on the dataset *transport, transoceanic freight ship {OCE}* as proxy due to the lack of specific datasets for installation and service vessels employed in the wind energy context. This leads to uncertainties regarding the environmental impact of vessel infrastructure and port infrastructure, which contribute about 10-15% to the environmental impact of *transport, transoceanic freight ship {OCE},* but which might have different contributions in the wind energy context due to specialised vessel types and different operation times over the entire life cycle of the vessel.

Furthermore, only HFO is considered as fuel in the dataset *transport, transoceanic freight ship*, which was used as proxy for both HFO and MGO consumptions. This might lead to additional uncertainties.

6.2.6 Cabling

For onshore wind farms, array and export cables were modelled for one wind farm (100 MW using 4.5 MW wind turbines) and scaled to the other onshore wind farms based on the length of cables. Regarding array cables, this assumption is estimated as realistic, as the size of the array cables is not expected to be farm size dependent. In terms of export cables, the length-based scaling may under- or overestimate the mass of export cables, as they may increase in size along with an increasing farm size. The effect of this assumption on the results is estimated as medium, as the cabling contributes between 4-10% to the environmental impacts of onshore wind power.

For offshore wind farms, average array cable and export cables were modelled specifically for the IEA 740 MW reference offshore wind farm derived by TUM (Kainz, 2025). Array cables were scaled by length for the 150 MW and the 1’005 MW, since as for onshore wind farms, the size of average array cables is not expected to depend on the farm size. The export cables were scaled based on installed power and length.

The impact on the overall results is estimated as medium, considering the contributions of cabling are around 10% to the environmental impact of offshore wind power.

6.2.7 Maintenance and operation

The highest uncertainty within O&M is related to assumed vessel activities for offshore wind farms (see discussion in chapter 6.2.5).

The leakage of 5% of SF_6 over the lifetime of the wind turbines and substations represents an assumption which is in line with other studies, but which is connected to uncertainty with low to medium impact on the results. A 5% leakage of SF_6 led to negligible contributions of less than 0.5% to the GHG emissions of wind power. On the other hand, a complete release of the remaining SF_6 at end-of-life would increase the contribution of SF_6 to about 5%.

6.2.8 Decommissioning and end-of-life treatment

Decommissioning of wind turbines as well as of electrical components was modelled assuming the same energy and work demand as for installation, which is subject to high uncertainty. While the impact of this uncertainty on the results is negligible regarding onshore wind turbines, the impact for offshore wind turbines could be relevant, since the fuel consumption of vessels is one of the dominating parameters for offshore wind power.

As decommissioning of today's wind farms will take place in the future, an additional uncertainty is related to the used waste treatment shares as well as background data for decommissioning efforts and the end-of-life treatments, which represents current technologies and do not take into account future developments. Considering the decarbonisation goals in the energy sector and in the maritime shipping sector, the contributions of decommissioning in this study might be overestimated.

6.3 Future Research Priorities

Considering the uncertainties in the updated LCI for wind energy, several aspects emerged that could be investigated in further studies and that are described here below.

Deriving representative wind farms in terms of relevant parameters in the European context was beyond the scope of this study but could be investigated in future studies. In particular, the inventory of offshore wind energy depends on various location-dependent parameters that have a relevant impact on the results, such as water depth, type of substructure and distances to ports. Beside the derivation of representative values for these parameters, a parameterisation of average inventory as a function of relevant parameters would help to estimate the inventory and environmental impact of different types of offshore wind turbines and upcoming technologies.

Furthermore, we recommend establishing specific background data for specialised vessels used in the offshore wind energy sector and for different marine fuel types, considering the high contribution of vessel activities to the environmental impact of offshore wind energy.

Regarding impact assessment, there are environmental impacts of wind energy which are covered neither in current inventories nor in current impact assessments methods. For example, during their operation, wind turbines can pose a risk to birds and bats, which is an environmental impact not considered in the present study. In addition, noise could be an important environmental aspect of wind energy that is not analysed in this study.

Another aspect which was not part of this study, but which should be included in future studies regarding energy strategies is the temporal variability of wind electricity production and electricity demand. Wind speeds depend on the weather and vary not only between different locations but also over the course of the day and year. Electricity production therefore does not always coincide with electricity demand. If wind energy is to make up a substantial proportion of the grid electricity mix in the future, electricity storage technologies are therefore required. There is a need for research into how renewable energies perform from a life cycle assessment perspective if various electricity storage technologies such as pumped storage power plants and batteries and potential backup technologies are taken into account. 'Surplus' wind power that cannot be fed into the grid for capacity reasons can also be used to convert into synthetic fuels using power-to-gas technology. Produced methane for example could then be fed into the natural gas grid.

6.4 GENERAL CONCLUSION

This report describes comprehensive inventories for onshore and offshore wind farms for the Swiss and European context and brings the FOEN database up to date for assessing electricity generation from wind power. It covers four different onshore turbine sizes with a capacity from 2.3 to 6.2 MW and three offshore turbine sizes with a capacity from 5 to 15 MW as well as their corresponding wind farms.

For future updates, we propose a more differentiated modelling of the installation of onshore wind turbines, as well as vessel activities related to offshore wind energy, modelling of new upcoming wind power technologies as well as inclusion of additional impacts such as on local biodiversity, currently not included in the inventories.

With life cycle GHG emissions from 10.4 g of CO_2-eq to 22.7 g of CO_2-eq per kWh, wind energy remains among the power generation technologies with the lowest impact on climate change. If replacing power generation from fossil energy, further expansion of wind energy in Switzerland and Europe can contribute to reducing the climate change impact of grid electricity.

Bibliography

BAFU DQRv2. (2024). *BAFU-Ökobilanzdatenbestand 2024*. treeze Ltd., Bundesamt für Umwelt (BAFU) und Bundesamt für Energie (BFE).

Bauer, L., & Matysik, S. (2025). *Wind turbines database*. Wind-Turbine-Models.Com. https://en.wind-turbine-models.com/turbines

BFE. (2025). *Bundesamt für Energie BFE - Storymap Windenergieanlagen*. Windenergieanlagen. https://www.uvek-gis.admin.ch/BFE/storymaps/EE_WEA/index.php?lang=de

Bortolotti, P., Tarres, H. C., Dykes, K., Merz, K., Sethuraman, L., Verelst, D., & Zahle, F. (2019). *IEA Wind TCP Task 37: Systems Engineering in Wind Energy—WP2.1 Reference Wind Turbines* [Technical Report]. IEA Wind TCP.

Burger, B., & Bauer, C. (2007). Windkraft. In R. Dones (Hrsg.), *Sachbilanzen von Energiesystemen: Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz: Bd. ecoinvent report No. 6-XIII, v2.0*. Paul Scherrer Institut Villigen, Swiss Centre for Life Cycle Inventories. www.ecoinvent.org

Cooperman, A., Eberle, A., Hettinger, D., Marquis, M., Smith, B., & Tusing, R. F. (2023). *Renewable Energy Materials Properties Database: Summary* (NREL/TP-5000-82830). National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy23osti/82830.pdf

Costanzo, G., Brindley, G., & Tardieu, P. (2025). *Wind energy in Europe—2024 Statistics and the outlook for 2025-2030*. WindEurope. https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2024-statistics-and-the-outlook-for-2025-2030/

CranesToday. (2020). Focus on fuel. *Cranes Today Magazine*, *July 2020*. https://www.cranestodaymagazine.com/analysis/focus-on-fuel-8020451/?cf-view&Top-Article-Share-Button-clicked:%20Copy%20Link

Eberle, A., Roberts, J., Key, A., Bhaskar, P., & Dykes, K. (2019). *NREL's Balance-of-System Cost Model for Land-Based Wind* (NREL/TP--6A20-72201, 1569457; S. NREL/TP--6A20-72201, 1569457). https://doi.org/10.2172/1569457

Enercon. (2011). *LCA of ENERCON Wind Energy Converter E-82 E2*. Enercon GmbH.

ENTSO-E. (2017). *Statistical Factsheet 2016, Provisional values as of 4 May 2017*. ENTSO-E AISBL. https://eepublicdownloads.entsoe.eu/clean-documents/Publications/Statistics/Factsheet/entsoe_sfs_2016_web.pdf

ENTSO-E. (2018). *Statistical Factsheet 2017, Provisional values as of 4 May 2018*. ENTSO-E AISBL. https://eepublicdownloads.entsoe.eu/clean-documents/Publications/Statistics/Factsheet/entsoe_sfs_2017.pdf

ENTSO-E. (2019). *Statistical Factsheet 2018, Provisional values as of 5 June 2019*. ENTSO-E AISBL. https://eepublicdownloads.entsoe.eu/clean-documents/Publications/Statistics/Factsheet/entsoe_sfs2018_web.pdf

ENTSO-E. (2023a). *Statistical Factsheet 2021, Provisional values as of March 2023*. ENTSO-E AISBL. https://eepublicdownloads.entsoe.eu/clean-documents/Publications/Statistics/Factsheet/entsoe_sfs2021_web.pdf

ENTSO-E. (2023b). *Statistical Factsheet 2022, Provisional values as of June 2023*. ENTSO-E AISBL. https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/Publications/Statistics/Factsheet/entsoe_sfs2022_web.pdf

ENTSO-E. (2024a). *Statistical Factsheet 2019, Provisional values as of November 2024*. ENTSO-E AISBL. https://eepublicdownloads.entsoe.eu/clean-documents/Publications/Statistics/Factsheet/entsoe_sfs2019_web.pdf

ENTSO-E. (2024b). *Statistical Factsheet 2020, Provisional values as of November 2024*. ENTSO-E AISBL. https://eepublicdownloads.entsoe.eu/clean-documents/Publications/Statistics/Factsheet/entsoe_sfs2020_web.pdf

ENTSO-E. (2024c). *Statistical Factsheet 2023, Provisional values as of April 2024*. ENTSO-E AISBL. https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/Publications/Statistics/Factsheet/entsoe_sfs2023_web.pdf

ENTSO-E. (2025). *Statistical Factsheet 2024, Provisional values as of March 2025*. ENTSO-E AISBL. https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/Publications/Statistics/Factsheet/entsoe_sfs2024_web.pdf

Eymann, L., Stucki, M., Fürholz, A., & König, A. (2015). *Ökobilanzierung von Schweizer Windenergie*. Zürcher Hochschule für Angewandte Wissenschaften; Im Auftrag des Bundesamts für Energie BFE. www.zhaw.ch/lca

Frischknecht, R., Althaus, H.-J., Dones, R., Hischier, R., Jungbluth, N., Nemecek, T., Primas, A., & Wernet, G. (2007). *Renewable Energy Assessment within the Cumulative Energy Demand Concept: Challenges and Solutions*. SETAC Europe 14th LCA case study symposium: Energy in LCA - LCA of Energy, 3-4 December 2007.

Frischknecht, R., Doka, G., Lasvaux, S., Margni, M., Oberschelp, C., & Zschokke, M. (2023). *Database protocol—FOEN LCI data DQRv2* (S. 105). treeze Ltd. commissioned by the Swiss Federal Office for the Environment (FOEN).

Frischknecht, R., Krebs, L., Dinkel, F., Kägi, T., Braunschweig, A., Itten, R., & Stucki, M. (2021). *Ökofaktoren Schweiz 2021 gemäss der Methode der ökologischen Knappheit. Methodische Grundlagen und Anwendung auf die Schweiz* (Umwelt-Wissen Nr. 2121: 260 S). Bundesamt für Umwelt (BAFU).

Gaertner, I., Rinker, J., Sethuraman, L., Zahle, F., Anderson, B., Barter, G., Abbas, N., Meng, F., Bortolotti, P., Skrzypinski, W., Scott, G., Feil, R., Bredmose, H., Dykes, K., Shields, M., Allen, C., & Viselli, A. (2020). *IEA Wind TCP Task 37 Definition of the IEA Wind 15-Megawatt Offshore Reference Wind Turbine* (Technical Report NREL/TP-5000-75698). IEA Wind TCP. https://www.nrel.gov/docs/fy20osti/75698.pdf

Garrett, P., & Rønde, K. (2011). *Life Cycle Assessment of Electricity Production from a V90-2.0 MW Gridstreamer Wind Plant.* Vestas Wind Systems A/S. https://www.vestas.com/content/dam/vestas-com/global/en/sustainability/reports-and-ratings/lcas/LCA_V902MW_version1.pdf.coredownload.inline.pdf

Grothe, O., Kächele, F., & Watermeyer, M. (2022). Analyzing Europe’s Biggest Offshore Wind Farms: A Data Set with 40 Years of Hourly Wind Speeds and Electricity Production. *Energies*, *15*(5), 1700. https://doi.org/10.3390/en15051700

IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg1/

Jonkman, J., Butterfield, S., Musial, W., & Scott, G. (2009). *Definition of a 5-MW Reference Wind Turbine for Offshore System Development* (Technical Report NREL/TP-500-38060). IEA Wind TCP. https://docs.nrel.gov/docs/fy09osti/38060.pdf

Kainz, S. (2025). *Life Cycle Inventory of the IEA Wind 740-10-MW Reference Offshore Wind Plant with irregular layout* [Dataset]. Zenodo. https://doi.org/10.5281/ZENODO.15880601

Kainz, S., Guilloré, A., & Bottasso, C. L. (2024). How do technological choices affect the economic and environmental performance of offshore wind farms? *Journal of Physics: Conference Series*, *2767*(8), 082005. https://doi.org/10.1088/1742-6596/2767/8/082005

Kainz, S., Quick, J., Souza de Alencar, M., Sanchez Perez Moreno, S., Dykes, K., Bay, C., Zaaijer, M. B., & Bortolotti, P. (2024). *IEA Wind TCP Task 55 The IEA Wind 740-10-MW Reference Offshore Wind Plants*. IEA Wind TCP.

Kaufmann, U. (2024). *Schweizerische Statistik der erneuerbaren Energien. Ausgabe 2023*. Bundesamt für Energie BFE.

Kouloumpis, V., & Azapagic, A. (2022). A model for estimating life cycle environmental impacts of offshore wind electricity considering specific characteristics of wind farms. *Sustainable Production and Consumption*, *29*, 495–506. https://doi.org/10.1016/j.spc.2021.10.024

Mali, S., & Garrett, P. (2023). *Life Cycle Assessment of Electricity Production from an onshore EnVentus V162-6.2 MW Wind Plant*. Vestas Wind Systems A/S. https://www.vestas.com/content/dam/vestas-com/global/en/sustainability/reports-and-ratings/lcas/LCA%20of%20Electricity%20Production%20from%20an%20onshore%20EnVentus%20V162-6.2.pdf.coredownload.inline.pdf

Martinez Aguado, O., & Garrett, P. (2025). *Life Cycle Assessment of Electricity Production from an onshore V163-4.5 MW Wind Plant*. Vestas Wind Systems A/S. https://www.vestas.com/content/dam/vestas-com/global/en/sustainability/environment/Life%20Cycle%20Assessment%20of%20electricity%20production%20from%20an%20onshore%20V163-4.5MW%20wind%20plant.pdf.coredownload.inline.pdf

Milne, C., Jalili, S., & Maheri, A. (2021). Decommissioning cost modelling for offshore wind farms: A bottom-up approach. *Sustainable Energy Technologies and Assessments*, *48*, 101628. https://doi.org/10.1016/j.seta.2021.101628

Ormiston, J. (2012). *Ormonde Offshore Wind Farm*. https://www.territoire-energie.com/wp-content/uploads/2017/03/dp_vattenfall_inaugure_la_ferme_eolienne_en_mer_d_ormonde_190912.pdf

Pan, B., Wang, G., Shi, H., Shen, J., Ji, H.-K., & Kil, G.-S. (2020). Green Gas for Grid as an Eco-Friendly Alternative Insulation Gas to SF6: A Review. *Applied Sciences*, *10*(7), Article 7. https://doi.org/10.3390/app10072526

Prime, J., Abdulkadir Ahmed, I., Akande, D., Elhassan, N., Melnikov, Y., & Whiteman, A. (2025). *Renewable Capacity Statistics 2025*. IRENA. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Mar/IRENA_DAT_RE_Capacity_Statistics_2025.pdf

Razdan, P., & Garrett, P. (2017). *Life Cycle Assessment of Electricity Production from an onshore V117-3.45 MW Wind Plant*. Vestas Wind Systems A/S. https://www.vestas.com/content/dam/vestas-com/global/en/sustainability/reports-and-ratings/lcas/V1263%2045MW_Mk3a_ISO_LCA_Final_31072017.pdf.coredownload.inline.pdf

REpower. (2025). *The 5-megawatt power plant with 126 metre rotor diameter*. REpower Systems S. https://www.renugen.co.uk/content/large_wind_turbine_brochures/large_wind_turbine_brochures/repower_5m.pdf

Stucki, M., Götz, M., de Wild-Scholten, M., & Frischknecht, R. (2024). *Environmental Life Cycle Assessment of Electricity from PV Systems*. IEA PVPS Task 12, International Energy Agency Photovoltaic Power Systems Programme. https://doi.org/10.69766/ALGS2169

Suisse Eole. (2025). Schweizer Windparks und Projekte. *Suisse Eole*. https://suisse-eole.ch/de/windenergie/windparks/

Treyer, K., & Bauer, C. (2024). *Wind turbine construction, 4.5MW, onshore—Global—Wind turbine, 4.5MW, onshore* [Dataset]. https://ecoquery.ecoinvent.org/3.10/cutoff/dataset/2086/documentation

UVEK DQRv2. (2022). *KBOB-Ökobilanzdatenbestand 2022 und UVEK-Ökobilanzdatenbestand 2022*. treeze Ltd., Bundesamt für Umwelt (BAFU) und Bundesamt für Energie (BFE).

ANNEX I LCI OF ONSHORE AND OFFSHORE WIND TURBINES

Table A 1 Inventory of modelled onshore wind turbines

	Name	Unit	wind turbine 2.3MW, onshore, moving parts {CH} U	wind turbine 3.4MW, onshore, moving parts {RER} U	wind turbine 4.5MW, onshore, moving parts {RER} U	wind turbine 6.2MW, onshore, moving parts {RER} U	wind turbine 2.3MW, onshore, tower, concrete {CH} U	wind turbine 2.3MW, onshore, tower, steel {CH} U	wind turbine 3.4MW, onshore, tower {RER} U	wind turbine 4.5MW, onshore, tower {RER} U	wind turbine 6.2MW, onshore, tower {RER} U	wind turbine 2.3MW, onshore, foundation {CH} U	wind turbine 3.4MW, onshore, foundation {RER} U	wind turbine 4.5MW, onshore, foundation {RER} U	wind turbine 6.2MW, onshore, foundation {RER} U
	Location		RER	RER	RER	RER	RER	RER	RER	RER	RER	RER	RER	RER	RER
	InfrastructureProcess		1	1	1	1	1	1	1	1	1	1	1	1	1
	Unit		unit	unit	unit	unit	unit	unit	unit	unit	unit	unit	unit	unit	unit
Inputs from nature	Transformation, from pasture and meadow	m2	0	0	0	0	0	0	0	0	0	1.11E+2	9.45E+1	1.01E+2	1.70E+2
	Transformation, to industrial area, built up	m2	0	0	0	0	0	0	0	0	0	1.11E+2	9.45E+1	1.01E+2	1.70E+2
	Occupation, industrial area, built up	m2a	0	0	0	0	0	0	0	0	0	2.77E+3	2.36E+3	2.53E+3	4.25E+3
materials	Aluminium, production mix, at plant {RER} U	kg	1.38E+3	1.08E+3	2.00E+3	3.12E+3	0	2.87E+3	1.74E+3	2.71E+3	5.77E+3	0	4.39E+0	9.09E+1	0
	Boron carbide, at plant {GLO} U	kg	0	0	0	0	0	0	0	0	0	0	4.19E+1	0	0
	Carbon fiber production, weaved, at factory {RER} U	kg	0	1.89E+3	0	0	0	0	0	0	0	0	0	0	0
	Cast iron, at plant {RER} U	kg	7.76E+4	3.07E+4	7.83E+4	1.02E+5	0	0	0	0	0	0	0	0	0
	Chromium steel 18/8, at plant {RER} U	kg	4.57E+4	1.74E+4	2.73E+4	6.75E+4	0	0	2.14E+2	3.16E+2	8.80E+2	0	2.72E+3	0	9.13E+3
	Chromium, at regional storage {RER} U	kg	0	0	0	0	0	0	0	0	0	0	5.85E+2	0	0
	Cobalt, at plant {GLO} U	kg	0	0	0	0	0	0	0	0	0	0	1.43E+0	0	0
	Concrete, normal, at plant {CH} U	m3	0	0	0	0	3.32E+2	0	0	0	0	4.58E+2	5.62E+2	6.07E+2	1.03E+3
	Copper, at regional storage {RER} U	kg	1.33E+4	3.68E+3	3.19E+3	5.15E+3	0	1.44E+3	1.75E+2	1.42E+2	2.58E+2	0	2.36E+1	4.55E+1	6.25E+1
	Electronics for control units {RER} U	kg	0	0	5.53E+3	6.85E+3	0	0	0	0	0	0	0	0	3.13E+1
	Epoxy resin, liquid, at plant {RER} U	kg	0	1.21E+4	0	0	0	0	2.33E+2	0	0	0	3.86E+1	0	0
	Gallium, semiconductor-grade, at regional storage {RER} U	kg	0	0	0	0	0	0	0	0	0	0	2.68E-2	0	0
	Glass fibre reinforced plastic, polyamide, injection moulding, at plar	kg	2.95E+4	1.56E+3	0	0	0	0	0	0	0	0	0	0	0
	Glass fibre, at plant {RER} U	kg	0	3.26E+4	3.47E+4	4.68E+4	0	0	0	0	0	0	0	0	0
	Graphite, at plant {RER} U	kg	0	0	0	0	0	0	1.57E+1	0	0	0	0	0	0
	Lanthanum oxide, at plant {CN} U	kg	0	6.88E+0	0	0	0	0	0	0	0	0	3.45E-1	0	0
	Lead, at regional storage {RER} U	kg	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lithium, at plant {GLO} U	kg	0	0	0	0	0	0	3.09E+0	0	0	0	9.33E-3	0	0
	Lubricating oil, at plant {RER} U	kg	1.85E+2	2.77E+2	3.63E+2	5.05E+2	0	0	0	0	0	0	0	0	0
	Manganese, at regional storage {RER} U	kg	0	0	0	0	0	0	0	0	0	0	1.27E+3	0	0
	Neodymium oxide, at plant {CN} U	kg	0	1.40E+2	0	0	0	0	0	0	0	0	0	0	0
	Nickel, 99.5%, at plant {GLO} U	kg	0	0	0	0	0	0	0	0	0	0	1.33E+3	0	0
	Permanent magnet, for electric motor {RER} U	kg	0	0	9.65E+1	5.31E+2	0	0	0	0	0	0	0	0	0
	Pig iron, at plant {RER} U	kg	0	2.15E+3	0	0	0	0	7.83E+1	0	0	0	3.27E+1	0	0
	Polyester resin, unsaturated, at plant {RER} U	kg	0	3.73E+3	0	0	0	0	0	0	0	0	0	0	0
	Polyethylene, HDPE, granulate, at plant {RER} U	kg	0	0	0	0	0	2.21E+3	0	0	0	0	0	0	0
	Polypropylene, granulate, at plant {RER} U	kg	0	1.13E+3	2.78E+4	3.88E+4	0	0	4.45E+2	0	0	0	0	7.27E+2	6.25E+1
	Polyurethane, rigid foam, at plant {RER} U	kg	0	1.69E+3	0	0	0	0	0	0	0	0	0	0	0
	Sawnwood, beam, hardwood, dried (u=10%), planed, at sawmill {R	m3	0	2.02E+1	0	0	0	0	0	0	0	0	0	0	0
	Silicone product, at plant {RER} U	kg	0	1.20E+2	0	0	0	0	0	0	0	0	0	0	0
	Silver, at regional storage {RER} U	kg	0	0	1.45E-1	0	0	0	0	0	0	0	0	0	0
	Solder, paste, Sn95.5Ag3.9Cu0.6, for electronics industry, at plant {(	kg	0	0	3.78E+0	0	0	0	0	0	0	0	0	0	0
	Steel, low-alloyed, at plant {RER} U	kg	5.30E+4	6.11E+4	7.18E+4	6.88E+4	1.03E+5	1.39E+5	3.02E+5	2.47E+5	4.77E+5	5.23E+4	6.74E+4	7.90E+4	1.17E+5
	Sulphur hexafluoride, liquid, at plant {RER} U	kg	4.18E+0	6.25E+0	8.19E+0	1.14E+1	0	0	0	0	0	0	0	0	0
	Tantalum, powder, capacitor-grade, at regional storage {GLO} U	kg	0	0	0	0	0	0	0	0	0	0	1.97E-1	0	0
	Tin, at regional storage {RER} U	kg	0	0	0	0	0	0	0	0	0	0	9.75E-2	0	0
	Zinc, primary, at regional storage {RER} U	kg	0	1.79E+0	2.41E+2	0	0	0	0	0	0	0	1.19E+1	0	0
Processing	Aluminium product manufacturing, average metal working {RER} U	kg	1.30E+3	1.08E+3	2.00E+3	3.12E+3	0	2.87E+3	1.74E+3	2.71E+3	5.77E+3	0	4.39E+0	9.09E+1	0
	Copper product manufacturing, average metal working {RER} U	kg	1.33E+4	3.68E+3	3.19E+3	5.15E+3	0	1.44E+3	1.75E+2	1.42E+2	2.58E+2	0	2.36E+1	4.55E+1	6.25E+1
	Sheet rolling, steel {RER} U	kg	5.30E+4	6.11E+4	7.18E+4	6.88E+4	1.03E+5	1.39E+5	3.02E+5	2.47E+5	4.77E+5	5.23E+4	6.74E+4	7.90E+4	1.17E+5
	Sheet rolling, chromium steel {RER} U	kg	4.57E+4	1.74E+4	2.73E+4	6.75E+4	0	0	2.14E+2	3.16E+2	8.80E+2	0	2.72E+3	0	9.13E+3
	Injection moulding {RER} U	kg	0	4.35E+3	2.78E+4	3.88E+4	0	0	4.45E+2	0	0	0	0	7.27E+2	6.25E+1
	Welding, arc, steel {RER} U	m	0	0	0	0	0	3.61E+2	4.18E+2	3.72E+2	5.66E+2	0	0	0	0
	Wire drawing, copper {RER} U	kg	0	0	0	0	0	0	0	0	0	0	0	0	0
	Electricity, production mix ENTSO {ENTSO-E} U	kWh	1.10E+5	8.67E+4	1.26E+5	1.70E+5	0	0	0	0	0	0	0	0	0
Transportation, Installa	Transport, freight, lorry, fleet average {RER} U	tkm	1.59E+5	1.50E+5	2.02E+5	2.74E+5	3.80E+5	6.20E+4	1.29E+5	1.06E+5	2.06E+5	5.72E+4	7.06E+4	7.62E+4	1.29E+5
	transport, freight, lorry 16-32 metric ton, EURO 5 {RER} U	tkm	2.28E+4	1.81E+4	2.63E+4	3.55E+4	5.80E+4	1.50E+4	3.12E+4	2.56E+4	4.96E+4	7.08E+4	8.79E+4	9.49E+4	1.60E+5
	Transport, transoceanic freight ship {OCE} U	tkm	1.87E+6	1.34E+6	2.01E+6	2.72E+6	0	0	0	0	0	0	0	0	0
	Operation, freight train, diesel {RER} U	tkm	4.42E+4	4.84E+4	6.43E+4	8.68E+4	2.06E+4	2.92E+4	6.09E+4	5.00E+4	9.68E+4	1.05E+4	1.47E+4	1.60E+4	2.53E+4
	Diesel, burned in building machine, average {CH} U	MJ	3.78E+2	3.74E+2	4.72E+2	9.71E+2	9.38E+2	1.36E+2	3.29E+2	2.41E+2	7.07E+2	0	0	0	0
	Excavation, hydraulic digger, average {CH} U	m3	0	0	0	0	0	0	0	0	0	6.88E+2	8.44E+2	9.10E+2	1.55E+3
EoL treatment	Recycling steel and iron {RER} U	kg	1.80E+5	1.09E+5	1.72E+5	2.31E+5	9.77E+4	1.34E+5	2.87E+5	2.35E+5	4.54E+5	4.97E+4	6.67E+4	7.51E+4	1.20E+5
	Disposal, steel, 0% water, to construction waste landfill {CH} U	kg	9.48E+3	5.75E+3	9.03E+3	1.21E+4	5.14E+3	7.03E+3	1.51E+4	1.24E+4	2.39E+4	2.62E+3	3.51E+3	3.95E+3	6.33E+3
	Disposal, aluminium, 0% water, to sanitary landfill {CH} U	kg	6.88E+1	5.41E+1	9.99E+1	1.56E+2	0	1.44E+2	8.68E+1	1.36E+2	2.88E+2	0	2.20E-1	4.55E+0	0
	Disposal, plastics, mixture, 15.3% water, to municipal incineration {(	kg	0	4.12E+3	1.39E+4	1.94E+4	0	1.10E+3	2.23E+2	0	0	0	1.72E-1	3.64E+2	3.13E+1
	Disposal, plastics, mixture, 15.3% water, to sanitary landfill {CH} U	kg	0	4.12E+3	1.39E+4	1.94E+4	0	1.10E+3	2.23E+2	0	0	0	1.72E-1	3.64E+2	3.13E+1
	Disposal, glass fibre-reinforced polymer panel, polyester resin, to m	kg	1.48E+4	1.69E+4	1.70E+4	2.29E+4									
	Disposal, inert material, 0% water, to sanitary landfill {CH} U	kg	1.48E+4	1.69E+4	1.70E+4	2.29E+4									
	Disposal, inert material, 0% water, to sanitary landfill {CH} U	kg	1.90E+2	1.52E+4	6.96E+3	8.87E+3	7.91E+5	0	2.52E+2	0	0	1.09E+6	1.34E+6	1.44E+6	2.45E+6

Table A 2 Inventory of modelled offshore wind turbines

	Name	Unit	wind turbine 5MW, offshore, moving parts {RER} U	wind turbine 10MW, offshore, moving parts {RER} U	wind turbine 15MW, offshore, moving parts {RER} U	wind turbine 5MW, offshore, tower {RER} U	wind turbine 10MW, offshore, tower {RER} U	wind turbine 15MW, offshore, tower {RER} U	wind turbine 5MW, offshore, jacket substructure {RER} U	wind turbine 10MW, offshore, monopile substructure {RER} U	wind turbine 15MW, offshore, monopile substructure {RER} U
	Location		RER	RER	RER	RER	RER	RER	RER	RER	RER
	InfrastructureProcess		1	1	1	1	1	1	1	1	1
	Unit		unit	unit	unit	unit	unit	unit	unit	unit	unit
Inputs from nature	Transformation, from pasture and meadow	m2	0	0	0	0	0	0	0	0	0
	Transformation, from sea and ocean	m2	0	0	0	0	0	0	1.27E+2	1.27E+2	1.57E+2
	Transformation, to industrial area, built up	m2	0	0	0	0	0	0	1.27E+2	1.27E+2	1.57E+2
	Occupation, seabed, infrastructure	m2a	0	0	0	0	0	0	3.18E+3	3.18E+3	3.93E+3
	Occupation, industrial area, built up	m2a	0	0	0	0	0	0	0	0	0
materials	Chromium steel 18/8, at plant {RER} U	kg	4.19E+4	2.43E+5	2.00E+4	0	0	2.27E+2	0	0	0
	Aluminium, production mix, at plant {RER} U	kg	5.96E+3	2.91E+4	1.33E+4	3.98E+3	0	4.89E+3	0	7.04E+3	0
	Boron carbide, at plant {GLO} U	kg	0	0	6.22E+1	0	0	0	0	0	0
	Carbon fiber production, weaved, at factory {RER} U	kg	0	0	1.28E+4	0	0	0	0	0	0
	Cast iron, at plant {RER} U	kg	1.67E+5	0	2.82E+5	0	0	0	0	0	0
	Cement, unspecified, at plant {CH} U	kg	0	0	0	0	0	0	9.75E+3	0	0
	Chromium, at regional storage {RER} U	kg	0	0	4.04E-1	0	0	0	0	0	4.68E+2
	Cobalt, at plant {GLO} U	kg	0	0	0	0	0	0	0	0	2.06E+1
	Copper, at regional storage {RER} U	kg	1.38E+4	6.05E+4	4.58E+4	0	0	2.06E+3	0	0	0
	Electronics for control units {RER} U	kg	0	7.04E+3	0	0	0	0	0	0	0
	Epoxy resin, liquid, at plant {RER} U	kg	1.77E+4	4.93E+4	3.06E+4	0	0	6.95E+1	0	0	0
	Glass fibre, at plant {RER} U	kg	4.64E+4	9.16E+4	1.53E+5	0	0	0	0	0	0
	Gallium, semiconductor-grade, at regional storage {RER} U	kg	0	0	0	0	0	0	0	0	2.47E-1
	Glass fibre reinforced plastic, polyamide, injection moulding, at plant {RER} U	kg	0	0	6.24E+3	0	0	0	0	0	0
	Graphite, at plant {RER} U	kg	0	0	0	0	0	9.65E+1	0	0	0
	Pig iron, at plant {RER} U	kg	0	0	6.21E+3	0	0	9.56E+0	0	0	6.14E+2
	Lead, at regional storage {RER} U	kg	0	0	0	0	0	0	0	0	0
	Lithium, at plant {GLO} U	kg	0	0	0	0	0	1.91E+1	0	0	3.51E-4
	Steel, low-alloyed, at plant {RER} U	kg	1.68E+5	2.92E+5	4.87E+5	2.17E+5	5.52E+5	6.36E+5	7.29E+5	1.05E+6	1.27E+6
	Manganese, at regional storage {RER} U	kg	0	0	0	0	0	0	0	0	2.40E+4
	Molybdenum, at regional storage {RER} U	kg	0	0	1.13E+1	0	0	0	0	0	0
	Neodymium oxide, at plant {CN} U	kg	0	0	3.13E+3	0	0	3.62E+0	0	0	0
	Nickel, 99.5%, at plant {GLO} U	kg	0	0	8.08E-1	0	0	0	0	0	1.80E+4
	Tantalum, powder, capacitor-grade, at regional storage {GLO} U	kg	0	0	0	0	0	0	0	0	3.71E+0
	Coating powder, at plant {RER} U	kg	0	7.49E+3	0	0	0	0	0	1.24E+4	0
	Polyurethane, rigid foam, at plant {RER} U	kg	0	0	6.64E+3	0	0	0	0	0	0
	Polyester resin, unsaturated, at plant {RER} U	kg	0	0	3.14E+4	0	0	0	0	0	0
	Tetrafluoroethylene, at plant {RER} U	kg	0	0	0	0	0	0	0	0	0
	Polyethylene, HDPE, granulate, at plant {RER} U	kg	2.74E+3	0	0	0	0	0	0	0	0
	Polypropylene, granulate, at plant {RER} U	kg	0	0	9.52E+3	0	0	1.83E+3	0	0	0
	Lanthanum oxide, at plant {CN} U	kg	0	0	1.51E+3	0	0	0	0	0	6.51E+0
	Polyvinylchloride, at regional storage {RER} U	kg	0	2.21E+4	0	0	0	0	0	0	0
	Ceramic tiles, at regional storage {CH} U	kg	0	0	0	0	0	0	0	0	0
	Synthetic rubber, at plant {RER} U	kg	0	1.70E+3	0	0	0	0	0	0	0
	Gravel, crushed, at mine {CH} U	kg	0	0	0	0	0	0	2.01E+6	2.01E+6	2.48E+6
	Sand / concrete gravel, in sorting plant {CH} U	kg	0	0	0	0	0	0	1.13E+4	0	0
	Sulphur hexafluoride, liquid, at plant {RER} U	kg	9.09E+0	1.82E+1	2.77E+1	0	0	0	0	0	0
	Silicone product, at plant {RER} U	kg	0	0	4.08E+2	0	0	0	0	0	0
	Silver, at regional storage {RER} U	kg	0	0	4.04E-1	0	0	0	0	0	0
	Tin, at regional storage {RER} U	kg	0	0	6.06E+0	0	0	0	0	0	1.66E+0
	Lubricating oil, at plant {RER} U	kg	4.03E+2	8.06E+2	1.23E+3	0	0	0	0	0	0
	Zinc, primary, at regional storage {RER} U	kg	0	0	1.05E+1	0	0	0	0	0	1.99E+2
	Bitumen, at refinery {RER} U	kg	0	0	0	0	0	0	0	0	0
	Kraft paper, unbleached, at plant {RER} U	kg	0	0	0	0	0	0	0	0	0
	Fibreboard soft, at plant (u=7%) {CH} U	m3	0	0	0	0	0	0	0	0	0
	Sawnwood, beam, hardwood, dried (u=10%), planed, at sawmill {RER} U	m3	3.40E+1	0	1.76E+2	0	0	0	0	0	0
	Concrete, normal, at plant {CH} U	m3	0	0	0	0	0	0	0	0	0
	Zinc coating, coils {RER} U	m2	0	0	0	0	0	0	0	0	0
Processing	Aluminium product manufacturing, average metal working {RER} U	kg	5.96E+3	2.91E+4	1.33E+4	3.98E+3	0	4.89E+3	0	7.04E+3	0
	Copper product manufacturing, average metal working {RER} U	kg	1.38E+4	6.05E+4	4.58E+4	0	0	2.06E+3	0	0	0
	Sheet rolling, steel {RER} U	kg	1.68E+5	2.92E+5	4.87E+5	2.17E+5	5.52E+5	6.36E+5	7.29E+5	1.05E+6	1.27E+6
	Sheet rolling, chromium steel {RER} U	kg	4.19E+4	2.43E+5	2.00E+4	0	0	2.27E+2	0	0	0
	Injection moulding {RER} U	kg	2.74E+3	1.76E+3	3.73E+4	0	0	1.83E+3	0	0	0
	Welding, arc, steel {RER} U	m	0	0	0	3.42E+2	4.52E+2	0	0	1.28E+2	6.84E+1
	Wire drawing, steel {RER} U	kg	0	0	0	0	0	0	0	0	0
	Wire drawing, copper {RER} U	kg	0	0	0	0	0	0	0	0	0
	Electricity, production mix ENTSO {ENTSO-E} U	kWh	2.33E+5	4.02E+5	5.64E+5	0	0	0	0	0	0
Transportation, Installa	Transport, freight, lorry, fleet average {RER} U	tkm	0	4.78E+5	0	4.42E+4	2.76E+5	1.29E+5	5.51E+5	1.54E+6	7.59E+5
	transport, freight, lorry 16-32 metric ton, EURO 5 {RER} U	tkm	6.68E+4	1.12E+5	1.56E+5	3.30E+4	8.28E+4	9.65E+4	2.31E+5	2.79E+5	3.45E+5
	Transport, transoceanic freight ship {OCE} U	tkm	1.77E+8	1.58E+8	2.20E+8	2.07E+7	2.36E+7	2.47E+7	1.97E+8	8.33E+7	8.58E+7
	Operation, freight train, diesel {RER} U	tkm	1.12E+5	1.98E+5	2.93E+5	4.42E+4	1.10E+5	1.29E+5	1.46E+5	2.13E+5	2.64E+5
	Diesel, burned in building machine, average {CH} U	MJ	1.14E+4	9.88E+3	1.38E+4	5.72E+3	7.24E+3	8.47E+3	3.01E+4	3.01E+4	3.72E+4
	Excavation, hydraulic digger, average {CH} U	m3	0	0	0	0	0	0	0	0	0
EoL treatment	Recycling steel and iron {RER} U	kg	3.71E+5	5.66E+5	7.99E+5	2.06E+5	5.25E+5	6.07E+5	6.93E+5	9.94E+5	1.21E+6
	Disposal, steel, 0% water, to construction waste landfill {CH} U	kg	1.95E+4	2.98E+4	4.21E+4	1.09E+4	2.76E+4	3.19E+4	3.65E+4	5.23E+4	6.38E+4
	Disposal, aluminium, 0% water, to sanitary landfill {CH} U	kg	2.98E+2	1.46E+3	6.64E+2	1.99E+2	0	2.45E+2	0	3.52E+2	0
	Disposal, plastics, mixture, 15.3% water, to municipal incineration {CH} U	kg	1.37E+3	1.19E+4	2.78E+4	0	0	9.13E+2	0	0	3.26E+0
	Disposal, plastics, mixture, 15.3% water, to sanitary landfill {CH} U	kg	1.37E+3	1.19E+4	2.78E+4	0	0	9.13E+2	0	0	3.26E+0
	Disposal, glass fibre-reinforced polymer panel, polyester resin, to municipal incinerati	kg	2.24E+4	4.41E+4	7.96E+4						
	Disposal, inert material, 0% water, to sanitary landfill {CH} U	kg	2.24E+4	4.41E+4	7.96E+4						
	Disposal, inert material, 0% water, to sanitary landfill {CH} U	kg	2.31E+4	6.81E+4	5.94E+4	0	0	1.89E+2	2.03E+6	2.02E+6	2.52E+6

ANNEX II LCI OF ELECTRICAL BALANCE OF PLANT FOR ONSHORE AND OFFSHORE WIND FARMS

Table A 3 Inventory of modelled EBoP for onshore wind farms

	Name	Unit	array and export cables, 33kV/110kV, onshore wind farm {RER} U	substation, 200MW onshore wind farm {RER} U
	Location		RER	RER
	InfrastructureProcess		1	1
	Unit		km	unit
Inputs from nature	Transformation, from pasture and meadow	m2	0	0
	Transformation, from sea and ocean	m2	0	0
	Transformation, to industrial area, built up	m2	0	0
	Occupation, seabed, infrastructure	m2a	0	0
	Occupation, industrial area, built up	m2a	0	0
materials	Aluminium, production mix, at plant {RER} U	kg	3.67E+3	9.14E+2
	Bitumen, at refinery {RER} U	kg	0	0
	Boron carbide, at plant {GLO} U	kg	0	3.90E+0
	Carbon fiber production, weaved, at factory {RER} U	kg	0	0
	Cast iron, at plant {RER} U	kg	0	0
	Cement, unspecified, at plant {CH} U	kg	0	0
	Ceramic tiles, at regional storage {CH} U	kg	0	0
	Chromium steel 18/8, at plant {RER} U	kg	0	0
	Chromium, at regional storage {RER} U	kg	0	1.61E+3
	Coating powder, at plant {RER} U	kg	0	0
	Cobalt, at plant {GLO} U	kg	0	1.80E+1
	Concrete, normal, at plant {CH} U	m3	0	5.24E+1
	Copper, at regional storage {RER} U	kg	9.29E+2	4.12E+4
	Electronics for control units {RER} U	kg	0	0
	Epoxy resin, liquid, at plant {RER} U	kg	0	2.71E+1
	Fibreboard soft, at plant (u=7%) {CH} U	m3	0	0
	Gallium, semiconductor-grade, at regional storage {RER} U	kg	0	1.31E-1
	Glass fibre reinforced plastic, polyamide, injection moulding, at	kg	0	3.28E+2
	Glass fibre, at plant {RER} U	kg	2.38E+1	2.61E+3
	Graphite, at plant {RER} U	kg	0	0
	Gravel, crushed, at mine {CH} U	kg	0	0
	Kraft paper, unbleached, at plant {RER} U	kg	0	0
	Lanthanum oxide, at plant {CN} U	kg	0	6.05E-1
	Lead, at regional storage {RER} U	kg	0	1.18E+1
	Lithium, at plant {GLO} U	kg	0	8.93E-4
	Lubricating oil, at plant {RER} U	kg	0	0
	Manganese, at regional storage {RER} U	kg	0	3.11E+3
	Molybdenum, at regional storage {RER} U	kg	0	0
	Neodymium oxide, at plant {CN} U	kg	0	0
	Nickel, 99.5%, at plant {GLO} U	kg	0	2.03E+3
	Permanent magnet, for electric motor {RER} U	kg	0	0
	Pig iron, at plant {RER} U	kg	0	6.29E+1
	Polyester resin, unsaturated, at plant {RER} U	kg	0	0
	Polyethylene, HDPE, granulate, at plant {RER} U	kg	0	0
	Polypropylene, granulate, at plant {RER} U	kg	8.12E+3	6.65E+3
	Polyurethane, rigid foam, at plant {RER} U	kg	0	0
	Polyvinylchloride, at regional storage {RER} U	kg	0	0
	Sand / concrete gravel, in sorting plant {CH} U	kg	0	0
	Sawnwood, beam, hardwood, dried (u=10%), planed, at sawmill	m3	0	0
	Silicone product, at plant {RER} U	kg	0	1.12E+4
	Silver, at regional storage {RER} U	kg	0	0
	Solder, paste, Sn95.5Ag3.9Cu0.6, for electronics industry, at pla	kg	0	0
	Steel, low-alloyed, at plant {RER} U	kg	0	2.23E+5
	Sulphur hexafluoride, liquid, at plant {RER} U	kg	0	0
	Synthetic rubber, at plant {RER} U	kg	0	0
	Tantalum, powder, capacitor-grade, at regional storage {GLO} U	kg	0	3.34E-1
	Tetrafluoroethylene, at plant {RER} U	kg	0	0
	Tin, at regional storage {RER} U	kg	0	1.65E+0
	Zinc coating, coils {RER} U	m2	0	0
	Zinc, primary, at regional storage {RER} U	kg	0	4.97E+1
Processing	Aluminium product manufacturing, average metal working {RER	kg	3.67E+3	9.14E+2
	Copper product manufacturing, average metal working {RER} U	kg	9.29E+2	4.12E+4
	Sheet rolling, steel {RER} U	kg	0	2.23E+5
	Sheet rolling, chromium steel {RER} U	kg	0	0
	Injection moulding {RER} U	kg	8.12E+3	1.79E+4
	Welding, arc, steel {RER} U	m	0	0
	Wire drawing, steel {RER} U	kg	0	0
	Wire drawing, copper {RER} U	kg	9.29E+2	0
	Electricity, production mix ENTSO {ENTSO-E} U	kWh	0	0
Transportation,	Transport, freight, lorry, fleet average {RER} U	tkm	7.64E+3	2.51E+5
	transport, freight, lorry 16-32 metric ton, EURO 5 {RER} U	tkm	1.36E+3	3.77E+4
	Transport, transoceanic freight ship {OCE} U	tkm	0	0
	Operation, freight train, diesel {RER} U	tkm	2.56E+3	5.96E+4
	Diesel, burned in building machine, average {CH} U	MJ	0	0
	Excavation, hydraulic digger, average {CH} U	m3	0	0
EoL treatment	Recycling steel and iron {RER} U	kg	8.82E+2	2.51E+5
	Disposal, steel, 0% water, to construction waste landfill {CH} U	kg	4.64E+1	1.32E+4
	Disposal, aluminium, 0% water, to sanitary landfill {CH} U	kg	1.83E+2	4.57E+1
	Disposal, plastics, mixture, 15.3% water, to municipal incineratic	kg	4.06E+3	9.11E+3
	Disposal, plastics, mixture, 15.3% water, to sanitary landfill {CH}	kg	4.06E+3	9.11E+3
	Disposal, glass fibre-reinforced polymer panel, polyester resin, t	kg		
	Disposal, inert material, 0% water, to sanitary landfill {CH} U	kg		
	Disposal, inert material, 0% water, to sanitary landfill {CH} U	kg	2.38E+1	1.34E+5

Table A 4 Inventory of modelled EBoP for offshore wind farms

	Name	Unit	array cable, 66kV, offshore wind farm {RER} U	export cable, 220kV, offshore wind farm {RER} U	substation, offshore, 740MW offshore wind farm {RER} U	substation, land-based, 740MW offshore wind farm {RER} U	substation,offshore, 150MW offshore wind farm {RER} U	substation, offshore, 1005MW offshore wind farm {RER} U
	Location		RER	RER	RER	RER	RER	RER
	InfrastructureProcess		1	1	1	1	1	1
	Unit		km	km	unit	unit	unit	unit
Inputs from nature	Transformation, from pasture and meadow	m2	0	0	0	0	0	0
	Transformation, from sea and ocean	m2	0	0	0	0	0	0
	Transformation, to industrial area, built up	m2	0	0	0	0	0	0
	Occupation, seabed, infrastructure	m2a	0	0	0	0	0	0
	Occupation, industrial area, built up	m2a	0	0	0	0	0	0
materials	Chromium steel 18/8, at plant {RER} U	kg	0	0	0	0	0	0
	Aluminium, production mix, at plant {RER} U	kg	0	0	4.12E+4	4.01E+4	8.96E+4	0
	Boron carbide, at plant {GLO} U	kg	0	0	0	0	0	0
	Carbon fiber production, weaved, at factory {RER} U	kg	0	0	0	0	0	0
	Cast iron, at plant {RER} U	kg	0	0	0	0	0	0
	Cement, unspecified, at plant {CH} U	kg	0	0	0	0	0	0
	Chromium, at regional storage {RER} U	kg	0	0	0	0	0	5.47E+3
	Cobalt, at plant {GLO} U	kg	0	0	0	0	0	1.47E+2
	Copper, at regional storage {RER} U	kg	6.82E+3	2.51E+4	8.36E+4	8.30E+4	5.43E+4	8.22E+4
	Electronics for control units {RER} U	kg	0	0	0	0	0	0
	Epoxy resin, liquid, at plant {RER} U	kg	0	0	7.54E+2	6.71E+2	0	0
	Glass fibre, at plant {RER} U	kg	0	0	3.76E+3	3.76E+3	0	0
	Gallium, semiconductor-grade, at regional storage {RER} U	kg	0	0	0	0	0	1.60E+0
	Glass fibre reinforced plastic, polyamide, injection moulding, at plant {RER} U	kg	0	0	0	0	0	0
	Graphite, at plant {RER} U	kg	0	0	0	0	0	0
	Pig iron, at plant {RER} U	kg	0	0	0	0	0	3.51E+3
	Lead, at regional storage {RER} U	kg	7.07E+3	2.92E+4	0	0	0	0
	Lithium, at plant {GLO} U	kg	0	0	0	0	0	2.06E-3
	Steel, low-alloyed, at plant {RER} U	kg	9.70E+3	1.91E+4	5.84E+6	3.91E+5	1.33E+6	7.46E+6
	Manganese, at regional storage {RER} U	kg	0	0	0	0	0	1.39E+5
	Molybdenum, at regional storage {RER} U	kg	0	0	2.78E+0	0	0	0
	Neodymium oxide, at plant {CN} U	kg	0	0	0	0	0	0
	Nickel, 99.5%, at plant {GLO} U	kg	0	0	0	0	0	1.03E+5
	Tantalum, powder, capacitor-grade, at regional storage {GLO} U	kg	0	0	0	0	0	2.11E+1
	Coating powder, at plant {RER} U	kg	0	0	3.36E+2	3.36E+2	0	0
	Polyurethane, rigid foam, at plant {RER} U	kg	0	0	0	0	0	0
	Polyester resin, unsaturated, at plant {RER} U	kg	0	0	0	0	0	0
	Tetrafluoroethylene, at plant {RER} U	kg	0	0	1.39E+2	0	0	0
	Polyethylene, HDPE, granulate, at plant {RER} U	kg	3.69E+3	1.61E+4	0	0	0	0
	Polypropylene, granulate, at plant {RER} U	kg	2.28E+3	9.32E+3	0	0	0	0
	Lanthanum oxide, at plant {CN} U	kg	0	0	0	0	0	3.71E+1
	Polyvinylchloride, at regional storage {RER} U	kg	0	0	8.33E+1	9.68E+1	0	0
	Ceramic tiles, at regional storage {CH} U	kg	0	0	2.05E+4	1.41E+4	0	0
	Synthetic rubber, at plant {RER} U	kg	0	0	0	0	0	0
	Gravel, crushed, at mine {CH} U	kg	0	0	0	0	0	0
	Sand / concrete gravel, in sorting plant {CH} U	kg	0	0	0	0	0	0
	Sulphur hexafluoride, liquid, at plant {RER} U	kg	0	0	8.33E+1	0	1.69E+1	1.16E+2
	Silicone product, at plant {RER} U	kg	0	0	0	0	0	0
	Silver, at regional storage {RER} U	kg	0	0	1.67E+0	0	0	0
	Tin, at regional storage {RER} U	kg	0	0	0	0	0	9.66E+0
	Lubricating oil, at plant {RER} U	kg	0	0	1.63E+5	1.63E+5	1.51E+5	0
	Zinc, primary, at regional storage {RER} U	kg	0	0	1.39E+2	0	0	1.16E+3
	Bitumen, at refinery {RER} U	kg	2.67E+3	5.17E+3	0	0	0	0
	Kraft paper, unbleached, at plant {RER} U	kg	0	0	5.03E+3	6.74E+3	0	0
	Fibreboard soft, at plant (u=7%) {CH} U	m3	0	0	1.28E+2	1.28E+2	0	0
	Sawnwood, beam, hardwood, dried (u=10%), planed, at sawmill {RER} U	m3	0	0	0	0	0	0
	Concrete, normal, at plant {CH} U	m3	0	0	0	0	0	0
	Zinc coating, coils {RER} U	m2	2.96E+2	5.80E+2	0	0	0	0
Processing	Aluminium product manufacturing, average metal working {RER} U	kg	0	0	4.12E+4	4.01E+4	8.96E+4	0
	Copper product manufacturing, average metal working {RER} U	kg	0	0	8.36E+4	8.30E+4	5.43E+4	8.22E+4
	Sheet rolling, steel {RER} U	kg	0	0	5.84E+6	3.91E+5	1.33E+6	7.46E+6
	Sheet rolling, chromium steel {RER} U	kg	0	0	0	0	0	0
	Injection moulding {RER} U	kg	5.97E+3	2.54E+4	2.22E+2	9.68E+1	0	0
	Welding, arc, steel {RER} U	m	0	0	0	0	0	0
	Wire drawing, steel {RER} U	kg	9.70E+3	1.91E+4	0	0	0	0
	Wire drawing, copper {RER} U	kg	6.82E+3	2.51E+4	0	0	0	0
	Electricity, production mix ENTSO {ENTSO-E} U	kWh	0	0	0	0	0	0
Transportation,	Transport, freight, lorry, fleet average {RER} U	tkm	1.95E+4	6.26E+4	3.09E+6	3.61E+5	3.24E+5	1.56E+6
	transport, freight, lorry 16-32 metric ton, EURO 5 {RER} U	tkm	4.23E+3	1.33E+4	9.15E+5	9.70E+4	2.33E+5	1.16E+6
	Transport, transoceanic freight ship {OCE} U	tkm	1.82E+7	8.40E+6	3.67E+8	3.25E+6	4.76E+8	4.28E+8
	Operation, freight train, diesel {RER} U	tkm	6.48E+3	2.09E+4	1.30E+6	2.11E+5	3.84E+5	1.56E+6
	Diesel, burned in building machine, average {CH} U	MJ	2.94E+2	5.87E+1	3.29E+4	0	3.29E+4	4.15E+4
	Excavation, hydraulic digger, average {CH} U	m3	0	0	0	0	0	0
EoL treatment	Recycling steel and iron {RER} U	kg	1.57E+4	4.20E+4	5.62E+6	4.50E+5	1.31E+6	7.17E+6
	Disposal, steel, 0% water, to construction waste landfill {CH} U	kg	8.26E+2	2.21E+3	2.96E+5	2.37E+4	6.90E+4	3.77E+5
	Disposal, aluminium, 0% water, to sanitary landfill {CH} U	kg	0	0	2.06E+3	2.01E+3	4.48E+3	0
	Disposal, plastics, mixture, 15.3% water, to municipal incineration {CH} U	kg	2.98E+3	1.27E+4	1.11E+2	4.84E+1	0	1.85E+1
	Disposal, plastics, mixture, 15.3% water, to sanitary landfill {CH} U	kg	2.98E+3	1.27E+4	1.11E+2	4.84E+1	0	1.85E+1
	Disposal, glass fibre-reinforced polymer panel, polyester resin, to municipal incine	kg						
	Disposal, inert material, 0% water, to sanitary landfill {CH} U	kg						
	Disposal, inert material, 0% water, to sanitary landfill {CH} U	kg	9.94E+3	3.48E+4	2.12E+5	2.07E+5	1.51E+5	2.49E+5

ANNEX III LCI OF ELECTRICITY AT WIND FARM

Table A 5 Inventory of modelled Swiss electricity mix for wind power and of modelled electricity datasets at wind farm level.

Name	Unit	electricity, at wind farm {CH} U	electricity, at 100MW wind farm, onshore, 2.3MW turbines {RER} U	electricity, at 200MW wind farm, onshore, 3.4MW turbines {RER} U	electricity, at 100MW wind farm, onshore, 4.5 MW turbines {RER} U	electricity, at 100MW wind farm, onshore, 6.2MW turbines {RER} U	electricity, at 150MW wind farm, offshore, 5MW turbines {RER} U	electricity, at 740MW wind farm, offshore, 10MW turbines {RER} U	electricity, at 1005MW wind farm, offshore, 15MW turbines {RER} U
Location		CH	RER	RER	RER	RER	RER	RER	RER
InfrastructureProcess		0	0	0	0	0	0	0	0
Unit		kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh
Energy, kinetic (in wind), converted	MJ	3.87E+0	3.87E+0	3.87E+0	3.87E+0	3.87E+0	3.87E+0	3.87E+0	3.87E+0
wind turbine 2.3MW, onshore, moving parts {CH} U	unit	7.78E-9	8.44E-9						
wind turbine 2.3MW, onshore, tower, concrete {CH} U	unit	3.60E-9							
wind turbine 2.3MW, onshore, tower, steel {CH} U	unit	4.19E-9	8.44E-9						
wind turbine 2.3MW, onshore, foundation {CH} U	unit	7.78E-9	8.44E-9						
wind turbine 3.4MW, onshore, moving parts {RER} U	unit	1.56E-9		5.71E-9					
wind turbine 3.4MW, onshore, tower {RER} U	unit	1.56E-9		5.71E-9					
wind turbine 3.4MW, onshore, foundation {RER} U	unit	1.56E-9		5.71E-9					
wind turbine 4.5MW, onshore, moving parts {RER} U	unit				4.31E-9				
wind turbine 4.5MW, onshore, tower {RER} U	unit				4.31E-9				
wind turbine 4.5MW, onshore, foundation {RER} U	unit				4.31E-9				
wind turbine 6.2MW, onshore, moving parts {RER} U	unit					3.13E-9			
wind turbine 6.2MW, onshore, tower {RER} U	unit					3.13E-9			
wind turbine 6.2MW, onshore, foundation {RER} U	unit					3.13E-9			
wind turbine 5MW, offshore, moving parts {RER} U	unit						2.68E-9		
wind turbine 5MW, offshore, tower {RER} U	unit						2.68E-9		
wind turbine 5MW, offshore, jacket substructure {RER}	unit						2.68E-9		
wind turbine 10MW, offshore, moving parts {RER} U	unit							1.34E-9	
wind turbine 10MW, offshore, tower {RER} U	unit							1.34E-9	
wind turbine 10MW, offshore, monopile substructure {F	unit							1.34E-9	
wind turbine 15MW, offshore, moving parts {RER} U	unit								8.92E-10
wind turbine 15MW, offshore, tower {RER} U	unit								8.92E-10
wind turbine 15MW, offshore, monopile substructure {F	unit								8.92E-10
array and export cables, 33kV/110kV, onshore wind far	km	1.17E-8	8.24E-9	1.22E-8	8.24E-9	8.83E-9			
substation, 200MW onshore wind farm {RER} U	unit	1.16E-10	9.68E-11	9.68E-11	9.68E-11	9.68E-11			
array cable, 66kV, offshore wind farm {RER} U	km						2.41E-9	2.53E-9	1.77E-9
export cable, 220kV, offshore wind farm {RER} U	km						2.33E-9	3.66E-9	3.80E-9
substation,offshore, 150MW offshore wind farm {RER}	unit						8.92E-11		
substation, offshore, 740MW offshore wind farm {RER}	unit							1.81E-11	
substation, land-based, 740MW offshore wind farm {RI	unit							1.81E-11	1.81E-11
substation, offshore, 1005MW offshore wind farm {REF	unit								1.33E-11
Road {CH} U	my	2.89E-5	2.43E-5	1.22E-5	2.46E-5	2.45E-5			
Lubricating oil, at plant {RER} U	kg	1.80E-5	1.96E-5	1.98E-5	1.96E-5	1.98E-5	1.35E-5	1.35E-5	1.35E-5
Transport, freight, light commercial vehicle {CH} U	tkm	1.80E-6	0	0	0	0			
Transport, freight, light commercial vehicle {RER} U	tkm	0	1.96E-6	1.98E-6	1.96E-6	1.98E-6			
Transport, transoceanic freight ship {OCE} U	tkm						1.11E-1	2.78E-1	2.05E-1
Sulfur hexafluoride	kg	2.12E-09	1.77E-9	1.78E-9	1.77E-9	1.78E-9	1.29E-9	1.29E-9	1.29E-9
Disposal, used mineral oil, 10% water, to hazardous w	kg	1.80E-5	1.96E-5	1.98E-5	1.96E-5	1.98E-5	1.35E-5	1.35E-5	1.35E-5

ANNEX IV LCI OF EUROPEAN ELECTRICITY MIX

Table A 6 Inventory of modelled European electricity mix from wind power

	Name	Unit	electricity, at wind farm {RER} U
	Location		RER
	InfrastructureProcess		0
	Unit		kWh
Inputs	electricity, at 100MW wind farm, onshore, 2.3MW turbines {RER} U	kWh	5.01E-1
	electricity, at 200MW wind farm, onshore, 3.4MW turbines {RER} U	kWh	2.23E-1
	electricity, at 100MW wind farm, onshore, 4.5 MW turbines {RER} U	kWh	9.98E-2
	electricity, at 100MW wind farm, onshore, 6.2MW turbines {RER} U	kWh	4.79E-2
	electricity, at 150MW wind farm, offshore, 5MW turbines {RER} U	kWh	4.52E-2
	electricity, at 740MW wind farm, offshore, 10MW turbines {RER} U	kWh	6.95E-2
	electricity, at 1005MW wind farm, offshore, 15MW turbines {RER} U	kWh	1.36E-2

ANNEX V USED BACKGROUND DATASETS FOR MATERIALS

Table A 7 Used background datasets for material production and processing, as well as used material groups regarding transportation to manufacturing sites and waste treatment sites.

Material name*	Used background dataset for material	Used dataset for processing, if not included in material dataset	Transport category**	EoL category***
chromium steel	Chromium steel 18/8, at plant {RER}	Sheet rolling, chromium steel {RER}	other metals	steel_iron
aluminium	Aluminium, production mix, at plant {RER}	Aluminium product manufacturing, average metal working {RER}	aluminium	aluminium
balsa	Sawnwood, beam, hardwood, dried (u=10%), planed, at sawmill {RER} (used density for conversion: 96.4 kg/m^3)		sawn timber	other
boron	Boron carbide, at plant {GLO}		other chemicals	other
carbon fiber	Carbon fiber production, weaved, at factory {RER}		other chemicals	other
cast iron	Cast iron, at plant {RER}	(dataset for material already includes casting process)	other metals	steel_iron
cement	Cement, unspecified, at plant {CH}		concrete	other
chromium	Chromium, at regional storage {RER}		other metals	other
cobalt	Cobalt, at plant {GLO}		other metals	other
concrete	Concrete, normal, at plant {CH} (used density for conversion: 2380 kg/m^3)		concrete	other
copper	Copper, at regional storage {RER}	Copper product manufacturing, average metal working {RER} For cables; Wire drawing, copper {RER}	other metals	steel_iron
dysprosium	Lanthanum oxide, at plant {CN}		other chemicals	other
Electronics	Electronics for control units {RER}		other metals	other
epoxy	Epoxy resin, liquid, at plant {RER}		plastics	other
fiberglass	Glass fibre, at plant {RER}		float glass	other
gallium	Gallium, semiconductor-grade, at regional storage {RER}		other metals	other
glass reinforced plastic	Glass fibre reinforced plastic, polyamide, injection moulding, at plant {RER}		plastics	plastic
graphite	Graphite, at plant {RER}		other chemicals	other
iron	Pig iron, at plant {RER}		other metals	steel_iron

lead	Lead, at regional storage {RER}		other metals	other
lithium	Lithium, at plant {GLO}		other metals	other
low-alloyed steel	Steel, low-alloyed, at plant {RER}	Sheet rolling, steel {RER} For cables; Wire drawing, steel {RER}	other metals	steel_iron
manganese	Manganese, at regional storage {RER}		other metals	other
molybdenum	Molybdenum, at regional storage {RER}		other metals	other
neodymium	Neodymium oxide, at plant {CN}		other chemicals	other
nickel	Nickel, 99.5%, at plant {GLO}		other metals	other
niobium	Tantalum, powder, capacitor-grade, at regional storage {GLO}		other metals	other
other	(Not modelled specifically, but considered via increasing share of all known materials, keeping total mass constant)			
Paint and Coating	Coating powder, at plant {RER}		other metals	other
PET foam	Polyurethane, rigid foam, at plant {RER}		plastics	plastic
plastic	Polypropylene, granulate, at plant {RER}	Injection moulding {RER}	plastics	plastic
polyester	Polyester resin, unsaturated, at plant {RER}	Injection moulding {RER}	plastics	plastic
polyethylene	Polyethylene, HDPE, granulate, at plant {RER}	Injection moulding {RER}	plastics	plastic
polypropylene	Polypropylene, granulate, at plant {RER}	Injection moulding {RER}	plastics	plastic
praseodymium	Lanthanum oxide, at plant {CN}		other chemicals	plastic
PVC and other plastics	Polyvinylchloride, at regional storage {RER}	Injection moulding {RER}	plastics	plastic
PVC foam	Polyurethane, rigid foam, at plant {RER}		plastics	plastic
PTFE	Tetrafluoroethylene, at plant {RER}	Injection moulding {RER}	plastics	plastic
HDPE	Polyethylene, HDPE, granulate, at plant {RER}	Injection moulding {RER}	plastics	plastic
Porcelain	Ceramic tiles, at regional storage {CH}		plastics	other
Rubber	Synthetic rubber, at plant {RER}		plastics	plastic
crushed rock	Gravel, crushed, at mine {CH}		gravel / sand	other
sand	Sand / concrete gravel, in sorting plant {CH}		gravel / sand	other
SF6	Sulphur hexafluoride, liquid, at plant {RER}		other chemicals	other
silicone	Silicone product, at plant {RER}	Injection moulding {RER}	plastics	plastic
silver	Silver, at regional storage {RER}		other metals	other
terbium	Lanthanum oxide, at plant {CN}		other chemicals	other
thermoplastic	Polypropylene, granulate, at plant {RER}	Injection moulding {RER}	plastics	plastic
tin	Tin, at regional storage {RER}		other metals	other
titanium	Pig iron, at plant {RER}		other metals	steel_iron
transformer oil	Lubricating oil, at plant {RER}		other chemicals	other
lubrication oil	Lubricating oil, at plant {RER}		other chemicals	other
tungsten	Molybdenum, at regional storage {RER}		other metals	other

vanadium	Chromium, at regional storage {RER}		other metals	other
zinc	Zinc, primary, at regional storage {RER}		other metals	other
zinc galvanization	Zinc coating, coils {RER} (used conversion factor: 0.679 kg zinc/m^2)		other metals	other
bitumen	Bitumen, at refinery {RER}		plastics	other
wood, chipboard	Fibreboard soft, at plant (u=7%) {CH} (used density for conversion: 140 kg/m^3)		particle board	other
Kraft paper	Kraft paper, unbleached, at plant {RER}		plastics	other
solder paste	Solder, paste, Sn95.5Ag3.9Cu0.6, for electronics industry, at plant {GLO}		other metals	other
magnet	Permanent magnet, for electric motor {RER}		other metals	other

* as used in data sources

** transport category used for transportation distances of raw materials to the sites of component manufacturing (according to Table 9)

*** EoL categories used for transportation distances to the waste treatment sites (according to Table 11)

Annex VI New, replaced and obsolete datasets within the FOEN database

Table A 8 List of all created new datasets regarding onshore and offshore wind energy, as well as previous datasets for wind energy mixes to be replaced within the FOEN database.

New dataset	Replaced dataset
wind turbine 2.3 MW, onshore, moving parts {RER} wind turbine 2.3 MW, onshore, tower, concrete {CH} wind turbine 2.3 MW, onshore, tower, steel {CH} wind turbine 2.3 MW, onshore, foundation {RER} electricity, at 100MW wind farm, onshore, 2.3MW turbines {RER}	
wind turbine 3.4 MW, onshore, moving parts {RER} wind turbine 3.4 MW, onshore, tower {RER} wind turbine 3.4 MW, onshore, foundation {RER} substation, 200MW onshore wind farm {RER} electricity, at 200MW wind farm, onshore, 3.4MW turbines {RER}	
wind turbine 4.5 MW, onshore, moving parts {RER} wind turbine 4.5 MW, onshore, tower {RER} wind turbine 4.5 MW, onshore, foundation {RER} array and export cables, 33kV/110kV, onshore wind farm {RER} electricity, at 100MW wind farm, onshore, 4.5 MW turbines {RER}	
wind turbine 6.2 MW, onshore, moving parts {RER} wind turbine 6.2 MW, onshore, tower {RER} wind turbine 6.2 MW, onshore, foundation {RER} electricity, at 100MW wind farm, onshore, 6.2MW turbines {RER}	
wind turbine 5 MW, offshore, moving parts {RER} wind turbine 5 MW, offshore, tower {RER} wind turbine 5 MW, offshore, jacket substructure {RER} substation, offshore 150MW offshore wind farm {RER} electricity, at 150MW wind farm, offshore, 5MW turbines {RER}	
wind turbine 10 MW, offshore, moving parts {RER} wind turbine 10 MW, offshore, tower {RER} wind turbine 10 MW, offshore, monopile substructure {RER} array cable, 66kV, offshore wind farm {RER} export cable, 220 kV, offshore wind farm {RER} substation, offshore, 740MW offshore wind farm {RER} substation, land-based, 740MW offshore wind farm {RER} electricity, at 740MW wind farm, offshore, 10MW turbines {RER}	
wind turbine 15 MW, offshore, moving parts {RER} wind turbine 15 MW, offshore, tower {RER} wind turbine 15 MW, offshore, monopile substructure substation, offshore, 1005MW offshore wind farm {RER} electricity, at 1005MW wind farm, offshore, 15MW turbines {RER}	
electricity, at wind farm {CH}	Electricity, at wind power plant {CH}
electricity, at wind farm {RER}	Electricity, at wind power plant {RER}

Table A 9 List of previous datasets regarding wind energy within the FOEN database which become obsolete with the LCI update derived in this study.

Obsolete datasets
Wind power plant 2MW, offshore, moving parts {OCE} U
Wind power plant 2MW, offshore, fixed parts {OCE} U
Electricity, at wind power plant 2MW, offshore {OCE} U
Wind power plant 30kW, moving parts {CH} U
Wind power plant 30kW, fixed parts {CH} U
Electricity, at wind power plant Simplon 30kW {CH} U
Wind power plant 150kW, moving parts {CH} U
Wind power plant 150kW, fixed parts {CH} U
Electricity, at wind power plant Grenchenberg 150kW {CH} U
Wind power plant 600kW, moving parts {CH} U
Wind power plant 600kW, fixed parts {CH} U
Electricity, at wind power plant 600kW {CH} U
Wind power plant 800kW, moving parts {CH} U
Wind power plant 800kW, fixed parts {CH} U
Electricity, at wind power plant 800kW {CH} U
Wind power plant 800kW, moving parts {RER} U
Wind power plant 800kW, fixed parts {RER} U
Electricity, at wind power plant 800kW {RER} U

Annex VII Dataset of the IEA Wind 740-10-MW Reference Offshore Wind Plant

(author of ANNEX VII: Samuel Kainz, TUM)

For the IEA Wind 740-10 MW Reference Offshore Wind Plant, detailed LCI was provided by the Wind Energy Institute of the Technical University of Munich. The LCI was calculated specifically for this project with TUM's *Design and Evaluation Toolchain with Eco-Conscious Targets* (DETECT). The dataset has been published as open-source in Kainz, S. (2025).

To calculate the mass-per-material specific inventory of original turbine and balance-of-plants components, DETECT relies on common scaling models from literature. The components of the rotor nacelle assembly of the IEA 10-MW Reference Offshore Turbine are scaled using the INNWIND mass and cost model (Chaviaropoulos et al., 2014). Tower and monopile are designed using the DTU support structure mass surrogate model (McWilliam et al., 2022). Scour protection is sized following corresponding DNV guidelines (Det Norske Veritas, 2014). Array and export cabling are dimensioned based on the cabling plan as defined for the reference plant, and data from an offshore power cable database (ABB, 2010). For each cable section, the cable type with the smallest capacity surplus relative to the transferred rated power is selected. The total cable mass per cable type is then calculated with the corresponding length-dependent mass rates. The masses of main components in the offshore and the onshore substations are scaled as suggested by Maness et al. (2017). Corrosion protection (coating and sacrificial anodes) is sized following corresponding DNV guidelines (Det Norske Veritas 2010 and Det Norske Veritas 2016). Finally, all calculated component masses are allocated to 27 different materials (Kainz et al., 2024).

The transport distances from production site to port are taken from Razdan and Garrett, 2019. The vessel fuel mass required for the main wind farm installation activities are derived via the total vessel usage hours per vessel type and per operating mode (idling at port, transit, operational on site) calculated based on NREL's ORBIT toolchain (Nunemaker et al., 2020). The vessel usage hours are then translated into fuel mass via fuel consumption per vessel type and operating mode as proposed by Arvesen et al. (2013). Port crane hours for the installation activities are calculated with ORBIT.

To calculate spare part material and vessel fuel demand during the operations and maintenance phase, both scheduled and unscheduled maintenance are considered. Following a conservative approach, a vessel is dispatched from port to the site for each turbine whenever a failure occurs or service is required. Only turbine components are considered, whereas maintenance of the balance of plant (monopiles, cables and substations) is neglected. For scheduled maintenance, fuel consumption is modelled as suggested by Dinwoodie et al. (2015) while material demand is neglected. Unscheduled maintenance is modelled based on component-specific failure rates, downtimes, and replacement costs provided by Carroll et al. (2016) and Donnelly et al. (2024), and the distance to service port. Similar to component installation, the required fuel mass is derived via the fuel consumption per vessel type and operating mode as proposed by Arvesen et al. (2013). The required spare part mass per component replacement activity is derived via a cost-based allocation, where material demand of the original components is scaled by the ratio of material costs for replacement activities to the costs of the original components.

Decommissioning is treated as the inverse of the installation process, except that the scour protection material is assumed to remain on the seabed. All components are assumed to be transported by truck to a regional recycling or disposal facility, as proposed by Razdan and Garrett (2019). Several end-of-life treatment pathways are considered. Components replaced within the final five years of operation are assumed to be resold, in line with DNV GL, 2017. Recycling rates are based on data from Razdan and Garrett, 2019. Components classified as waste are either incinerated or landfilled, using allocation ratios from Razdan and Garrett (2019); for items not specified in their study, relevant values are sourced from corresponding ecoinvent datasets.

BIBLIOGRAPHY

ABB (2010) XLPE Submarine Cable Systems Attachment to XLPE Land Cable Systems - User's Guide

Arvesen A, Birkeland C and Hertwich E G (2013) Environ. Sci. Technol. 47 2948–2956

Carroll J, McDonald A and McMillan D (2016) Wind Energy 19 1107–1119

Chaviaropoulos, P K and Karga, I and Harkness, C and Hendriks, B (2014) PI-based assessment of innovative concepts (methodology) INNWIND.EU Deliverable 1.23

Det Norske Veritas (2014) Design of offshore wind turbine structures DNV-OS-J101 Offshore Standard

Det Norske Veritas (2010) Cathodic protection design DNV-RP-B401 Recommended Practice

Det Norske Veritas (2016) Corrosion protection for wind turbines DNVGL-RP-0416 Recommended Practice

DNV GL (2017) Dakota Range Wind Project - Decommissioning Cost Analysis Nr. 10050292-HOU-R-03

Dinwoodie I, Endrerud O E V, Hofmann M, Martin R and Sperstad I B (2015) Wind Engineering 39 1–14

Donnelly O, Anderson F and Carroll J (2024) *Wind Energy Science* 9 1345–1362

Kainz, S., Guilloré, A., & Bottasso, C. L. (2024). How do technological choices affect the economic and environmental performance of offshore wind farms? *Journal of Physics: Conference Series*, *2767*(8), 082005. https://doi.org/10.1088/1742-6596/2767/8/082005

Kainz, S. (2025). *Life Cycle Inventory of the IEA Wind 740-10-MW Reference Offshore Wind Plant with irregular layout; https://doi.org/10.5281/zenodo.15880602*

Maness M, Maples B and Smith A (2017) *NREL Offshore Balance-of-System Model Tech. Rep. TP-6A20-66874*

McWilliam M K, Friis-Møller M, Pollini N, Dykes K and Jensen M (2022) J. Phys.: Conf. Ser. 2265 042048

Nunemaker J, Shields M, Hammond R and Duffy P (2020) ORBIT: Offshore Renewables Balance-of-System and Installation Tool, NREL/TP-5000-7708

Nunemaker J, Shields M, Hammond R and Duffy P (2020) ORBIT: Offshore Renewables Balance-of-System and Installation

ANNEX VIII REVIEW REPORT

CENTRE OBSERVATION, IMPACTS, ENERGIE (O.I.E.)

Data Quality Review of LCI Data of Wind Power

Authors :

Name	Structure	Position
Mathilde Marchand-Lasserre	Mines Paris – Université PSL	LCA researcher
Joanna Schlesinger	Mines Paris – Université PSL	LCA engineer

21/07/2025
Final version

Context

On behalf of the Federal Office for the Environment (FOEN), the Zurich University of Applied Science (ZHAW) updated the life cycle inventory models for wind power electricity for the federal administration database. Two experts from Mines Paris - PSL University were commissioned to review and validate the Life Cycle Inventories (LCIs) (and associated report) of the electricity produced by wind turbines, developed by ZHAW.

The aim of this review is to assess the updated LCIs according to the DQR_v2:2023 quality guidelines and the data quality requirements, as well as the associated documentation. In particular, the validation includes the check for:

- completeness of the documentation;
- consistency with the data quality guidelines;
- plausibility of the input and output flows;
- mathematical correctness of the calculations.

Subject of the review

The review was performed on the LCI data of electricity production by onshore and offshore wind farms. The following documents were subject to review:

Version	Reception date	Document
1	18/04/2025	2025-Update-LCI-Wind-UVEK-database-v0.2-for review-20250418.docx Ecospold-BFE-Wind-LCI-update-v0.15-for review-20250418.xlsx
2	13/06/2025	Ecospold-BFE-Wind-LCI-update-v0.20.xlsx 2025-Update-LCI-Wind-UVEK-database-v0.7-for-review-20250613.docx
3	14/07/2025	Ecospold-BFE-Wind-LCI-update-v0.22-for-review-14072025.xlsx 2025-Update-LCI-Wind-UVEK-database-v0.9-for-review-14072025-CLEAN.docx
4 (final version)	18/05/2025	Ecospold-BFE-Wind-LCI-v1.0.xlsx Kröhnert_et_al_2025-LCI-Wind-Energy-v1.0.docx

Main stages of the review

The review was made on three different stages representing the wind electricity production process, namely:

- Stage A: Manufacturing LCIs which model the wind turbines and foundations
- Stage B: LCIs of the wind electricity production at wind farm scale which model the manufacturing of all components of the farm (eg wind turbines and foundations, cables, transmission station…) the installation on site, the maintenance and the decommissioning of the wind turbines on a site
- Stage C: LCIs of the wind electricity production at European scale and at national Swiss scale which model the environmental impact of the kWh of electricity produced by wind turbines in Europe and in Switzerland.

Review statement

The review was performed based on the five steps outlined in the database protocol of the FOEN LCI database DQRv2 (Frischknecht, 2023) [1].

Completeness of the documentation

The final version of the report and datasets are complete and inform the users of the datasets about the system outline, the technologies covered, the main data sources used, the data processing steps, the results and the main contributors.

Consistency with the quality guidelines

All final LCI datasets are established following the current version of the database protocol.

For manufacturing inventories, data quality was assessed based on the transparency of data source and on intermediate variables (such as aggregated mass). Plausibility checks on aggregated masses of the report and datasets lead to changes in inventory data. The plausibility checks on the final version was successful and did not reveal any remaining inconsistencies or errors.

Completeness of inputs and outputs

The final version of the datasets comprised updates of all major material and energy inputs and emissions. The final version datasets are considered complete.

Mathematical correctness of calculations

The review did not reveal mathematical errors in the datasets nor in the Excel-files used to process the original raw data.

General comments

The reviewers would like to highlight the high-quality of the report associated to the datasets. A lot of efforts were made by ZHAW to take into account the reviewers comments and to make the report as clear and transparent as possible, especially by:

- Providing sources and assumptions associated with foreground data.
- Explaining clearly how the inventories were resized in case of missing data and/or in order to harmonize the inventories of different wind farms.

[1] Frischknecht R. (2023) Database protocol; FOEN LCI data DQRv2. treeze Ltd., Uster, CH.

- Explaining clearly how the inventories were scaled up from a specific wind farm dataset to a market dataset.
- Discussing the main limits of the datasets in a dedicated part.

According to the reviewers, the main difficulty & limit of this work is the scale-up from a specific wind farm dataset to a market dataset. This could be improved in further versions.

Limits of the review

Individual data was not verified one by one. Only the plausibility of aggregated masses and fuel consumption was assessed. The compliance of amounts of all individual flows of manufacturing inventories with original data sources is under responsibility of ZHAW.

As mentioned in (Frischknecht, 2023), the responsibility for the contents of all datasets remains with the expert and institute who investigated and compiled the data.

Conclusion

The reviewers state the compliance of the assessed LCI with the DQR documentation and validate thereby the further use of these LCIs in the FOEN background datasets pool.

Annex 1: Detailed comments and answers of the review

Excel file “2025.07_Review_Wind DQR_FOEN_vf_21072025” attached to this report

Number	Initials reviewer	Chapter / table / scheme	Page number of the report	Line number	Type of comment	Level of importance of the comment	Reviewer's comment	Potential suggestion of reviewer	Generic answer of the LCA practionner	Answer of the LCA practionner - potential modification done - where (line, page) the modification was done - or why the comment was not taken into account	Reviewer anwser	Final answer LCA practionner	
Version 1 of report - 18/04/2025									Version 2 of report - 13/06/2025			Version 3 of report - 14/07/2025	
1	MML	2.	6	21	M - Methodology	Important	Goal and scope definition	It would be beneficial to explicitly define the objectives related to the work on the electricity mix, particularly by clarifying how the detailed data on the wind power sector—at the level of turbines, wind farms, and infrastructure—contributes to improving the environmental modelling of the Swiss electricity mix. This would help highlight the potential impact of wind energy development on overall environmental indicators, especially in the context of prospective or comparative energy scenarios.	Not taken into account	Not yet taken into account, but will be done for the final version of the report.	to be checked in the final version	Explanation regarding the overall objectives was added in section 1.	ok
2	MML	2.	6	28	M - Methodology	Recommandation	Relation between the main goal provide up-to-date LCI and impact assessment	Refer to DQR and chapter 9.4	Not taken into account	Not yet taken into account, but will be done for the final version of the report.	to be checked in the final version	Explaination on impact assessment was added at the beginning of chapter 2	ok
3	MML	2.1	6	34-35	DT - Data, technical	Recommandation	"For each considered wind turbine size, a corresponding electricity dataset on wind farm level was created"	Please could you reformulate this sentence and perhaps give an example.	Taken into account	We added an example	ok		
4	JSM	2.1	6	35	Other	Editing	missing precision about swiss wind electricity mix	even if it is obvious, mention that wind electricity is exclusively onshore for swiss mix (additional note : I saw it is mentionned later in the report)	Taken into account	Modification done in section 2.1.	ok		
5	JSM	2.1	7	table 1 + lines 45-46	M - Methodology	Important	for swiss wind mix : in table 1, 1 wind farm with 2 MW turbines whereas lines 45-46, turbines 2 MW + 3.4 MW	correct that in table 1 and/or in lines 45 46 to make it consistent	Taken into account	Modification done in section 2.1.	ok		
6	JSM	2.1	7	53	DT - Data, technical	Recommandation	averaged nominal capacity ??	mention average in number or in installed power or in electricity produced	Taken into account	Wording was adjusted in section 2.1.	ok		
7	MML	2.1	8	68	DT - Data, technical	Editing	The position of the figure 2 just after the § might help the reading	Move the figure	Taken into account	(the position of the figure might still change, depending on potential changes of the text before)	ok		
8	MML	2.1	9	76	DT - Data, technical	Editing	"The modelled turbine sizes of 4.5 MW and 6.2 MW play a less relevant role in the current European onshore fleet."	Use the same capacity cutting that in the figure (4-5 or 5-6 MV)	Taken into account	The wording in the respective sentence in section 2.1 was adjusted.	ok		
9	JSM	figure 2	9	77	DT - Data, technical	Recommandation	the title suggests that the figure shows the installed capacity in 2024 whereas the graph shows the installed capacity from 2000 to 2024	Modify the title	Taken into account	The titles were removed from the figures, while the figure descriptions were adjusted.	ok		
10	MML	2.1	9	81	DT - Data, technical	Editing	In the figure, the share is floats and in the text is percentage.	Use the same writting in both	Not taken into account	The unit was changed to percentages in all the figures.	The unit of figure 3 was not changed	The modification was done, see comment 53.	ok
11	JSM	figure 3	10	90	DT - Data, technical	Recommandation	the title suggests that the figure shows the installed capacity in 2024 whereas the graph shows the installed capacity from 2000 to 2024	Modify the title	Taken into account	The titles were removed from the figures, while the figure descriptions were adjusted.	ok		
12	JSM-MML	2.2	10	97-98 + 104-105-106	Other	Important	"transportation is not mentionned" (97-98) then it is mentionned(104-105) The use of terms maintenance and replacement is a bit confusing as spare parts replacement is maintenance.	At the begining of the paragraph, define clearly each stage = what is covered by each stage & Include transportation in the covered stage. Explain well how "operation" is divided into maintenance and replacements and what each activity covers. As discussed, I suggest 1/ to present the stages "chronogically" (eg: manufacturing of materials, transport of materials, manufacturing of components, transport of components, installation of components, maintenance spare parts, maintenance operation....). 2/ to present how the stages are aggregated in the inventory based on UVEK guidelines. Optional : you can mention that for offshore, survey stage and bulding of port infrastructure are not included	Taken into account	We added an introduction to chapter 3 which explains all processes which are taken into account for the inventory of wind turbines and infrastructure. The term "operation" is now avoided in chapter 3 to prevent confusion.	ok		
13	JSM-MML	2.2	10	100	Other	Editing	the term "moving part" might be confusing.	As it is clearly defined, it does not have to be changed. However, I suggest that in the inventories themselves, the term shall be reexplained again (blades, hub, nacelle).	Taken into account	In the inventory chapter, this term is only used in the tables, where the structure of the table makes it clear of which components the moving parts consist. This is considered sufficiently clear and was therefore not	ok		
14	MML	2.2	10	104	DT - Data, technical	Editing	The use of therm onshore substation for the case of offshore wind power is disturbing.	Is it possible to use another term ?	Taken into account	The term was changed to 'land-based substation'.	ok		
15	MML	2.2	10	111-112	DT - Data, technical	Important	SF6 emissions	Please precise the term of this pollutant and the emission compartiment	Taken into account	we think there's sufficient information in chapter 4.1.3 and ANNEX III (SF6 leackage is modelled as emission to air)	ok		
16	MML	2.3	12	129	DT - Data, technical	Important	REMPD	This first time this siggle is used without before defined	Taken into account	Solved: It *was* actually defined a few lines above.	ok		
17	JSM	2.3 / table 2	12	137	DT - Data, technical	Important	Only the turbine for [electricity, at wind farm, offshore, 1005 MW {RER}]. No cables or electric station ??	add the electrical infrastructure datasets in the table	Taken into account	Table 2 was completed with all datasets in version 2 of the report.	ok		
18	JSM-MML	2.	xx	xx	M - Methodology	Recommandation	In the goal and scope section, no end of life section	optional : add a end of life section in the "goal and scope" section. Even if The end of life modeling is explained later on in the inventory part, The cut off approach also affects how the recycled input material for the manufacturing inventories are modeled. This is why it might be relevant to explain the methodology in the goal and scope.	Not taken into account	Will be taken into account in the final version of the report.	to be checked in the final version	A clarification on the EoL approach was added in section 2.4.	ok
19	MML	3.1	14	149	M - Methodology	Important	The origine of the data in this section is not precised: collected on site, from references ?	Please precise this information. Perhaps a table in the beginning of the document resuming the origine of the different size of turbines could be relevant	Taken into account	This information is given in Table 2. A reference to Table 2 was added in section 3.1.	ok		
20	JSM	3.1 / table 3	14	148	DT - Data, technical	Recommandation	is the submarine export cable distance one of the two distances mentionned ?	if yes, specify it in the table	Taken into account	Export cables length is not the same as distance to ports. Regarding wind turbines and infrastructure, disctances to ports are relevant as they influence the fuel consumpition for installation, replacementsa and decommissioning.The length of array and export cables are important on wind farm level and are included in Table 17,	ok		
21	JSM	3.2	14	153	DT - Data, technical	Recommandation	nothing about how the replacement of spare parts was modelled ?	if this data is provided by the mentionned studies, you can mention it. If it is calculated based on a common hypothesis for all studies, ecxplain how it was calculated	Taken into account	information on replacements rates were moved to chapter 3.2	ok		
22	JSM	3.2	15	162	DT - Data, technical	Important	The 10 MW wind turbine (without foundation) is heavier than the 15 MW wind turbine (1400 t vs 1350t). The mass / MW is alsomuch higher for the 10 MW turbine.	can you explain that ? If not, i would suggest at least to mention it and to refer to reference studies for more information. If might also affect a lot the impact results, so this should be kept in mind when computing the results in then dedicated section.	Taken into account	Solved: Masses for nacelle and hub of 15 MW offshore turbine were low compared to 5MW and 10 MW turbines. Solution: Masses were upscaled to masses given in IEA report for 15 MW reference WT. (see chapter 3.2) Values in Table 5 and 6 were updated accordingly.	ok		
23	MML	3.2	16	169	DT - Data, technical	Important	In this line the unit used is kV and in the table 2 is only V.	Please verfy and correct it.	Taken into account	The units in Table 2 were corrected to kV.	ok		
24	JSM	3.2	15	xx	DT - Data, technical	Important	how are the input recycled material (steel, copper, aluminium…) used for building the farm modeled ?	as it influences a lot the impact results, the hypothesis made shall be explained	Taken into account	This information was added in section 3.2.	ok		
25	JSM	3.2	15	xx	DT - Data, technical	Important	How are the processing of the materials modeled ?	it can be briefly mentionned as the modeling is mentioned in the excel file	Taken into account	Solved: Used processing datasets are listed in ANNEX V (together with used material datasets) See also text in chapter 3.2	ok		
26	JSM	3.2	16	168	DT - Data, technical	Recommandation	Offshore substation technology is missing ?	Mention if it is an AC or DC connection.	Not taken into account		is it possible to mention it in the report ?	specific information is not available; information was therefore not included	ok

Number	Initials reviewer	Chapter / table / scheme	Page number of the report	Line number	Type of comment	Level of importance of the comment	Reviewer's comment	Potential suggestion of reviewer	Generic answer of the LCA practionner	Answer of the LCA practionner - potential modification done - where (line, page) the modification was done - or why the comment was not taken into account	Reviewer anwser	Final answer LCA practionner	
27	JSM	3.2	16	168	DT - Data, technical	Important	length of the cables (array and export cables) is missing	add this information	Taken into account	See also reply to comment 20: length of cables are given in Table 17; in the updated version, the inventory for all cables is given per km in Table	ok		
28	JSM	3.2	17	190	DT - Data, technical	Recommandation	2kg/cm2. Where does this data comes from ?	mention the source. Optional : mention orders of magnitude, what is the area for a 2 MW onshore turbine, and for a 10 MW offshore turbine for example, so that the lecturer can get familiar with the	Taken into account	The source, as well as the order of magnitude were added in section 3.2.	ok		
29	MML	3.3 and 3.4	17	193-201	DT - Data, technical	Editing	Reference to information with the page numbers	Please use reference to section number	Taken into account	The reference was changed to the chapter title.	ok		
30	MML	3.3.1	17	207	M - Methodology	Important	"All components are assumed to be manufactured in Europe."	What is the impact of this assumptions ? It is really true ? Please add this information	Taken into account	Wording was adjusted in section 3.3.1.	I was waiting for you to add a clarification concerning the veracity of this hypothesis: are many wind turbines manufactured in Europe? As with PV, if we take this hypothesis, it's debatable because it's not representative of the current market.	A clarification regarding this assumption was added in section 3.2.	ok
31	JSM	3.3	17	198	Other	Recommandation	"includes the transportation of the components to the wind farm site"	suggestion: "includes the transportation of the components to the onshore wind farm site or to the offshore wind farm port of installation" (it is mentionned on page 18, but i think the formulation here is confuising)	Taken into account	Wording was adjusted in section 3.3.2	ok		
32	MML	3.3.3	19	225-226	DT - Data, technical	Important	It is not clear that transportation for recycling parts is integrated and which value ?	Please precise it	Taken into account	According to the FOEN database protocol, transportation for recycling parts is not included. The wording was adjusted accordingly in section	ok		
33	MML	Table 9	19	230	DT - Data, technical	Important	Which material(s) for which treatment process(es)?	Please precise it	Taken into account	This information is given in section 3.5. A reference to this section was added in section 3.3.3.	ok		
34	MML	3.4.1	19	235	DT - Data, technical	Recommandation	Why the formula is in footnote ?	If it is important please integrate it in the text	Taken into account	The formula was moved from the footnote to the text, in section 3.5.1.	ok		
35	JSM	Table 10	20	239	DT - Data, technical	Important	Mass of the tower is missing (177t is the mass of the moving parts only)	correct the data	Taken into account	The value was corrected in Table 12	ok		
36	MML	Table 10	20	239	DT - Data, technical	Important	Only data for 3.4 MV are available or 2, 4.5 and 6.2 MW don't required energy consumption ?	Precise it	Taken into account	Table 12 was completed with the values for all modelled onshore wind turbines.	ok		
37	JSM	3.4.2	20	249	M - Methodology	Recommandation	Crane operation modeling do not take into account the crane infrastructure (only the fuel consumption)	this hypothesis is ok as the energy consumption is the main contributor to impacts for this activity, but mention that contrary to ship transportation (that includes the vessels infrastruture), it is not taken into account for crane operations	Taken into account	Yes, somehow inconsistent. But justifiyable: Port crane operation makes of so far less than 1% of GWP, while freight ship operation contributes 30% to GWP (of which We might still include a proxy for the crane, but this won't have an impact on results	I do not suggest to add a proxy for the crane infrastructure, i just suggest to mention explicitely that crane and vessel operations are modeled in different ways (without or with infrastructure) and that is it ok as crane operations contributes quite few to impacts, but just mention it.	At the end, the infrastructure of the crane operation was not included any more, as the mpact on the final results is negligle.	ok
38	JSM	Table 11	21	256	DT - Data, technical	Editing	to be comparable between farm, the resulting inputs might be presented /MW/km (distance to shore)	to be discussed later	Taken into account	Not yet taken into account, but might be later on. However, we think that there are many parameters which influence the results distance to port, foundation type, turbine size)so that deriving comparable, relative values might be difficult	contrary to wind turbines for mass/MW, we do not expect same order of magnitudes, but it might be a way to show that these fuel consumptions only depend or not only depends on (?) these parameters.	At the end, we decided not to include the parametrisation in the Table for sake of reader-friendlyness. However, scaling of inputs was added as additional information in the Table (now Table 13)	ok
39	MML	Table 11	21	257	DT - Data, technical	Recommandation	If only data for 10 MW are available, perhaps it is not necessary to include columns for 5 and 15 MW ?	Clarify it	Taken into account	current version includes values for 5 MW and 10MW turbines	ok		
40	JSM	3.5	21	264	Other	Recommandation	it is a bit confusing to have the replacement data in this part whereas it was mentionned earlier in part 3.2 that the replacement is included in the manufacturing inventory.	reorganize to clarify that	Taken into account	The section on replacements was moved up to section 3.2	ok		
41	JSM	3.5 / table 14	22	279	DT - Data, technical	Recommandation	is it per wind turbine for the all lifetime (25 years) ?	clarify that in the table	Taken into account	yes, values were for the entire lifetime. This information was added to the caption of the table now table 15)	ok		
42	JSM	3.5	22	the all part	M - Methodology	Important	as metionned in previous comments, it is not clear what is included in "operation" (besides manufacturing of spare parts).	As discussed, what is included in the maintenance activitiesand how it is divided between infrastructure and "maintenace" shall be well explained. If possible at the beginning in 2,2. "service and repair" (part 4.1 line 323) is a bit confusing as spare parts replacement could be understood as part of repairing.	Taken into account	The wording was adjusted and description was specified.	ok		
43	MML	3.6	22	285	DT - Data, technical	Important	"it is assumed that decommissioning requires the same amount of energy as installation described in section 3.4"	What is the impact of this assumptions ? It is really true ? Please add this information	Taken into account	It is a common assumption in LCA studies of wind power. This information, including sources was added in section 3.5.	ok		
44	MML	3.6	22	289-290	Other	Editing	"Crushed rock used for score protection of offshore wind turbines is considered to not be treated at end-of-life but left in place on the seabed"	This information is alreday mentionned in section 3.3.3	Taken into account	That's true, but we would keep it in both sections as it is relevant for both.	ok		
45	JSM	4.1	24	307	DT - Data, technical	Important	where does the length of array cables comes from ? (kainz?) Where does the capacity factor for the offshore wind farm come from ?	precise the sources	Taken into account	we added the sources	ok		
46	MML	Table 16	24	315	DT - Data, technical	Important	Why the information concerning the number of turbines is missing for 1 0005 MW?	Please chek this value	Taken into account	The tables were completed with all information on all the modelled wind turbines.	ok		
47	MML	4.1.1	24	317	M - Methodology	Important	Why the operation maintenance is not included in the operation phase ?	We didn't see this procedure in the DQR	Taken into account	The structure and wording was adjusted so that operation now only refers to maintenance activities.	ok		
48	JSM	4.1.1	24	318	Other	Editing	100 pkm ?? Not clear	We saw this unit in the guidelines but we suggest to explain it in the document	Taken into account	The full name of the unit is given in section 4.1.1	ok		
Version 2 of report - 13/06/2025									**Version 3 of report - 14/07/2025**			**Final version of report - 18/07/2025**	
49	MML	1. Introduction	4	18	DT - Data, technical	Recommandation	Capacity factor	Please define the term "capacity factor" , It is an important component in the operation of a wind power system.	Taken into account	The definition of the term was added in section 4.1.	OK		
50	JSM	2, 1	5	34-	M - Methodology	Recommandation	"no farm level was created but rather the turbines were directly used as inputs to the electricity mix". It seems that the electrical infrastructure (cables, connection to the grid...) is not taken into account for swiss onshore data but just the turbines. Is is the case ?	If yes, mention the limit of this modeling choice. If no, it would it be clearer to say that it is modeled as one farm with a mix of 2,3 MW and 3.4 MW turbines ?	Taken into account	Wording was adjusten in section 2.1.	ok		
51	MML	2, 1	6	52-56	DT - Data, technical	Important	70% + 25% -> 5% missing. Perhaps they correspond to the cutt-off threshold.	To be justified	Taken into account	Wording was adjusted in section 2.1.	OK		
52	MML	2, 1	7	71-80	DT - Data, technical	Important	85 % of the fleet is explaned. What about for the 15 % remaining ?	Please add this information	Taken into account	Wording was adjusted in section 2.1.	OK		
53	JSM	2, 1	9	100	DT - Data, technical	Editing	shares are not in %	Fig 3 : put % to harmonize with fig 1 and fig 2	Taken into account	The shares were changed to percentages, in line with the other graphs.	ok		

Number	Initials reviewer	Chapter / table / scheme	Page number of the report	Line number	Type of comment	Level of importance of the comment	Reviewer's comment	Potential suggestion of reviewer	Generic answer of the LCA practionner	Answer of the LCA practionner - potential modification done - where (line, page) the modification was done - or why the comment was not taken into account	Reviewer anwser	Final answer LCA practionner	
54	JSM	2, 1	9	105	M - Methodology	Recommandation	for swiss, repartition was made based on electricity shares whereas for Europe (onshore and offshore) it was made based on the power capacity	Ideally, the repartition should be calculated based on electricity production as it is the reference flow of the LCI. With This choice of repartition based on nominal capacity, it is assumed that the capacity factor does not depend on nominal capacity. It might overestimate the contribution of large size turbine (higher nom power capacity, higher height, more wind, higher elec capactity fator). This choice of modeling is completely understandable but it could be 1. justified by the lack of data (elec production repartition per nominal capacity) 2/ the implications of this modeling choice could be mentioned at the end of part 2.1. This comment is more relevant for part 4.2.2.	Taken into account	capactiy factors do not depend primarily on size of turbines. We did the test on our statistics of offshore wind farms: The contributions per wind turbine sizes to the installed power capacity and the contributions per wind turbine size to the produced electrity are almost the same. Since the information on installed nominal capacity distrubtion is more accurate (not year-dependent) and avaiable, we used this as basis. A discussion of the implication of the modelling choice was added to 6.2.2	ok		
55	MML	2, 2	9	107	M - Methodology	Important	Is a cut-off threshold used, and if so, what is its	Please precised it and estimate its impact on the results	Taken into account	This information was added in section 3.2.	OK		
56	JSM-MML	2, 2	9 and 10	118-120	DT - Data, technical	Important	The term "infrastructure dataset" is not clear.	Suggestion line 118 : one "infrastructure dataset" is created for each part presented above. Each "infra dataset" gathers manufacturing, transportation, installation, decom, waste treatment for original and replaced components. Suggestion line 121 : the electricity production at wind farms are modelled with 3 types of inputs : infra datasets, operation dataset, and road dataset for onshore)	Taken into account	In order to avoid confusion about the word 'infrastructure', the term 'electrical infrastructure' was changed to 'EBoP'. Wording was further adjuste in section 2.2 to make the term 'infrastructure dataset' clearer.	ok		
57	JSM	2, 2	10	121	M - Methodology	Recommandation	fig 4 could be clearer and help clarify the "infrastructure dataset" term and LCI architecture	Suggestions : 1. delete "life cycle stages box" 2. gather component manuf, installation, decom& waste, replacements and introduce "infrastructure dataset" term 3. Put "operation box below.	Not taken into account	It was internally decided that the depiction of the life cycle stages needs to be included in this figure. The term 'infrastructure dataset' is now assumed to be clear in the text, after the modifications that were made.	ok, clearer with the new terminology		
58	MML	2, 3	11	132-135	M - Methodology	Important	The age (2011 and 2015) of the references raises the question of the temporal representativeness of the data.	Please justify	Taken into account	Justification was added in section 2.3.	OK		
59	JSM	2, 3	11	136	M - Methodology	Recommandation	Is the tower for 3.4 onshore turbine steel based or concrete based	this information could be added in the text - even if mentionned later on in table 4	Not taken into account	The tower information is only mentionned in this part for the 2.3MW turbine as it is the only case where 2 towers were modelled and they are based on different data sources. It is only about mentionning the relevant data sources here, therefore the towers of the other turbines are not yet mentionned in this part.	ok , justified		
60	JSM	2, 3	11	144	DT - Data, technical	Important	5MW offshore trubine : unclear if the turbine inventory comes from Repower or from Kouloumpis	clarify that in the text	Taken into account	the data sources in chapter 2.3 were adjusted to clarify that data was mainly taken from Kouloumpis	ok		
61	JSM	2, 3	12	162	DT - Data, technical	Editing	Table 2 : when looking at the table 2, the way cables and onshore inventories are presented (for onshore inventories) might be a bit confusing.	suggestion; put substation and cables line in blue and mention in the subtitle of Table 2 that these inventories are included in all onshore electricity inventories. It is though really clear in the text so it is not a high priority comment;	Taken into account	The colour code was added in table 2.	ok		
62	JSM	2, 3	11 and 12	144-163	DT - Data, technical	Important	Text + table 2 for offshore. It is a bit unclear to me where the inventories come from: especially for: 1. the array cables + export cables + land base substation ? Are they derived from data for 10 MW turbine (TUM IEA) for the 3 offshore farms ? 2. the vessel activities.	important : make it clearer in the text suggestion : for the table, same suggestion as the comment above > add a color (eg, green) for inventories used for the three offfshore farms + maybe add a line for vessel activities.	Not taken into account	color code was added in Table 2. Additionally, it was highlighted in all Tables with inventory data (Table 4, 5, 13, 14, 15,16), when data was extropolated from sources for other wind turbines or wind farms.	ok, clearer		
63	MML	2.4	13	Table 3	M - Methodology	Important	"Only" 3 impacts cateories are assessed.	Please include a jusitfication for their selection	Taken into account	These are the impact categories required according to the database protocol. A reference was added to clarify this. Note: As we do not yet have the new database version, we will need to update the impact assessment at a later point. The new version will also include other methods so we will potentially extend our assessment with e.g. EF.	OK		
64	JSM	3, 1	15	table 4	DT - Data, technical	Important	hub height onshore 4.5 MW is really low compared to other hub heights but also to rotor diameter.	double check this data (even if low height is consistent with low tower mass per MW in table 6)	Taken into account	Hub height was double checked, it is indeed 98 metres.	ok		
65	MML	3, 1	15	table 4	DT - Data, technical	Editing	What are the differences between : N/A, - or empty cell ?	Please clarify it	Taken into account	There is no difference, it was adjusted to be consistent.	OK		
66	MML	3, 1	17	Table 5	DT - Data, technical	Editing	Difference between «-» and empty cell ?	Please clarify it	Taken into account	There is no difference, it was adjusted to be consistent.	OK		
67	JSM	3, 2	18	table 6	DT - Data, technical	Important	mass monopile to be discussed		Taken into account	Mass of 15MW substructure was adjusted according to the IEA report of the reference turbine (values adjusted in Table 6 and information given in text above)	ok, it changes a lot the results and seems more consistent. Surprising that the data is such different in the other database.	Just as information: We informed NREL about the discrepancy but we did not get a feedback so far.	ok
68	JSM	3, 2	19	236	DT - Data, technical	Recommandation	"The dataset" is not 100% clear.	suggestion : The land-based substation dataset was modelled specifically…	Taken into account	Wording was adjusted in section 3.2.	ok		
69	JSM	3, 2	19	236	DT - Data, technical	Important	upscaling of electrical infrastructure : the upscaling of electrical infrastructure (related to total power capacity of the farm) seems not harmonized. For onshore : no upscaling of onshore substation and scaling of cables based only on km For offshore: specific model for offshore substation, no upscaling for cables (except km), upscaling of onshore substation but only for 1005 MW (what about 150 MW farm?)	I have been through part 4 and now it is clearer. Maybe mention that the electrical infratructure inventories are resized for each farm and that the sizing is explained in part 4.	Taken into account	Reference to section 4.1 was added.	ok		
70	MML	3, 2	19	241	DT - Data, technical	Important	Are the reported SF6 emissions below regulatory thresholds?	Please add this information		We could only find deadlines by when the SF6 use is to be phased out and thresholds for when SF6 emissions need to be reported, monitored and measured. Therefore, we did not include information on this aspect.	ok		
71	JSM	3, 2	20	243	DT - Data, technical	Important	SF6 emissions to be discussed		Taken into account	The SF6 inputs were adjusted and harmonised, which was described in section 3.2. The assumptions regarding SF6 emissions was described in section 4.1.3.	For the 1005 MW offshore wind farm, no SF6 input considered ? then in part SF6 leakage, there are some leakages.	Information of the resulting range of SF6 quantities in the wind turbines was added in chapter 3.2 (~line 294 in current version) in order to make it clearer that SF6 was considered in all wind turbines.	ok
72	MML	3, 2	20	248-251	DT - Data, technical	Important	What is the temporal unit of the SF6 emissions ? Correspond to the whole lifetime ?	Please clarify it	Taken into account	The temporal unit of the SF6 emissions was added in section 3.2.	OK		
73	MML	3, 2	1	253-259	M - Methodology	Important	How useful is this information (land occupation) since only GWP, ecological scarcity and CED impact categories are assessed?	Please clarify it	Not taken into account	This information is kept in the models for means of completeness. If other users are to assess land use as an impact, then this information is necessary.	OK		
74	JSM	3, 2	21	257	DT - Data, technical	Important	"the required surface for the foundation is calculated based on the outer diameter of the monopile." how did you do the calcultation for	explain the proxy used for the farm with jacket foundation.	Taken into account	explaination of proxy was added to Table 6 and in the text (and value for 15MW turbine was corrected)	ok		
75	MML	3, 3	21	278	DT - Data, technical	Editing	Check the format of this reference, it is not the same of before references to the Annex (ANNEX before)		Taken into account	References to the annexes was adjusted.	OK		
76	MML	4, 1	28	414	DT - Data, technical	Editing	"The modelled 700 MW offshore wind farm represents the IEA Wind 740-10 MW reference …"	Why is written as and not 10-740 MW ?	Taken into account	*740-10 MW* , is used in the IEA report for the reference wind farm and we wanted to keep this terminology .	OK		
77	JSM	4, 1	29	428	M - Methodology	Recommandation	resizing of electrical infrastructure is a bit confusing (both text and table 17). In table 17, "Number of land-based" substations hides the fact that it was resized. In table 17, Length of array and export cables are not given for 2 onshore farms.	See comment 69. I would suggest to do a table to summarize which are your reference inventory and if you have no specific inventory, how you resize it (for cables, onshore substation, onshore substation)	Taken into account	Inputs in Table 17 were specificalle marked when derived from different data sources. Addionally, modelling of infrastructure was explained in more detail in the text.	ok		
78	JSM	4,1, 1	31		M - Methodology	Recommandation	scaling up of the maintenance activities for 1005 MW wind farm could be simply justified	by the fact both farms have the same distance to service port	Taken into account	scaling of maintenance activity was adjusted to scaling by trubine numbers and distance to service port (section 4.1.1)	ok		

Number	Initials reviewer	Chapter / table / scheme	Page number of the report	Line number	Type of comment	Level of importance of the comment	Reviewer's comment	Potential suggestion of reviewer	Generic answer of the LCA practionner	Answer of the LCA practionner - potential modification done - where (line, page) the modification was done - or why the comment was not taken into account	Reviewer anwser	Final answer LCA practionner
79	JSM	4,1, 1	31		M - Methodology	Recommandation	The title of the part is maintenance whereas in fig 4 it is called operation.	harmonize the terminology (also in part 5 for contribution analysis)	Taken into account	Terminology was consistently changed to O&M.	ok	
80	MML	5, 1	36		DT - Data, technical	Editing	"The GHG emissions of the electricity from all wind farms is dominated by the infrastructure of the wind turbine and foundation ..."	Could you use the same names than the corresponding Figure ?	Taken into account	Names in text and figures were harmonised.	OK	
81	JS	5, 1	37	fig 5	M - Methodology	Important	Why is Operation/maintenace so high for 150 MW offshore farm ? Whereas distance to service port is small (10km vs 50 km for other farms) ?	double check this results	Taken into account	Values were corrected and explaination of extrapolation was added to section 4.1.1	ok	
82	MML	references	39		M - Methodology	Important	A number of references are widely used as data sources (TUM, REMPD,...). How reliable are these references?	Perhaps you can add a general sentence to validate the quality of these data	Taken into account	The data quality and comprehensiveness, including uncertainties, and representativeness of the data was discussed in chapter 6.	OK	
83	JSM	6, 0	39		M - Methodology	Important	For European electricity mix : The repartition btw offshore and onshore and turbine sizes was clearly explained and justified. In contrary, the choices of values for the following sizing variables were not justified (while they have a large influence on the impact results) : distance to port installation, distance to port for maitencance + type and sizing of fundations (water depth, nominal capacity, other ?). Therefore the modeled offshore wind farms are less representative of the european offshore wind farms than the onshore ones. As the share of offshore electricity is quite low at European scale, it affect few the results for the european electricity mix.	to be discussed to be included in the last version	Taken into account	A discussion on the representativeness regarding distances to ports, foundations types and water depths was included in chapter 6.	ok	
Version 3 of report - 14/07/2025									**Final version of report - 18/07/2025**			
84	JSM	2, 3	17	143	M - Methodology	Important	background database and version is not explicitely mentionned in this part. If I am not wrong this information is mentioned somewhere else in the report but I think it shall be explicitely mentioned here in this section.	Mention it at at the begining of this part.	Taken into account	This information was added in section 2.3.	ok	
85	JSM	6,2,2	50	110	AI - Analysis/interpretation	Recommandation	Talking about uncertainty/representativeness could led to also discuss variability.	Suggestion but not high priority comment : :Inter annual variability of capacity factor that is due to inter-annual variability of wind is decreased as the capacity factors are averaged over few years. the dataset is not representative of a specific year (eg 2024) but is representative of a year with averaged wind conditions.	Taken into account	Consideration of wind speed variability was added in section 6.2.2	ok	
86	JSM/MML	6,2,3 & 6,2,5 and 6.2.7	50-51	128-132	Other	Important	The use of the term "representative" for water depth and distance to port can be discussed. indeed, but we do not know if they are representative of the distribution of these values.	Suggestion : the distance to ports, and water depth values used are in the middle of the range of these values for existing wind farms. However, an additional work could be conducted to better assess the representativeness of the data at market level. This affects fundations, installation & decommissioning & O&M inventories.	Taken into account	Discussion enhanced at the end of chapter 6.2.3, whjich now more explictly addresses the way how representative wind farms were establishd in the present study and which kind of assessment could be part of further studies.	ok	
87	JSM	6,2,6	52	172	AI - Analysis/interpretation	Recommandation	"the size of average array cables is not expected to depend on the farm size". It is suprising, I am not sure this assertion is true ?!	either put a reference, either suggest to investifgate the influence of farm size on cable sizing.	Taken into account	Comment solved with JSM: Assumptions for scaling array and export cables are ok. No action needed	ok (I initially missread the text)	
88	JSM	6, 4	54	236	AI - Analysis/interpretation	Important	the "environmental" intensity. "environmental" term is not precise enough.	replace "environmental "intensity" by a term that is specific for climate chnge, eg "carbon content" / "carbon intensity" GHG content"....	Taken into account	Wording changed to "climate change impact"	ok	