Post 2030 offshore wind employment in the Netherlands

First indications of an outlook on direct employment regarding construction and operations & maintenance phases

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MANAGEMENT SUMMARY

Offshore wind energy plays an important role in the global energy transformation needed to significantly reduce energy-related CO_2 emissions. Therefore, the Netherlands will substantially increase its offshore wind power from 1 GW in 2019 to 11.5 GW in 2030. The roll-out of offshore wind power in the Dutch waters of the North Sea will continue after 2030.

The purpose of this working paper is to give first indications of an outlook on direct employment regarding post 2030 construction and operations & maintenance (O&M) of Dutch offshore wind parks based on an outlook of 55 GW capacity in 2050. Baseline employment figures of the current employment situation are extrapolated taking into account the downtrend in labour intensity per offshore wind capacity due to e.g. innovation, economies of scale, and standardisations. Project boundaries for this working paper are given by RVO. This is the reason why this working paper has a limited scope and a limited depth (also in terms of methodologies) and provides figures which are indicative.

<u>Conclusions:</u>

- Offshore wind at the North Sea will play a highly important role in the post 2030 ambitions and measures to achieve CO_2-neutral electricity production by 2050. A higher offshore wind capacity growth rate will be needed after 2030.
- In general, substantial post 2030 employment (Dutch and foreign) regarding Dutch offshore wind farms will be related to supply packages (mostly nacelle supply, rotor supply, turbine foundation supply, and substation supply) and operations & maintenance (O&M) (which are continuing activities during the exploitation of an offshore wind farm).
- There will be substantial post 2030 employment for involved Dutch supply chains regarding offshore installation activities and O&M. Companies in these fields will likely have the resources and the capabilities to serve the post 2030 Dutch offshore wind ambitions and the future international offshore wind markets.
- Two-third of the post 2030 supply-related direct employment will not or will hardly be related to Dutch supply chains looking at the current situation in the supply chains of the supply packages. This is mostly employment related to nacelle and rotor manufacturing and assembly. One-third could be well fulfilled by Dutch supply chains: foundation supply, and substation supply.
- Offshore wind will be an integrated part of an offshore energy system and ecosystem. It is perceived that in various domains of this future energy system and ecosystem (new) employment opportunities will rise: ships, grippers, and cranes, green hydrogen, multi-use of offshore spatial area, nature enhancement, and decommissioning / recommissioning, and circularity.

<u>Recommendations:</u>

- Create policy attention on ‘strengthening the strength’ and ‘filling the gap’ with respect to Dutch supply chain involvement and related employment in offshore wind being part of an integrated offshore energy system and ecosystem. ‘Strengthening the strength’ focuses on Dutch supply chains in offshore wind that are well developed (to serve national and international markets) (e.g. foundations, substations, transport & installation (including specialistic ships, grippers, and cranes), cables, and O&M). ‘Filling the gap’ focuses supply chains where the involvement of Dutch companies is absent or very limited (e.g. supply packages on nacelles and rotors). ‘Filling the gap’ focus should also be focused on new and/or growing employment opportunities related to green hydrogen, multi-use, and circularity.

- Elaborate what the future employment opportunities are for the Netherlands when looking at the specific nacelle assembly strategies of turbine suppliers: how will turbine suppliers further optimize and upscale their nacelle and rotor assembly infrastructures across Europe to serve the European offshore wind energy ambitions the coming three decades?

- Elaborate what the future employment opportunities are for the Netherlands when looking at specific post 2030 ambitions and opportunities: green hydrogen generated with offshore wind power, multi-use of offshore wind farm locations (e.g. floating solar, agriculture at sea, and nature enhancement), and decommissioning / recommissioning, and circularity.

- Elaborate what the future (employment) opportunities are for the Netherlands looking at domains that are currently labelled as ‘indirect employment domains’ in the offshore wind sector: e.g. specialistic ships, grippers, cranes, and other advanced tooling and facilities relevant for the offshore wind sector.

- Facilitate investigations that could define the Dutch educational capacities needed considering the future employment developments in offshore wind. Consider the roles of public-private partnerships - like learning communities – to enhance innovation, education, and lifelong learning matching the post 2030 offshore energy system and ecosystem ambitions. Develop a nationwide educational approach for offshore wind professionals (supply, transport & installation, and O&M) addressing the roles and responsibilities of policy makers, the education sector (all relevant education levels), (applied) research, and the industry.

CONTENT

1. INTRODUCTION

Offshore wind energy plays an important role in the global energy transformation needed to significantly reduce energy-related CO_2 emissions (decarbonisation).

Until 2019 around 1 GW of offshore wind capacity has been realized in the Dutch waters of the North Sea.[1] In 2020 two offshore wind farms (each 0.7 GW) are to be installed resulting in an offshore wind capacity of around 2.4 GW by the beginning of 2021. The coming years three additional offshore wind farms - each with a capacity of around 0.7 GW - will be installed as part of the so-called Roadmap 2023. This results in a cumulative capacity of approx. 4.7 GW in 2024 (see appendix 1). The government increases the pace of deployment of offshore wind farms as from 2024. This is Roadmap 2030 (see appendix 1). The ambition is to install an average of at least 1 GW per year in the period 2024-2030. This results in a major expansion of the installed offshore wind power in the coming decade: from around 1 GW in 2019 to 11.5 GW in 2030 (e.g. MinEZK, 2020b).

The roll-out of offshore wind power in the Dutch waters of the North Sea will continue after 2030 and it is expected that the deployment rate will further increase. We label the post 2030 Dutch offshore wind capacity potentials used in in this working paper as the Outlook 2050. As suggested by RVO we set this Outlook 2050 on 55 GW installed Dutch offshore wind capacity in 2050 being the average of two energy outlook scenarios of the North Sea Energy Outlook (NEO) of DNV GL (2020).[2] In this working paper post 2030 decommissioning is out of scope and therefore not taken into account. This results in 43.5 GW added capacity between 2030-2050 for this working paper's Outlook 2050 (see appendix 1).

Purpose of this working paper

The purpose of this working paper is to give first indications of an outlook on post 2030 direct employment related to Dutch offshore wind farms. Project boundaries for this working paper are given by Netherlands Enterprise Agency RVO. This is the reason why this working paper has a limited scope and a limited depth (also in terms of methodologies) and provides figures which are indicative. The focus is on the construction and operations & maintenance (O&M) phases of Dutch offshore wind farms; included job roles in the employment indications are given in appendix 2. The working paper includes direct employment indications related to Roadmap 2030 and the above-indicated Outlook 2050. RVO has commissioned consultancy ECHT regie in transitie to develop this working paper. Research and analysis are done in collaboration with consultancy Qeam. It is based on desk research, industry consultation, and an extension of the Dutch offshore wind labour market indications given by Knol & Coolen (2019).[3] Key stakeholders from the Dutch industry have been consulted to offer specific employment-related data and/or to give a reflection on this working paper.[4]

Content of this working paper

Chapter 2 gives a brief overview of global and European developments in offshore wind. The Dutch developments in offshore wind are also briefly described in chapter 2. Chapter 3 presents post 2030 direct employment indications. Chapter 4 focuses briefly on an offshore wind package – as an example - that has not come to fulfilment in the Netherlands (in terms of employment) and is valuable for the international offshore wind industry: nacelle supply. The last chapter gives conclusions and recommendations. The document has 4 appendixes.

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[1] In this document Dutch offshore wind solely relates to wind farms on sea; lake-related offshore wind is excluded.

2 DNV GL (2020) elaborated on two offshore wind scenarios regarding post 2030 technical and economic possibilities for energy production on the Dutch part of the North Sea. One scenario is related to a setting of energy import dependency in 2050 and puts central 38 GW installed capacity of offshore wind in 2050. The other scenario focuses on energy self-sufficiency and puts central 72 GW of installed Dutch offshore wind capacity.

[3] Knol & Coolen (2019) was based on a bottom-up analysis of direct employment on the level of packages (workload estimations for specific fields of activities) based on consultations of industry actors with Dutch offshore wind farm installation and exploitation experiences (mostly Gemini and Borssele 1+2).

[4] Turbine manufacturer, monopile manufacturer, offshore wind farm operations, offshore wind installation, and offshore shipping (e.g. MHI Vestas, and Deutsche Windtechnik BV).

2. BRIEF OVERVIEW OF OFFSHORE WIND

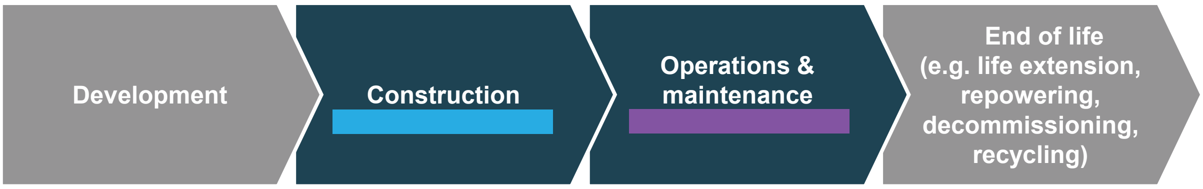
This chapter will give a brief overview of offshore wind to indicate non-exhaustingly the Dutch offshore wind employment setting. Topics in this chapter are: 1) offshore wind packages, 2) global and European developments, 3) post 2030 Dutch offshore wind scenarios, 4) post 2030 energy system and ecosystem related to offshore wind, 5) innovation for Dutch offshore wind, and 6) export aspects.

2.1 Phases and packages in offshore wind

The supply chain related to the development and exploitation of offshore wind farms in the Netherlands is internationally organised. The supply chain structure strongly relates to the phases of offshore wind farm development:

- Development
- Construction (including supply and installation)
- Operations and maintenance
- End of life (e.g. life extension, repowering, decommissioning, recycling)

Within each phase activity packages can be identified. Packages are set of bundled activities mostly as contracts awarded by offshore wind farm developers. Figure 1 gives an overview of packages related to the phases of offshore wind farm development. The coloured phases are put central in this working paper.



Development
- Site selection
- Environmental impact assessments
- Technical feasibility studies (including coastal, wind and seabed assessments)
- Financial feasibility studies and tendering
- Engineering design
- Project development

Construction
- Tower, nacelle, hub and blades supply
- Foundation substation supply
- Cable supply
- Substation supply
- Foundation supply
- Foundation installation
- Turbine installation
- Array cable installation
- Installation support
- Export cable installation
- Substation foundation installation
- Substation installation

Operations & maintenance
- Wind farm operations
- Turbine maintenance
- Structural inspection & maintenance
- Maintenance & service logistics
- Array cable inspection
- Export cable inspection
- Substation operations & maintenance
- Maintenance & service logistics for substations

End of life
- Feasibility studies: life extension, product recovery (refurbish), reuse (components / structures), re-manufacturing, material recycling
- Planning
- Ports and logistics
- Marine operations
- Salvage and recycling
- Project management

Figure 1 Phases and packages in offshore wind

2.2 Global and European developments in offshore wind

Offshore wind energy plays a highly important role in the energy transition ambitions across the world. For years, Europe had the lead in the cumulative installed offshore wind capacity. Since a few years offshore wind has become a developing and maturing sector in many countries around the world. As indicated by IRENA (2019) offshore wind energy could grow significantly over the coming decades, with the total installed offshore wind capacity rising from around 23 GW in 2018 to approx. 228 GW in 2030, and near 1,000 GW in 2050 (IRENA, 2019). The offshore wind energy potentials for Europe and the North Sea region are substantial, with outlook scenarios of 450 GW for Europe and 210 GW for the North Sea region in 2050 (WindEurope, 2019a; GWEC, 2020b). Asian offshore wind potentials are around 600 GW in 2050. US offshore wind could reach 170 GW in 2050 (GWEC, 2020b).

2.3 Post 2030 offshore wind in the Netherlands

As indicated in the introduction of this document around 1 GW of offshore wind capacity has been realised in the Netherlands until 2019. With the execution of Roadmap 2023 around 4.7 GW cumulative offshore wind capacity will be installed in 2024 (see appendix 1). The ambition of Roadmap 2030 is to increase the deployment of offshore wind resulting in 11.5 GW cumulative installed capacity in 2030.

The Dutch National Climate Agreement (MinEZK, 2019) formulates the ambition to combat climate change by implementing measures that put the Netherlands on track for a 49% reduction of greenhouse gas emissions by 2030 compared to 1990. The agreement formulates measures to be adopted per sector, e.g. built environment, mobility, industry, electricity, agriculture and land use, and cross-sectoral themes. The National Climate Plan sets out the broad outlines of Dutch climate policy for the next 10 years (MinEZK, 2020a). The above-mentioned Roadmap 2023 and Roadmap 2030 are important Dutch programmes to enlarge the share of sustainable electricity the coming decade and to support the ambitions of the mentioned Dutch National Climate Agreement.

With respect to post 2030 offshore wind the Dutch Klimaatwet (Climate Act) (Rijksoverheid, 2019) gives clear target: a 100% CO_2-neutral electricity production in the Netherlands by 2050. The recent DNV GL (2020) North Sea Energy Outlook supports the elaboration on follow-up options and considerations for a post 2030 Dutch climate agreement to achieve CO_2-neutral energy production by 2050, as laid down in the Dutch Climate Act. Insights from the North Sea Energy Outlook form an important building block for energy and climate policy to be developed. It is acknowledged that the North Sea will play an important role in this energy transition. It shows that that offshore wind, hydrogen, natural gas, CCS (carbon capture and storage), and other innovative marine technologies can contribute to this goal (see also PBL, 2018; TKI Wind op Zee, 2019; North Sea Energy, 2020; MinEZK, 2020b and 2020c). Ambitions and measures will also give sufficient economic opportunities for the Netherlands in the energy transition on the North Sea.

DNV GL (2020) has studied two scenarios that helps to define the role of Dutch offshore wind in the energy system the coming three decades. The import-dependent scenario of DNV GL (2020) is based on insufficient energy production in the Netherlands to cover domestic demand and the Netherlands relies on international exchange of energy. The self-sufficient scenario is based on maximizing the production of energy in the Netherlands and limiting imports from abroad. Depending on international market conditions, this scenario may involve the active export of renewable energy. In both scenarios most of the electricity production in the Netherlands in the period 2030 to 2050 could come from Dutch offshore wind farms. The scenarios consider 38 GW cumulative offshore wind capacity (import-dependent scenario) and 72 GW cumulative capacity (self-sufficient scenario) in 2050. To achieve this offshore wind capacity growth a higher growth rate is needed compared to the deployment rates of Roadmap 2023 and Roadmap 2030. Clear policy directions are needed to support the Dutch offshore wind industry to scale up for post 2030 roll-out of offshore wind.

2.4 Energy system and ecosystem related to offshore wind in the Netherlands

The future energy system and ecosystem related to offshore wind in the Netherlands has various (interconnected) domains:

- Interconnects between international electricity transmission systems, including hybrid offshore wind farms.[5]

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[5] A hybrid offshore wind project is one where an offshore wind project connects into an offshore electricity interconnector. Hybrid offshore wind projects allow offshore wind power to be used by more than one country (GWEC, 2020b).

- Power-to-x, including hydrogen.[6]
- CCS (carbon capture and storage) (including usage of existing oil and gas infrastructure).
- Onshore (port) facilities to facilitate offshore wind, power-to-x, and CCS.
- Offshore facilities (e.g. energy island hub or existing platforms / infrastructures) to facilitate offshore wind, interconnects with electricity transmission systems, power-to-x, CCS, and agriculture at sea.
- Other (future) offshore energy concepts (floating solar, airborne wind energy, aquatic biomass, tide energy etc.) (see paragraph 2.5).
- Fishery, and aquaculture / agriculture at sea.
- Other sectors and societal domains like shipping, tourism, telecoms, and military.
- Nature enhancement (including biodiversity).

'Programma Noordzee' (RVO, 2020) as well as its related community of practice strengthen the balance between the domains energy, shipping, nature and food on the Dutch part of the North Sea. The community of practice is a network of entrepreneurs, research institutes, civil society organisations, governments, and Dutch 'topsector' organisations. Relevant resources related to the above-mentioned interlinked domains are e.g. OFL (2018), Stichting De Noordzee (2018), NSWPH consortium (2019), WindEurope (2019b), Guidehouse - Navigant (2020), North Sea Energy (2020), DNV GL (2020), Bureau Waardenburg (2020), De Rijke Noordzee (2020), and WindEurope (2020a).

An important development in the Netherlands is the collaboration between the offshore wind sector and the industry in order to facilitate large-scale electrification of the industry (Wind meets industry, 2020).

2.5 Innovation for Dutch offshore wind

The offshore wind market is growing substantially, and in the meantime cost reductions are one of the most important aspects for having solid business cases for offshore wind. In this setting of market growth and cost reduction the development and dissemination of innovations are important: 1) technological innovations, 2) organisational innovations, and 3) system innovations.

The Dutch government has set-up mission-driven innovation policies with specific innovation programmes related to renewable energy and offshore wind. The so-called MMIP (multi-annual mission-driven innovation programme) on 'offshore generated renewable energy' puts central the following innovation targets (e.g. TKI Wind op Zee, 2019):

1) Reducing the cost of electricity and developing specific applications. Innovation areas are: support structures; wind turbines and the wind farm; network and digitization; transport, installation and logistics; and management and maintenance.
2) Integration of large amounts of renewable electricity into the energy system. Innovation areas are: smart transmission systems, balancing and chain integration; transmission infrastructure at sea; and conversion and storage.
3) Integration of renewable electricity production systems into the environment (ecological and spatial). Innovation areas are e.g. cooperation models (organisational, technical, economic) between various users of the North Sea; interaction offshore wind farms & ecology; and reducing CO_2 footprint of offshore wind farms (e.g. based on circularity; see Moonshot project on circular wind farms).

Some renewable energy concepts could become complementary to offshore wind energy in the Netherlands the coming decades, like floating solar parks, aquatic biomass, and airborne wind energy.[7] As indicated by DNV GL (2020) it is less likely that these renewable energy concepts will be able to compete with offshore wind on the basis of production costs in 2050. However, there are several benefits that could be linked to these concepts, such as

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[6] Power-to-x refers to the conversion of surplus renewable energy into liquid or gaseous chemicals (e.g. hydrogen, methanol, and ammonia) through electrolysis and further synthesis processes (GWEC, 2020b).

[7] Potential capacity in the Netherlands in 2050 at CAGR 22% (DNV GL, 2020): floating solar = 10 GW; aquatic biomass = 10 GW, and airborne wind energy = 1.4 GW.

the possibility of multiple use of space (spatial optimisation) and increasing the efficiency of the transmission network (cable pooling).

In order to scale-up innovation and the teaching of (future) professionals about innovations in offshore wind energy (e.g. via formal learning and informal learning) it is relevant to stimulate the interaction and collaboration between research (including applied research when it come to innovation implementation), education institutes, companies, and organisations active in offshore wind industry.[8] Appealing Dutch initiatives where industry, research and education collaborate in the field of offshore wind are e.g. field lab Zephyros, centre of expertise Water & Energy, Energy Port ecosystem (Zeeland region), and offshore wind ecosystem in the Groningen region. More information: Baken (2020).

2.6 Brief reflection on Dutch export potentials

Export potentials[9] related to the Dutch offshore wind industry are: 1) involvement in the construction and O&M of offshore wind farms abroad, and 2) export of offshore wind electricity.

Offshore wind developments outside the Netherlands offer relevant business opportunities for various Dutch companies active in offshore wind, maritime services, port facilities, and offshore logistics services (PWC, 2018). Important in the context of offshore wind in (North-West) Europe are the Dutch ports.[10] These ports are characterized by their deep waterways, direct access to sea and inland shipping, limited tides effects, and good facilities such as reinforced quays, long quays, (mobile) cranes, assembly facilities, and helicopter platforms (PWC, 2018, Knol & Coolen, 2019). These ports are highly suitable to serve offshore wind projects.

Cumulative offshore wind capacity on the North Sea could be around 60 GW in 2030 looking at the policies, ambitions and energy outlooks of UK, Germany, Denmark, Belgium, and the Netherlands. As indicated earlier in this chapter a potential capacity target for offshore wind on the North Sea could be around 210 GW in 2050. When considering an average single turbine capacity of 17 MW (post 2030; see also paragraph 4.2) this means that between 2030 and 2050 8,800 WTGs will be installed on the North Sea (including the Netherlands). This offers interesting business opportunities for Dutch companies in offshore wind and marine services. Besides the business opportunities on the North Sea these companies could also serve the construction of offshore wind farms in other parts of Europe (a scenario is 450 GW capacity in 2050) and the world (a scenario is 1,000 GW capacity in 2050) (see paragraph 2.2).

As indicated in DNV GL (2020) a further expansion of offshore wind capacity with the aim of actively exporting renewable energy could provide an economic opportunity for the Netherlands. The LCoE (levelized cost of electricity) of Dutch offshore wind energy could be competitive compared to surrounding countries due the favourable characteristics of the Dutch part of the North Sea: good wind resource, shallow waters (<40 m), easy soil conditions (sandy), free from extreme weather conditions, and relatively short coastal distance of offshore wind farms. Looking at the limited spatial area for offshore wind in countries such as Belgium and Germany and the need for affordable renewable energy, it is perceived as possible to generate and export Dutch offshore wind-based electricity.

The above-given information gives a brief reflection on Dutch export potentials regarding offshore wind in order to give in this chapter a sound overview of the aspects related to Dutch offshore wind. Nevertheless, a more profound elaboration is needed to highlight the Dutch export potentials in the fields of offshore wind, offshore energy systems and ecosystems (see paragraph 2.4).

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[8] It is perceived that these learning communities (collaboration between industry, research, and education) play highly relevant roles in knowledge generation and knowledge sharing. These well-focused collaborations (e.g. in the field of offshore wind) are well suited to support ambitions of the so-called multi-annual mission-driven innovation programs stimulating the energy transition in the Netherlands (Knol & Velzing, 2019).

[9] See WindEurope (2020b) for more information on European export related to offshore wind.

[10] Ports of Amsterdam and IJmuiden, Port of Den Helder, Port of Eemshaven (Groningen Seaports), Port of Harlingen, Port of Rotterdam, and Ports of Vlissingen and Terneuzen (Zeeland Seaports).

3. FIRST INDICATIONS OF AN OUTLOOK ON POST 2030 DIRECT EMPLOYMENT

This chapter gives first indications of the direct employment for certain employee categories (see appendix 2) regarding the construction and O&M related to Roadmap 2030 and Outlook 2050.[11]

3.1 Methodology

Within the project boundaries as given by RVO (see chapter 1) we used for this working paper the following methodologies:

1) Usage of existing employment data:

Existing employment indications are used as baseline. For most of the packages under study the employment indications of Knol & Coolen (2019) are used. These figures are based on industry supplied workload indications regarding certain employee categories related to existing Dutch offshore wind farms like Gemini and Borssele (see appendix 2). During that study key players from the industry were involved to validate the estimated employment indications on package level: turbine manufacturer, monopile manufacturer, transition piece manufacturer, offshore wind farm operator, maritime and offshore wind installation companies, and offshore shipping company. These bottom-up generated employment figures are perceived as rather robust and therefore suitable to be used in this study looking at the scope and purpose.

For the supply packages (which were not part of the scope of the above-mentioned study) we used employment indications of QBIS (2020). Its construction phase employment figures relate to existing Danish offshore wind farms and European offshore wind farms in general. It is perceived that the QBIS employment figures on supply (production of wind turbines and production of balance of plant (components)) are suitable to be used in this study looking at the scope and purpose. Nevertheless, a follow-up study should elaborate on potential correction factors due to characteristic differences between the Outlook 2050 Dutch offshore wind farms and the wind farms considered in the QBIS study.

2) Transformation of existing data towards various supply packages:

The scopes of the QBIS (2020) employment figures related to the production of wind turbines and the production of balance of plant (components) are not fully in line with the packages put central in this study (see paragraph 2.1). Therefore, we transformed the QBIS figures with the aid of supply workload distributions of IRENA (2018). This has led to baseline employment indications for the various supply packages under study in this working paper: nacelle supply, rotor supply, tower supply, cable supply etc.

3) Generation of employment data for specific packages:

The above-mentioned studies and other available studies (see also the reference section in this working paper) could not be used for employment indications related to certain specific installation and O&M packages (lack of data). Based on consultations of industry players (existing Dutch offshore wind farms Gemini and Borssele) we are able to give base line employment estimations for the packages array cable inspection, export cable inspection, substation operations & maintenance, and maintenance & service logistics substations.

4) First indications of an outlook on post 2030 employment figures based on baseline figures (see above) in combination with a specific labour intensity correction factor to facilitate the extrapolation of current employment figures:

In order to offer first indications of an outlook on post 2030 employment it is necessary to take into account a large set of labour intensity influencing factors linked to e.g. innovation

[11] See WindEurope (2020b) for estimates on European employment developments in onshore and offshore wind till 2030.

(incremental, radical etc.), learning curves, standardisation in the sector (on multiple levels), supply chain developments, characteristics of (future) Dutch offshore wind farms, and economies of scale. A full-scale investigation on these factors is out of the scope in this project. Regarding the scope of this working paper we created a labour intensity correction factor which follows the downtrend in CAPEX and OPEX forecasts for European offshore wind farms (see paragraph 3.2). For the scope of this working paper this approach is perceived as suitable to give first indications on post 2030 employment regarding Dutch offshore wind farms. For follow-up studies on post 2030 employment more advanced research methodologies and analysis approaches should be used to create more robust employment indications and related sensitivity checks.

3.2 Correction factor regarding future labour intensity per capacity

Innovation[12], economies of scale, supply chain developments, characteristics of future Dutch offshore wind farms, standardisation (on multiple levels), and learning curves are examples of domains that influence the future labour intensity for construction and O&M activities. It is expected that the direct employment per capacity will gradually become lower the coming decades.

For this working paper, an in-depth analysis could not be made on the future labour intensity per capacity. In stead, we used 2030 and 2050 CAPEX and OPEX estimates of Energinet & Danish Energy Agency (2018)[13] (table 1) as reference for labour intensity correction factors to be incorporated in our employment indications. The Danish estimates are based on elaborations of Horns Rev 3 (DK), Kriegers Flak (DK), Borssele 1+2 (NL), Borssele 3+4 (NL), and Vesterhav North+South (DK). It is the question if the Danish 2030 and 2050 estimates match with the future Dutch offshore wind farm constellations (financially, economically, and technically).[14] Nevertheless, our labour intensity correction factors based on these Danish estimates are perceived as suitable looking at the scope and purpose of this working paper.

Financial indicators offshore wind in (the Danish part of) the North Sea		2020	2030	2050
CAPEX	CAPEX (€$_{2015}$/kW), excluding costs of grid connection	1,920	1,650	1,400
	Relative change from 2020		-14%	-27%
OPEX	OPEX (€$_{2015}$/kW/year)	60	50	43
	Relative change from 2020		-17%	-28%

Table 1: Financial indicators of offshore wind in the North Sea (Energinet & Danish Energy Agency, 2018)

Correction factors for direct employment estimations	Roadmap 2030	Outlook 2050
Construction phase	Mean correction percentage over extrapolated figures over period 2024-2030: **-11%**	Mean correction percentage over extrapolated figures over period 2030-2050: **-18%**
O&M phase	Mean correction percentage over extrapolated figures over period 2024-2030: **-13%**	Mean correction percentage over extrapolated figures over period 2030-2050: **-23%**

Table 2: Correction factors for direct employment estimations used in this working paper

[12] Two examples to give some ideas: larger turbines (with larger capacities per turbine) and robotic assistance in O&M activities (leading to more remote-controlled O&M strategies).

[13] The estimates of Energinet & Danish Energy Agency (2018) are also used in the analysis of Afry (2020).

[14] Aspects: e.g. concession terms, economic lifetime, inclusion of grid connection costs in CAPEX and OPEX definitions, coastal distance of wind farm, modes of electricity transmission to shore, and O&M strategies.

Table 2 summarizes the correction factors that are incorporated in the direct employment extrapolations whereby the employment indications of Knol & Coolen (2019), QBIS (2020), IRENA (2018) form the core of the 2020 baseline figures.

3.3 First indications of direct employment related to Roadmap 2030

This paragraph gives a first indication of the direct employment regarding the phases construction and O&M related to Roadmap 2030: installing 6.1 GW offshore wind capacity resulting in a cumulative installed capacity of 11.5 GW in 2030.

The tables 4 and 5 indicate the direct employment (FTE) related to Roadmap 2030. Most (engineering and technology-related) job roles are included in the employment indications (see appendix 2). However, the indications do not include all known job roles in the offshore wind sector. To some degree various (specialistic) job roles are not included, like geotechnical, environmental, marine, biology, and fishing site experts. See on this matter also the discussions and elaborations in Knol & Coolen (2019). In table 4 the installation employment figures incorporate installation staff and vessel crew.

Supply chain boundary demarcation plays an important role in the direct employment elaborations, especially when focussing on the supply packages (e.g. turbine manufacturing).[15] Therefore, in table 4 the direct employment indications related to the supply packages are reasonable linked to the final stages of the manufacturing supply chain: assembly main components, final assembly, and factory acceptance tests.

Scale definition on today's possible involvement of Dutch supply chain(s) in terms of employment (see tables 4 and 5)	**Scale indicator**
No to very poor possibilities of involvement of Dutch supply chain(s) (in terms of employment) in comparison with involved foreign supply chain(s)	○○○○
Poor possibilities of involvement of Dutch supply chain(s) (in terms of employment) in comparison with involved foreign supply chain(s)	●○○○
Reasonable possibilities of involvement of Dutch supply chain(s) (in terms of employment) in comparison with involved foreign supply chain(s)	●●○○
Good possibilities of involvement of Dutch supply chain(s) (in terms of employment) in comparison with involved foreign supply chain(s)	●●●○
Excellent possibilities of involvement of Dutch supply chain(s) (in terms of employment) in comparison with involved foreign supply chain(s)	●●●●

Table 3: Scale definition on possible involvement of Dutch supply chain(s) in terms of employment

The direct employment figures in the tables 4 and 5 are not specifically addressing the direct employment for Dutch companies or professionals working in or from the Netherlands. The relative involvement of Dutch supply chains (in terms of employment) per package is indicated qualitatively in the tables 4 and 5 (most right columns). The definition of the used scales is given in table 3. For tables 6 and 7 we converted the 4 scale indicator into a binary indicator due to higher uncertainties about post 2030 Dutch offshore wind supply chain involvements and to propel coming discussions on Dutch supply chain setting and opportunities. The qualitative indications on Dutch offshore wind supply chain involvement are based on interpretations of Roland Berger (2015), EIB (2016), PWC (2018), and Knol & Coolen (2019). It should be noted that specific up-to-date data on this topic is not available and could not be harvested within the scope of this working paper.

[15] It is perceived by us that IRENA (2018b) incorporates a much wider supply chain boundary demarcation in their direct employment indications about the supply packages (e.g. manufacturing of main components; manufacturing of parts for main components).

Construction phase packages	First indications of one-off direct employment regarding Roadmap 2030 (6.1 GW in total and deployment rate of 1.0 GW/year)			
	Direct employment per GW (FTE/GW)	Average direct employment per year (yearly FTE)	Cumulative direct employment (cumulative FTE 2024 - 2030)	Indication of today's possible involvement of Dutch supply chain in terms of employment
Nacelle supply	950	950	6,000	○○○○
Rotor supply (including blades)	550	550	3,500	○○○○
Tower supply	400	400	2,500	○○○○
Cable supply	100	100	500	●○○○
Substation supply	400	400	2,500	●●●○
Foundation supply turbine	850	850	5,000	●●●○
Subtotal	*3,250*	*3,250*	*20,000*	
Foundation installation turbine	70	70	400	●●●○
Turbine installation	80	80	500	●●●○
Array cable installation	80	80	500	●●●○
Installation support	90	90	600	●●●○
Export cable installation	80	80	500	●●●○
Substation installation	30	30	200	●●●○
Subtotal	*430*	*430*	*2,700*	
Total	**3,680**	**3,680**	**22,700**	

Table 4: First indications of direct employment related to construction phase of Roadmap 2030

O&M phase packages	First indications of recurring direct employment per year regarding Roadmap 2030 (6.1 GW)		
	Yearly direct employment per GW (yearly FTE/GW)	Yearly direct employment (related to all Roadmap 2030 wind farms installed during 2024-2030) (yearly FTE)	Indication of today's possible involvement of Dutch supply chain in terms of employment
Wind farm operations	13	80	●●●○
Turbine maintenance	37	220	●●●○
Structural inspection & maintenance	7	40	●●●○
Maintenance & service logistics	7	40	●●●●
Crew cable and substation	1	10	●●●○
Array cable inspection	1	10	●●●○
Export cable inspection	1	10	●●●○
Substation operations & maintenance	1	10	●●●○
Maintenance & service logistics substations	4	20	●●●●
Total	**72**	**420**	

Table 5: First indications of direct employment related to O&M of Roadmap 2030

3.4 First indications of direct employment related to Outlook 2050

This paragraph elaborates on the first indications of the potential direct employment related to Outlook 2050 as defined for this working paper (see chapter 1). The tables 6 and 7 summarise the first indications of our outlook regarding direct employment for the construction phase and the O&M phase. These figures are based on the methodology as described in paragraph 3.1 and based on the incorporation of correction factors as explained in paragraph 3.2. Most (engineering and technology-related) job roles are included in the employment indications of tables 6 and 7 (see appendix 2).

In tables 6 and 7 we give a qualitative (binary) indication of the capacity availability in Dutch supply chain at this moment. For this document we see capacity as the collective ability of individuals and organisations (in terms of resources, skills and knowledge, power) to manage their affairs successfully in (packages) related to Dutch offshore wind.

Construction phase packages	First indications of an outlook regarding one-off direct employment regarding Outlook 2050 (43.5 GW and deployment rate of 2.2 GW/year)			
	Direct employment per 10 GW (FTE/10 GW)	Average direct employment per year related to period 2030-2050 (yearly FTE)	Cumulative direct employment (cumulative FTE 2030-2050)	Indication of future possible involvement of Dutch supply chain in terms of employment looking at the current situation (yes: ● no: ○)
Nacelle supply	9,100	2,000	39,000	○
Rotor supply (including blades)	5,000	1,100	22,000	○
Tower supply	3,600	800	16,000	○
Cable supply	1,000	200	4,000	○
Substation supply	3,500	800	15,000	●
Foundation supply turbine	7,800	1,700	34,000	●
Subtotal	*30,000*	6,600	*130,000*	
Foundation installation turbine	600	100	3,000	●
Turbine installation	700	200	3,000	●
Array cable installation	700	200	3,000	●
Installation support	800	200	4,000	●
Export cable installation	700	200	3,000	●
Substation installation	300	100	1,000	●
Subtotal	*3,800*	*1,000*	*17,000*	
Total	**33,800**	**7,600**	**147,000**	

Table 6: First indications of an outlook on direct employment related to the construction phase of Outlook 2050 (future possible Dutch supply chain involvement indication: yes: ● and no: ○)

O&M phase packages	First indications of an outlook regarding recurring direct employment per year for Outlook 2050 (43.5 GW)		
	Yearly direct O&M employment per 10 GW (yearly FTE / 10 GW)	Yearly direct employment related to all Outlook 2050 wind farms installed during 2030-2050 (yearly FTE)	Indication of future possible involvement of Dutch supply chain in terms of employment looking at the current situation (yes: ● no: ○)
Wind farm operations	110	480	●
Turbine maintenance	330	1,440	●
Structural inspection & maintenance	60	270	●
Maintenance & service logistics	60	270	●
Crew cable and substation	10	40	●
Array cable inspection	10	40	●
Export cable inspection	10	40	●
Substation operations & maintenance	10	40	●
Maintenance & service logistics substations	30	140	●
Total	**630**	**2,760**	

Table 7: First indications of an outlook on direct employment related to O&M of Outlook 2050 (future possible Dutch supply chain involvement indication: yes: ● and no: ○)

Tables 6 and 7 suggest that in principle post 2030 direct employment related to substation supply, foundation supply, installation and O&M could be (completely) fulfilled by Dutch supply chains (Dutch companies and companies located in the Netherlands).

Cumulative direct employment for Dutch supply chains regarding construction (foundation supply, substation supply, and installation) is 66,000 FTE (period 2030-2050). This is around 3,300 direct FTE per year. Dutch supply chain employment for installation will be around 17,000 cumulative direct FTE over the period of 2030-2050. The direct employment for foundation supply could be largely related to Dutch supply chains: approx. 34,000 cumulative direct FTE. This post 2030 foundation supply employment represents approximately a quarter of the total direct employment related to the supply packages for the future Dutch offshore wind farms. The direct employment for substation supply could be largely related to Dutch supply chains: approx. 15,000 cumulative direct FTE.

Table 6 indicates that two-third of the supply employment (approx. 81,000 cumulative direct FTE over the period 2030-2050) will not or will hardly be related to Dutch supply chains looking at the current situation in the supply chains of the supply packages.

To summarize, the construction of post 2030 Dutch offshore wind farms could lead to a cumulative direct employment for Dutch supply chains of around 66,000 FTE when looking at the current situation of the Dutch supply chains focussing on offshore wind.[16]

The direct employment in O&M will be substantial taking into account that O&M have a duration of more than 30 years (presumably around 40 years when considering the recent discussions on the extension of the contract period of future Dutch offshore wind farms). The yearly direct employment for O&M will be around 2,700 FTE as from 2050 (when all Outlook 2050 WTGs are installed and maintained during the decades after 2050). This employment could be largely fulfilled by Dutch supply chains. It is suggested by the industry that there are opportunities for Dutch supply chains in major repairs (it is perceived that in this specific field the Dutch supply chain involvement could be enhanced). It is hard to predict

[16] Note: this direct employment indication is only about the workload on the level of packages for substation supply, foundation supply (fabrication and assembly) and offshore installation works (installation of foundations and WTGs) (see also appendix 2).

what innovative robotic concepts will be developed to fulfil offshore O&M work. Nevertheless, it could be expected that in the future the yearly direct employment for O&M works could be partially replaced by robotics. Further predictions on this matter are recommended.

Although this working paper is focussed on direct employment related to Dutch offshore wind farms, post 2030 indirect Dutch employment in various segment could be substantial also looking at the current capabilities and market shares (e.g. specialistic ships, grippers, and cranes). It is recommended to expand employment elaborations to certain indirect employment domains.

The figure below summarizes the direct employment indications regarding Outlook 2050.

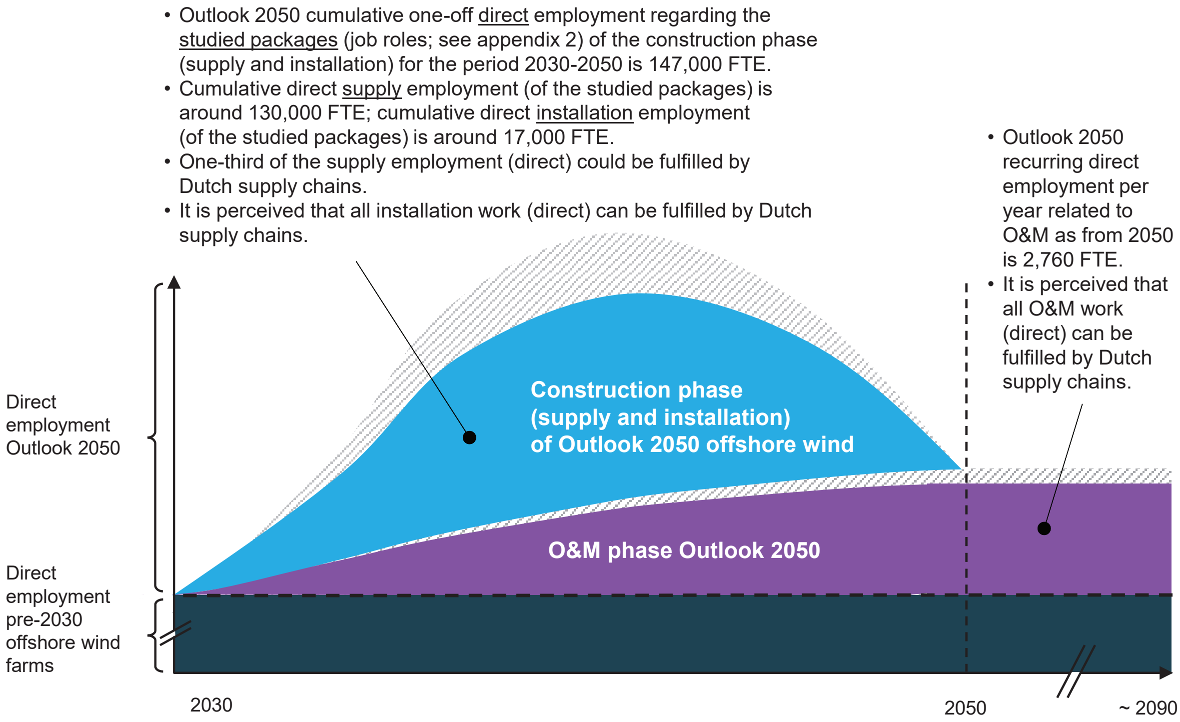

Figure 2: Summary of first indications of direct employment related to Outlook 2050

4. BRIEF REFLECTION ON SUPPLY PACKAGE ‘NACELLE SUPPLY’ FROM EMPLOYMENT PERSPECTIVE

4.1 Introduction

Chapter 3 has shown the direct employment indications regarding construction and O&M of Dutch offshore wind farms. Strong Dutch supply chain involvement (in terms of direct employment) is present in substation supply, foundation supply, offshore installation works, and in O&M. In these packages the Dutch industry has the resources and the capacities (e.g. knowledge and skills) to deliver, not only for the Dutch market but also for international markets - especially in the field of transport and installation (ships, grippers, cranes etc.). The current Dutch supply chains are important to serve the future offshore wind markets in Europe and abroad. From innovation and economic policy perspectives these supply chains are relevant.

Chapter 3 also indicates that the current Dutch supply chain involvement (in terms of employment) in certain packages is not existing or very limited. Especially in the supply packages related to wind turbines. It could be relevant for Dutch innovation and economic policies to also look at the packages with low Dutch supply chain involvement: what is currently less well developed in the Netherlands but valuable for the international offshore wind industry. Therefore, as an example - in this chapter we would like to give a brief reflection on the supply package ‘nacelle supply’ from an employment perspective.

4.2 Offshore wind turbines

An offshore wind turbine is a highly advanced technical system that consists of more than 65,000 individual parts and components (Poulsen & Lema, 2017) linked to various subsystems (main components) like blades, rotor, generator, and control and data systems. Direct drive generator technology reduces the number of rating and wear-prone components in offshore turbines, making them simpler to maintain. Currently, modern offshore wind turbines have a capacity of around 9-11 MW.[17] It is expected that the coming years turbines with a single turbine capacity of 13-15 MW will become commercially available.[18] Single turbine capacity could go towards 17 MW and higher the coming decades.[19]

The current setting in offshore wind - continuous growth in the capacity per turbine – is increasingly limiting the business case for offshore wind companies to support cost reductions across the supply chain. E.g. it will become too costly to develop and build new generation crane vessels for larger turbines with higher towers, and larger rotors.

The wind turbine industry is considering further standardisations in a) offshore wind turbine specifications (e.g. maximum tip height resulting in maximum capacities for turbines; e.g. around 17 MW per turbine) and b) offshore wind farms constellations, in order to pave the road for further cost reductions across the supply chain (see also IRENA, 2018a; IRENA, 2019; TKI Wind op Zee, 2019; ETIP, 2020; Spoelstra & Schut, 2020). It also paves the roads for further steps in circularity in the offshore wind industry (e.g. Dutch Moonshot project: circularity in the Dutch offshore wind sector). Standardisation could give various types of suppliers (related to supply, transport & installation, O&M, decommissioning /

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[17] European offshore wind turbine and blades manufacturers have strong markets positions (see WindEurope, 2020b).

[18] Examples are the offshore wind turbines GE Haliade-X 14 MW, and Siemens Gamesa 14-222DD 14 MW. Also MHI Vestas is following with next generation offshore wind turbines.

[19] GWEC (2020) indicates that from a technical point of view the single turbine capacity could be 20 MW in 2030. It also indicates that factors related to regulation, logistics, installation, and standardisation could lead to a certain single turbine capacity plateau which could be lower than 20 MW in 2030. GWEC (2020) hints that – from a technical point of view - the single turbine capacity could be 20-25 MW in 2050.

recommissioning, and circularity) stronger business cases to invest in product, process, organisational, and system innovations, to reduce costs in combination with higher potentials for circularity, and lower CO_2 footprints.

There are a dozen or more large manufacturers of offshore wind turbines on the world, including European manufacturers like Siemens Gamesa Renewable Energy and MHI Vestas, US manufacturer GE Renewable Energy, and Chinese companies like Shanghai Electric Wind Power Group, Envision, and Goldwind.[20] The Chinese companies seem to focus mainly on the Asian offshore wind markets due to the substantial offshore wind ambitions in Asia (around 100 GW installed capacity in 2030 and around 600 GW in 2050) and specifically in China (around 54 GW installed offshore capacity in 2030 and around 380 GW in 2050) (e.g. GWEC, 2020b).

4.3 Employment perspectives regarding nacelle assembly

Wind turbines will become larger and heavier[21] the coming decades resulting in larger logistic challenges for turbine suppliers to transport assembled (or partly assembled) turbines from manufacturing and assembly factories to ports. This is also the reason why turbine manufacturers set up highly modern assembly factories in ports with e.g. advanced roll-on/roll-off (ro-ro) vessels for sea transport (see e.g. Siemens Gamesa Renewable Energy factory in Cuxhaven, Germany, and GE Renewable Energy nacelle factory in Saint-Nazaire, France; see also appendix 4).

Currently, the European offshore wind nacelle manufacturing capacity is around 8 GW yearly (WindEurope, 2020b). With the increasing deployment rate of offshore wind parks after 2030 it will become a discussion for turbine factories to further optimize and upscale nacelle assembly factories. Highly hypothetical for the moment, it could become (even) more relevant to elaborate on additional assembly activities in Europe when non-European turbine manufacturers (e.g. Chinese companies) also decide to serve European markets with their offshore wind turbines some moment the coming three decades (see Poulsen & Hasager, 2017).

A first indication of an outlook on the direct employment for nacelle assembly related to the Outlook 2050 period is around 150 direct FTE/GW. This figure is based on QBIS (2020), IRENA (2018b), and De Vries (2018, 2020), and includes correction factors as discussed in chapter 3 (innovation, economies of scale, learning curves, and standardisation). When considering the scenario that between 2030 and 2050 150 GW offshore wind capacity will be installed on the North Sea (paragraph 2.2) it means that around 22,500 cumulative direct FTE will be involved in nacelle assembly in the period 2030-2050.

It is valuable for the Dutch offshore wind industry to consult the European (and non-European) offshore wind turbine suppliers about their nacelle assembly facilities strategies for the coming decades: how will they further optimize and upscale their nacelle (and rotor) assembly infrastructures across Europe?

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20 Top 10 offshore wind turbine suppliers (global market share in 2019) (GWEC, 2020a): Siemens Gamesa Renewable Energy (39.8%), MHI Vestas (15.7%), Shanghai Electric Wind Power Group (10.0%), Envision (9.5%), Goldwind (9.43%), Mingyang (7.3%), GE Renewable Energy (4.3%), CSIC Haizhuang (2.3%), Senvion (1.67%), and XEMC (0.1%). See also WindEurope (2020b) for more detailed information about manufacturing facilities in worldwide and in Europe regarding towers, blades, castings, generators, converters, forgings, nacelles, bearings, and gearboxes.

21 Current state of the art: nacelle weight of GE's Haliade-X 14 MW is around 600 tonnes; the turbines' blades are 107 metres long. Nacelle weight of Siemens Gamesa's 14-222DD 14 MW will be around 500 tonnes.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- Offshore wind at the North Sea will play a highly important role in the post 2030 ambitions and measures to achieve CO_2-neutral electricity production by 2050, as laid down in the Dutch Climate Act. A higher offshore wind capacity growth rate will be needed after 2030 compared to the deployment rates of Roadmap 2023 and Roadmap 2030.

- In general, substantial post 2030 employment (Dutch and foreign) regarding Dutch offshore wind farms will be related to supply packages (mostly nacelle supply, rotor supply, turbine foundation supply, substation supply) and operations & maintenance (O&M) (which are continuing activities during the complete exploitation period of an offshore wind farm).

- There will be substantial post 2030 employment for involved Dutch supply chains regarding offshore installation activities and operations & maintenance. Installation employment (related to the studied job categories) will be around 17,000 cumulative direct FTE over the period of 2030-2050. Yearly direct O&M employment will be around 600 FTE per installed 10 GW capacity. Companies in the fields of installation and O&M will likely have the resources and the capabilities to serve the post 2030 Dutch offshore wind ambitions and the future international offshore wind markets.

- Most of the supply packages (excluding turbine foundation supply and substation supply) will have limited future Dutch supply chain involvement (in terms of employment) looking at the current situation in offshore wind. Two-thirds of the total supply employment (approx. 81,000 cumulative direct FTE over the period 2030-2050) will not or will hardly be related to Dutch supply chains looking at the current situation in the supply chains of the supply packages. One-third could be well fulfilled by Dutch supply chains: foundation supply, and substation supply.

- In order to meet the future offshore wind demand turbine suppliers will have to define their nacelle (and rotor) assembly infrastructure strategies for the post 2030 ambitions. An industry example is the new nacelle assembly facility of Siemens Gamesa Renewable Energy in Cuxhaven (Germany).

- Offshore wind will be an integrated part of an offshore energy system and ecosystem. This working paper has indicated this setting. It is perceived that in various domains of this future energy system and ecosystem (new) employment opportunities will rise, e.g. in the fields of ships, grippers, and cranes, major repairs, green hydrogen, multi-use of offshore spatial area, nature enhancement, and decommissioning / recommissioning, and circularity.

5.2 Recommendations

- Create policy attention on ‘strengthening the strength’ and ‘filling the gap’ with respect to Dutch supply chain involvement and related employment in offshore wind being part of an integrated offshore energy system and ecosystem. ‘Strengthening the strength’ focuses on Dutch supply chains in offshore wind that are well developed (to serve national and international markets) (e.g. foundations, substations, transport & installation (including specialistic ships, grippers, and cranes), cables, and O&M). ‘Filling the gap’ focuses on supply chains where the involvement of Dutch companies is absent or (still) very limited. The challenge will be to look for opportunities (from employment perspective) to enable involvement of Dutch companies in these supply chains. For both areas (‘strengthening the strength’ and ‘filling the gap’) clear innovation and economic policy directions are needed to support the Dutch offshore wind industry to scale up for post 2030 roll-out of offshore wind energy.

- Elaborate what the future (employment) opportunities are for the Netherlands when looking at the specific nacelle assembly strategies of European and non-European turbine suppliers (‘filling the gap’). It is valuable for the Dutch offshore wind industry and Dutch policy makers to elaborate on these strategies: how will turbine suppliers further optimize and upscale their nacelle (and rotor) assembly infrastructures across Europe to serve the European offshore wind energy ambitions the coming three decades?

- Elaborate what the future (employment) opportunities are for the Netherlands when looking at the specific post 2030 ambitions and opportunities in the field of green hydrogen generated with offshore wind power (and other offshore renewable energy).

- Elaborate what the future (employment) opportunities are for the Netherlands looking at the forthcoming ambitions and developments on multi-use of offshore wind farm locations (e.g. floating solar, agriculture at sea, and nature enhancement).

- Elaborate what the future (employment) opportunities are for the Netherlands looking at the forthcoming European and Dutch ambitions and developments on decommissioning / recommissioning and circularity in offshore wind.[22] These activities are perceived as quite in line with existing installation capabilities of the Dutch offshore industry, and gives additionally business opportunities for the existing Dutch offshore industry. Decommissioning, recommissioning, and circularity ambitions will require specific facilities and capacities. E.g. the recycling of thousands of rotor blades from North Sea WTGs the coming decades.

- Elaborate what the future (employment) opportunities are for the Netherlands looking at domains that are currently labelled as ‘indirect employment domains’ with the offshore wind sector: e.g. specialistic ships, grippers, cranes, and other advanced tooling (including robotics) and facilities relevant for the offshore wind sector.

- Facilitate investigations that could define the Dutch educational capacities needed considering the future employment developments in offshore wind (being part of an integrated offshore energy system and ecosystem) in the Netherlands and abroad. Consider the roles of public-private partnerships - like learning communities - to enhance education and lifelong learning matching the post 2030 offshore wind ambitions. Develop a nationwide educational approach for offshore wind professionals (supply, transport & installation, O&M, end of life etc.) addressing the roles and responsibilities of policy makers, the education sector (all relevant education levels), (applied) research, and the industry.

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[22] It is not imaginary to have future tender criteria that take into account CO_2 footprint, and circularity of offshore wind farms.

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DEFINITIONS AND ABBREVIATIONS

CAPEX: Capital expenditure; upfront capital costs for the development of an offshore wind farm, including packages related to development and construction (supply, balance of plant, and installation). CAPEX definitions regarding offshore wind are not (yet) uniform in Europa, e.g. including or excluding the grid connection up to the onshore transformer.

Crew: standard marine manning for a vessel.

Direct employment: jobs that relate specifically to offshore wind activities.

Direct GVA: gross value added related to direct employment.

FTE: full-time equivalent; unit obtained by comparing an employee's average number of hours worked to the average number of hours of a full-time worker. In this study the Dutch guidelines for a regular work week will be used as one FTE, namely 38 working hours a week. For practical reasons 1 FTE is equal to 1 person-years in this working paper (see also reflections on this matter in Knol & Coolen, 2019).

Indirect employment: jobs outside of the offshore wind energy sector but which are part of the supply chain to the sector by supplying the inputs to offshore wind projects.

GVA: gross value added: total value of goods and services produced by the economy minus the value of goods and services used to produce the final products. Dutch: toegevoegde waarde.

LCoE: Levelized cost of electricity.

Nacelle: housing the gearbox and generator connecting the tower and rotor.

O&M: operations & maintenance.

OEM: original equipment manufacturer.

Offshore wind parks in the Netherlands: in this working paper offshore wind parks in the Netherlands are defined as the wind farms created and to be created on the Dutch part of the North Sea. In this working paper offshore wind in Dutch lakes is excluded from the scope.

One-off activities: in this study a cluster of activities that will be performed only once, e.g. to build up infrastructure during the construction phase of an offshore wind farm.

OPEX: Operation and maintenance expenditures of a shore wind farm.

Package: bundle of activity clusters within an offshore wind phase. In this report the following packages related to the construction phase are studied: foundation supply, foundation installation, turbine installation, array cable installation, installation support. The following packages related to the operations and maintenance phase are studied: wind farm operations, turbine maintenance, structural inspection and maintenance, and maintenance and service logistics.

Phases: in the life cycle of an offshore wind farm four main stages can be recognised: development, construction, operations and maintenance, and decommissioning. This report focuses on certain fields of activities part of the construction phase and operations and maintenance phase.

Recurring activities: in this study a cluster of activities during the operation and maintenance phase with a repetitive character.

Ro-ro vessel: roll-on/roll-off vessel contributing to cost efficiency in the transport of wind turbine components / assemblies.

Scopes of work: main activity clusters within each package.

Supply chain: network of organizations that cooperate to transform materials into higher value products.

Staff: pending the activity to be executed a specialised staff will be based on a vessel

TSO: transmission system operators.

WTG: wind turbine generator.

APPENDIX 1: OVERVIEW OF DUTCH OFFSHORE WIND

Offshore wind energy farms in the Netherlands	Installation start year	Commissio-ning start year *	Total capacity (GW) **	Single turbine power (MW) ***	Total number of WTGs ***
Pre-Roadmap 2023					
PAWP - Prinses Amalia	2006	2008	0.120	2	60
OWEZ - Egmond aan Zee	2006	2007	0.108	3	36
Luchterduinen	2014	2015	0.129	3	43
Gemini	2015	2017	0.600	4	150
Subtotal			*0.957 GW*		*289 WTGs*
Total cumulative			*0.96 GW*		*289 WTGs*
Roadmap 2023 ****					
Borssele 1+2	2019	2020	0.752	8	94
Borssele 3+4	2019	2020	0.732	9.5	77
Hollandse Kust South 1+2	2021	2022	0.760	11	70
Hollandse Kust South 3+4	2021	2022	0.760	11	70
Hollandse Kust North	2022	2023	0.759	11	69
Subtotal			*3.763 GW*		*380 WTGs*
Total cumulative capacity			*4.72 GW*		*669 WTGs*
Roadmap 2030					
Hollandse Kust West	2024	2024-2025	1.4	13	108
Ten noorden van de Waddeneilanden	2025	2026	0.7	14	50
IJmuiden Ver 1	2026	2027-2028	1.0	15	67
IJmuiden Ver 2	2027	2027-2028	1.0	15	67
IJmuiden Ver 3	2028	2029-2030	1.0	15	67
IJmuiden Ver 4	2029	2029-2030	1.0	15	67
Subtotal			*6.1 GW*		*426 WTGs*
Wind farm to be decided			0.9 GW	-	-
Decommissioned capacity (indication)			-0.2 GW	-	-
Indication of total installed cumulative capacity			*11.5 GW*		-
Outlook 2050 used in this working paper *****					
Cumulative 43.5 GW	Post 2030	Post 2030	43.5	17	2,559 WTGs
Decommissioned capacity			*Not included*		-
Subtotal			*43.5 GW*		*2,559 WTGs*
Indication of total installed cumulative capacity based on Outlook 2050			*55.0 GW*		-

Table 8: Existing and future Dutch offshore wind farms (4C Offshore, 2018 and MinEZK, 2018a, 2019b)

* Commissioning year of future wind farms is an indication based on information from various sources;
** Realised and projected capacities; rounded figures with no decimals;
*** Indication of single turbine capacity and total number of WTGs of realised projects and future projects;
**** Borssele 5 is an innovation site of 19 MW and excluded in this overview;
***** The offshore wind capacity related to this working paper's Outlook 2050 is based on the average of two energy outlook scenarios for the North Sea as studied by DNV GL (2020): scenario 1 = 38 GW installed capacity of Dutch offshore wind in 2050 (delta 2030-2050: 26.5 GW), and scenario 2 = 72 GW in 2050 (delta 2030-2050: 60.5 GW).

APPENDIX 2: USED EMPLOYEES CATEGORIES PER PACKAGE FOR DIRECT EMPLOYMENT INDICATIONS

This appendix gives information about the employee categories used for the estimation of the direct employment indications in this working paper. Much of the research on the included employee categories is done by Knol & Coolen (2019) in collaboration with key players from the Dutch offshore wind industry: turbine manufacturer, monopile manufacturer, transition piece manufacturer, offshore wind farm operator, maritime and offshore wind installation companies, and offshore shipping company. It is important to notice that for the direct employment estimations (in Knol & Coolen (2019) and in this working paper) not all employee categories within the packages are included (excluded are e.g. marketing, communication, training, administration, finance, insurance, legal, onshore logistics, warehousing, research etc.).

Construction phase:

Tower, nacelle, hub and blades supply: Included employee categories: engineers, planners, process operators, technicians, factory / assembly workers, and QA professionals. Conversion to person-years is based on 1.500 productive hours per year per employee.

Cable supply: Included employee categories: engineers, planners, process operators, technicians, factory workers, and QA professionals. Conversion to person-years is based on 1.500 productive hours per year per employee.

Substation supply: Included employee categories: engineers, planners, process operators, technicians, factory / assembly workers, and QA professionals. Conversion to person-years is based on 1.500 productive hours per year per employee.

Foundation supply: Included employee categories: factory workers (like welders and coaters), engineers, planners, process operators, maintenance technicians, and QA professionals. Conversion to person-years is based on 1.500 productive manufacturing hours per year per employee.

Foundation installation: Included employee categories: a) staff: offshore construction manager, piling operators, superintendent, surveyors, riggers, lifting supervisors, QC and HSE professionals, and b) marine crew: master, 1st officer, 2nd officer, chief engineer, chief mate, electrician, jacking engineer, bosun, deckhands, stewards, camp boss, night cook. Approximately 2 client representatives and 2 warranty surveyors on board are excluded in the calculations. Conversion to person-years is based on 1.500 productive hours per year per employee.

Turbine installation: Included employee categories: a) staff installation contractor: offshore construction manager, superintendent, surveyor, lifting supervisors, QA and HSE professionals, riggers, b) staff WTG contractor: site manager, foreman, WTG technicians and engineers, and riggers, and c) marine crew: master, 1st officer, 2nd officer, chief engineer, chief mate, electrician, jacking engineer, bosun, deckhands, stewards, camp boss, night cook. Approximately 2 client representatives and 2 warranty surveyors on board are excluded in the calculations. Conversion to person-years is based on 1.500 productive hours per year per employee.

Array cable installation: Included employee categories: a) staff: offshore construction manager, superintendent, welder, bosun, deckhand, crane operator, cable operator, deck foreman, tower teams, ROV pilot, b) marine crew; captain, chief mates, 2nd mate, dynamic positioning operator, survey, chief engineer, 2nd engineer, rating engine room, 3rd engineer, electrician, cook, and c) CTV crew. Approximately 2 client representatives and 2 warranty surveyors on board are excluded in the calculations. Conversion to person-years is based on 1.500 productive hours per year per employee.

Installation support: Per project. Included vessels (based on reference project): 2 x CTV (6 FTE), 1 x OSV supply vessel (5 FTE), 1 x guard vessel, 1 x multipurpose vessel (44 crew members + 6 client representatives), 1 x survey vessel, 1 x pre-lay grapnel run (PLGR) workboat (normal vessel crew, 2 x survey, 1 x client representative) = approximately 75 FTE. Marine crew employment is indicated in FTE (persons) per project (mostly 1 offshore wind farm project).

Export cable installation: Included employee categories: a) staff: offshore construction manager, superintendent, welder, bosun, deckhand, crane operator, cable operator, deck foreman, tower teams, ROV pilot, b) marine crew; captain, chief mates, 2nd mate, dynamic positioning operator, survey, chief engineer, 2nd engineer, rating engine room, 3rd engineer, electrician, cook, and c) CTV crew. Conversion to person-years is based on 1.500 productive hours per year per employee.

Substation foundation installation: Included employee categories: a) staff: offshore construction manager, piling operators, superintendent, surveyors, riggers, lifting supervisors, QC and HSE professionals, and b) marine crew: master, 1st officer, 2nd officer, chief engineer, chief mate, electrician, jacking engineer, bosun, deckhands, stewards, camp boss, night cook. Conversion to person-years is based on 1.500 productive hours per year per employee.

Substation installation: Included employee categories: a) staff installation contractor: offshore construction manager, superintendent, surveyor, lifting supervisors, QA and HSE professionals, riggers, b) staff substation contractor: site manager, foreman, technicians and engineers, and riggers, and c) marine crew: master, 1st officer, 2nd officer, chief engineer, chief mate, electrician, jacking engineer, bosun, deckhands, stewards, camp boss, night cook. Conversion to person-years is based on 1.500 productive hours per year per employee.

O&M phase:

Wind farm operations: Per offshore wind farm. Included employee categories: management, monitoring and marine coordinators, technical specialists, data analysts, and administration. Capacity per employee category: management 1 FTE, maritime 2 FTE, and technical 8 FTE. Based on 1,500 productive hours per year per FTE.

Turbine maintenance: Recurring employment indication per turbine per year: 200 effective preventive maintenance hours by technicians, independent of geographical distance of the wind farm to the nearest port and largely independent from the single turbine capacity (e.g. 3 MW turbine versus 9.5 MW turbine) as experienced in the Dutch offshore wind industry so far. Based on 1,200 productive hours per year per FTE. Included employee categories: technicians level 4 - 7, and onshore (back office) professionals.

Structural inspection and maintenance: Recurring employment indication per year for inspection and standard maintenance. Based on 1,200 productive hours per year per FTE. Included employee categories: inspection and maintenance technicians.

Maintenance and service logistics: Per offshore wind farm. Standard SOV crew is around 15 FTE and standard CTV crew is 2 FTE (12-hour shift). Based on 1,500 productive hours per year per FTE. Based on assumption that wind farm Borssele 3+4 will use the SOV concept (2-weeks shifts, 12 working hours per day during shift, two rotating shift teams). Based on CTV concept for all Roadmap 2023 wind farms excluding Borssele 3+4 (estimation of 2 CTVs per shift).

Array cable inspection: Per offshore wind farm. Bathymetric survey annually (1 vessel; 30 working days; 2-3 staff; vessel crew), data processing (maps, analysis and conclusions), visual inspection of cable exits (on demand).

Export cable inspection: Per offshore wind farm. Bathymetric survey annually (1 vessel; 3 working days; 2-3 staff; vessel crew), data processing (maps, analysis and conclusions), visual inspection of cable exits (on demand).

Substation operations & maintenance: Per substation. Several maintenance types: 3 monthly, 6 monthly, annual, every 3 and 5 years. Included employee categories: maintenance technicians, troubleshooting professionals (standby all the time), remote monitoring and control, expert/switch operator.

Maintenance & service logistics for substations: Per substation. Standard SOV crew is around 15 FTE and standard CTV crew is 2 FTE (12-hour shift). Based on 1,500 productive hours per year per FTE.

APPENDIX 3: GROSS VALUE ADDED PER DIRECT FTE

This appendix will express the post 2030 direct employment indications in economic figures: gross value added (GVA; expressed in euros) of the direct employment. GVA is defined as the total value of goods and services produced by the economy minus the value of goods and services used to produce the final products. The GVA figures are highly indicative.

As indicated by WUR (2019) existing statistics (e.g. CBS, 2017) and studies (e.g. PWC, 2018) do not give unambiguous answers about the economic impact (GVA) related to the construction and exploitation of Dutch offshore wind farms. Besides, WUR (2019) clearly indicates that the GVA with respect to multi-year offshore wind farm exploitation should be based on economic studies.[23]

Regarding the scope and purpose of the working paper we followed the pragmatism as seen in (foreign) studies to give first indications of the economic impact (GVA) of offshore wind farms. A non-exhaustive inquiry was made on GVA/FTE indicators in relationship with offshore wind.[24] This inquiry gave directions for a best guess range for GVA/FTE to be used in this working paper (see table a).

Best guess range for GVA/FTE	Low GVA/direct FTE (€2020)	High GVA/direct FTE (€2020)
Construction phase	75,000	120,000
Operations & maintenance phase	110,000	170,000

Table a: Best guess range for GVA/FTE indicators for usage in Outlook 2050

Construction phase		First indications of an outlook regarding direct cumulative GVA for the construction of 43.5 GW (period 2030-2050)	
		Low (M€2020)	High (M€2020)
Supply	Supply employment not or hardly fulfilled by future Dutch supply chains looking at the current situation: nacelle, rotor, tower, and cable.	6,000	9,000
	Supply employment strongly fulfilled by future Dutch supply chains looking at the current situation: foundation supply, and substation supply.	3,500	6,000
	Subtotal	9,500	15,000
Installation: strongly fulfilled by future Dutch supply chains looking at the current situation.		1,200	2,000
Total direct GVA (cumulative)		**10,700**	**17,000**
Total direct GVA (average/year)		**540**	**850**
Direct GVA related to possible Dutch supply chain involvement (cumulative)		**4,700**	**8,000**
Direct GVA related to possible Dutch supply chain involvement (average/year)		**235**	**400**

Table b: First indication of an outlook on direct GVA related to the construction phase

[23] Taking into account e.g. annual energy production (current and future output), electricity prices (current and future developments), exploitation subsidies per kWh, and costs (and costs developments)

[24] E.g. SQWenergy (2010), CPL/PBL (2015), Regeneris (2015), EIB (2016), CBS (2017), Catapult (2018), PWC (2018), Biggar (2019), CBS (2019), PBL (2019), WUR (2019), and EirWind (2020).

O&M phase	Yearly direct GVA for O&M related to 43.5 GW (related to offshore wind farms installed during 2030-2050)	
	Low (M€$_{2020}$)	High (M€$_{2020}$)
O&M (total per year): strongly fulfilled by future Dutch supply chains looking at the current situation.	400	600

Table c: Indication of yearly direct GVA related to O&M

The tables b and c indicate the direct GVA based on the direct employment indications (paragraph 4.2) and the best guess GVA/FTE indicators (table a).

The total direct GVA (cumulative) for the construction of Dutch offshore wind farms (included employee categories: see appendix 2) over the period 2030-2050 is between €10 billion (low) and €17 billion (high). Roughly one-third of this direct employment-related gross value added could be related to Dutch supply chain involvement looking at the current Dutch supply chain constellation. The yearly direct GVA for the O&M of Dutch offshore wind farms constructed in the period of 2030-2050 will be between €400 million (low) and €600 million (high). This future O&M will be largely fulfilled by Dutch supply chains looking at the current situation.

Again, it should be noted that the figures in the tables b and c are first indications. In-depth analysis based on economic input-output models[25] are needed to generate more robust economic impact figures regarding the construction and O&M of offshore wind farms in the Dutch waters of the North Sea.

[25] See for example Connoly (2020).

APPENDIX 4: MODERN NACELLE ASSEMBLY FACILITY IN CUXHAVEN (GERMANY)

The assembly facility of Siemens Gamesa Renewable Energy (SGRE) in Cuxhaven (Germany) is an interesting source of inspiration. This factory (55,000 m^2; ceiling height of 32m) is active since 2018 and is able to assembly around 300 offshore wind turbine turbines per year (current status), including future turbine generations (with higher capacities) and a production increase to 400 turbines per year the coming years (De Vries, 2018; SGRE, 2020). The plant has all main necessary assembly operations under one roof: assembly, testing, and pre-commissioning of 1) nacelle back-ends, 2) generator integration, and 3) rotor-hub assemblies. The plant is located near the waterfront.

Production philosophy of SGRE is to industrialise all processes as much as possible and therefore the company closely studied truck manufacturing processes to look for similarities (De Vries, 2018). Examples are industrial robots, self-propelled modular transporters, and the advanced roll-on/roll-off (ro-ro) vessels for sea transport. Long-distance land transportation of large and heavy components to shipping/installation ports is eliminated due to the usage of ro-ro vessels, leading to more cost-efficient logistic processes (up to 20% cost reduction compared to traditional transport procedures). Currently more than 800 employees work at the Cuxhaven assembly facility.

SGRE has expressed that it will expand its global manufacturing network for offshore wind turbines, including a new combined plant for nacelles and blades in France. The nacelle assembly facility in Taiwan will be expanded to form a regional offshore wind nacelle industrial hub together with local suppliers. Specialisation in specific plants is a further option under consideration by SGRE (De Vries, 2020).