



POTENTIAL IMPACTS OF SOLAR, GEOTHERMAL AND OCEAN ENERGY ON HABITATS AND SPECIES PROTECTED UNDER THE BIRDS AND HABITATS DIRECTIVES

Final Report



September 2020



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INTRODUCTION

The development of renewable energy sources (RES) is crucial for achieving the EU's energy and climate targets. At the same time, such developments may give rise to conflicts with EU biodiversity goals, especially those related to nature conservation. With an aim to assist stakeholders in managing these potential trade-offs and to understand better the potential direct and indirect impacts that the different forms of renewable energy developments (wind, solar, ocean, geothermal energy and bioenergy) may have on habitats and species protected under the EU legislation and the ways of mitigating them, the European Commission has implemented the project titled "Reviewing and mitigating the impacts of renewable energy developments on habitats and species protected under Birds and Habitats Directives"¹.

This report aims to review the possible impacts of solar energy, ocean energy (tidal and wave) and geothermal energy to habitats and species protected under the Birds and Habitats Directives (2009/147/EC on the conservation of wild birds² and Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora Directive³) and to provide an analysis of the available mitigation strategies. It is the outcome of one of the 6 Tasks of the aforementioned project titled "Reviewing and mitigating the impacts of renewable energy developments on species and habitats protected under the Birds and Habitats Directives"⁴.

The EU has established ambitious targets to decarbonise the economies of Member States (MS) through a range of actions including the continued development of RES. The revised Renewable Energy Directive 2018/2001⁵, establishes an overall policy for the production and promotion of energy from RES. It requires the EU to achieve 32% of energy production from renewables by 2030. Through this, EU MSs have committed to specific renewable energy targets, adopted through national renewable energy action plans, and supported by a number of related policies and legal instruments.

Whilst hydropower, biofuels and wind energy dominate the renewable energy sector throughout most of Europe, a growing number of marine-based energy technologies are experiencing growth and development and are becoming the focus of new policy and legal frameworks. For example, the Blue Growth initiative (Innovation in the Blue Economy: realising the potential of our seas and oceans for jobs and growth - Corrigendum, 2014) highlights the role that ocean energy can have in the European energy mix, mirrored in the international arena (e.g. the 2030 Agenda for Sustainable Development (Resolution adopted by the General Assembly on 25 September 2015, 2015)). To ensure their sustainable

¹ https://ec.europa.eu/environment/nature/natura2000/management/natura_2000_and_renewable_energy_developments_en.htm

² Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds, OJ L 20, 26.1.2010, p. 7-25 (2010). Retrieved from <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009L0147>

³ Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora, OJ L 206/7 22.07.1992 (1992). Retrieved from <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31992L0043&from=EN>

⁴ https://ec.europa.eu/environment/nature/natura2000/management/natura_2000_and_renewable_energy_developments_en.htm

⁵ Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources, OJ L 328, 21.12.2018, p. 82-209 (2018). Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC

development in Europe, the Maritime Spatial Planning Directive 2014/89/EU⁶ aims to create a common framework to reduce conflicts between sectors and create synergies, encourage investment and cross-border cooperation, as well as preserving the environment, in line with protection measures required by the Marine Strategy Framework Directive (MSFD) 2008/56/EC⁷ or Water Framework Directive 2000/60/EC⁸. Solar energy, mainly through the use of PV, is also experiencing significant growth across MSs, driven by rapid technological progress, cost reductions and relatively short project development times. Geothermal energy remains a relatively small part of the overall renewable energy sector, although this too is experiencing considerable growth as a source of direct heating and cooling in urban areas.

In parallel, the European Union has adopted in December 2019 the European Green Deal⁹ which resets the Commission's commitment to tackling climate change and environmental related challenges. In 2011 an ambitious Biodiversity Strategy setting out specific targets and actions aiming to halt the loss of biodiversity and ecosystem services in the EU by 2020 was adopted. In May 2020, a new Biodiversity Strategy¹⁰ for the period after 2020 was adopted. In addition, the 7th Environment Action Programme, that entered into force in January 2014 and is guiding European environmental policy until 2020, identifies as one of its three key objectives the protection, conservation and enhancement of the EU's natural capital.

Cornerstones to EU's biodiversity policy, the Habitats 92/43/EEC¹¹ and Birds 2009/147/EC¹² Directives include strict legal provisions relating to the assessment of planned developments that have the potential to affect nature conservation interests of the Natura 2000 network. Both Directives aim to support the delivery of the EU Biodiversity Strategy, which aims to 'halting the loss of biodiversity and the degradation of ecosystem services in the EU by 2020 and restoring them in so far as feasible'. As recently a post-2020 EU biodiversity strategy has been adopted, this document looks to align with the 2030 SDGs, in particular Goal 14 ('Life below water') and 15 ('Life on land'), as the recognised basis for international biodiversity action to 2030.

Reconciling the two basic objectives to meet the need to reach 2030 targets for renewables whilst maintaining the integrity of the Natura 2000 network and meeting the need to reach the ambitious targets in the new Biodiversity Strategy 2030 on 30% of land and sea covered by protected areas, requires an understanding of the effects of the various technologies that

⁶ Directive 2014/89/EU of the European Parliament and of the council of 23 July 2014 establishing a framework for maritime spatial planning, OJ L 257/135 28.08.2014 (2014). Retrieved from <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0089&from=EN>

⁷ Directive 2008/56/EC of the European Parliament and of the council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive), OJ L 164/19 25.6.2008 (2008). Retrieved from <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0056&from=EN>

⁸ Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, OJ L 327, 22.12.2000, p. 1–73 (2000). Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0060>

⁹ https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

¹⁰ https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/actions-being-taken-eu/eu-biodiversity-strategy-2030_en

¹¹ <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:01992L0043-20130701>

¹² <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009L0147>

are available, and policy implementation at national levels to ensure that adverse effects on site integrity are avoided through avoidance, mitigation and, in rare cases, compensation.

An earlier study, undertaken for DG Environment in 2014 (Howes, Adriaenssens, Rizzi, & et al., 2014) summarised a literature review undertaken between December 2012 and June 2013 on the environmental impact of renewable energy sources (RES) in the European Union (EU). Although undertaken at a higher level than the current project, the study concluded that:

- solar power was of medium significance to biodiversity, while acknowledging that, at the time, little data was available on monitoring the effects of large-scale solar power plants;
- the impacts of both wave and tidal RES were of medium significance although, in both cases, the significance of cumulative effects was potentially high;
- the impacts of geothermal RES were of low significance to biodiversity, although construction impacts could be of medium significance if not appropriately mitigated.

This Task 3 report seeks to expand on the findings of the 2014 report, and to collate more recent available information on the present understanding of the impacts of solar, geothermal and ocean energy sources on the protected species and habitats under the EU Birds and Habitats Directives, and the measures that can be deployed to ensure their adequate protection.

The focus of this document is on the pre-construction, construction, operation and decommissioning of the electricity generating infrastructure only. Associated transmission infrastructure is covered by other relevant European Commission guidance¹³.

Each of the RES is discussed individually. First, the technical features of the different technologies are described which is essential to understand how impacts might be caused, in particular for innovative technologies where general knowledge amongst stakeholders is limited. Secondly, the likely evolution in the EU is presented. This is followed by a review of potential impacts on biodiversity (with a focus on species and habitats protected under the Birds and Habitats Directives), including theoretical impacts that may have been postulated in advance of evidence obtained through the monitoring of completed or in-construction projects. Additionally, a review is made of literature derived from such monitoring and an assessment is made as to whether earlier postulated impacts are likely to significantly affect EU protected species and habitats. Finally, a description of the possible mitigation measures to avoid or minimise such impacts are included.

¹³ Energy transmission infrastructure and EU Nature legislation, OJ C 213, 18.6.2018, p. 62-169 (2018). Retrieved from [https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1542188309010&uri=CELEX:52018XC0618\(02\)](https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1542188309010&uri=CELEX:52018XC0618(02))

METHODOLOGY

The literature review was conducted using a range of sources, including:

- published material in peer-reviewed and other published literature, obtained through internet searches including Google Scholar
- technical review of public-domain appropriate assessments (AA)¹⁴, or related screening exercises
- published outputs of any ecological monitoring work from in-construction or operational projects.

For each of the renewable energy sectors covered, literature was examined to determine the extent to which impacts to species and habitats protected under the Birds and the Habitats Directive might occur. It also examined the measures that have been taken to eliminate such impacts. The literature review primarily focused on EU cases. However, as there is very little experience with some innovative RES in the EU, impacts of such RES developments were examined in other parts of the world on similar species groups or families as those included in the EU Birds and Habitats Directives. For example, solar energy is a more mature RES in the United States, and lessons learned there had some relevance to the deployment of the technology in the EU.

For each form of renewable energy production that is covered, primary focus is given to birds, bats and marine mammals (where appropriate). However, where impacts on other species groups or sensitive habitat types are identified, and there is a reasonable likelihood of significant effects on the integrity of Natura 2000 sites or on Annex IV species, these are also documented.

Potential positive effects are also considered, such as habitat creation in former species-poor arable fields given over to solar PV developments or the creation of fishing exclusion areas in the vicinity of ocean energy projects.

¹⁴ For ocean energy, AAs for the MeyGen and Seagen projects were reviewed; for solar the AA of the Shotwick solar park (UK) was reviewed; for geothermal energy no AAs were found.

1 SOLAR ENERGY

1.1 Solar energy in the EU

Deployment of solar energy is widespread across Member States (MS) of the EU, accounting for 2.63% of EU gross renewable energy inland consumption in 2015. There is a great deal of variation between MS, dependent upon factors such as policy implementation, public perception, land availability, and resource availability. In 2017, solar power generation in Spain was dominated by concentrated solar power (CSP), which yielded 2.7 GW. CSP requires high intensity sunlight and low annual cloud cover rendering the majority of the EU unsuitable for its use. However, today - in the remainder of MS but also in Spain - PV generation is the most widely, and increasingly, deployed technology. Germany is the leading producer of PV energy, with an installed capacity of 42.9 GW in 2017, with Italy (19.3 GW) and the UK (12.6 GW) the next largest (Solar Power Europe, 2018).

A rapidly increasing market are floating solar PV panels. Thus far, the most paramount floating solar projects have been built in Asia. But also in Europe, countries have started to become increasingly interested in utilizing 'floatovoltaics' (Mesbahi, 2018). Most floating systems perform better than PV panels on land, because evaporating water keeps them cool and because decreased presence of dust (Nguyen, 2017). They are currently installed inland on for instance lakes and reservoirs, where they can produce renewable energy in areas where land is scarce. Recently, first ideas have been launched to establish marine solar farms, whether or not integrated with wind farms. Also in the EU, pilot projects are being set up. In the Netherlands for example, there are plans to turn an offshore seaweed farm into a floating solar farm by 2021. The project will begin with a test, namely a 30 m² solar farm about nine miles off the coast of the Hague. The farm will be positioned between two existing offshore wind turbines and connected to the same cables, meaning the project won't require any additional infrastructure (Thompson, 2018).

1.2 Technical features of solar energy

In general, solar energy technologies fall into two broad categories (Green Sarawak):

- photovoltaic cells (PV), converting sunlight into electric current;
- concentrating solar power (CSP), using reflective surfaces to focus sunlight into a beam to heat a working fluid in a receiver. This type of technology includes:
 - parabolic troughs (parabolic mirrors);
 - heliostat power towers (flat mirrors)
 - parabolic dish (bowl-shaped mirrors).

For each of these technologies, there are various design variations or different configurations, depending on whether thermal energy storage is included, and what methods are used to store the solar energy thermally.

1.2.1 Photovoltaic cells (PV) (International Finance Corporation, 2015)

Solar PV applications are usually ground-mounted, rooftop or (inland or offshore) floating. As rooftop systems generally have no impact on Natura 2000, we will not further discuss this technology.

Ground-mounted PV systems are generally large, utility-scale solar power plants. Their solar modules are held in place by racks or frames that are attached to ground based mounting supports.

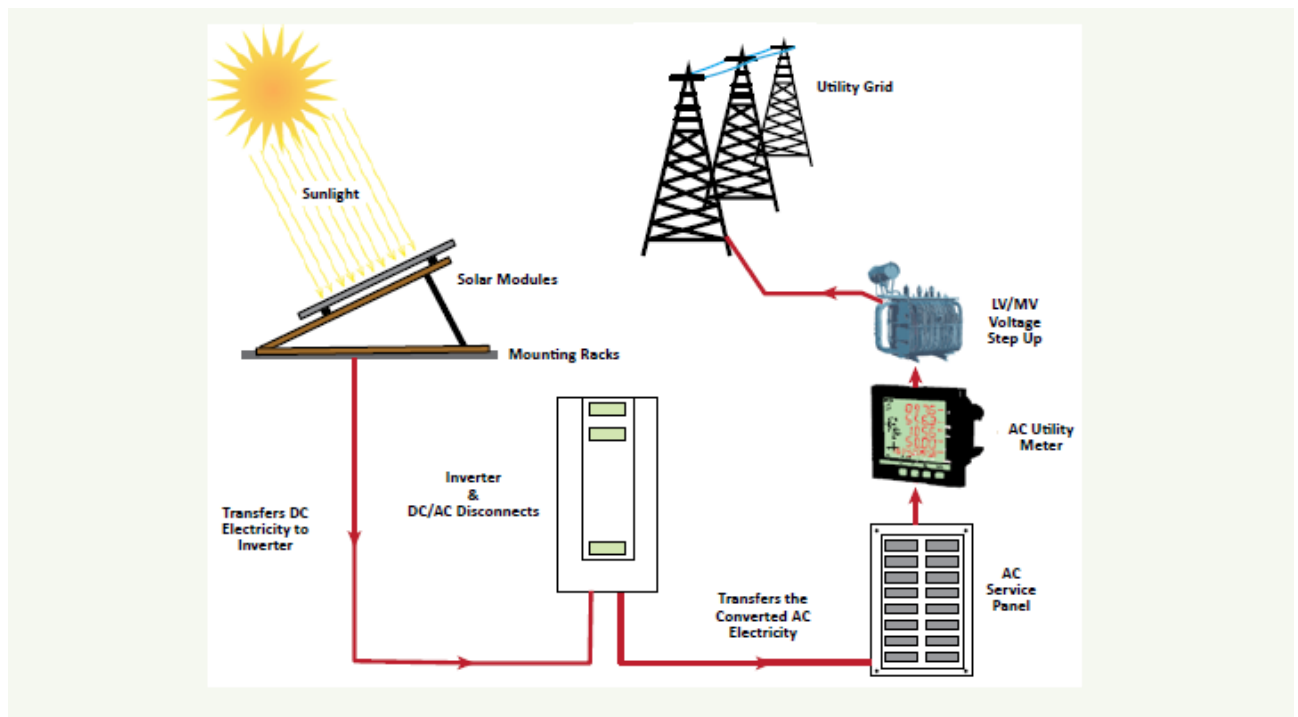


Figure 1: Overview of Solar PV Power Plant (International Finance Corporation, 2015)

Figure 1 gives an overview of a megawatt-scale grid-connected solar PV power plant. The main components include:

- Solar PV modules: the output from a PV cell is direct current (DC) electricity. Main PV technologies are crystalline silicon (c-Si) cells and thin-film cells. Research is mainly focused on either improving module efficiency or reducing manufacturing costs.
- Inverters: they convert DC electricity to alternating current (AC) for connection to the utility grid.
- Module mounting or tracking systems: these systems attach the PV modules to the ground at a fixed tilt angle or on sun-tracking frames.
- Step-up transformers: these transformers take the output from the inverters to the required grid voltage, depending on the grid connection point and country standard.
- Grid connection interface: where the electricity is exported into the grid network. The substation and metering point are often external to PV power plant and are typically located on the network operator's property.

Mounting structures are typically fabricated from steel or aluminium. Foundation options for ground-mounted PV systems include:

- Driven piles (see Figure 2): structural profile driven into the ground, low-cost and quick installation;

- Pre-cast concrete ballast (see Figure 3): low tolerance to uneven or sloping terrain, but easy to install and suitable for ground which is difficult to penetrate;
- Concrete piers cast in-situ (see Figure 4): for small systems, and with high tolerance to uneven and sloping terrain;
- Earth screws (see Figure 4): low-cost, and tolerant to uneven or sloping terrain.

These systems differ in their impact during construction, the ease of removal when the solar park is dismantled and design options (e.g. shade impact).

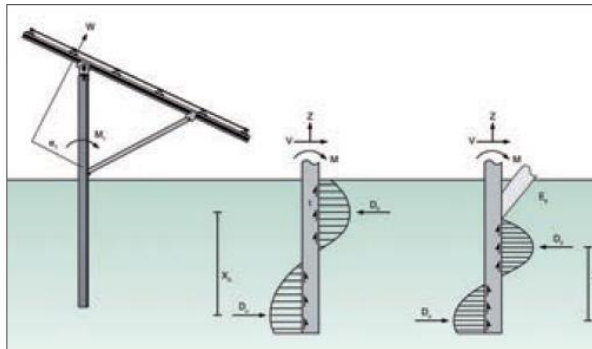


Figure 2: Driven-pile system (Schletter, n.d.)



Figure 3: Pre-cast concrete ballast systems (Schletter, n.d.)

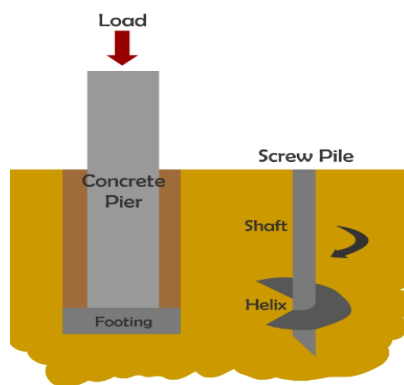


Figure 4: Concrete pier (left) and earth screw (right) system (Green Sarawak)

Floating solar PV systems consist of the following components (see Figure 5) (Nguyen, 2017):

- Floating platform: a floating body that allows the installation of the PV modules;
- Anchoring and mooring system: can adjust to water level fluctuations while maintaining its position in a southward direction;
- DC and AC cables: on the water surface lifted by buoys or submerged, transfers the generated power from land to the PV system;
- PV system: PV generation equipment, i.e. PV modules, inverter, controller, substation and distribution line.

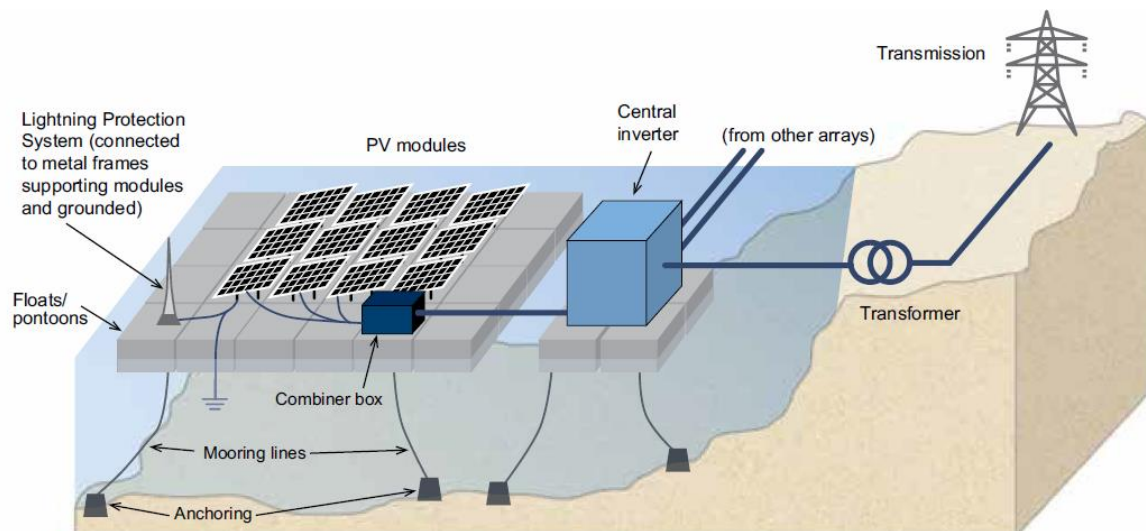


Figure 5: Schematic of a typical large-scale floating PV system with its key components (Source: Solar Energy Research Institute of Singapore (SERIS) at the National University of Singapore (NUS) (International Bank for Reconstruction and Development / The World Bank, 2018)

Floating solar PV systems generally have a higher energy output, ensure land conservation and increase water conservation by reduction of evaporation. Disadvantages include unstable power output due to more exposure to hydraulic and weather conditions, corrosion of modules and structures, and fishing and transportation activities may be affected.

Floating PV systems are mainly installed in Asia (e.g. Japan and China). In Europe, the technology is applied in a limited number of Member States, such as the UK, the Netherlands, Belgium, France and Germany.

Currently, floating PV systems are primarily designed for inland freshwater bodies. Innovative systems are being developed that can cope with the demands of oceanic environments. Off-shore systems need to withstand very challenging conditions, including movement and vibration caused by larger waves, salt water and electrical losses through long cable runs.

1.2.2 Concentrating solar power (CSP)

CSP systems produce electricity by focusing sunlight to heat a fluid. The fluid then boils water to create steam that spins a conventional turbine and generates electricity or it powers an engine that produces electricity. The following CSP systems can be distinguished (Mendelsohn, Lowder, & Canavan, 2012):

- Parabolic trough;
- Heliostat power tower;
- Parabolic dish;
- Other.

Parabolic trough

CSP trough (parabolic trough) systems are the most mature and commercially proven CSP technology. It includes the following components (see Figure 6) (Mendelsohn, Lowder, & Canavan, 2012):

- curved mirrors with sun-tracking, concentrating sunlight on thermally efficient receiver tubes or heat collection elements. A heat transfer fluid (HTF) circulates in the tubes absorbing the sun's heat;
- heat exchangers that produce steam from the heat collected by the HTF;
- conventional steam cycle turbine to generate electricity or a combined steam and gas turbine cycle;
- thermal energy storage, providing the ability to store thermal energy collected by a solar field in a reservoir for conversion to electricity at another time. Storage can be used to balance energy demand, so the turbine can operate at a fairly constant rate. Indirect systems, such as most CSP trough plants, use a separate HTF that passes through a heat exchanger to heat the storage medium. Direct systems use the same fluid, such as steam, for both the HFT and the storage fluid, eliminating the need for a heat exchanger.

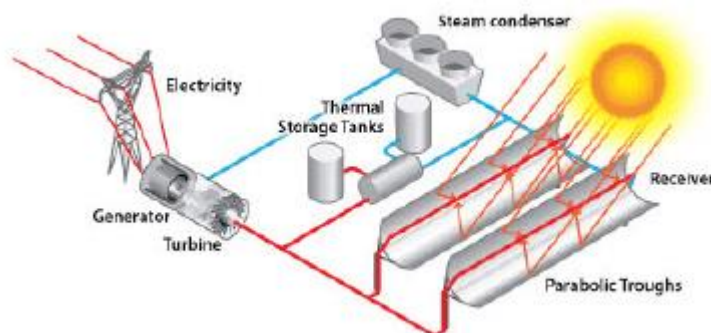
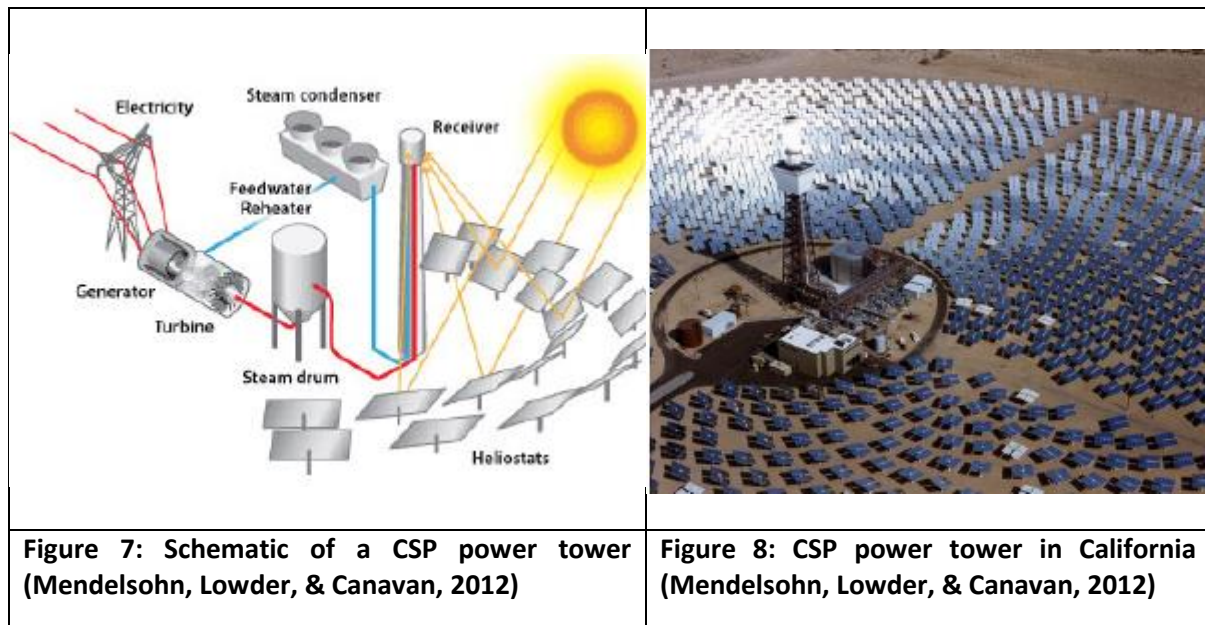


Figure 6: Schematic of a parabolic trough system (Mendelsohn, Lowder, & Canavan, 2012)

Heliostat power tower

CSP power systems (power towers or central receivers) use a field of mirrors called heliostats that individually track the sun on two axes and redirect sunlight to a receiver at the top of a tower (see Figure 7 and Figure 8). Various HTFs are used, including steam, air and molten nitrate salts. (Mendelsohn, Lowder, & Canavan, 2012)



Parabolic dish

Parabolic dish systems are individual units comprised of a solar concentrator, a receiver, and an engine or generator (see Figure 9). The concentrator typically consists of multiple mirror facets that form a parabolic dish, which tracks the sun on two axes and redirects solar radiation on a receiver. The receiver is mounted on an arm at the focal point of the reflectors and contains a motor-generator combination that operates using either a Stirling engine or a small gas turbine. Conversion efficiency of this technology is higher than that of other CSP technologies. Another advantage of parabolic dish technology is that only small quantities of water are used, mostly for washing concentrators free of dust (Mendelsohn, Lowder, & Canavan, 2012).

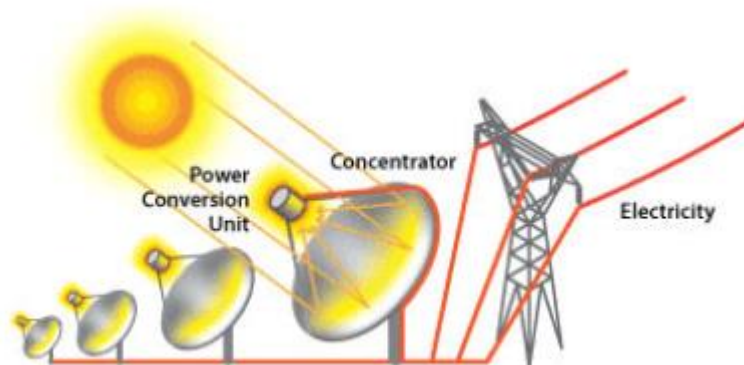


Figure 9: Schematic of a parabolic dish system (Mendelsohn, Lowder, & Canavan, 2012)

Other

Other CSP technologies include Linear Fresnel reflector systems (made up of (nearly-) flat mirrors arrays) and solar-fossil hybrid power systems (combining solar collecting fields with fossil fuel combustion).

Steam-driven CSP plants require a consistent source of fresh water. Water consumption is primarily connected to the cooling system. The three most common cooling systems are (Mendelsohn, Lowder, & Canavan, 2012):

- open loop: pulls heat from the power plant by withdrawing large quantities of water from rivers and other sources, and returning the warm water to its source;
- closed loop: cools and recirculates water within the power plant. During the cooling process water is lost via evaporation;
- dry cooling or air cooling: uses air to condense heat and cool power plants. These systems have minimal water requirements and can generally be used in all steam cycle power plant technologies. But this system is more expensive and can lower the efficiency and output of the power plant.

1.3 Possible impacts of solar energy and mitigation measures

The majority of PV deployment is ground-based giving rise to several concerns over potential impacts. The stakeholder consultation carried out under Task 1 has revealed a good overview of the potential impacts of solar farms on BHD species and habitats (see Table 1). Most literature, however, still shows a lack of data to analyse the possible effects of solar farms on biodiversity. There is a need for more research on the most preferable technical solutions (e.g. the height of panels, orientation etc.) and on regular maintenance measures of the habitat under the PV cells (e.g. grazing, moving etc.). Section 1.3.1 provides more detail on the possible impact of ground-mounted solar parks on protected species and habitats under the Birds and Habitats Directives.

With regard to the impacts of floating solar panels, literature is scarce. It is generally stated that environmental impact is low and does not impair the cleanliness of water. Section 1.3.2 deals with the potential impact of floating solar parks on biodiversity.

It is widely acknowledged that rooftop-based installations have negligible effects on biodiversity and may even have beneficial effects if combined with green roofs (Gasparatos, Doll, Esteban, Ahmed, & Olang, 2017). Therefore, we will not further discuss this type of solar panels.

Table 1: Overview of potential impacts of onshore solar farms

Impact groups (C: construction / O: operation / D: decommissioning)	Affected species and habitats
Habitat loss and degradation (C), including soil compaction, surface etc.	Dependent on location: birds, bats, mammals, reptiles, amphibians, fish (inland lakes), invertebrates
Fragmentation (e.g. fencing) (C, O)	Mammals, reptiles, amphibians
Disturbance and displacement (C, O, D), e.g. by light (during the night), human presence	Birds, bats, mammals, invertebrates
Collision (O)	Birds, bats, invertebrates
Singeing (O)	Birds, invertebrates
Altered microclimate (O)	Vegetation, invertebrates
Increased use of herbicides (O)	Vegetation, invertebrates, ground-nesting bird species
Attraction of invertebrates (O) (e.g. insects like water beetles that confuse panels with water)	Birds, bats (increase availability of prey), invertebrates
Habitat creation e.g. by increasing groundwater level, by extensive management of flower strips, etc. (O)	Potential positive impacts on several fauna groups and habitat types, depending on location and type of measures

1.3.1 Ground-mounted solar parcs (PV and CSP)

Habitat loss and degradation

Turney and Fthanakis (Turney & Fthanakis, 2011) assert that the major impact to species and habitats from large-scale solar parks is due to direct land occupancy of the plant itself. Hernandez *et al.* (Hernandez, et al., 2014) highlight that this can vary considerably with land-use efficiency (including the spacing and layout of panels), footprint and infrastructural design. Solar sites occupy relatively large areas, but the impact on biodiversity will obviously depend on the type of land occupied. Feedback from the stakeholder consultation under the project “Reviewing and mitigating the impacts of renewable energy developments on habitats and species protected under Birds and Habitats Directives” has revealed that extensive agricultural land, valuable grasslands and steppic habitats are particularly vulnerable habitats as these are often considered for solar farm deployment i.a. in the south of Europe, due to the lower economic value of these type of lands and their better accessibility. These habitats often shelter important populations of EU protected bird species, such as Great Bustard, Imperial Eagle, Black Bellied Sandgrouse, Montagu’s Harrier and Calandra Lark and are also the ultimate refuge of EU threatened species like the Little Bustard, the Dupont’s Lark, the Black Bellied Sandgrouse and the Pin-tailed Sandgrouse. These species already suffer a sharp decline due to wide habitat transformation caused by changes in agricultural management.

Habitats transformed into solar farms will suffer from a wide range of impacts such as reduced vegetative cover, compaction of soil, reduced infiltration, increased runoff, decreased soil activity, decreased soil organic matter, and impaired water quality (New Jersey Department of Environmental Protection, 2017). An important impact of ground-mounted solar installations occurs when all natural habitat in the vicinity is cleared, stripping vegetation (Hernandez, et al., 2014). This practice has for instance been documented for desert CSP sites in California, where vegetation is frequently removed, soils are scraped and the ground levelled (Gasparatos, Doll, Esteban, Ahmed, & Olang, 2017). This may be due to the need for the heliostats to be positioned with high degree of accuracy and to be able to track the sun’s movement without hindrance by vegetation. No evidence from literature was found for this

practice in Europe. Furthermore, construction actions (e.g. earth movements and clearings) could also create an appropriate habitat for invasive alien species.

Habitat degradation is also caused by a changing microclimate. PV panels will cause shading, alter temperature and change rainfall distribution (with impacts on soil moisture) and will therefore change microclimate (Armstrong, Ostle, & Whitaker, 2016) (Elamri, Cheviron, Mange, Dejean, & Liron, 2018) (Klaassen, et al., 2018) (Beatty, Macknick, McCall, Braus, & Buckner, 2017). When no light or rain reaches the soil, it will degrade and no vegetation will be able to develop (Lovich & Ennen, 2011). Much will depend on park design (distance between panels and arrays, the angle of panels, the use of fixed versus tracking systems, the height of the panels, orientation, etc.). See Figure 10 for the difference in shading depending on the orientation of arrays. Fixed panel arrays are usually oriented in east to west rows and are spaced to maximum interception of direct sunlight. Often distance between the array lines is very little, which prevents sunlight from reaching the vegetation and soil. Tracking arrays can be placed north to south, with the panels daily following the sun east to west. Another disadvantage of fixed panels is that they redirect all collected rain water towards a narrow outlet on the width of the panels. Under the panels, soil risks to be compacted with crust formation. Tracking arrays have a tilting angle varying in time, and they can even be “controlled” and tilted in order to have rain interception minimized during rain events (Mendelsohn, Lowder, & Canavan, 2012).

It should be noted though that shading in some regions can have beneficial effects for some shade-tolerant plants. Moreover, in some countries, solar parks are combined with agricultural land (“agrophotovoltaics”), e.g. in the US, Germany, China, Croatia, Italy, Japan and France (Jossi, 2018). This dual-use of land demonstrates that a smart design/configuration of the solar park can allow for a successful revegetation of the site.



Figure 10: Fixed panel photovoltaic array arranged in east-west rows, maximizing shading effects versus solar tracker arrays arranged in north-south rows that allow sun to reach the ground (right) (Beatty, Macknick, McCall, Braus, & Buckner, 2017)

Habitat fragmentation

Solar parks usually have a considerable size, consist of open habitats with no trees or shrubs and are fenced-off. This makes solar PV parks cause habitat fragmentation and isolation for different species (i.a. farmland birds). Barriers for wildlife may lead to a depletion of feeding and resting places and genetic isolation of metapopulations (Lovich & Ennen, 2011).

Collision and disturbance

Apart from habitat loss and habitat fragmentation, solar parks can also have direct mortality impacts on wildlife and insects.

Birds

A limited number of studies on the collision impact on birds with solar PV panels is available. Birds can collide with any fixed object, so also PV panels and fences of the solar park. But in general, there is little scientific evidence that demonstrates a significant impact of solar PV on birds (Harrison, Lloyd, & Field, 2017) (Feltwell, 2013). More studies are available on collision impact of CSP sites. Between April 1982 and May 1983, McCrary et al. conducted a systematic study of wildlife casualties at an early CSP installation in southern California, sited in the near vicinity of extensive ponds and agricultural fields. It was concluded that 60 birds may have died as a result of the operation of the CSP site, of which six were incinerated. The remaining fatalities were concluded to have resulted from collision with plant structures and especially the heliostat mirrors. In a more recent study, Kagan *et al.* (Kagan, Viner, Trail, & Espinosa, 2014) studied bird mortality at three solar energy facilities in southern California, namely one PV site and two CSP sites, i.e. one trough systems with parabolic mirrors and one power tower. Most mortalities were found for the power tower, the least with the trough system. Next to trauma, solar flux injury (singeing) was found for the power tower. Trauma took two forms: impact trauma resulting from collision; and predation trauma, where birds collide, are injured and become vulnerable to predation. At the power tower site, severe singeing led to catastrophic loss of flying ability leading to impact with the ground or other structures; while less severe singeing led to flight impairment and a vulnerability to predation and starvation. The remains of 71 different species were examined, ranging from humming birds to pelicans, occupying a broad range of ecological niches, from aerial feeders such as swallows, to aquatic feeders including grebes, and raptors.

Bats

Literature on the collision of bats in solar parks is very scarce. Montag *et al.* (Montag, Parker, & Clarkson, 2016) examined the effects of solar parks on bats and found no statistically significant difference in bat species composition passes between PV sites and control sites in southern UK. However, they found a significantly higher level of bat activity over the control sites than over the PV sites, speculating that this may be due to the difficulty bats have in discerning the artificially smooth surfaces of solar panels. Kagan *et al.* (Kagan, Viner, Trail, & Espinosa, 2014) incidentally reported nineteen bat carcasses recovered from the CSP power tower facility, but found no evidence to support the proposition that solar PV arrays cause fatalities in bats. Potential concerns relate primarily to two factors: the extent to which bats may be drawn to PV arrays by the presence of polarotectic insects (see below) and therefore

be at risk of collision while foraging low over the panels; and the possibility that bats may mistake the smooth panels for water and collide while attempting to drink. Greif and Seimers (Greif & Siemers, Innate recognition of water bodies in echolocating bats., 2010) examined the ability of bats to discriminate between water and a series of horizontally-placed artificial plates. All of the bats attempted to drink from the smooth plates of all three materials, and none from the textured plates. Critically, none of the bats collided with any of the plates to the extent of causing injury. In a further study, Greif *et al.* (Greif, Zsebok, & Siemers, Acoustic mirrors as sensory traps for bats, 2017) found that bats did collide with vertically-placed reflective sheets, both in laboratory and natural conditions. Although no casualties were found, the authors suggested that smooth, vertical surfaces should be avoided at crucial sites such as migratory highways, key foraging habitats, or bat colonies. It is possible, therefore, that further research is required where solar panels are arranged at steeper angles.

Other species

Polarotectic insects are those that are attracted to polarised, reflected light, for example, from water. Horvath *et al.* (Horvath, et al., 2010) indicate that insects that lay eggs in water are especially attracted to artificial structures such as buildings with glass surfaces and solar panels because they reflect horizontally polarised light and thus resemble water surfaces that are used as egg laying sites. They found that solar panels reflect significantly more horizontally polarised light than water bodies. Mayflies, stoneflies, dolichopodid and tabanid flies were most attracted to solar panels and exhibited oviposition behaviour above solar panels more often than above water. However, they tended to avoid solar panels with white borders and white grid patterns. The authors suggest that, where positioned close to water, solar panels without such white patterns may act as ecological 'traps' that can lead to reproductive failure and rapid population declines.

The potential death of polarotectic insects when they collide with PV cells that have been warmed up during operation, and the impact of the alteration on the microclimate on invertebrates should also be considered.

Cumulative impact

A solar energy development plan or project can act in combination with other plans and projects resulting in cumulative effects on EU protected habitats or species. Cumulative environmental effects can be defined as effects on the environment which are caused by the combined results of past, current and future activities. Although effects of one development may not be significant, the combined effects of several developments together can be significant. Cumulative effects are a particular and crucial aspect of a credible impact assessment process. Cumulative effects are very relevant in the case of solar energy deployment. There is for instance a risk that large PV arrays may be clustered together due to limitations of location choices in terms of climate, topography, access, existing land uses, etc. While each solar farm may be of little risk to wildlife individually, this clustering could potentially give rise to significant cumulative environmental impacts (BirdLife Europe, 2011). This risk might increase given the continuously growing number of applications for solar energy production and expected increase in capacity over the coming years.

Assessing cumulative effects is perceived as a major challenge by most stakeholders. The main reason is the lack of solid methodological guidance, despite the fact that the assessment of cumulative effects of plans and projects is a requirement of the SEA Directive, EIA Directive

(Annex III and IV) and Article 6(3) of the Habitats Directive. The main challenges relating to wind energy might apply to solar energy too:

- There is general confusion with regard to scoping the activities that have to be considered. Typical questions are:
 - Which activities should be considered: only other solar energy developments or also other activities? Very often, only similar developments are taken into account, while other types of activities are only sporadically taken into account.
 - Which status of activities should be considered: only existing projects, only permitted projects or also planned projects?
 - Which spatial scope should be considered: only within a certain radius (e.g. 10 or 20 km)? And related to this: which Natura 2000 sites? This relates to another main challenge, i.e. understanding how impacts accumulate (see below).
- Secondly, there is a marked lack of understanding of how effects accumulate or how they might do so, what the important ecological thresholds are and when these will be exceeded. This is indeed a complex issue and it needs to be acknowledged that there are many uncertainties; moreover, all uncertainties related to the challenge of determining significance are also relevant for cumulative impact assessment but now the complexity is even higher.
- A third reason is the lack of data, not only with regard to effects (e.g. mortality, displacement) but also with regard to the activities to be considered. Post monitoring data are often not stored in a public database and are rarely processed in a way that useful information (e.g. patterns, effectiveness of measures) can be obtained for future plan or project assessments. Public databases with a spatial overview of existing and planned activities and related information on their main characteristics (e.g. number of wind turbines, height of turbines, exact location, link to GIS, etc.) are widely lacking.
- Finally, a common challenge related to cumulative impact assessment is how to deal with the attribution of the 'burden' of cumulative effects when project developments take place sequentially. The predominant approach at this moment is based on the "first come, first served" principle, which means that the last project takes into account all impacts of all previous projects. As a consequence, additional plans and projects to those that are already approved in the same area face increased consenting risk due to the increased risk of significant impacts.

Recommended approaches on how to deal with the abovementioned challenges are the following:

- In principle, all human activities that have effects on the same EU protected species and habitats that might be affected by a solar energy development plan or project should be considered jointly, i.e. not only other solar energy developments but also other human activities. Furthermore, not just existing developments need to be taken into account, but also developments which are reasonably foreseeable, e.g. subject of published plans or ongoing permit applications. However, this is often constrained by data availability on other activities.
- Therefore, EU Member States should take appropriate measures to solve this constraint. In some cases it might be appropriate if the government prepares the cumulative impacts assessment, as they have the best overview and knowledge about other activities in large areas. Or at least the government could collect all relevant information and provide it to the project developers and consultants. In the same sense, the overview of different activities would be much facilitated if a state or regional level database would be created, preferably including a dynamic map, in which all projects, including those which are still in the planning phase, can be searched. The quality of decision-making thus would be improved.

- The spatial scope should be defined to encompass the geographic area within which all plan or project activities and their accumulated effects are likely to have implications on the conservation objectives of the Natura 2000 sites in question. The principle of proportionality should be applied in relation to the scale of effort needed to complete a cumulative effects assessment that is appropriate to the requirements of Article 6(3) of the Habitats Directive.
- A strategic approach to the assessment of cumulative effects of plans is fundamental to identifying “areas suitable for low-ecological-risk deployment” in accordance with the revised Renewable Energy Directive. However, the absence of spatial plans for solar energy development and assessment of cumulative effects at the appropriate spatial scale typically limits the ability to confidently identify such areas.

Best practice mitigation measures

Appropriate site planning by avoiding locations which are important for EU protected species and habitats, is the best mitigation measure. To achieve this goal, it is advisable to develop sensitivity/exclusion maps for priority species and habitats potentially more sensitive to the implementation of these energy infrastructures. These maps also play an important precautionary role, so that the promoters of these infrastructures know the areas more important for biodiversity and those managers dealing with environmental assessment processes evaluate with greater accuracy the proposals of solar energy projects.

In principle, not only Natura 2000 sites but functionally linked land (ecological functionality) to a Natura 2000 site e.g. as forage area as well as the distribution range of threatened species associated, should be avoided as this might affect site integrity and favourable conservation status of species in the Natura 2000 site. The same principle applies to habitats of Annex IV species of the Habitats Directive.

Ideally, solar parks are sited in the vicinity of already altered natural habitats by infrastructures (paved roads, railways, etc.) or buildings (urbanized areas). The establishment of buffer zones around these humanized areas to promote this energy development is recommended, also taking into consideration the need to avoid fragmentation and promote biodiversity connectivity.

Another suitable option is the installation of solar parks on low biodiversity value brownfields or other types of degraded land with low biodiversity values. In these cases, solar parks can significantly improve biodiversity. This is for instance the case when the former agricultural land is converted into extensively managed grassland. If appropriately located, solar PV farms could potentially increase the value of buffer areas around Natura 2000 sites. In particular when intensive agriculture in the immediate surroundings of a N2000 site could be replaced by a more extensive type of land management (less or no fertilizers, pesticides) such as a solar farm which would also allow for increased groundwater levels, major benefits for biodiversity would be achieved (Peschel, 2010) compared to the baseline situation.

To ensure a positive impact of the solar farm on biodiversity, it is important to assess its environmental impacts through annual specific field studies, which include a whole life cycle of the most vulnerable species to this kind of projects (e.g. farmland birds). It is recommended that this study covers at least two phases during breeding, in early and late spring, and one

more throughout wintering. The management of the site should take the results of this research into account.

The ecological benefits of siting solar parks on former agricultural land have been demonstrated in several studies. In most cases, the results also point to the low ecological value of the current agricultural landscape in the vicinity of the solar farm. Armstrong *et al.* (Armstrong, Ostle, & Whitaker, 2016) demonstrated the development of a species-rich meadow habitat in the gap areas (albeit through seeding) of a solar park on a formerly arable cropping area (fixed panels, angle of 30°, 11.2 m gap between rows, faced south, see Figure 11). Montag *et al.* (Montag, Parker, & Clarkson, 2016), for example, found that botanical diversity was greater at PV sites than at control site, in part because of seeding with wildflower mixes but, even where seeding had not taken place, diversity was greater than at arable control plots. Butterfly, bumblebee and bird abundances were also higher than at control sites. Photographic evidence of birds nesting on the underside of a PV module is also available (see Figure 12).



Figure 11: Westmill Solar Park (UK) (Armstrong, Ostle, & Whitaker, 2016)



Figure 12: PV modules support serve as nesting place for birds (Photo: BELECTRIC (International Bank for Reconstruction and Development / The World Bank, 2018))

CASE STUDY 2: APPROPRIATE SITING IN GERMANY, A GUIDING DOCUMENT

The German Society for Nature Conservation (NABU) and the German Solar Industry Association agreed on a list of criteria with regard to site selection and construction, which has been documented in the German Renewable Energies Agency document *Solar Parks: Opportunities for Biodiversity* (Peschel, 2010). The key criteria are:

- no intervention in protected areas (preference to be given to sites previously subjected to high stress levels, e.g. intensively farmed or brownfield sites);
- avoiding exposed sites (solar plants should not dominate the landscape);
- sealed area of site should be small (< 5%);
- fencing should not present a barrier to small mammals and amphibians;
- sites to be maintained with the help of sheep grazing or mowing, no synthetic fertilizers or pesticides; and
- local community to be involved in the project planning to increase acceptance.

Furthermore, a whole range of measures can be taken to enhance biodiversity values in a solar farm. Reducing or avoiding biocides and fertilizers is an obvious measure. To clean the solar panels, one should make sure that the water and products used do not contaminate the biodiversity values of the site. Sheep grazing or mowing are options to be considered. This gentle, extensive form of site maintenance can create valuable, species-rich habitats of the kind currently in danger of disappearing either through the increasing use of monocropping or because of a lack of maintenance (BirdLife Europe, 2011). Applying solar panels with white borders and white grid patterns is a useful measure for avoiding population effects on polarotectic insect groups (Horvath, et al., 2010).

By integrating the improved sites in a biotope network, positive impacts on biological diversity can be achieved that go beyond the individual solar parks themselves (BirdLife Europe, 2011). To make these parks a functional link in a biotope network, solar parks should not be a barrier for wildlife. Options for wildlife friendly or permeable fencing include use of hedges or ditches, fences with regular passages (e.g. culverts) or larger mesh sizes and a ground clearance under the fence of at least 10-15 cm for small animals. However, a site-specific approach is required. For example, allowing large mammal access may not be appropriate on a site designed to protect ground-nesting birds. In areas where species vulnerable to collision, e.g. specific birds, attention should be paid to fence design to ensure it is visible (BRE National Solar Centre, 2014) (Peschel, 2010).

Secondly, to further improve wildlife to move between habitats, boundary features should be enhanced, ideally connecting to features in the wider landscape. Usually boundary features can be enhanced with little or no impact upon the solar array, for instance by including hedgerows, ditches, stone walls, hedgebanks, field margins and scrub on the solar park site. These features not only provide a corridor or sheltering area, but also provide a nesting and foraging area. Relevant guidelines were prepared by the UK-based BRE National Solar Centre (Case study 3).

CASE STUDY 3: GUIDELINES OF THE BRE NATIONAL SOLAR CENTRE

The UK-based BRE National Solar Centre has produced guidelines on this matter for developers and consenting authorities (BRE National Solar Centre, 2014). Recognising that biodiversity enhancement will vary on a site-by-site basis, the guidance suggests that a Biodiversity Management Plan should be developed to lay out the specific objectives for biodiversity and the means by which these objectives will be achieved, including the protection of existing species and habitats, the establishment of specific enhancements, their maintenance and monitoring. BRE's recommendation is that the Plan should:

- identify key elements of biodiversity on site, including legally protected species, and species and habitats of high conservation value, such as those in designated areas in close proximity to the proposed site;
- identify any potential impacts arising from the site's development, and outline mitigation to address these;
- detail specific objectives for the site to benefit key elements of biodiversity and the habitat enhancements that are planned to achieve these;
- contribute to biodiversity in the wider landscape and local ecological network by improving connectivity between existing habitats;
- identify species for planting and suitable sources for seed and plants;
- consider wider enhancements such as nesting and roosting boxes;
- summarise a management regime for habitats for the entire life of the site;
- provide a plan for monitoring the site; and adapting management as appropriate to the findings of this monitoring; and,
- set out how the site will be decommissioned.

The BRE guidance sets out in detail a range of management options including: planting with wildflower seed mixes between rows of panels to enhance floral diversity but also to provide food for pollinating insects and seeds for birds; enhancement of boundary features; provision of log piles for invertebrates, amphibians, reptiles and fungi; and provision of ponds.

1.3.2 Floating solar panels

Literature on the environmental impact of floating solar panels is scarce. Some possible impacts relate to the reduction of sunlight penetration into the water body, reduction of wave mixing and impair oxygen absorption into the water column, with consequent effects on phytoplankton production and subsequent ecosystem function. On lakes, depending on the covering rate, also effects on lake ecology (O₂-production rate, influence on lake layer temperatures) as well as on animals (e.g. can waterfowl or sea bird species differentiate between panels and lake water) are possible. The significance of such effects are the subject of ongoing studies but, as yet, remain speculative. In the Netherlands, a tool has been developed to calculate the effects of a floating PV system on the water quality and ecological status. The impact will depend on parameters such as the proportion of the water surface covered and the depth of the water body. Calculated effects include (Loos & Wortelboer, 2018):

- Impact on available light in the water body: availability of light is required for vegetation growth. Water plants have a crucial role in the cleanliness of water through competition for light and

nutrients with algae. Abundance of water plants is an important quality criterium following the EU Water Framework Directive.

- Impact on water temperature and heat distribution in the water column.
- Oxygen availability.
- Impact on algae and aquatic plants.

Aquatera (Aquatera, 2017) compares the potential impact of inland floating panels versus offshore floating panels. With regard to inland floating panels, a slight disturbance to the benthos is expected, either through direct loss of benthic habitat or from sediment plumes which can block the respiratory systems or feeding appendages of benthic organism. A positive effect is expected for fish, where underwater structures (e.g. devices and moorings) create a 'reef effect'. In lakes, devices will create obstacles to trawl fishing which will help to protect local fish stocks. For birds, no impact is expected as long as the ecological quality of the water is maintained and areas important for birds are avoided or impacts are appropriately mitigated. During stakeholder consultation, interviewees or workshop participants warned though that on lakes and ponds, it should be avoided that panels take up habitat from waterfowl (breeding birds, migratory birds and hibernators).

For offshore floating panels, Aquatera considers potential impact on plankton and benthos. Floating solar would block sunlight from reaching the sea surface and thus would limit the growth of phytoplankton in deployment areas which could have an impact upon the food chain. Equally, this could result in a positive impact through reducing algal bloom and thus improving water quality, particularly in sheltered embayment where water circulation may be limited. A small impact is expected on benthos during placement of anchor, mooring systems and cables. Conversely, devices create obstacles to bottom trawling which help to protect seabed communities. Like for inland floating panels, devices and moorings create a 'reef effect', attracting and aggregating fish. Through creation of obstacles, local fish stocks are protected from trawl fishing. For marine mammals, floating solar arrays could create artificial barriers for surface breathing animals and could hold some entrapment and entanglement risks. Sensitive areas should therefore be avoided. For sea birds, there is a potential loss of feeding grounds. Conversely, the infrastructure could serve as roosting platform. Furthermore, the impact of the construction of the floating solar plant should be considered, and more specifically, how the solar plant is anchored into the waterbed. The piling of concrete piers and earth screws and the presence of anchor lines could negatively impact aquatic organisms. On the other hand, the introduction of new structures into the water can serve as artificial 'reefs' and can positively modify surrounding natural habitats. A specific issue of concern is the combination of floating solar plants with an offshore wind power park or with hydropower plants, but no research has been identified that examines potential cumulative impact.

2 GEOTHERMAL ENERGY

2.1 Geothermal energy in the EU

Within the EU in 2017, geothermal energy was only used to produce 1.5 GW of electricity, mainly in Italy (916 MW), with Germany as the next largest producer (38 MW) (European Geothermal Energy Council, 2017). However, it is estimated that it is possible, with the increasing development of shallow geothermal energy, to utilise geothermal energy in Europe to the equivalent of 80-100 GW. The objective of the International Energy Agency is to increase the use of geothermal in electricity production to 3-6 GW, and the use of geothermal for domestic house heating or cooling to 39-60 GW by the year 2020. The long-term goal is to increase the electricity production using geothermal up to 15-30 GW and the direct use of geothermal for heating or cooling up to 300 GW¹⁵.

2.2 Technical features of geothermal energy

Geothermal energy is energy stored as heat beneath the surface of the solid earth¹⁶. There are two broad categories: deep geothermal (see Figure 13) involves extraction of heat, either in the form of steam or naturally heated water (between 170°C and 200°C) from depths of below 400 m; and shallow geothermal, in which heat is exchanged with the ground at depths of up to 100 m, either directly by drawing on warm groundwater ('open' systems), or indirectly through a heat exchange system ('closed' system). Within the category of deep geothermal plants, an important distinction is drawn between so-called binary plants (see Figure 14) and dry and flash steam technologies (see Figure 15). The latter two involve direct contact of hydrothermal fluids with a generating turbine, either through steam that naturally occurs as the fluid rises into the lower pressure zone of the extraction well (dry steam); or where hydrothermal fluid is pumped at high pressure into a flash tank artificially held at a lower pressure, causing the fluid to vaporise quickly, driving the turbine. In binary systems, the hydrothermal fluid does not come into contact with the turbine but passes through a heat exchanger charged with a fluid with a lower boiling point. It is the secondary fluid which drives the turbine, before being recovered for re-use. Importantly, binary plants are closed loop systems, and only low levels of water vapour are released into the environment; whereas, in dry and flash steam plants, in addition to water vapour, emissions can contain gases and elements derived from the deep aquifer source material, including greenhouse gas (carbon dioxide), hydrogen sulphide, ammonia, arsenic and mercury.

¹⁵ <http://www.geothermaleranet.is/about-geothermal-era-net/geothermal-energy/>

¹⁶ http://www.nezeh.eu/assets/media/fckuploads/file/Legislation/RED_23April2009.pdf

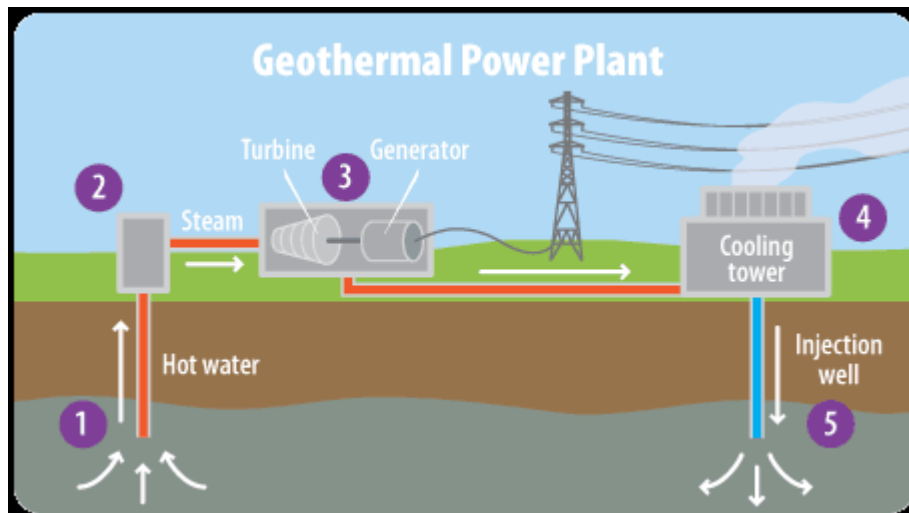


Figure 13: Deep geothermal power plant (EPA, 2016)



Figure 14: Pico Alto binary geothermal power plant, Azores / Portugal (source: Exergy ORC)



Figure 15: Larderello dry-steam geothermal plant in Italy, the oldest geothermal plant in the world (ThinkGeoEnergy, n.d.)

2.3 Impacts of geothermal energy

There is little research on the environmental impact of geothermal plants, although some (research) projects are currently in execution, such as the H2020 project GEOENVI¹⁷. The GEOENVI project (Tackling the environmental concerns for deploying geothermal energy in Europe, 2018-2021) aims at setting an adapted methodology for assessing environmental impacts for project developers and exchange of best practices.

The potential impacts of geothermal energy on EU protected species and habitats are listed in Table 2 and described below.

Table 2: Overview of potential impacts of geothermal energy

Impact groups (C: construction / O: operation / D: decommissioning)	Affected species and habitats
Habitat loss due to plant construction (C)	Birds, bats, reptiles, mammals and habitats (depending on location)
Disturbance due to noise, light, human presence (C, O, D)	Birds, bats, reptiles, mammals and habitats (depending on location)
Water pollution due to disposal of drilling effluent (C, O)	Fish, amphibians, aquatic habitats

2.3.1 Dry and flash steam geothermal plants

Impact of construction

Main impact of geothermal energy is related to the construction of the plant. The construction phase is dominated by the drilling operations, which are generally followed by the surface construction of the power plant. Construction impacts of geothermal plants relate primarily to land take, vegetation destruction, noise, and disposal of drilling effluent (which has the potential to contaminate surface and ground waters) (ENGINE).

Impact from operation: waste, noise and air emissions

Noise

Noise pollution is limited with geothermal plants but might affect species which are sensitive to noise (e.g. certain bird species). Noise pollution has been reported for plants that use air cooling instead of water cooling: cooling towers or air-cooled condensers are relatively tall structures with fans on top. Water cooling towers are smaller and use far fewer cells for a given plant power rating. Other noise sources are similar to other industrial plants, such as turbines, feed and injection pumps (DiPippo, 2012).

¹⁷ <https://www.geoenvi.eu>

Air emissions

The chemical characteristics of the fluid of a geothermal field can highly differ: from acid to alkaline, with high or low salinity, and potentially containing (high) concentrations of contaminants such as boron, arsenic, mercury and hydrogen sulphide. Flash and dry-steam geothermal power plants emit a range of non-condensable gases (NCGs), of which the amount and composition of NCGs emitted is mainly dependent on the underground reservoir geochemistry of the geothermal field. Hydrogen sulphide remains the pollutant of greatest concern for geothermal energy production (ENGINE). Depending on the geochemistry of the geothermal field, certain trace elements (arsenic, boron, antimony and mercury) can be present in the air emissions of the geothermal plant. These trace elements can bioaccumulate in ecosystems and cause irreversible effects over time, which may initially go unnoticeable but in the long run result into chronic effects (e.g. reduced photosynthesis and plant growth) (Mutia, 2016).

Waste

The geothermal fluid used in flash geothermal plants, with potentially significant levels of trace elements and other contaminants depending on the geochemistry of the reservoir, is normally re-injected in the reservoir. This practice prevents potential contamination of the environment (Hähnlein, Bayer, Ferguson, & Blum, 2013). In dry-steam geothermal plants, the geofluid consists of only steam, so there is no liquid or brine to dispose of.

2.3.2 Binary geothermal power plants

Impact of construction

The impact related to the construction of binary geothermal power plants is similar to dry and flash steam plants. See section 2.3.1 for more information.

Impact from operation: noise and thermal pollution

Noise pollution can be related to air cooling, but is only relevant for plants located in sensitive areas. See section 2.3.1 for more information.

Binary geothermal power plants are closed systems and generally release no hydrogen sulphide or sulphur emissions (ENGINE). The main possible form of pollution from this type of geothermal plants is thermal pollution. Binary plants discharge more waste heat per unit of power output than other thermal plants. Griebler *et al.* (Griebler, et al., 2016) also investigated temperature impacts, asserting that these can considerably alter the groundwater chemical composition and quality, the metabolism of organisms, and, consequently, biogeochemical processes and ecosystem functions. Combining original data from current studies with a compact review of recent findings, they show that a moderate increase in groundwater/aquifer temperature generally causes only minor changes in water chemistry, microbial biodiversity, and ecosystem function in non-contaminated and energy-poor (oligotrophic) groundwater systems. In aquifers that are contaminated with organics, nutrients, and heavy metals, typical in urban areas and at sites with intensive land use (e.g., agriculture), significant changes in water quality and ecological patterns can result. Severe temperature alterations lead to a reduced biodiversity of the aquifer's microbial community, with the establishment of altered thermophilic assemblages. However, there is no evidence that this alteration of groundwater chemistry and microbial biodiversity in aquifers has adverse impacts on EU protected species and habitats.

2.3.3 Shallow geothermal energy

Impact of construction

Shallow geothermal energy is generally used for heating and cooling of buildings through the use of ground-sourced heat pumps. Construction works are therefore limited with this type of geothermal energy.

Impact from operation: thermal pollution

Hähnlein *et al* (Hähnlein, Bayer, Ferguson, & Blum, 2013) specifically considered the sustainability of shallow geothermal energy systems, including ground-sourced heat pumps (GSHP). They concluded that the influence of shallow systems on above-ground flora and fauna was minor, decreasing with increasing depth. For soil flora and fauna, however, shallow systems can induce changes in microclimate, with consequential effects on bacteria and groundwater invertebrate species composition and their ecosystem servicing functions such as water purification and filtration. In certain circumstances, such as contaminated aquifers, Hähnlein *et al*. (Hähnlein, Bayer, Ferguson, & Blum, 2013) suggest that this could be beneficial, if groundwater temperature elevates microbial decomposition, thus aiding reclamation of contaminated land. But in general, it is necessary to keep temperature anomalies within a range of a few degrees to protect the natural state and functionality of soil ecosystems. The secondary use of waste thermal energy and water – if there is any – is advised to direct to agriculture: greenhouse, aquaculture, etc. if appropriate, not to Natura 2000 and protected sites.

2.4 Best practice mitigation measures

Impact of land take and vegetation destruction can be limited by appropriate siting, often instructed by SEA or EIA and AA in case of potential significant impacts on site integrity of Natura 2000 sites or on Annex IV species. Generally, geothermal development and operations need a relatively small area (ENGINE). Construction impacts on vegetation can be minimised through careful planning of plant layout and road layouts to minimise land intake, and the use of directional drilling. Control of drilling effluent is controlled via the Water Framework Directive and can be achieved through water treatment and the use of drilling waste sumps (Bromley, 2012).

Technical solutions are available to minimise noise emissions, such as insulation of installations, reduction of turbine speed, noise barriers, etc. (INERIS, 2017)

For dry and flash steam geothermal plants, there are many reliable, cost-effective H₂S abatement systems that convert hydrogen sulphide to elemental sulphur, which can then be used as a soil amendment and fertilizer feedstock (Matek, 2013) (ENGINE). Abatement technologies should also be implemented to remove trace elements from plant emissions. Monitoring of these trace elements should be included in plant monitoring (as is normally the case for H₂S emissions) (DiPippo, 2012).

However, each project will need to be carefully assessed on a site-by-site basis, and the absence of likely significant effects confirmed before consenting. Deep geothermal projects do not appear to be likely to become widespread within the EU, based on current technologies. However, those technologies are advancing and may create new opportunities in the future (Ruggero, 2018). The acceptability of future deep geothermal sources will be dependent on parallel advances in emission controls and waste processing.

In general, in all cases where geothermal plants are located in areas with high biodiversity values (e.g. Natura 2000 sites) intensive monitoring should be implemented to avoid any harmful impact.

3 OCEAN ENERGY

3.1 Ocean energy in the EU

Aside from tidal range technologies, no other ocean energy technology is market ready or commercially deployed worldwide. As discussed in the LCEO Technology Development Reports on Ocean Energy by Magagna (Magagna D. , Ocean Energy Technology, 2018), tidal energy technology is at pre-commercial scale, with wave energy at demonstration level, whilst ocean thermal energy conversion (OTEC) and salinity gradient technologies are still at early stage of development. All technologies still require R&D efforts to reduce costs and to increase the energy output and reliability of the devices. Magagna's market report (Magagna D. , Ocean Energy Technology, 2019) shows that with current cost estimates, tidal energy may enter the European electricity market in a commercially significant way by 2040. The same cannot be said for wave energy, which may still only play a limited role in the European energy market by 2050.

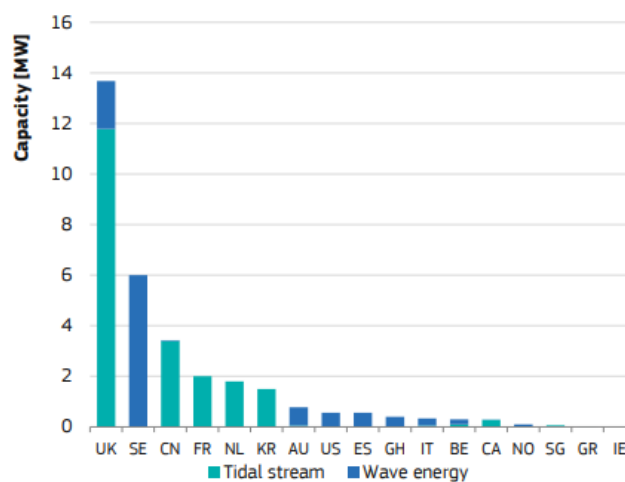


Figure 16: Global ocean energy installed capacity in 2018 per country (Magagna D. , Ocean Energy Technology, 2019)

Ocean energy remains a small contributor to the overall renewable energy production of the EU. Most of the deployments have taken place in the UK, followed by Sweden, China and France (Figure 16). In Europe, the United Kingdom, France and the Netherlands are the countries with the highest tidal energy capacity installed. For what concerns wave energy, the UK, Sweden, Denmark, Portugal and Spain are the countries with the most capacity installed in Europe. Outside Europe, Australia, China, Ghana and the US are among the countries driving the development of the sector (Magagna D. , Ocean Energy Technology, 2019).

The majority of the deployments consist of single-unit technology prototype testing and demonstrators. Projects are either small scale prototypes usually comprising single machines under test conditions or initial phases of potentially larger schemes. Small ocean energy farms and arrays have been deployed since 2016. The largest installed capacity of ocean energy is in the United Kingdom, consisting of 11.8 MW of tidal and 1.9 MW of wave energy capacity currently operational.

Failure rates are high for technical, but also due to financial reasons. Nevertheless, ocean energy has the possibility to provide a significant share of electricity generation, both at European and global scale. Given their technological advancement and potential within the EU, tidal stream and wave energy technologies are those expected to provide the greatest contribution to the EU energy system in the near future (Magagna D. , Ocean Energy Technology, 2018). The European Commission recognised the enormous potential of ocean energy, particularly in the Atlantic arc between Scotland and Portugal. Europe represents the main hub for research and development on ocean energy technologies. Ocean Energy Europe states that the industry plans to deploy 100 GW of production capacity by 2050, which would meet 10% of electricity demands and power around 76 million households. The EU has made funding available for actions benefiting ocean energy technologies. For instance, a joint programme for ocean energy has been set up within the European Energy Research Alliance (EERA). Member State involvement is being encouraged through a European Research Area network (ERA-net) of national and regional research programmes that has been established specifically on ocean energy. The ocean energy sector was highlighted in the Commission's Blue Growth Strategy as one of five developing areas in the 'blue economy'¹⁸. Europe is leading the world in tidal energy installations. In 2019, European tidal stream projects (27.7 MW) generated 50% more electricity than the year before. The installed capacity of wave energy in Europe (11.8 MW) grew in 2019 by 25% compared to the year before, continuing the sector's steady growth over the past decade¹⁹.

The western coast of Europe is characterized by particularly high wave energy potential (see Figure 18). Denmark, Ireland, Norway, Portugal, Sweden and the United Kingdom have for a long time been perusing waves a feasible energy source. These countries have significant wave resources or see an export potential of the developed technologies, and have been actively engaged in wave energy development for many years. This has led to a large amount of DG-RTD work and considerable progress in wave power conversion.

The highest potential for tidal can be found in France (Figure 17) and the UK (Atlantic Ocean) (see Figure 19). Local topography enhances the tidal ranges in places to produce localised hot spots in large estuaries; such as the Severn estuary between England and Wales, which has the second-highest tidal range in the world at 13 m, and the Rance estuary in France, which has an average tidal range of 8 m. The Iberia, Baltic, Norwegian coasts and Mediterranean have limited potential due to low tidal ranges. Tidal stream resources are generally largest in areas where the water depth is relatively shallow, where a tidal range exists, and where the speed of the currents is amplified by the funnelling effect of the local coastline and seabed.

¹⁸ https://ec.europa.eu/maritimeaffairs/policy/ocean_energy

¹⁹ <https://www.oceanenergy-europe.eu/ocean-energy-statistics-european-tidal-power-generation-jumps-by-50-in-2019/>



Figure 17: La Rance Tidal Barrage (France) © Y. Le Gal - EDF (IUCN France, 2014)

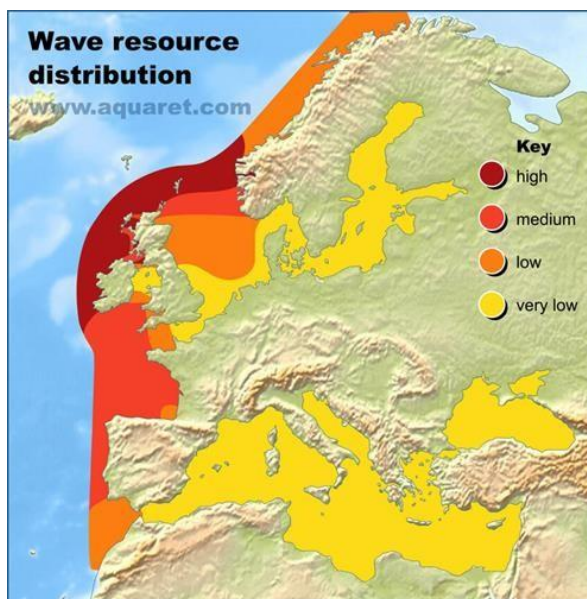


Figure 18: Level of wave resource across Europe (Source: <http://www.aquaret.com>)

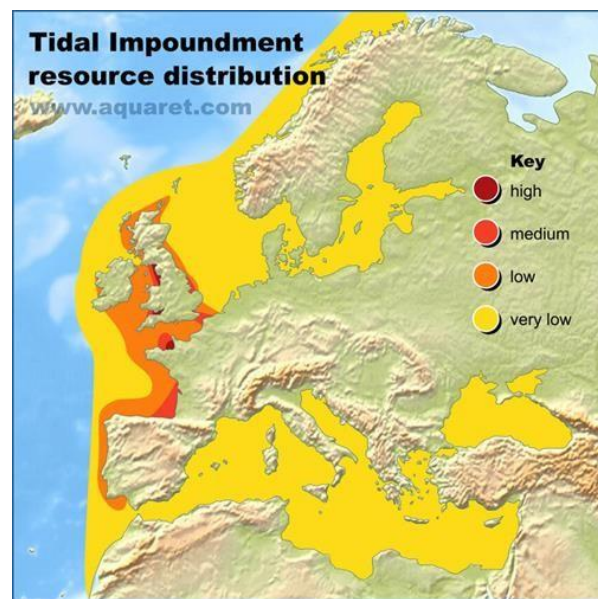


Figure 19: Level of tidal resource across Europe (Source: <http://www.aquaret.com>)

3.2 Technical features of ocean energy

Ocean energy comprises five distinct technologies (Ocean Energy Forum, 2016) (Baring-Gould, Christol, LiVecchi, Kramer, & West, 2016):

- Wave energy uses the kinetic energy of ocean waves to generate electricity;
- Tidal stream energy uses the kinetic energy of tidal currents to generate electricity. Tidal turbines can be fixed directly to and mounted on the seabed, or tethered/moored to the seabed and buoyant, floating on surface or in mid water.

- Tidal range energy uses the vertical head difference in sea level between high and low tides to create power. Tidal range technology uses the same principles as conventional hydropower, and requires a barrier to impound a large body of water. The difference between the tide height inside and outside the impounded area causes water to be discharged from one side to the other. This water is forced through hydro turbines inside the structure to generate energy. Technologies include tidal barrages (dam-like structures that close off a tidal basin), tidal lagoons (similar to tidal barrages but with man-made water basins) and tidal fences (continuous row of vertical axis turbines mounted in a fence, spanning across channels or long straights between large bodies of land)²⁰;
- Ocean thermal gradients power uses the temperature differential between cold deep ocean water and warm surface water to generate electricity;
- Salinity gradient power utilises the pressure differential between salt and fresh water to generate electricity.

In this report, we will only discuss wave and tidal energy as they are currently the most mature technologies. As will be discussed in the next section, most ocean energy technologies have remained in an early stage of research and development, with primarily prototypes, test and demonstration models. Tidal barrages are considered to be reasonably mature, although such structures remain uncommon in the EU. Estuaries and embayments represent ideal physical conditions for tidal barrages. However, many are designated as part of the Natura 2000 network, and the widescale deployment of barrages in the future remains questionable.

3.3 Impacts of ocean energy

Wave and tidal energies are likely to have many of the same impacts and have been studied in conjunction by groups such as The European Marine Energy Centre LTD. Findings from an observational study of the impacts of these technologies on marine wildlife suggest limited impacts. Their analysis of around 18,000 hours of observations over 11 years in the Orkney Islands indicated a change in density and redistribution of some bird species, including the Common Loon (*Gavia immer*), Black Guillemot (*Cepphus grille*) and Common Murre (*Uria aalge*), Great Cormorant (*Phalacrocorax carbo*), European Shag (*Gulosus aristotelis*), ducks and geese, when construction work started. However, in nearly all cases, numbers returned to around previous levels once the tidal turbines were installed and operational. Observations of seals, whales and dolphins revealed similar findings²¹. The different impact groups are discussed below.

²⁰ Website <http://www.alternative-energy-tutorials.com/tidal-energy/tidal-energy.html>, consulted on 21 March 2019

²¹ <http://www.emec.org.uk/press-release-wave-and-tidal-energy-study-finds-no-long-term-disturbance-to-wildlife/>

Table 3: Overview of potential impacts of ocean energy

Impact groups (C: construction / O: operation / D: decommissioning)	Affected species and habitats
Habitat change and degradation is expected to be very limited (C, O, D). Also indirect positive impacts due to creation of fishing exclusion areas (O)	Benthic organisms, fish
Barrier, collision, entanglement impacts are expected to be very limited (C, O)	Marine birds, marine mammals, turtles, larger fish
Noise and vibrations (C, O) – depending on construction typology	Marine mammals, fish
Electromagnetic fields (O)	Turtles, fish

Ongoing research projects that may provide new insights in the future include the WESE project²² and SEA Wave project²³.

3.3.1 Tidal stream and wave energy devices

Habitat change and degradation

All marine renewable energy (MRE) devices must be attached to the sea bottom in some manner, either with gravity foundations, piled into the seafloor, or by one of several anchoring solutions. The placement on the seafloor, as well as movement of anchor lines, cables, and mechanical moving parts, can all affect the surrounding rocky or soft-bottom seabed and the benthic organisms these habitats support. Similarly, the presence of MRE devices on the seafloor or suspended in the water column may attract fish and benthic organisms, causing them to change their behaviour and settling locations, perhaps affecting population movement, structure, or success. In addition, installation of ocean energy devices and export cables may affect the system by changing natural flow patterns around devices and removing energy from the system. Changes in circulation and flushing can affect sediment transport and distribution, or alter water quality constituents such as nutrients, dissolved gases, and contaminants (Copping, et al., 2016).

Benthic communities and populations of reefing fish have not been seen to be adversely affected by wave or tidal devices, with the exception of some loss of habitat immediately under the devices²⁴. Changes associated with wave and tidal devices are not expected to be widespread nor are they expected to affect benthic habitats differently than other marine industries that place structures in the ocean. Modelling studies have provided insight into natural processes that may be affected by MRE devices, such as sedimentation patterns and hydrodynamics, which in turn can affect benthic habitats and communities. However, most

²² <https://wese-project.weebly.com/wese-project.html>

²³ <http://www.emec.org.uk/projects/ocean-energy-projects/environmental-monitoring/sea-wave-strategic-environmental-assessment-of-wave-energy-technologies/>

²⁴ <https://tethys.pnnl.gov/sites/default/files/Short-Science-Summary-Benthic-Habitats.pdf>

of these models have not been validated with field data to ensure their accuracy or realism (Frid, et al., 2012).

Physical impact from small scale tidal stream generation pilot projects has been found to be reversible on decommissioning, especially as the areas most suitable for tidal power generation are located where high current flow causes natural disturbance to the sediments. The number of devices deployed in an area must be very large to affect changes in flow and/or create measurable effects of energy removal on a changing system. However, the cumulative effect of multiple turbines needs to be considered with respect to far field impacts (Frid, et al., 2012) (OSPAR, 2014).

Some researchers are looking at potential positive impacts, such as coastal protection from the strategic placement of tidal stream and wave energy devices. The installation of tidal and wave energy devices may also provide opportunities for creating and enhancing habitats that favour benthic species, increase the number of fish in an area as they reef around the devices, and create de facto marine protected areas (Frid, et al., 2012). Inger et al. (Inger, et al., 2009) assert that the proposed construction of ocean energy devices will increase the amount of hard substrate in coastal environments and thus may have a significant impact in terms of the provision of artificial reefs, which attract a wide range of marine organisms, and can increase species diversity significantly when compared with soft-bottom areas. They also draw attention to the possibility that floating wave energy devices could act as fish aggregation areas, given the known potential for fish numbers to concentrate around floating objects worldwide. Kaiser et al. (Kaiser, et al., 2006) argue that the creation of fishing exclusion areas, for safety and protection of infrastructure will, by default, benefit fish stocks and create the potential for nursery areas in which juvenile fish are able to mature and for benthic habitats to recover from repeated trawling.

Direct impact: barrier, collision, entanglement

Tidal stream and wave energy devices are less likely to produce a barrier, unless multiple devices are very closely packed. Collision risk depends on the structure and diameter of the tidal stream device, the number of devices, local site environment (current velocity, visibility) but also on the species concerned (size, capacity to detect and avoid obstacles). No instances of marine mammals, fish, diving seabirds, or other marine animals colliding with an operational tidal turbine have been observed to date. Laboratory simulations have shown that fish may pass through turbines but very few are likely to be harmed. Studies have shown that a marine mammal colliding with a tidal turbine may be injured but not necessarily killed, and that animals are likely to recover from many of those injuries²⁵. In contrast to tidal barrages, tidal stream turbines are mounted in the open flow field, so the rate of revolution is much lower and organisms have plenty of opportunity to avoid direct contact.

In contrast to the collision risk associated with offshore wind, wave energy installations may present a novel risk of underwater collision for seabirds and marine mammals. Wave energy is likely to cause some disturbance during construction, maintenance and decommissioning.

²⁵ https://tethys.pnnl.gov/sites/default/files/Short-Science-Summary-Collision-Risk_0.pdf

However, impacts related to construction activities are likely to be minimized as there is no requirement for pile driving associated with current wind technologies. There is a potential to change environmental processes indirectly around the devices, which in turn may alter habitat assemblages. Disturbance can have deleterious impacts on foraging efficiency, however; if instalments enhance habitats by acting as fish aggregation devices and de facto marine protected areas, then the reverse may be true, as birds could profit from an increase in food availability. Unlike wind, wave energy structures will provide roosting sites that could help marine birds to exploit an aggregated and protected resource (Grecian, 2010).

A risk for wave energy devices is entanglement of marine mammals, turtles, larger fish and seabirds in moorings and electrical interconnections (Frid, et al., 2012). Although Baring-Gould et al. (2016) consider entanglement to be a relatively low risk due to cable thickness and mooring line tension (Baring-Gould, Christol, LiVecchi, Kramer, & West, 2016). There are insufficient data though on how tidal and wave stream devices will impact fish and marine mammals. Collision risk for seabirds is considered to be low, except for some deep diving species, who might be attracted to the moving blades as potential prey. But the slow turbine speeds relative to the agility of diving bird species makes the risk of mortality rather low (Frid, et al., 2012). A positive impact of tidal stream and wave energy devices might be that foundations, fouled buoys, etc. might serve as a colonisation platform (Graham, Farcas, Merchant, & Thompson, 2017; Ocean Energy Forum, 2016)

Noise and vibrations

Noise generation relating to marine renewables can take a number of distinct forms, for example: construction noise, particularly where foundations are piled into the seabed; device operational noise (although this is unlikely to be significant in the case of floating wave technologies); and the noise generated by operations and maintenance vessels or survey equipment such as echo sounders or sub-bottom profilers. Impacts are most commonly associated with marine mammals and the potential for disruption to foraging, orientation and communication. The effects of underwater noise on fish is less understood and is likely to vary between species. Inger *et al* (Inger, et al., 2009) highlighted the need for systematic research in this area (Inger, et al., 2009). Baring-Gould *et al.* (2016) noted the difficulty to translate the insight gained from small-scale or pre-commercial deployments to full sized devices or to larger arrays of devices (INERIS, 2017).

Tidal stream farms and wave energy farms are civil engineering structures, and so construction (and decommissioning) activities will include considerable noise generating activities at levels potentially damaging to marine life. If installation involves pile driving, explosive or seismic work, nearby noise levels are likely to exceed threshold values for the protection of fish and marine mammals. Effects could be direct, by damaging sensory or sensitive tissues, or indirect, by changing behaviours (Frid, et al., 2012). Caution is required in reviewing literature, as the overwhelming majority of documents relate to offshore wind turbines, which are beyond the scope of the present report. Nevertheless, some general conclusions, drawn from studies at offshore wind farms, can be applied, especially to tidal current turbines, which can require foundation piling in a similar manner to offshore wind farms. Madsen *et al.* (Madsen, Wahlberg, Tougaard, Lucke, & Tyack, 2006) concluded, on the basis of a literature review, that activity in both seals and porpoises declined significantly during pile-driving operations at two wind farms, to considerable distances (up to 10 km).

However, activity levels returned to normal with a few hours or, in an exceptional instance, a few days, once pile-driving had ceased.

Recent information is coming to light from an in depth programme of monitoring at the Beatrice Offshore wind farm in Scotland. Monitoring of harbour porpoise activity during pile driving activity has indicated that porpoises are displaced from the immediate vicinity of the pile driving activity with a 50% probability of response occurring at approximately 7 km (Graham, Farcas, Merchant, & Thompson, 2017). This monitoring also indicated that the response diminished over the construction period and that porpoise activity recovered between pile driving events. Gilles *et al.* (Gilles, Scheidat, & Siebert, 2009) suggest that sensitivity in harbour porpoises may vary spatially and seasonally. Their data suggested that porpoises move to distinct areas on a seasonal basis as their biological requirements change. In this case the animals move into German waters in early spring, reach high numbers in early summer and move out of the area in autumn. Important aggregation sites were identified, where higher proportions of mothers and calves were recorded than elsewhere. Good mapping is therefore required to take into account these spatial and seasonal sensitivity of species.

It is not clear yet to what extent operational noise of any of wave and tidal energy generation installations is ecologically significant, as comprehensive evidence is lacking and there is very little information on the sound levels produced by these devices (INERIS, 2017). Operational noise from generators, rotating equipment, and other moving parts may have comparable frequencies and magnitudes to those measured at offshore wind farms; however, the underwater noise created by a wind turbine is transmitted down through the pilings, whereas noises from tidal stream farms are likely to be greater because they are at least partially submerged (OSPAR, 2014). Also the impact of noise and vibrations caused by the cables, chains and ropes have been understudied, although they have a continuous impact (Ocean Energy Forum, 2016). Future research deliverables in the offshore wind and floating solar energy sector could be relevant for ocean energy as well.

Another point of attention are cumulative impacts. In the case of tidal stream farms, the operational noise from a small number of units may not exceed threshold levels, but the cumulative noise production from large numbers of units has the potential to mask the communication and echolocation sounds produced by aquatic organisms in the vicinity of the structures.

Hastie *et al.* (Hastie, et al., 2017) studied the response of harbour seals to acoustic signals that simulated the sound of an operating underwater current turbine in a narrow, tidally energetic channel on the west coast of Scotland. Their results showed that there was a significant increase in the distance of seals from the playback location during turbine playbacks, indicating avoidance behaviour, while overall numbers of seals within the wider area did not change significantly. Tougaard *et al.* (Tougaard, Henriksen, & Miller, 2009) recorded underwater noise at three completed offshore windfarms during periods of normal operation and calculated audibility levels for harbour porpoises and harbour seals. Audibility was low for harbour porpoises extending 20-70 m from the foundation, whereas audibility for harbour seals ranged from less than 100 m to several kilometers. Behavioural reactions of porpoises to the noise appeared unlikely other than in proximity to the foundations. However, behavioural reactions from seals could not be excluded up to distances of a few hundred

meters. It was considered unlikely that the noise reached levels causing injury or hearing loss at any distance from the turbines and that the noise was unlikely to mask acoustic communication by seals and porpoises. In many cases, projects are deployed in naturally noisy environments (e.g. wind and wave-generated noise), where ambient background pre-project sound sources are present (INERIS, 2017). Furthermore, the constant low-intensity sound from operating have also been compared to light to normal density shipping and a conventional ferry or subway (Ocean Energy Forum, 2016). From literature it is clear that noise production, its scale of impact and potential mitigation measures are key areas of interest required from future studies. Resolution of the significance or otherwise of noise impacts will require information about the device's acoustic signature (e.g., sound pressure levels across the full range of frequencies) for both individual units and multiple-unit arrays, similar characterization of ambient noise in the vicinity of the farm, the hearing sensitivity of fish and marine mammals that inhabit the area, and information about the behavioural responses to anthropogenic noise (e.g., avoidance, attraction, changes in schooling behaviour or migration routes) (INERIS, 2017).

Electromagnetic Interference

The deployment of marine renewable technologies inevitably requires the transmission of generated electricity to transformers and onwards to the mainland. Transmission technologies and cables are similar in offshore wind, wave and tidal energy and therefore learnings from offshore wind energy are relevant for wave and tidal energy. Although transmission infrastructure was outside the remit of the present study, the unique effects of networks of underwater cables connecting individual elements of ocean RES warrants consideration.

Cables have the capacity to produce electromagnetic fields that have the potential to interfere with some electro- or magneto-sensitive species and may therefore cause localised interference with prey detection and orientation. Modelling undertaken in support of the Telford, Stevenson and MacColl Offshore Wind Farms and Transmission Infrastructure Environmental Impact Assessment (Telford, Stevenson, & MacColl, 2012) showed that the magnetic field produced by DC and AC cables decreases rapidly both vertically and horizontally. In all cases, where cables are buried to 1 m depth, the predicted magnetic field is expected to be below the earth's magnetic field. Where DC cables cannot be buried and are instead protected, the magnetic field was expected be below the earth's magnetic field within 5 m from the seabed. Effects are therefore likely to be highly localised.

Gill and Bartlett (Gill & Bartlett, 2010) specifically set out to examine whether migratory fish species such as eels, salmon and sea trout may be affected, but found in published literature either no, or very limited, evidence of impacts. A literature review of Frid et al. (Frid, et al., 2012) found no impact on survival and reproduction of several benthic organism, but a relevant impact on sea turtles. Given the important role of magnetic information in the movements of sea turtles (particularly loggerhead turtles), impacts of magnetic field disruption could range from minimal (i.e., temporary disorientation near a cable or structure) to significant (i.e., altered nesting patterns and corresponding demographic shifts resulting from large-scale magnetic field changes). Scott *et al.* (Scott, Harsanyi, & Lyndon, 2018) found that edible crabs showed a clear preference for shelters that were exposed to electromagnetic fields, causing a reduction in foraging time by 21%, with potentially negative

effects on survival and fitness. In the EC guidance on energy transmission infrastructure (European Commission, 2018), several studies are mentioned which also indicated temporary and individual changes in behaviour of eels related to magnetic fields, and of lesser spotted dogfish, thornback ray and spurdog related to electrical fields. According to the MaRVEN study, field studies clearly show that EMFs are emitted into the marine environment at levels of intensity that are detectable and may cause a reaction in sensitive species. Studies have shown that, for certain EMF sensitive animals, exposures to high levels of EMF may alter early life stages of the animal's development, although it is not clear that these potential alterations will affect populations of animals, or whether animals may be exposed to such high levels of EMFs in the marine environment²⁶. The crucial question is whether EMFs have any biologically relevant impacts (Telford, Stevenson, & MacColl, 2012). However, the understanding of electromagnetic fields on marine organisms remains poorly understood and continues to develop. Given the paucity of information on the subject, a precautionary approach should be taken when planning wave and tidal energy generation installations. This is important when considering multiple encounters with EMFs and plausible cumulative effects.

Current practice in Europe involves consideration of EMF in EIA and consent processes but with different levels of obligation regarding the monitoring and investigation of any potential effects in different Member States (Hastie, et al., 2017). The MaRVEN (MaRVEN, 2015) study showed that several Member States believe that there is a lack of methodologies for measuring the electromagnetic field, and thus no regulations or guidelines have been developed. However, field demonstrations of the MaRVEN study have demonstrated that commercial sensors that measure both magnetic and electrical field are available. Measurements can be performed by both suspending the sensors from the side of a boat as well as by sledging.

Best practice mitigation measures

Minimising disturbance during construction phases relates particularly to tidal current turbines which require piled foundations. Such activities should be planned outside sensitive periods, such as fish migratory seasons. 'Soft start' techniques, whereby the intensity of piling is gradually increased over a sufficient period to allow sensitive marine mammals to depart from the impact area, and the use of bubbling curtains etc. can reduce impact, although it is unlikely that piling operations can completely avoid causing disturbance or injury. Other aspects of construction, and specifically disturbance caused by vessel movements, can also be minimised. A suggested mitigation measure in the Brims Tidal Array - Environmental Statement (OpenHydro/SSE, 2016) for example, was the development of a vessel management plan which would have established a standard transit route and range of vessel speeds for traffic to and from the array area. To reduce the risk of entanglement for species that frequent particular areas, either through site fidelity or seasonally, the exact placement of tidal and wave farms should be considered in mitigation and risk management. Good mapping is therefore required to take into account for spatial and seasonal sensitivity of species.

²⁶ <https://tethys.pnnl.gov/sites/default/files/EMF-One-Pager.pdf>

Noise pollution can be reduced through underwater noise-reduction measures such as acoustic dampening and shielding; or tuning devices to operate at different frequencies. For example, the OpenHydro shrouded horizontal axis turbine that was planned to be deployed at the Brims Tidal Array in northern Scotland, featured turbine blades that were arranged around the inner side of a circular turbine (the shroud). Acoustic modelling carried out as part of the Environmental Impact Assessment for the project predicted operational noise emissions to be significantly lower than for the more wind turbine-like unshrouded alternative.

With regard to electromagnetic (EMF) interference, some mitigation is already incorporated through industry standard shielding which restricts the directly emitted electrical field, but not the magnetic component. Other possibilities include cable type and design, reductions in current flow, and deeper burial (European Commission, 2018). The MaRVEN study reflects, however, that such measures can have unexpected outcomes. Increasing the burial depth of the cables can mitigate the impact for one species by reducing the EMF dose, but a lower emission may provide a great potential attraction for other species (MaRVEN, 2015). Finally, monitoring enables rapid response / intervention if thresholds (e.g. noise, EMFs) are likely to be breached.

Two case studies are described below:

- MeyGen Tidal Energy Project Phase 1, Pentland Firth, Scotland
- SeaGen Tidal Energy Project, Strangford Narrows, Northern Ireland.

CASE STUDY 1: MEYGEN TIDAL ENERGY PROJECT PHASE 1, PENTLAND FIRTH, SCOTLAND²⁷

The MeyGen tidal stream project was granted a licence in 2014. The licence gave consent for the deployment of up to 61 three-bladed horizontal axis turbines. Prior to gaining consent, extensive surveys and research were undertaken to inform appropriate assessments under the Habitats Directive. The species considered in the appropriate assessments were birds, marine mammals and migratory fish.

At the initial stage of the assessment (screening for likely significant effect), it was necessary, owing to the wide-ranging behaviour of all of the species concerned, to take account of a large number of Natura 2000 sites. Nineteen Special Protection Areas (SPA) were considered, ranging from the Hermaness, Saxa Vord and Valla Field SPA in north Shetland, to the Caithness and Sutherland Peatlands SPA in the south. Seven Special Areas of Conservation (SAC) were identified for marine mammals, extending to the north-east coast of England; and nineteen SACs were examined for migratory fish (Atlantic salmon and sea lamprey).

Marine Scotland, which undertook the assessment, concluded that appropriate assessments were required for 14 of the SPAs; that there was no likely significant effect on any of the SACs designated for marine mammals; and that appropriate assessment was required for all of the SACs designated for migratory fish.

Marine Scotland took account of the low likelihood that the presence of the tidal turbines would affect benthic habitats, that there was an acceptably low risk of pollution incidents, and that collision risk to birds was sufficiently low to have no effect on bird populations and

²⁷ <http://marine.gov.scot/ml/mevgen-tidal-energy-project> & <https://tethys.pnnl.gov/project-sites/mevgen-tidal-energy-project-phase-i>

was able to conclude that there would be no adverse effect on the integrity of any SPA. Similarly, it was able to conclude that the predicted effects of both construction and operation on migratory fish would be of insufficient magnitude to have an adverse effect on the integrity of any SAC.

Critically, however, as a precautionary approach, a condition was imposed that the first phase of the MeyGen project should be limited to no more than six turbines and that monitoring should be undertaken to gain further knowledge of the interactions of fish with tidal turbines, and that this monitoring would inform subsequent appropriate assessment of further stages of the project. It was on this basis that the appropriate assessment was made.

This adaptive response approach is indicative of the way on which uncertainties concerning the impacts of relatively recent developments in marine renewable technology can be overcome within the framework of the Habitats Directive and associated application of the precautionary principle, allowing development to proceed while enhancing understanding of likely effects at future projects.

A second example is the SeaGen Tidal Energy Project.

CASE STUDY 2: SEAGEN TIDAL ENERGY PROJECT, STRANGFORD NARROWS, NORTHERN IRELAND

SeaGen that operated from 2008 to 2019 was an underwater tidal turbine located in Strangford Narrows within the Strangford Lough SPA, Ramsar site, SAC and Marine Conservation Zone (MCZ). Haslet *et al.* (Haslett, Garcia-Llorente, Harrison, Li, & Berry, 2018) used the project to explore stakeholder attitudes to the potential impacts of the turbine. Review of the uncertain effects was carried out iteratively and the effects reduced progressively by careful management and science-led monitoring of agreed indicators of environmental impacts. Data gathered from views of the stakeholders and the reports led to a list of 11 negative impacts related to biodiversity and included: protected habitats, protected species, birds, marine mammals, sharks/other elasmobranchs, teleost fish, shellfish, benthic communities, plankton communities, cabling to land-electric fields, abrasion, and noise/vibration effects on marine mammals. Additionally, two positive impacts were identified: new marine habitat and improved biodiversity protection from access and fishing prevention. These factors were used to inform the development of an Environmental Action and Safety Management Plan (EASMP) to monitor the construction and operation of the SeaGen turbine. The report stressed the importance of stakeholder engagement throughout the development process, in the absence of clear precedent from similar projects. Royal Haskoning (Royal Haskoning on behalf of Marine Current Turbines, 2011) reported the results of a complex, three-year monitoring programme undertaken at, and in the vicinity of, the SeaGen marine current turbine. To answer the key question as to whether the turbine would have adverse effects on marine mammals, the following monitoring techniques were used:

- shore-based survey;
- passive acoustic monitoring (T-PODs);
- carcass post-mortem;
- aerial survey;
- harbour seal telemetry;
- underwater noise monitoring; and

- data collection during mitigation (active sonar).

Key findings of the monitoring work were:

1. No major impacts on marine mammals were detected across the 3 years of post-installation monitoring.
2. Porpoise activity declined during installation; however, there were no long-term changes in abundance of either seals or porpoises that could be attributed to the presence or operation of the device.
3. A few of the metrics monitored were naturally highly variable and therefore comparisons between phases lacked suitable statistical power to confidently rule out undetected changes. This was particularly the case for grey seals and porpoise sighting rates from the shore-based visual observation. However, given the wide-ranging nature of these species, it was considered highly unlikely that any changes at this spatial scale would have a significant effect at the population level.
4. Seals and porpoises regularly made transits past the operating turbine, clearly demonstrating a lack of any barrier effect.
5. The only changes observed after three years of operation of the device were relatively small-scale changes in the behaviour and distribution of seals and harbour porpoises, suggestive of a degree of local avoidance of the device.

Overall, the seals transited at a relatively higher rate during periods of slack tide, indicating avoidance. This avoidance reduced the risk of any direct interactions with the moving rotors and suggested that both seals and porpoises have the capacity to adjust their distributions at local scales in response to a potential hazard. These findings were subsequently analysed by Savidge *et al.* (Savidge, et al., 2014), who noted that the EASMP that was a licensing condition of the SeaGen project was the first programme relating to the environmental impact of a full-scale, grid-connected, commercial tidal device. They concluded that, while several statistically significant effects were shown, the magnitude of these effects was generally very small and so it was considered unlikely that any of the effects would have significant ecological consequences for the area. It was considered encouraging for the industry that this was the case.

3.3.2 Tidal barrage

Habitat change and degradation

Building tidal barrages across and within a bay/estuary will destroy the former benthic habitat under the physical structure and modify other areas within the development footprint. For the construction of the tidal barrage of La Rance, France (see Figure 17), the estuary was closed for 3 years with obviously a large impact on the ecological functioning of the estuary. However, the barrage of La Rance was built more than 50 years ago and it can be assumed that new constructions will be built without closing the estuary or bay.

The presence of a barrage also influences habitats upstream and downstream of the facility. Upstream, under ebb-only generation²⁸, the upper intertidal remains submerged for a longer period; there is then a steady fall in tide level until the tide starts rising again. The former

²⁸ The sluice gates are opened to allow the tide to flood into a basin (estuary, fjord or bay); at high tide the sluices in the barrage are closed and the tide outside falls. Once a sufficient height differential has occurred the turbines are opened and the contained water flows out through the turbines. This continues until the tide turns and the differential head is eroded. The sluices are then opened to allow the basin to refill.

lower shore remains submerged. These changes will shift the balance between marine intertidal species with upper shore specialists potentially being squeezed out. The retention of water also significantly alters the exposure of tidal flats to feeding birds, although the resource in the tidal flats when they are exposed may increase in quantity and quality (Ocean Energy Forum, 2016) (Copping, et al., 2016). Clark (Clark, 2006) suggests that the building of a tidal barrage reduces the tidal range by about half, reducing the availability of intertidal feeding opportunities within the enclosed intertidal area. Loss or disruption of intertidal feeding habitat for passage and wintering waterfowl is the most commonly voiced concern in relation to proposals to develop tidal barrages. The availability of alternative feeding/roosting sites is therefore often critical. Gasparatos et al. (Gasparatos, Doll, Esteban, Ahmed, & Olang, 2017) suggest the provision of intertidal areas/lagoons that can provide feeding grounds during the high water period landward of the barrage. Frid et al. (Frid, et al., 2012) note however that the economics of a barrage or fence scheme scale with the volume of the tidal prism, and hence the most favoured schemes tend to involve large estuaries or bays. But the larger the scheme, the more likely that there will not be alternative feed sites nearby. Clark (Clark, 2006) notes that reduced feeding areas and increased foraging costs (extra flights between sub-optimal grounds) will directly impact on population size. He expects that a substantial number of birds that use the estuary would be displaced and would be forced to settle in new wintering or stopover areas. In contrast to birds, Frid et al. (2012) expect the implications for tidally feeding fish are the opposite with greater periods for foraging available due to the retention/raising of water levels.

Downstream of the barrage, tidal range is also altered with likewise negative implications for birds, but the effect occurs at the same time as the flats above the barrage become exposed. Energy generation on the flood and ebb (dual mode²⁹) reduces considerably the changes in exposure of the intertidal area and so reduces potential impacts on the bird community, because the extent to which intertidal habitat is unavailable to feeding birds is reduced¹⁸.

Changed spatial flow patterns will result in altered patterns of sediment deposition and movement. These will have impacts on benthic communities. The outflow will be constrained to the locations where the turbines are, and in these areas sediments will be scoured and coarsened while upstream of the barrage the reduced flows and periods of no flow will lead to increased siltation and potentially an increasing quantity of fine material in the deposits. Changes in the nature of the habitats will alter their suitability as nursery or spawning areas for fish (Graham, Farcas, Merchant, & Thompson, 2017) (Ocean Energy Forum, 2016). Clark et al. (2006) also warns for a reduced inundation of long-established saltmarshes, leading to them becoming freshwater marshes, though this could be mitigated by flood pumping to ensure their continued existence.

Direct impact: barrier, collision, entanglement

Tidal barrages produce a barrier for fish and marine mammal passage. Collision risk of tidal barrages will be higher than for tidal and wave stream devices. Fish may move through sluices safely, but when these are closed, fish will seek out turbines and attempt to swim through

²⁹ Dual mode tidal energy generates power on the flood tide by refilling the basin through the turbines, while this generates power for more of the tidal cycle in comparison with ebb-only generation, it generates less power in total as there is less of a differential head. Both tidal flows may be harnessed in dual mode devices.

them. Also, some fish will be unable to escape the water speed near a turbine and will be sucked through. High-speed turbines can cause direct mortality of fish passing through, or the disorientation caused by passing through may lead to lowered ability to avoid predation in the period after passage.

Noise and vibrations

A tidal barrage is a major civil engineering structure, and so construction (and decommissioning) activities will include considerable noise generating activities. Environmental impact of these activities will be similar to the construction of tidal and wave farms.

Like for tidal and wave devices, little information is available on environmental impact of operational noise from generators, rotating equipment, and other moving parts.

See section 3.3.1 for more information.

Electromagnetic Interference

See section 3.3.1 for more information.

Best practice mitigation measures

Construction of a tidal barrage will require considerable noise generating activities. Activities during construction phases (such as vessel movements) should be planned outside sensitive periods, such as fish migratory seasons, to minimise disturbance.

After construction, the tidal barrage produces a barrier for fish and marine mammal passage. Siting of these structures will need to assure that they do not constrain access to fish and turtle spawning and nursery grounds, or access to feeding, haul out, breeding and pupping areas of marine mammals. Next to appropriate siting, engineering mitigation options are available to allow spaces for fish to pass, using salmon ladders, etc. To reduce collision risk, design measures that reduce fish entrainment should be implemented. Lowering turbine velocity will also decrease fish kills from physical contact with the blades (Graham, Farcas, Merchant, & Thompson, 2017) (Ocean Energy Forum, 2016). From the findings of the SeaGen (former tidal turbine in Northern Ireland) operational monitoring programme, Gasparatos et al. (Gasparatos, Doll, Esteban, Ahmed, & Olang, 2017) argue that the blades had no influence on animals that can hunt down prey in fast-moving and turbulent waters due to their low rotation speed. Animals are not more likely to collide with turbine blades than with rocks.

Just like for tidal stream energy production, noise pollution can be reduced through underwater noise-reduction measures such as acoustic dampening and shielding; or tuning devices to operate at different frequencies. Also with regard to electromagnetic (EMF) interference, the mitigation measures used for tidal stream energy production can be beneficial (e.g. shielding, changes in cable type and design, reductions in current flow, and deeper burial) (Hastie, et al., 2017). See more info in Chapter 3.3.1.

Finally, monitoring enables rapid response / intervention if thresholds (e.g. noise, EMFs) are likely to be breached.

4 SUMMARY

Solar energy

With respect to solar energy, negative impacts to biodiversity are largely depending on site-specific aspects. The main negative impacts of solar farms are habitat loss and degradation, and fragmentation (barrier effect by fencing). Impacts can be significant if the solar farm is located in sensitive habitats such as extensive grasslands (e.g. steppe grasslands with high biodiversity values). Therefore, avoidance of the Natura 2000 network remains desirable. Disturbance and displacement effects on birds and bats might occur (e.g. light disturbance). The impacts of floating solar are less known but significance will be highly dependent on the biodiversity value of the water body (e.g. important area for wintering and migrating waterfowl). Solar farms however, often can provide excellent opportunities for creating or enhancing biodiversity and this is being put in practice in many EU countries. As an example, habitats can be created between (e.g. wildflower strips) the solar panel arrays or on the borders of the site (e.g. hedgerows).

Geothermal energy

Knowledge about impacts of geothermal energy projects on Natura 2000 sites limited, and is considered to be mainly related to the construction of the site. Habitat destruction and degradation can be avoided by appropriate siting, often instructed by SEA or EIA and AA in case of potential significant impacts on site integrity of Natura 2000 sites or on Annex IV species. Generally, geothermal developments and operations need a relatively small area. Construction impacts on vegetation can be minimised through careful planning of plant layout and road layouts to minimise land intake, and the use of directional drilling. Control of drilling effluent is controlled via the Water Framework Directive and can be achieved through water treatment and the use of drilling waste sumps. Technical solutions are available to minimise noise emissions, such as insulation of installations, reduction of turbine speed, noise barriers, etc. In general, in all cases where geothermal plants are located in areas with high biodiversity values (e.g. Natura 2000 sites) intensive monitoring should be implemented to avoid any harmful impact.

Ocean energy

Finally, with respect to ocean energy, despite the limited available data by now, it looks like impacts on wildlife are of a much lesser magnitude than earlier anticipated. This is definitely the case for tidal stream and wave energy. The risk on significant impacts is higher for tidal range energy, due to the use of a tidal barrage.

For tidal stream and wave energy habitat destruction and degradation, as well as barrier, collision and entanglement impacts are limited. Noise disturbance might be significant but this is totally dependent on the construction typology (e.g. piled foundations for tidal current turbines). Tidal barrages in particular may result in marked alterations to estuarine sediment dynamics and intertidal habitat exposure, with consequent shifts in habitat availability for birds and intertidal species. They might also have significant barrier and collision impacts. Mitigating measures related to ocean energy are similar to those applied for the construction of offshore windfarms, such as appropriate siting, avoiding sensitive periods (e.g. fish migratory seasons) and 'soft start' techniques when piling is used, whereby the intensity of piling is gradually increased over a sufficient period to allow sensitive marine mammals to

depart from the impact area. Good mapping is therefore required to take into account for spatial and seasonal sensitivity of species. Finally, monitoring enables rapid response/intervention if thresholds (e.g. noise, EMFs) are likely to be breached.

The current approach of permitting small-scale developments and closely monitoring their effects provides much-needed information but must be replicated several times before sufficient confidence can be gained to proceed with utility-scale developments. In order to minimize the potential impacts, testing is recommended to be done outside core biodiversity areas, including Natura 2000. With the European Commission recognizing ocean energy to have an enormous potential to contribute to meeting 2030 targets, it is essential that research and development continues and accelerates

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