Sea Shepherd Australia
2 Ann Street
Williamstown VIC 3016
australia@seashepherd.org.au
Tel: 1300 623 267

Sea Shepherd Australia – Position on Offshore Wind Farm Development in Australia

Preamble

Installing offshore windfarms requires many high-impact procedures, which are often undertaken with little consideration of their effects on the delicately balanced ocean environment – on which over 3 billion people rely for their livelihoods.[i]

The marine realm is the largest component of the Earth's system that stabilizes climate and support life on Earth and human well-being. However, the First World Ocean Assessment released in 2016 found that much of the ocean is now seriously degraded, with changes and losses in the structure, function and benefits from marine systems. In addition, the impact of multiple stressors on the ocean is projected to increase as the human population grows towards the expected 9 billion by 2050.[ii]

This position paper has been developed in response to Australia's first proposed offshore wind farm development off the Gippsland coast of Eastern Victoria. The Star of the South project is billed as not only Australia's first of its type, but once completed, one of the largest offshore winds farms in the world.

Summary

- Sea Shepherd Australia (SSAU) supports the scientific consensus regarding the impacts of human-induced climate change; the outcomes of the Paris Agreement; and the need for a rapid transition from fossil fuels to energy generated from renewable sources.
- SSAU fully recognises the adverse impacts of climate change on our oceans and the marine life that inhabit them.
- SSAU believes that all creatures have the same rights to an intrinsic quality of life on our shared planet.
- SSAU recognises the rise of offshore wind as a renewable energy source, but believes this must not be at the expense of sustainability and protection of the surrounding marine environment.
- SSAU acknowledges that everything that humans do has an environmental footprint.
- SSAU understands that there are several methods of constructing offshore wind farms. Some methods are more destructive to the marine environment, while others are less.
- SSAU supports the methods of construction and operation of offshore wind farm that minimises adverse environmental impacts on marine life and birds, while at the same time provides local economic benefits.
- SSAU acknowledges that noise-intensive installation methods will harm marine life. In order to protect the surrounding marine environment of offshore wind farms, it is necessary to reduce this sound input into the ocean.
- SSAU acknowledges that it is more advantageous for marine life to avoid an impact than to minimise or mitigate it. SSAU therefore supports the use of "quiet foundation technologies" during construction of offshore wind farms, and opposes noisy construction methods such as pile-driving.
- SSAU supports the use of technologies that minimise the generation of carbon emissions from inspection and maintenance activities, such as robotics.

- SSAU believes that it is of utmost importance for effective mechanisms to be developed to assess the cumulative impacts of multiple offshore wind farms on the marine environment which have yet to be adequately determined.
- SSAU urges everyone involved in offshore wind developments to always take a precautionary approach when planning, constructing, operating and decommissioning offshore wind farms.
- **SSAU also recognises that some areas in our oceans are too sensitive for human development and should therefore not be considered for offshore wind production or development of any kind.**

Discussion

Our changing climate is one of the greatest planetary challenges currently being faced, and which impacts all species. A warmer earth will have devastating consequences for global ecosystems and their inhabitants (including human beings), as well as our infrastructure. Given that the oceans absorb over 90% of all of the excess heat that reaches the Earth's surface, the impact and consequences on our oceans and the marine life that inhabit them are huge.

A major step in mitigating "dangerous" human influence on the climate system is to change the world's energy production from fossil fuels to cleaner, renewable energy. Offshore wind power is a growing part of this shift since it can be one of the most reliable and environmentally friendly energy sources available. However, the demand for offshore wind energy must not be met at the expense of sustainability and protection of the surrounding marine environment and its inhabitants.

Offshore wind (OSW) energy is the use of 'wind farms' constructed in the ocean (traditionally on a shallow continental shelf) to harvest wind energy to generate electricity.

The world's first offshore wind turbine was commissioned in 1990 in Swedish waters. A year later the first offshore windfarm (Vindeby) was constructed off the coast of Denmark with eleven 450 kW turbines and with a total capacity of 4.95 MW. The offshore wind industry has continued to build on this technology which has led to Europe being the leader in offshore wind power with 84% of all installed capacity by the end of 2017 (18,814MW). By mid-2018 the USA had one 30MW grid connected offshore wind facility, but had 25,434MW in the 'project pipeline'.[iii]

At the end of 2020, the total worldwide offshore wind power capacity was 35.3 GW.[iv] United Kingdom (29%), China (28%) and Germany (22%) account for more than 75% of the global installed capacity. As of 2020, the 1.2 GW Hornsea Project One in the United Kingdom is the largest offshore wind farm in the world.[v] Other projects are in the planning stage, including Dogger Bank in the United Kingdom at 4.8 GW, and Greater Changhua in Taiwan at 2.4 GW.[4]

Spending on global offshore renewable energy infrastructure over the next ten years is expected to reach over AUD 22 billion.[vi]

Once operational, and notwithstanding inspection and maintenance activities, OSW power production emits no greenhouse gases – a major cause of global warming. It emits no air pollutants that cause acid rain; and no micro-particles, which cause cancer and respiratory diseases. It uses virtually no water and therefore reduces the threat to water security and, throughout its life cycle has one of the lowest CO_2 emissions of all energy sources.

However, as with all energy production, offshore wind power also affects the environment to some degree. It is therefore crucial to mitigate the negative impacts and conserve the marine ecosystem and biodiversity in areas where offshore wind power projects are planned or constructed.

Environmental impacts of offshore windfarms include destruction of the sea bottom impacting benthic communities, disruption of migrating species such as birds via barrier effects, and disturbance of sound-sensitive marine species through increased underwater noise.[vii]

According to Best and Halpin in their 2019 paper written for the US offshore wind development "market"[viii] overseas studies summarise impacts on wildlife in terms of a hazard-vulnerability-exposure model. Hazards, which are to be considered cumulatively, are considered in terms of:

- hazard intensity and phases of development (pre-construction, construction, operation, and decommissioning);
- vulnerability of species; and
- exposure in terms of space and time;

Impacts can be direct, that is, cause injuries and even mortality to marine animals. Impacts can also be indirect and influence individual behaviour so as to reduce the long-term success for the survival of affected species through, for example, forced movement out of foraging or reproductive areas.

Both direct and indirect impacts to the marine environment caused by acoustic noise generated during the construction of an OSW farm, especially due to pile driving, are among the greatest concerns (if not the greatest). For instance, disturbance of harbor porpoises in Germany was demonstrated to reach distances more than 25 km from the pile driving site.[ix] This will be discussed in more detail within this paper.

There are lesser concerns and scientific knowledge regarding possible impacts of the acoustic noise generated during the operation of an OSW farm, but since both phases generate large amount of acoustic energy which may negatively affect marine animals, both phases will be discussed.

Among other ecological issues, the underwater noise emissions have moved into focus, since the most offshore foundations are anchored in the seabed with the impact pile-driving procedure. This noise-intensive installation method leads to impulsive noise emissions (so- called pile-driving noise), which could harm the marine life[x]. For the environmentally sustainable use of renewable energy sources at sea, it is therefore necessary to reduce this sound input into the water.

Furthermore, the potential impacts of electromagnetic emissions and the possible impacts on birds and bats of wind turbines and their rotating blades during the operation of an OSW farm will be briefly discussed.

The introduction of Australia's first offshore windfarm has the potential to be a great contribution to Australia's transition to renewable energy, or a disaster to the marine environment. Constructed and operated with the wider view in mind, the latter may be avoided and can create a template for future Australian developments of this type.

Star of the South

The Star of the South (SOTS) is Australia's first offshore wind project, proposed to be located between 10 and 25 kilometres off the south coast of Gippsland, Victoria. It is a joint development by Australian founders and Copenhagen Infrastructure Partners (CIP) – a global entity specialising in offshore wind. If built, it would be one of the largest offshore wind farms in the world, supplying approximately 18% of Victoria's energy needs (approx. 8,000 GWh).

Although initial media reports indicated the project would comprise approximately 250 turbines, according to the company's Environmental Effects Statement (EES) referral comments, the project will comprise:

- Approximately 400 wind turbine generators[xi] (WTG) and offshore substations (OSS) in the ocean over an almost 500 km^2 licence area
- Subsea cables to transfer energy to the coast
- A transmission network of cables and substations connecting to the Latrobe Valley.

In addition, upgrades to ports to allow for construction and operation may be required.

Although the project has Victorian government support, it has been referred for the environmental assessment process which is expected to take 2-3 years. However, on 23 November 2021, a $43.1 million partnership between Star of the South and the Victorian Government was announced to progress key development activities and kick-start a local offshore wind industry.

Environmental Effects Statement (Preliminary marine ecology report)

The Star of the South Preliminary Marine Ecology Report was prepared by RPS Group (WA) on 31/3/2020 and submitted as part of the EES referral. The report considers marine and bird life that may be impacted by this project; lists their EPBC Act status (endangered / vulnerable); and determines a likelihood of their occurrence within the referral area. This assessment is based on a literature review and the advice of subject matter experts rather than a physical count.

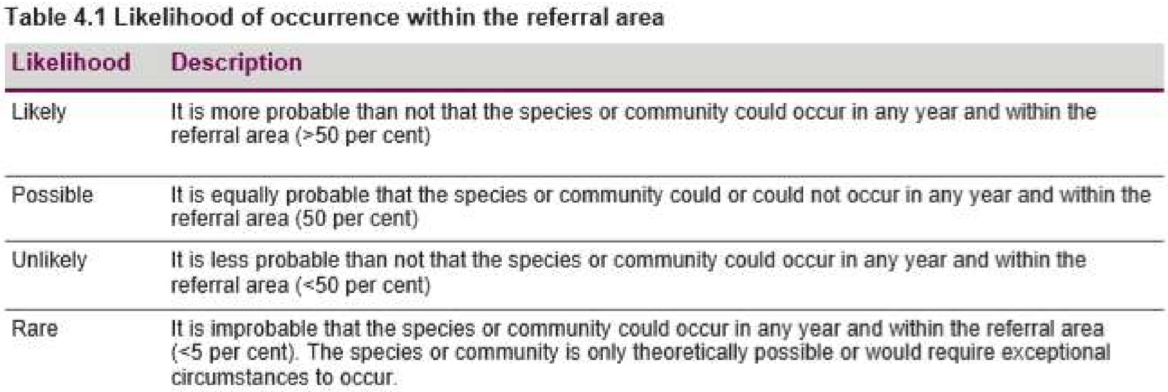


Table 4.1 Likelihood of occurrence within the referral area

Likelihood	Description
Likely	It is more probable than not that the species or community could occur in any year and within the referral area (>50 per cent)
Possible	It is equally probable that the species or community could or could not occur in any year and within the referral area (50 per cent)
Unlikely	It is less probable than not that the species or community could occur in any year and within the referral area (<50 per cent)
Rare	It is improbable that the species or community could occur in any year and within the referral area (<5 per cent). The species or community is only theoretically possible or would require exceptional circumstances to occur.

It also considers whether Biologically Important Areas (BIA) exist within the referral area for each species. BIAs are spatially defined areas where aggregations of individuals of a species are known to display biologically important behaviour such as breeding, foraging, resting or migration.[xii]

Fish

The most notable fish species present within the referral area is the white shark (*Carcharodon Carcharias*), which is "vulnerable", likely to be present and within a BIA.

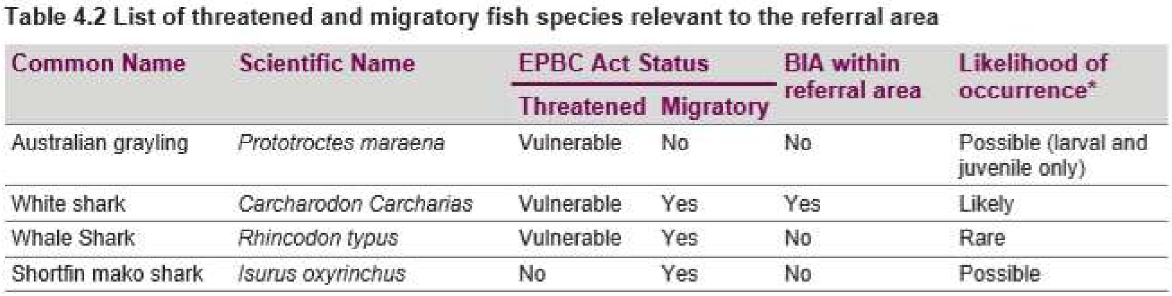


Table 4.2 List of threatened and migratory fish species relevant to the referral area

Common Name	Scientific Name	EPBC Act Status		BIA within referral area	Likelihood of occurrence*
		Threatened	Migratory		
Australian grayling	*Prototroctes maraena*	Vulnerable	No	No	Possible (larval and juvenile only)
White shark	*Carcharodon Carcharias*	Vulnerable	Yes	Yes	Likely
Whale Shark	*Rhincodon typus*	Vulnerable	Yes	No	Rare
Shortfin mako shark	*Isurus oxyrinchus*	No	Yes	No	Possible

Marine Mammals

The report identifies eight cetaceans (whales and dolphins) that may occur within or migrate through the referral area. Of those, five are classed as "endangered" or "vulnerable". Of these, three species of whale have a likelihood of occurrence within the referral area of "possible" (probability of 50%) or "likely" (probability greater than 50%) - Blue Whale (*Balaenoptera musculus*), Southern right whale (*Eubalaena australis*) and Humpback whale (*Megaptera novaeangiliae*). The Blue and Southern right whales are both "endangered" and the referral area constitutes a BIA. The likelihood of both in the area is "possible".

The Humpback whale is classified as "vulnerable" and its likelihood of occurrence is "likely"

Table 4.3 List of threatened and migratory marine mammal species relevant to the referral area

Common Name	Scientific Name	EPBC Act Status		BIA within referral area	Likelihood of occurrence*
		Threatened	Migratory		
Blue whale	*Balaenoptera musculus*	Endangered	Yes	Yes – possible foraging, migration	Possible
Southern right whale	*Eubalaena australis*	Endangered	Yes	Yes – migrating/ resting on migration	Possible
Humpback whale	*Megaptera novaeangliae*	Vulnerable	Yes	No	Likely

Although based on preliminary research, the results of this ecology report indicate significant marine activity in the referral area that may be impacted by the construction and operation of this project. Therefore, it is incumbent on the operator to ensure minimal impacts though the entire lifecycle of the project.

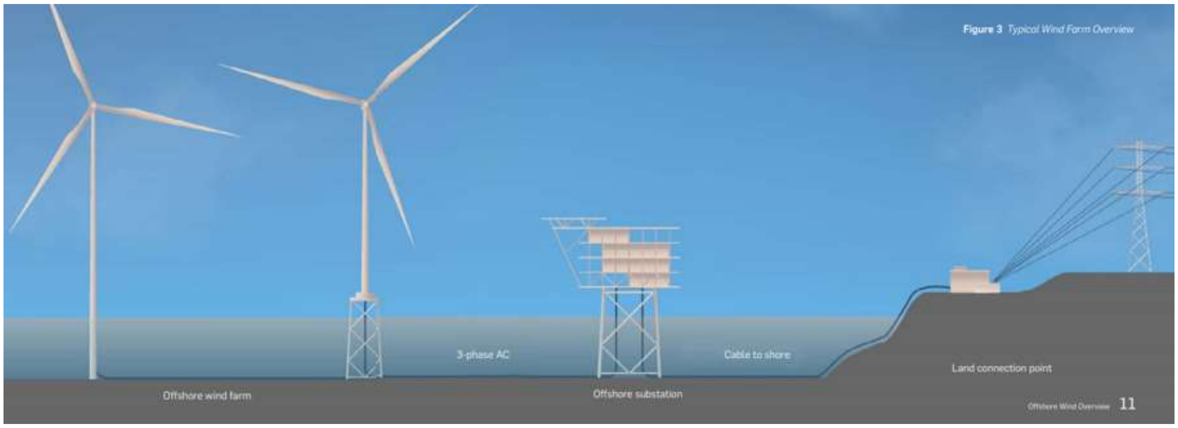
Birds

The report identifies 25 seabird species listed as “threatened” or “migratory” under the EPBC Act that may occur within the referral area. 21 are listed as threatened (four endangered and 17 vulnerable), and 18 are listed as migratory. The most notable of these were 14 types of albatross, petrels, terns and shearwaters.

An additional 54 species were listed as occurring within the referral area, including four critically endangered, three endangered and three vulnerable shorebirds.

Offshore Wind Infrastructure: Construction, Operation and Decommissioning

Offshore wind farms comprise the following infrastructure:
- Offshore electrical systems i.e. transmission systems
- Offshore and onshore cables, as well as offshore and onshore substations.
- Wind turbines
- Towers
- Foundations and substructures



From: Offshore Wind Handbook v2 2019 K&L Gates

All of the components of an OSW farm are important parts of the offshore wind infrastructure and all may impact both marine species and birds in various ways. However, this paper will focus mainly on foundations since they have the greatest impact on marine life. In addition, the impacts of electromagnetic emissions and subsea cabling will briefly be discussed as well as wind turbines impacts on birds and bats (noting that the presence of bats has not been identified within the Star of the South Preliminary Marine Ecology Report).

Offshore Transmission Systems

Offshore transmission systems are required to connect OSW farms to the onshore electrical systems in order to transport the energy generated at sea to the consumers at land. The offshore transmission system is made up of several components, including inter-array cables between devices (foundations and substations), submarine/export cables and onshore cables, offshore substations and onshore substations, i.e. connection points.

Offshore substations transform the collection voltage at the OSW farms into a transmission voltage suitable for long-distance transfer to onshore infrastructure. Hence, within the substations, transformers convert electricity from high voltages to lower voltages in order to deliver the electricity safely to consumers.

There are two different type of offshore export cable alternatives, HVAC transmissions (high voltage alternating current) and HVDC transmissions (high voltage direct current transmissions). The HVAC cables have limited range of about 100 km in point-to-point transmission due to losses in the transmission. The HVDC cables do not have this limitation since they avoid too large transmission losses at longer distances and they also have a large transmission capacity.

Since HVAC transmissions have so far been the most economical option due to lower substation costs and many of the current OSW farms have been close to the coast, this cable technology has commonly been used in OSW. With increased power rating and with OSW farms further away from shore, the use of HVDC cables are predicted to increase[xiii].

Both types of these high voltage cable alternatives emit a measurable electromagnetic field (EMF) around them, which has generated studies on the impact on fish and other marine species.[xiv] EMF concerns will be briefly discussed below in the following chapter; Operational Phase and Environmental Impacts.

Wind Turbines

Wind turbine generators (WTG) are larger than their onshore relatives and consist of several main components such as rotor blades and a nacelle which houses gears and a generator that connects the tower and rotor. Modern WTG come in various sizes and they all convert the wind's kinetic energy into mechanical power which is used to generate electricity by spinning the generator.

The first offshore WTGs had a capacity of 0.5 - 3 MW, with blades up to 35 - 50 metres long and with towers seated on concrete gravity foundations. Now many modern offshore WTGs have an 8 MW capacity, with blade lengths up to 80 meters and with towers commonly seated on steel monopile foundations of 7-10 meters diameter.[xv] The size and height seem to increase year by year, with 10 to 12 MW turbines under construction. WTG developers are taking even bolder steps to become competitive and new generation WTGs such as the Haliade-X offshore turbine (prototype) features a 13 MW and 14 MW capacity, 220-metre rotor, 107-metre blades, and digital capabilities.[xvi] Early 2021, the V236 – 15 MW turbine with 115.5 metre blades offering the largest swept area in the world was introduced. Each one of these enormous wind turbines is expected to deliver around 80 GWh of energy per year, depending on site-specific conditions, which would be enough to power 20,000 homes.[xvii] The steady increase of WTG sizes is expected to continue, with developers already planning for future 18-20 MW models.

The rapid advancement of the WTG technology with larger sizes and greater energy production capacity of the WTGs offers the potential to reduce the number of wind turbines deployed at OSW farms. However larger WTGs means that everything grows bigger, e.g. larger rotor blades with enormous swept areas and larger foundations which individually would have larger footprints on the seabed but together cover less area of the OSW farms.

All flying birds and bats may potentially collide with wind turbines, especially the moving rotor blades, which could cause injury or death. Barotrauma i.e. internal injuries caused by exposure to rapid pressure changes near the trailing edges of moving blades is another concern, especially for bats.[xviii] These concerns will briefly be discussed below in the following chapter – "Operational Phase and Environmental Impacts".

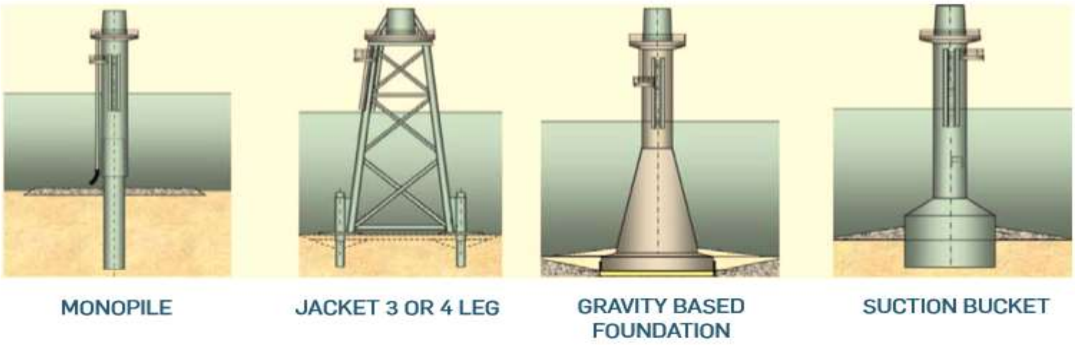
Foundations and Substructures

There are different types of OSW foundations and different methods to install them. Most types of foundations are fixed to the seabed, meanwhile floating foundation types have recently gained more and more attention. On top of the foundations, transition pieces, which carry the secondary steel elements i.e. platforms, boat landings and ladder are attached. The wind turbine tower is then bolted on the top flange to the transition piece.

Early design of OSW foundations drew from the experience within the offshore oil and gas industry; therefore, the majority of these early installations were founded on gravity base foundations. However, after gravity bases became too heavy for crane installation, monopiles became the prevailing foundation concept within the OSW industry. By 2015, monopiles comprised 70% of OSW foundations. This is reported as having increased to over 80% by 2020.[xix] This is an important factor as the piled foundation types have become the go-to methods for OSW developers, even though piling causes significant problems for the marine environment as discussed below in the following sub-chapter - “Construction Phase and Environmental Impacts”.

Methods of Foundation Construction

There are four generally recognised methods of “fixed bottom” foundations that rely on direct contact with the seabed: steel monopile, steel jacket, suction bucket and concrete gravity-based foundations.



Typical ‘fixed bottom’ foundation substructures.

Image from Offshore Wind Handbook Version 2 (2019), K&L Gates, SNC-Lavalin, Atkins

A fifth foundation method, floating wind turbines, is now on the verge of commercial maturity. Floating wind turbines have similar designs to floating oil and gas platforms. They are moored to the seabed with multiple mooring lines and anchors, thus presenting opportunities to install WTGs in deeper waters where fixed foundations are not feasible.

The world's first offshore wind farm using floating wind turbines, Hywind Scotland was commissioned in 2017. The farm has five 6 MW turbines moored in 95 - 120 metres of water with a total capacity of 30 MW. Prospective developments of floating wind turbines could be moored in water depths of approx. 1000 metres.[xx] The ability to install WTGs in deeper waters, where winds tend to be stronger and more consistent opens up large areas of the ocean for OSW developments with higher efficiency.

On one hand, floating wind technology presents new possibilities for reliable and clean energy production in areas of the ocean which otherwise might not be used for OSW developments. On the other hand, this added “industrial expansion” of the ocean might increase the risks to marine species whose dwindling living space will be further reduced.

Although negative impacts from floating wind turbines on marine species are speculative due to the technology's infancy stage, a few concerns will be highlighted. Floating turbines are secured to the seabed by mooring lines (normally by 8 long mooring lines) and anchors, as well inter-array power cables connecting the turbines to each other. These lines and cables may pose as an entanglement threat to wildlife, especially since marine debris such as discarded fishing gear could become ensnared in them, which consequently poses further entanglement risks. The power cables from the WTGs to the sea bed may also present an electromagnetic energy (EME) hazard (refer discussion on pp 15-16). Another possible threat is collision risks with the actual floating turbine both for marine species and birds[xxi] as well as collision risks with maintenance and construction vessels.

Although the global interest in floating offshore wind is growing, there are currently only a few floating wind turbines and mooring systems deployed. Since the technology is in its infancy and still have some major hurdles to overcome such as cost and design, floating offshore wind will be discounted from further consideration in this paper.

Foundation Installation Summary[xxii]

- Monopiles (up to 10-12 metres diameter) are driven into the sea bed using a hammer and anvil system before mounting transition pieces (if used) and feeding the cable into the foundation. This is done from specialised ships that would be transported half way around the world as these foundations are currently only manufactured in Europe.
- For jacket, pin piles are driven into the sea bed and the foundation lowered onto the pile heads and grouted into position. Alternatively, the jacket can be placed first and the piles driven through the pile sleeves. The remaining installation is similar to monopile foundations
- Concrete gravity foundations can weigh up to 5,000–10,000 tonnes. The foundation and tower are constructed on land and floated out to position before being sunk.
- Suction buckets are either built as a mono suction bucket (a monopile with a suction bucket at the bottom) or as a suction bucket jacket (jackets with suction buckets at the bottom of the pin piles).
- Offshore substation foundations may be installed in a similar way to turbine foundations but are significantly larger and resemble an oil rig in appearance.
- Cables are drawn from the sea bed through a J-tube into the foundation base to feed up to the wind turbine. This is not so for floating platforms as there is no foundation base – hence the possible additional EME hazard mentioned above.

Monopile

- Steel pile/cylinder driven i.e. hammered or vibrated 50-60 metres into the seabed.
- Suitable water depths: 5 to 45 metres.
- Installation generates potential harmful noise and ongoing vibration during operation.
- Noise mitigation measures available, e.g. bubble curtains, isolation casings, cofferdams and hydro sound dampers. Noise reduction of 10-20 dB SEL.
- Not well suited for certain soil conditions e.g. buried boulders, bedrock and certain chalks.

Jacket

- 3-4 pin piles per foundation driven 20-25 metres into the seabed.
- Suitable water depths: 20 to 80 metres
- Installation generates potential harmful noise albeit somewhat less than monopiles but during a longer period of time due to the 3-4 pin piles per jacket.
- Generates vibration during operation.

- Noise mitigation measures available e.g. bubble curtains,
- Similar soil suitability as monopiles.

Concrete Gravity foundation

- Concrete foundation that is steel reinforced. Placed on top of the seabed. Towed to the location and lowered down to the seabed.
- Suitable water depths: 20 to 80 metres
- Installation does not generate harmful piling noise.
- Not well suited for certain soil conditions e.g. more than 2 metres of thick layers of exceptionally weak soil – otherwise dredging would be required.

Suction Bucket

- Water is pumped out of the buckets, creating a pressure difference that forces the buckets into the seabed. A bucket is paired with a jacket or monopile substructure.
- Installation experience is limited within the OSW industry.
- Suitable water depths mono suction buckets: 20 to 50 metres
- Suitable water depths suction bucket jackets: 20 to 80 metres
- Installation does not generate potentially harmful piling noise.
- Not well suited at location with high seabed mobility, large sand waves or weak soil.

Most offshore foundations worldwide are anchored in the seabed via the impact pile-driving procedure with monopiles generally favoured up to 40 metres water depth, and jackets 30 – 60m. This noise-intensive installation method leads to impulsive noise emissions (so-called pile-driving noise), which are harmful to marine life. For truly environmentally sustainable use of renewable energy sources at sea, it is therefore necessary to reduce this sound input into the water.

Construction Phase and Environmental Impact

General Environmental Impacts of Construction

During the construction phase, temporary seabed disturbance and seafloor habitat destruction will take place. Sometimes preparational work e.g. levelling or dredging, might be required before the installation of the foundations. Transmission cables will generally be buried beneath the seafloor but they can also be laid on the surface of the seabed and be covered, e.g. by rocks so that they are protected from physical damage or do not create an obstacle[xxiii]. In order to bury the transmission cables, trenches have to be made in the sediment by water jets or by submarine ploughs.

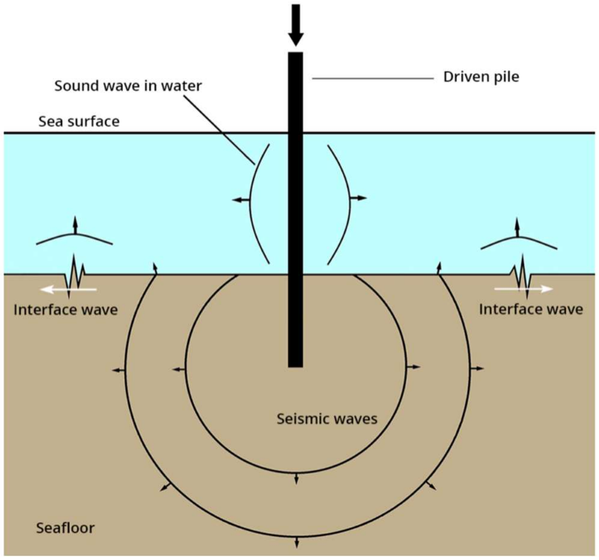
Trenching or digging or dredging the seafloor may cause turbidity and sediment suspension which increases the risk of contaminants being released and may smother or bury benthic animals, e.g. corals[xxiv] and sponges[xxv]. There are concerns that a reduction in visibility can also affect photosynthesis in algae and disrupt behaviours in marine animals. The overall function of the whole ecosystem may therefore be impacted due to the disturbance seabed caused by construction works. However, there are many variables that determine the severity and possible recovery of marine ecosystem after the work is completed. Some of these variants are the intensity, duration and frequency of the sediment disturbance, the sensitivity and health of the surrounding ecosystem, as well as the type of sediment, water exchange and currents in the area[xxvi]

During the construction phase there may be an increased collision risk for marine animals and heightened risk of pollution due the increased number of vessels involved in construction.

Noise Pollution – Construction phase

The key environmental concern during the construction phase is underwater noise pollution from the installation of the foundations i.e. acute anthropogenic noise created by pile driving. As stated above, most offshore wind turbines are currently installed on the seabed using monopile foundations. To support the wind turbines, monopiles – giant 50 - 80 meters steel tubes with a diameter that can be 10-12 metres and a weigh up to 1,300 tons – are hammered into the seabed.

The impulsive hammering during pile driving generates extremely high noise levels that propagate into the water and downward to the bottom (see figure; pile-driving). Piling noise can propagate very far and fast in water - about four times faster than in air due to the higher density of water. [xxvii] Already before the commencement of the OSW industry in the 1990s, studies about the impact on marine mammals from offshore oil and gas operations suggested that marine mammals may be expected to hear the anthropogenic sounds of offshore oil and gas operations out to distances as far as 100 nautical miles, and even further under highly favorable conditions.[xxviii] The installation of monopiles has moreover, shown to negatively affect the behaviour of marine mammals such as harbor porpoises at distances of at least 20-30 km i.e. 11-16 nautical miles.[xxix]



(Figure: pile-driving)[xxx]

The ocean is an acoustic world, where marine animals depend on sound for foraging, navigating, communicating, finding mates, raising their offspring, avoiding predators etc. The intense underwater sonic shockwaves from human development activities such as pile-driving may therefore pose a severe threat to the vital life functions of marine animals and the whole marine ecosystem. The adverse impacts of pile-driving on marine animals may be direct, causing tissue damage and injury including temporary hearing loss or permanent hearing impairment, and even death. The impacts may also be indirect, decreasing the chances of survival for individual animals as well as for the group as a whole, by causing behavioural changes such as forced movement out of foraging and reproductive areas, disorientation and negatively interfering with individuals' ability to communicate and feed.

Recent Australian research has shown that marine seismic surveys (although the noise output may differ from pile-driving it is still worth noting the effects) could cause a two to three-fold increase in mortality in zooplankton.[xxxi] This may have serious implications for the whole ocean since all marine animals rely on zooplankton as a source of food, either direct or through other food webs that rely on zooplankton.

Vulnerability to underwater noise and vibration varies significantly between different marine species, and their response to anthropogenic noise from construction depends on various factors such as life cycle stages e.g. spawning season and body sizes. Herring is one fish species that has been identified as particularly sensitive to noise. The herring population was observed to suffer significant decline over several seasons after the construction of the Scroby Sands OSW farm in the North Sea off the east coast of England.[xxxii] Two possible explanations have been suggested; direct mortality of the adult stock during pile driving, or displacement due to pile driving leading to long-term abandonment of the spawning area. The white shark, likely to be present in the Star of the South licence area, which possesses an inner ear and lateral line, is another fish that has been identified as sensitive to underwater vibrations and noise.

Even though there are no universally established maximum decibel levels of what harms and/or harasses and/or behaviourally affects marine species, there is a wealth of science showing that marine mammals (small cetaceans and large whales) respond, at least behaviourally, to received sound levels as low as 120-130 dB re 1μPa or less[xxxiii]. The North Atlantic Right Whale, which is the northern relative to the Southern Right Whale which may occur within the licence area of the Star of the South, shows negative behavioural responses such as reduction or cessation in feeding around 130 dB re 1μPa.
Another endangered whale occurring in the area, the blue whale, has been documented to alter its acoustic communication when exposed to seismic “sparkers” at 140 dB P-P (peak to peak) re 1μPa [xxxiv] and have ceased to call altogether when exposed to received sound levels at 143 dB P-P re 1μPa [xxxv]

Measured piling noise from European OSW farms exceeds above mentioned levels by far. The Belwind OW farm (Belgium), which used 5m diameter piles for 3 MW wind turbines, measured 196 dB SPL at 520 m distance. Gemini OSW park (Netherlands), which used 7m diameter piles for 4 MW wind turbines, measured 182 dB SEL at 732 m distance.[xxxvi] Since the decibel (dB) scale is logarithmic a 10 dB increase corresponds to a 10-fold increase in sound energy, which results in these noise levels being approx. 1,000,000 times more powerful than the potentially harmful 120-130 dB re 1μPa range. Furthermore, increasingly large turbine sizes and water depths will increase the sizes of the steel monopiles. The construction of enormous XXL monopiles will thus have implications for the noise radiated into the marine environment.[xxxvii]

Ways of reducing the amount of anthropogenic noise and the adverse impacts to marine ecosystems, might be achieved through noise mitigation/abatement measures and through the use of “quiet” foundation technologies where pile-driving is not required. Bubble curtains, isolation casings, cofferdams and hydro sound dampers are some of the noise mitigation measures for impact pile driving and with different noise reduction potentials existing between 10 to 20 dB.[xxxviii] ‘Quiet foundation’ technologies such as concrete gravity foundations and suction bucket foundations do not mitigate the negative impacts of pile driving - they eliminate the practice altogether and so completely avoid intense noise pollution.

Following the precautionary principle, Germany established in 2008 mandatory threshold values of 160 dB SEL/190 dB SPL at a distance of 750 m from the point of emission during underwater pile-driving works. In addition, the duration of the pile-driving works per monopile should not exceed 180 min and for Jacket-piles 140 min.[xxxix] These maximum noise levels and duration requirements during offshore construction, were put in place for the protection of the marine environment, especially the endangered harbour porpoise in the German North Sea. For commonly used piled foundations the mandatory threshold values can only be met by applying noise mitigation measures[xl] or using quiet foundation techniques. However, these threshold levels are not necessarily safe levels for surrounding marine animals and they may therefore be considered questionable compromises.

Since there is no evidence to suggest that marine animals will be safe during loud underwater noise activities such as piling, and as long as no safe levels have been established scientifically, a precautionary approach should be taken to avoid impulse noise emission during OSW construction.

Heavy Lift Vessel (HLV). A heavy lift crane vessel lifting monopile foundations into place. The HLV utilizes dynamic positioning rather than an anchoring system to hold its position during installation.

Image from Offshore Wind Handbook Version 2 (2019), K&L Gates, SNC-Lavalin, Atkins

Jack Up Vessel. A jack up rig or self-elevating until consisting of a buoyant hull fitted with a number of movable legs, capable of raising the hull over the sea surface. This allows transportation of the unit and all attached machinery to a desired location. Once the vessel is in place, it jacks its legs up to the required elevation above the sea surface supported by the sea bed. These are generally suitable for operations in depths of up to 40 metres.

Image from Offshore Wind Handbook Version 2 (2019), K&L Gates, SNC-Lavalin, Atkins

A concrete gravity-based foundation that has been constructed on land and being towed into place by commercial tug boats.

Image from Seatower AS - http://seatower.com/technology/

Operational Phase and Environmental Impacts

Biodiversity

The operational phase of an OSW farm might entail both positive and negative impacts on marine life and habitats. Introducing hard substructures into the sea might have the same effect as artificial reefs and can thus create biological hotspots. However, adding artificial substructures might attract new species, sometimes invasive, which could alter the local ecosystem and cause problems for indigenous species. This contraposition has been observed in OSW farms in Europe. Netherlands' first large scale OSW farm, Egmond aan Zee and its 36 wind turbines of a capacity 3 MW each, has been shown to act as a new type of habitat with a possibly increased use of the area by the benthos, fish, marine mammals and some bird species as well as a decreased use by several other bird species.[xli]

The same offshore wind farm showed in a survey between 2008 and 2011 that 9 non-indigenous species of which 8 invasive species, were found on the monopile foundations. One of the species, the Pacific oyster had even increased in abundance during the survey.[xlii]

OSW farms may also act as safe spaces for many commercially targeted species since fishermen tend to avoid OSW farms for fear of entanglement. In this way, an OSW farm has a potential benefit to increase the biodiversity and thus revitalise threatened ecosystems from the commercial fishing industry.

Noise pollution – Operational phase

The underwater operational noises by one or a few OSW turbines are relatively low and probably only faintly audible to many marine animals. However, there are concerns that marine species might be affected by the low frequency water-borne noises and vibrations emanating from 100s or 1000s of wind turbines in operation i.e. the park effect. This is an area of research that requires further work but a few highlights can be noted. Piled steel foundations are much more likely to act as underwater transmitters for noise and vibration from turbines trough the steel structures than concrete structures that have a greater mass and a dampening effect, since concrete absorbs much more vibrations than steel. Following the findings from the Royal Belgian Institute of Natural Sciences, wind turbines seated on concrete gravity foundations transmit up to 99% less noise to the underwater environment in comparison to wind turbines seated on steel foundations.[xliii]

Furthermore, anthropogenic noise from ship traffic in the OSW farm due to maintenance and repairs will be consistent throughout the operation. The strength of the noise and frequencies of these ships will vary depending on the vessels used. About 80% of the cost of maintaining OSW farms is spent on sending people to carry out inspections and repairs via helicopter, maintaining support vehicles, such as boats, and building offshore platforms to house turbine workers. All of these generate carbon emissions.[xliv] It has been suggested that a unified team of humans (working remotely), robots/unmanned aerial and underwater vehicles and AI working together could maintain this infrastructure with significantly less impact on the environment.[xlv]

Electromagnetic fields

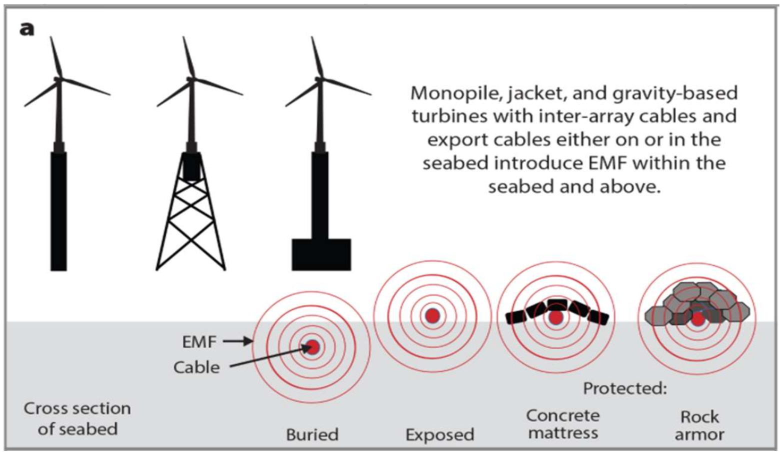
Electromagnetic fields (EMFs) include fields emitted from both electric and magnetic sources. EMFs are generated naturally (such as the Earth's magnetic field) as well as by human activities (anthropogenic EMFs). As stated above, OSW transmission systems, including inter-array cables between the foundations and substations, and export cables that transmit energy to shore, emit measurable EMFs during the operation of OSW farms.

It is only recently that potential ecological impacts from EMFs have started to become known, even though anthropogenic EMFs have been introduced into the marine environment from a wide variety of sources for over a century. For decades, power transmission cables have been installed across bays and river mouths, and connecting near-shore islands to the mainland, with little consideration of possible effects to marine species from EMFs.[xlvi] Since the OSW industry is expanding all around the world, including its commercial commencement in Australia, it is important that the knowledge gaps are addressed in order to move from understanding individual effects on marine animals to population-level impacts of anthropogenic EMFs.[xlvii]

Flynn[xlviii] states that spending on global offshore renewable energy infrastructure over the next ten years is expected to reach over US$16 billion and will involve creating an extra 2.5 million kilometres of global submarine cables by 2030.

Current OSW cables and the millions of kilometres of upcoming transmission cables present many known and unknown potential environmental effects. The EMFs emitted from these cables may affect marine organisms and species both behaviourally and physiologically, especially bottom-dwelling marine species. Magnetic fields are used for orientation and migration while electric fields allow fish to detect prey and predators which assists with feeding and predator avoidance.[xlix] Marine species' sensory abilities to use electric and magnetic cues in the essential aspects of their life and the potential disruption of these vital cues by EMFs from OSW transmission cables makes appropriate mitigation methods vital.

Since the transmission cables can be laid on the seabed with protection or be buried underneath the seafloor, which is the standard method of EMFs mitigation, possible impacts of EMFs on marine species may be mitigated to some degree (see figure a, below). Burial of the cables however, require dredging/ploughing of the seafloor in order to place them in trenches that in the end are covered by sediment, rocks or concrete "mattresses".[l] This process is highly disruptive to the marine ecosystem, especially benthic animals and organisms, as discussed in above chapter regarding construction impacts.



(Figure a: OSW cable-related anthropogenic EMFs)[li]

Technologies that minimise the impact on the burying of transmission cables are crucial, as well as mitigation of EMF transmission into the marine environment. Increased burial depth for transmission power cables, restrict/regulate over-tone emission and improve load balance on certain cables could be a few mitigation methods to EMF concerns. Importantly, a meshed offshore grid connecting offshore wind farms as well as electricity markets could provide significant environmental benefits and less cables emitting EMFs compared to the traditional point-to-point connection system current used in OSW.

In a 2014 study, the European Commission analyzed the benefits of the meshed offshore grid for the North Sea and concluded that a meshed grid would bring environmental benefits such e.g. less cabling.[lii] Less transmission cables means lesser marine areas affected by anthropogenic EMFs from the OSW farms. In 2020 it was concluded in the British National Grid study that a centralized grid approach, instead of the traditional developer-led point-to-point connections approach, could bring significant environmental and societal benefits, as the number of onshore and offshore assets, cables, and onshore landing points could be reduced by around 50%.[liii] These meshed grid systems would rely on the HVDC cable technology, which furthermore allows for greater flexibility of where landing points can be located and therefore offer greater potential to be located at less environmentally sensitive sites.[liv]

Impacts on Birds and Bats

One of the most significant environmental impacts of all wind energy production is the risk of birds colliding with wind turbine blades during operation.[lv] OSW farms can also pose as barriers for diurnal as well as long-distance bird migration and cause possible displacement due to behavioural including habitat changes. Another possible adverse impact is barotrauma, internal injuries caused by exposure to rapid pressure changes near the trailing edges of the moving wind blades. Contrastingly, OSW farms may sometime also bring potential benefits for birds and bats such as enhanced biological productivity inside the farm and resting areas for certain species.[lvi]

In relation to collision risks and possible collision mortality, there is accumulating evidence showing that there is a widespread avoidance of offshore wind turbines by many large-bodied birds – the knowledge about the behaviour of smaller birds and bats is less adequate. The largest to date empirical study on how birds behave within and around offshore wind farms in the UK, showed that seabirds avoid offshore wind turbines much more than previously predicted.[lvii] However, collision risks and collision mortalities by birds and bats are still serious OSW impacts, so deterrent and mitigation measures have been developed to reduce these risks. For example, simple cost-effective measures of "passive' visual cues may enhance the visibility of rotor blades enabling birds to take evasive action in due time. At the Norwegian Smøla wind-power plant the annual fatality rate was reduced at turbines with a painted dark blade by over 70%, relative to the neighboring unpainted control turbines.[lviii]

The Cattle Hill 144 MW Wind Farm is located on the southern side of the Central Plateau of Tasmania and comprises 48 wind turbines. In order to mitigate its impact on the endangered Tasmanian Wedge-tailed Eagle, the operator (Goldwind Australia) installed the IdentiFlight aerial monitoring and detection system.[lix] The technology uses tower-mounted optical units to detect flying objects, and then algorithms to identify them as eagles. The system then sends a signal to shut down any specific wind turbine, if an eagle's speed and flight path puts it on a collision path with that turbine. Sixteen of the units were to be installed and the location of the towers designed so they will be able to detect eagles and shut down any of the 48 turbines as necessary.[lx]

Similar deterrent and mitigation technologies should be considered for the Star of the South and other OSW projects inside and outside the Australian territory. Furthermore, more strategic national and international approaches to identify and assess e.g. population flyways, feeding distribution areas, cumulative impacts of multiple OSW farms should be developed in order to be able to select future OSW development sites, while at the same time ensuring a minimal risk to individual birds and bats, as well as whole populations.

Decommissioning Phase and Environmental Impact

The environmental aims when an OSW farm's life cycle reaches the end, should be to return the offshore site as close to its original state as is reasonably practicable and to sustainably deal with the basic components of the project i.e. turbines, foundations, cables etc. To reuse, preferred if possible, or at least recycle the components is an important environmental and sustainable issue during the decommissioning phase and ongoing afterwards. Another environmental aim during decommissioning, similar to the construction phase, is to minimise the impact of seabed disturbance and risks with increased vessel traffic including pollution and noise.

Several international and national regulations require some type of removal if feasible of disused infrastructure at the end of the life of a project. The OSPAR Decision 98/3 (1998), requires the removal of most offshore installations from the marine environment at the end of their useful life[lxi] in the OSPAR maritime area.[lxii]

In Australia, similar decommissioning requirements are included under subsection 572(3) of the Offshore Petroleum and Greenhouse Gas Act (2006), which require the titleholder to remove equipment and other property in their title area that is neither used, nor to be used for operations authorised by their title.

The Australian government are currently developing a regulatory framework for the development and generation of offshore wind power and has drawn on the rules that currently exist for offshore oil and gas explorations. In their 2020 discussion paper called, "Offshore clean energy infrastructure regulatory framework," it was suggested that the management plan includes a decommission plan and decommissioning bonds equal the amount it would cost government to decommission all infrastructure should the licence holder fail to meet its decommissioning obligations.[lxiii]

Even though decommissioning requirements are always present at the start of OSW projects, the decommissioning aspect has a limited attention in the design of the OSW foundations and due to financial discounting, only about 12% of the decommissioning costs are typically included in the project calculations[lxiv]. It is primarily the decommissioning of the OSW foundations that are of main concerns. The removal for the different OSW foundation technologies are discussed below.

Piled solutions:

There are two removal options for piled foundations after their lifespan of approx. 25 years. Either the complete foundations are removed, which is normally not an option, or the steel pipes are cut from a few meters below the mud line, approx. 3 metres, and left in the seabed. Extracting complete piles will require development of new tools and are costly operations. Piles are therefore normally removed by cutting, which leaves more than half of the steel embedded in the seabed, e.g. a monopile for an 8 MW turbine installed in water 25 meters deep is about 54 meters long, with about 29 metres embedded in the seabed. The detached part of both the monopile and jacket foundations can be recycled. The parts left in the seabed are lost resources.

Suction bucket foundations:

Suction bucket foundations (e.g. suction bucket jackets or mono suction buckets) are removed after their lifespan of approx. 25 years, by reversed installation. By pumping water into the buckets, the pressure will push the bucket out of the ground before the foundation is lifted to a transport vessel and transported to shore for disposal. The foundations can therefore be entirely removed and the steel can be recycled.

Gravity based foundations:

Gravity based foundations can be designed for a lifespan of 50 years or more[lxv], and there are two decommissioning options. One option is for the steel part on top to be removed for recycling, and the concrete foundation to be left so as not to disturb the marine habitat that will establish around and on the foundation. The other option is full removal, with no parts of the foundation left on the seabed.

Gravity based foundations are removed by reversed installation. The ballast material is pumped out of the foundations and the foundations are re-floated and towed to shore for reuse or recycling. The foundations can therefore be entirely removed and examples of reuse include, repowering with new turbines, use as mooring dolphins, unmanned lighthouses/navigational lighting, foundations for breakwaters, pedestrian bridges or piers (after recycling of steel sections), foundations for meteorology masts and artificial reefs.

The decommissioning of piled steel foundations in comparison to the decommissioning of 'the quiet foundations' (i.e. suction buckets and gravity base foundations) have larger environmental impacts on the marine environment, as well as being the less sustainable foundation choice.

Economic Opportunities

Over the last decade the European OSW industry has attracted average investments of €9.4bn (AUD15bn) per year, which is more than any other renewable technology in the region. Through these investments, a thriving industry had created 33,000 direct jobs and 140,00 indirect jobs in both the on- and offshore wind industry in Europe, by 2020.[lxvi]

While the majority of the infrastructure associated with offshore wind developments will be sourced from overseas specialised manufacturers, the big difference in job creation during construction of OSW foundations is driven by two factors:

1. Construction of gravity-based foundations takes place locally. Piles and jackets are fabricated in only a few locations around the world and exported to the site of installation. In general, few local jobs are created via pile and jacket foundations.
2. Concrete is more labour intensive; ie: there are much more jobs per dollar spent. With steel, more of each dollar pays for materials and equipment.

Furthermore, the fabrication of concrete gravity foundations can be performed in the same way as fabrication of buildings, bridges etc. Thus, the personnel and experience required for the fabrication is locally available and the foundations can thus give significant local content in form of labour and material supply.

While economic benefits are of minimal concern to SSAU, it would be incomplete not to present an additional compelling argument to support the use of gravity-based foundations.

Reduce Carbon Emissions and Ocean “Traffic’

In 2018, global shipping was reported to produce about 3 percent of the world’s carbon emissions, with a forecast increase of up to 250 percent by 2050. By avoiding the need to import steel foundations via multiple specialist ship transfers from halfway around the globe, significant carbon emissions are also avoided.

Conclusion

The introduction of Australia’s first offshore windfarm has the potential to be a great contribution to Australia’s transition to renewable energy, or a disaster to the marine environment. Constructed and operated with the wider view in mind, the latter may be avoided and this can be a template for future Australian developments of this type.

Sea Shepherd Australia is prepared to support the use of technologies and methods of construction and operation that avoid or at least minimise adverse impacts on marine life as well as birds and bats transiting the OSW areas. In particular, noise-intensive installation methods such as pile-driving must be avoided. Since it is more advantageous to avoid an impact than to try to minimise or mitigate it, Sea Shepherd Australia supports the use of gravity-based foundations. This foundation technology avoids noisy pile-driving altogether, while at the same time maximises local economic benefits.

During site selection, a precautionary approach must be taken when deciding whether the environmental risks are acceptable or not. The risks of an OSW project must always be regarded as not acceptable if they may adversely affect the population levels of species occurring or migrating through the proposed area. This is particularly so for nurseries and other sensitive marine locations. Hence, some areas of the oceans may not be suitable for any human development projects, due to specific sensitivity and/or importance for the life and survival of certain species.

Quantifying the impacts of a single wind project on marine and aviation animals is challenging. Understanding the cumulative impacts of multiple wind projects at full capacity, combined with other past, present, and reasonably foreseeable stressors operating over several decades is much more difficult. These cumulative impacts of multiple offshore windfarms have yet to be adequately determined. Given the number of offshore wind projects currently proposed in Australian waters, each of which would operate for 25+ years, developing effective mechanisms to deliver such assessments remains an urgent requirement for the immediate future.

Sea Shepherd Australia believes that it is possible to plan, construct, operate and decommission offshore wind farms without significantly damaging the marine environment, if the precautionary approach is always followed, including the use of the best environmental techniques and mitigation methods.

The oceans are the climate regulator of our planet. If the oceans die, we die, so let us make sure that offshore wind energy production is done in a sustainable manner that does not destroy the marine environment we all rely on.

Jeff Hansen
Managing Director
30 November 2021

About Sea Shepherd:

Sea Shepherd is an international, non-profit marine conservation organization that campaigns to defend, conserve and protect the world's oceans and the wildlife that inhabit them.

About the authors:

Katarina Halldén is a senior environmental advisor at Seatower AS and former research fellow and law lecturer at University of Copenhagen, Faculty of Law (Denmark). She holds a LL.B. degree from Queen Mary, University of London (U.K.) and a LL.M. degree from Raoul Wallenberg Institute/Lund University (Sweden). Katarina is an environmental activist and former crew member of Sea Shepherd.

Tony Smith OAM is a risk manager by profession. He holds Masters' degrees in Technology (Risk) Management (Swinburne) and OH&S (Newcastle), and is a Graduate Member Australian Institute of Company Directors. Tony is a director of Sea Shepherd Australia, and has a particular interest in the impacts of ocean warming on the marine environment. He completed global Climate Reality Leadership training in 2014, and advocates a risk-based approach to managing the effects of climate change while supporting rapid transition to a low carbon economy.

Glossary of Terms:

Bethnic species	Animals that live on the sea floor are called benthos. Most of these animals lack a backbone and are called invertebrates. Typical benthic invertebrates include sea anemones, sponges, corals, sea stars, sea urchins, worms, bivalves, crabs, and many more.
Capacity (or Installed Capacity)	The maximum instantaneous power that a power plant (wind farm) can produce, expressed in *megawatts*. The total electricity a plant can actually generate over a period of time is express in *megawatt hours*.
Decibels (dB)	A unit used to measure the intensity of a sound or the power level of an electrical signal by comparing it with a given level on a logarithmic scale. In general use: the degree of loudness. An increase of 3dB represents a doubling of the 'loudness'. An increase of 10dB represents a tenfold increase in the sound 'loudness'. 0.0 dB corresponds to about the normal threshold of hearing and 130 dB to the point where sound becomes painful to humans
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999. While the states have their own environmental protection legislation, the purpose of the EPBC Act is to focus Australian Government interests on the protection of matters of national environmental significance.
Megawatt (MW)	A unit for measuring power that is equivalent to one million watts.
Megawatt hour (Mwh)	Equal to 1,000 kilowatts of electricity used continuously for one hour.
Pelagic fish	Fish that live in the upper waters of open sea (as opposed to close to the bottom or near the shore). Example of pelagic fish are sharks, tuna, mackerel
SEL	Sound exposure level, expressed in dB re 1 $\mu Pa^2 s$. Can be given for both a single pulse, $SEL_{(ss)}$, and as a weighted mean over many pulses, $SEL_{(cum)}$.
SPL	Sound pressure level, expressed in dB re 1 µPa in water and dB re 20 µPa in air.

References (general):

Bergström L, et al (2014) Effects of offshore wind farms on marine wildlife—a generalized impact assessment. Environ. Res. Lett. 9 (2014) 034012 (12pp). Open Access IOP Publishing.

A guide to an Off-shore Wind Farms, BVG Associates. Crown Estate

Offshore Wind Handbook Version 2 (2019), K&L Gates, SNC-Lavalin, Atkins

Esteban MD, López-Gutiérrez J-S, Negro V (2019) Gravity-Based Foundations in the Offshore Wind Sector. Journal of Marine Science and Engineering

Halldén K (2019) Mitigating Environmental Impacts of Offshore Wind Power

Samson E (2020) Star of the South Marine Ecology Report. RPS Group EEN 19051.001

Endnotes:

---

[i] Flynn D, https://theconversation.com/how-robots-could-limit-the-environmental-impact-of-offshore-windfarms-161118 - accessed 21/5/2021

[ii] https://en.unesco.org/ocean-decade - accessed 8/8/2021

[iii] Best BD, Halpin PN (2019) Minimizing wildlife impacts for offshore wind energy development: Winning tradeoffs for seabirds in space and cetaceans in time. PLoS ONE 14(5): e0215722. https://doi.org/10.1371/journal. pone.0215722

[iv] Global Wind Report 2021. Global Wind Energy Council. 24 March 2021.

[v] Hornsea Project One - Fully Commissioned Offshore Wind Farm - United Kingdom | 4C Offshore". www.4coffshore.com.

[vi] Flynn, loc cit

[vii] Damian H-P, Merck T. Cumulative impacts of offshore windfarms. In: Agency FM and H, Safety FM for the E Nature Conservation and Nuclear, editors. Ecological Research at the Offshore Windfarm alpha ventus. Springer Fachmedien Wiesbaden; 2014. pp. 193–198. https://doi.org/10.1007/978-3-65802462-8_17

[viii] Best, Halpin, loc cit

[ix] Tougaard J, Carstensen J, Teilmann J, Skov H, Rasmussen P. Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (Phocoena phocoena (L.)). J Acoust Soc Am. 2009; 126: 11–14. https://doi.org/10.1121/1.3132523 PMID: 19603857

[x] Lucke et al., 2009

[xi] The final number of turbines will be driven by the size of the turbines selected at the time of construction to achieve the output required.

[xii] https://www.environment.gov.au/marine/marine-species/bias, Australian Government Department of Agriculture, Water and the Environment - accessed 01/07/2020.

[xiii] https://new.abb.com/news/detail/8270/hvdc-technology-for-offshore-wind-is-maturing - accessed 15/7/2021

[xiv] Loc cit

[xv] Bipin K. Gupta, Dipanjan Basu (2020) Offshore wind turbine monopile foundations: Design perspectives

[xvi] https://www.ge.com/renewableenergy/wind-energy/offshore-wind/haliade-x-offshore-turbine# - accessed 10/6/2021

[xvii] https://newatlas.com/energy/vestas-v236-15-mw-offshore-wind-turbine/ - accessed 27/7/2021

[xviii] Lawson, M., Jenne, D., Thresher, R., Houck, D., Wimsatt, J., Straw. B., (31 December 2020). An investigation into the potential for wind turbines to cause barotrauma in bats. https://doi.org/10.1371/journal.pone.0242485

[xix] Bipin et al, loc cit

Farr, H., Ruttenberg, B., Walter, R.K., Wang, Y., White, C., Potential environmental effects of deepwater floating offshore wind energy facilities, Ocean & Coastal Management, Volume 207, 2021

[xxi] Floating OSW farms will be installed farther away from shore where winds blow at a higher speed. Birds have shown a difference in their flight behaviours in faster-blowing speed which might lead to an increased risk of turbine collision.

[xxii] BVG Associates. A guide to an Off-shore Wind Farms, Crown Estate p 57

[xxiii] https://electrical-engineering-portal.com/installing-submarine-transmission-cable - accessed 20/6/2021

[xxiv] Erftemeijer, P.L.A., Riegl, B., Hoekserna, B.W., Todd, P.A., (September 2012) Environmental impacts of dredging and other sediment disturbannces on corals: A review, Marine Pollution Bulletin, Vol. 64, Issue 9, p. 1737-1765

[xxv] Schönberg C.H.L., (2016) Effects of dredging on filter feeder communities, with a focus on sponges. Report of Theme 6 - Project 6.1.1 prepared for the Dredging Science Node, Western Australian Marine Science Institution, Perth, Western Australia. 139 pp.

[xxvi] Hammar, L., Magnusson, M., Rosenberg, R., Granmo, Å. (2009). Miljöeffekter vid muddring och dumpning – En litteratursammanställning. Swedish Environmental Protection Agency, report 5999.

[xxvii] Andersson, M.H., Andersson, S., Ahlsén, J., Andersson, B.L., Hammar, J., Persson, L.K.G., Pihl, J.,Sigray,P., Wikström, A. A framework for regulating underwater noise during pile driving. A technical Vindval report, ISBN 978-91-620-6775-5, Swedish Environmental Protection Agency, Stockholm, Sweden (2016).

[xxviii] Gales, R.S., (1982) Effects of noise of offshore oil and gas operations on marine mammals: An introductory assessment, Volume 88 of Technical report (Naval ocean systems center (U.S.)), United States. Bureau of Land Management Naval Ocean Systems Center.

[xxix] Tougaard, J., Carstensen, J., Teilmann, J., Skov, H., Rasmussen, P., (2009) Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (Phocoena phocoena (L.)). The Journal of the Acoustical Society of America. 126. 11-4. 10.1121/1.3132523

[xxx] Sketch by Anthony D. Hawkins

[xxxi] McCauley, R.D., Day, R. Swadling, K.M., Fitzgibbon, Q., Watson, R. & Semmens, J.M., (2017) Widely used marine seismic survey air gun operations negatively impact zooplankton. Nature Ecology and Evolution. 1. 10.1038/s41559-017-0195.

[xxxii] Perrow MR, Gilroy JJ, Skeate ER, Tomlinson ML. Effects of the construction of Scroby Sands offshore wind farm on the prey base of Little tern Sternula albifrons at its most important UK colony. (2011) Marine pollution bulletin. 62. 1661-70.

[xxxiii] Observed in e.g. Blackwell SB, Nations C.S, McDonald T.L, Thode A.M, Mathias D, Kim K.H, et al. (2015) Effects of Airgun Sounds on Bowhead Whale Calling Rates: Evidence for Two Behavioral Thresholds. PLoS ONE 10(6): e0125720 (2015). Pirotta, E., Brookes, K.L., Graham, I.M. and Thompson, P.M., Variation in harbour porpoise activity in response to seismic survey noise, Biology Letters 10(5): 20131090 (2014). Miller, P.J.O., Johnson, M.P., Madsen, P.T., Biassoni, N., Quero, M. and Tyack, P.L., (2009). Using at-sea experiments to study the effects of airguns on the foraging behavior of sperm whales in the Gulf of Mexico, Deep-Sea Research I 56: 1168-1181

[xxxiv] Di Iorio, L., and Clark, C.W., (2010) Exposure to seismic survey alters blue whale acoustic communication, Biology Letter 6: pp. 51-54

[xxxv] McDonald, M.A., Hildebrand, J.A. and Webb, S.C., Blue and fin whales observed on a seafloor array in the Northeast Pacific, *J. Acoustical Soc'y of America* 98: 712-21 (1995).

[xxxvi] SEL stands for sound exposure level and is expressed in dB re 1 μPa^{2}s. Can be given for both single pulse, SEL$_{(ss)}$, and as a weighted mean over many pulses, SEL$_{(cum)}$. SPL stands for sound pressure level and it is expressed in dB re 1 μPa in water.

[xxxvii] Bellmann, M.A., Kühler, R., Matuschek, R., Müller, M., Betke, K., Schuckenbrock, J., Gündert, S., Remmers, P., (2018). Noise mitigation for large foundations (Monopile L & XL) - Technical options for

complying with noise limits, Noise mitigation for the construction of increasingly large offshore wind turbines, Berlin, Germany.

[xxxviii] Sven Koschinski, S. & Lüdemann, K., (March 2020). Noise mitigation for the construction of increasingly large offshore wind turbines. Technical options for complying with noise limits, Federal Agency for Nature Conservation (Bundesamt für Naturschutz, BfN), Isle of Vilm, Germany.

[xxxix] Bellmann M. A., Brinkmann J., May A., Wendt T., Gerlach S., Remmers P. (2020).Underwater noise during the impulse pile-driving procedure: Influencing factors on pile-driving noise and technical possibilities to comply with noise mitigation values. Supported by the *Federal Ministry for the Environment, Nature Conservation and Nuclear Safety* (*Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit* (BMU)), FKZ UM16 881500. Commissioned and managed by the *Federal Maritime and Hydrographic Agency* (*Bundesamt für Seeschifffahrt und Hydrographie* (BSH)), Order No. 10036866. Edited by the *itap GmbH*.

[xl] Koschinski, loc cit

[xli] Lindeboom, H., Kouwenhoven, H., Bergman, M., Bouma, S., Brasseur, S., Daan, R., Fijn, R., de Haan, D., Dirksen, S., Hal, R., Hille, R., Hille Ris Lambers, R., ter Hofstede, R., Krijgsveld, K., Leopold, M., Scheidat, M., (2011). Short-term ecological effects of an offshore wind farm in the Dutch coastal zone; a compilation. Environ. Res. Lett. 1341. 35101-13. 10.1088/1748-9326/6/3/035101

[xlii] Bouma, S. & Lengkeek, W., (6 February 2012). Benthic communities on hard substrates of the offshore wind farm Egmond aan Zee (OWEZ). Including results of samples collected in scour holes. Noordzewind, Report nr. OWEZ_R_266_T1_20120206_hard_substrate

[xliii] Norro, A, Rumes B, Degraer S. (2011). *Characterisation of the operational noise, generated by offshore wind farms in the Belgian part of the North Sea*, in: Degraer, S. *et al.* (Ed.) *Offshore wind farms in the Belgian part of the North Sea: Selected findings from the baseline and targeted monitoring.* pp. 17-26, Royal Belgian Institute of Natural Sciences. Brussels, Belgium

[xliv] Flynn, loc cit

[xlv] https://theconversation.com/how-robots-could-limit-the-environmental-impact-of-offshore-windfarms-161118 - accessed 01/06/2021

[xlvi] https://espis.boem.gov/final%20reports/5115.pdf - accessed 29/07/2021

[xlvii] Hutchison, Z.L., Secor, D.H., and A.B. Gill, A.B., (2020). The interaction between resource species and electromagnetic fields associated with electricity production by offshore wind farms. *Oceanography* 33(4):96–107, accessible at: https://doi.org/10.5670/oceanog.2020.409.

[xlviii] Flynn, loc cit

[xlix] Electromagnetic Field Effects on Marine Fishes in the Mid-Atlantic. Virginia Coastal Zone Management Program 2018.

[l] Press release: Study on subsea cable lifecycle published : EMEC: European Marine Energy Centre www.emec.org.uk - accessed 05/06/2021

[li] Artist interpretation of transmission cables and EMF, from Hutchison (2020), loc cit

[lii] European Commission, Study of the benefits of a meshed offshore grid in Northern seas region. Final Report (2014), availble at: https://ec.europa.eu/energy/sites/ener/files/documents/2014_nsog_report.pdf

[liii] Offshore Coordination Project, (2020) available at: https://www.nationalgrideso.com/document/177296/download

[liv] DNV, The Offshore Grid of the Future, available at: https://www.dnv.com/to2030/technology/the-offshore-grid-of-the-future.html

[lv] Skov, H., Heinänen, S., Norman, T., Ward, R., Méndez-Roldán, S., Ellis, I., (2018) OEJIP Bird Collision and Avoidance Study. Report by Offshore Renewables Joint Industry Programme (ORJIP). Report for Carbon Trust.

[lvi] WWF-Norway, Environmental Impacts of Offshore Wind Power Production in the North Sea, available at: https://www.wwf.no/assets/attachments/84-wwf_a4_report___havvindrapport.pdf

[lvii] Skov et al, loc sit

[lviii] May, R., Nygård, T., Falkdalen, U., Åström, J., Hamre, Ø., Stooke, B.G. (2020), Paint it black: Efficacy of increased wind turbine rotor blade visibility to reduce avian fatalities. Ecology and Evolution. 2020:00:1-9, https://doi.org/10.1002/ece.3.6592

[lix] https://reneweconomy.com.au/cattle-hill-wind-farm-set-to-test-new-eagle-protection-technology-95828/ - accessed 01/07/2020

[lx] https://www.goldwindaustralia.com/new-technology-trialed-protect-eagles-cattle-hill-wind-farm/ - accessed 01/07/2020

[lxi] Ministerial meeting of the OSPAR Commission, Sintra, 22-23 July 1998, Available at: https://www.ospar.org/documents?v=6875

[lxii] The Convention for the Protecting of the Marine Environment of the North-East Atlantic (OSPAR) regulates international cooperation on environmental protection in the North-East Atlantic. 15 European states and the European Union are contracting parties.

[lxiii] Australian Government, Department of Industry, Science, Energy and Resources. Offshore clean energy infrastructure regulatory framework. (January 2020). available at; https://consult.industry.gov.au/offshore-exploration/offshore-clean-energy-infrastructure/supporting_documents/offshorecleanenergyregulatoryframeworkdiscussionpaper.pdf

[lxiv] A typical discount rate used in offshore wind is 8% p.a. If you discount a cost that lies 27 years in the future by 8% p.a., the result is that you carry 12.5% of the cost in your NPV calculations. The formula is: 1 / (1+8%)^27 27 years is typical, as it accounts for 2 years construction time and 25 years of operations.

[lxv] The steel sections of the foundation are primarily dimensioned by fatigue loads in the material, while the concrete design is primarily governed by ultimate loads. If the lifespan of the foundations should be extended, the impact on the concrete parts would be limited (if any), while the steel structures would have to be redesigned.

[lxvi] The OSPAR Commission, Renewable Energy. Available at: https://www.ospar.org/work-areas/eiha/offshore-renewables