Environmental impacts of tidal power plants

Current status of the environmental impacts of conventional tidal power plants

*Claas Bredehöft**

FH Münster, Stegerwaldstraße 39, 48565 Steinfurt

Abstract

Meanwhile, renewable energy sources such as hydropower, solar and wind energy and biomass are increasingly being used to reduce dependence on fossil fuels and thus counteract the ongoing global warming. However, these are also associated with environmental impacts. To that effect, this article takes a closer look at tidal power plants, which are classified as hydroelectric power plants, by conducting a systematic literature review. The results show that the strength and form of the environmental impact depends on the specific location and type of plant. Tidal power plants have an impact on the habitats of marine animals and thus influence their behavior and population. In addition, the operation of tidal power plants changes the sediment distribution, causes a reduction in current velocities and a change in current direction in the surrounding area and leads to a change in wave height. The construction of the power plants is associated with noise, which primarily causes changes in the behavior of some species. Furthermore, the electromagnetic fields generated can also affect marine life. In order to assess the environmental impact of tidal power plants in comparison to other renewable energies, further studies should focus on the environmental impact of the different technologies in relation to the energy yield.

Keywords: tidal power plants, environmental impacts, tidal barrage, tidal stream, hydropower plants, renewable energy

1 Introduction

In recent centuries, fossil fuels such as coal, oil and natural gas have been used to generate electricity in power plants. However, these conventional energy sources emit greenhouse gases such as carbon dioxide when they are used. In order to counteract the ongoing global warming, there is an urgent need to reduce greenhouse gas emissions by reducing the consumption of fossil fuels. Instead, renewable energy sources such as hydropower, solar and wind energy and biomass are increasingly being used to reduce dependence on fossil fuels. Hydropower plants also include so-called tidal power plants, which are examined in more detail in this article. These use the tidal movements of the oceans to generate energy. Tidal power plants are therefore supposedly an emission-free and environmentally friendly source of energy. However, it should not be forgotten that renewable energy sources can also have a negative impact on the environment. The improper use of these can have the opposite effect to the basic idea of environmental protection. For this reason, this article will examine the impact of tidal power plants on the environment. The exact impact may depend on the type of power plant and its location. More detailed information on tidal power extraction methods can be found in Ref. [1, 2], while more information on operating locations can be found in Ref. [3]. Fig. 1 shows the theoretically achievable global energy yields from tidal power and shows which locations are suitable worldwide.

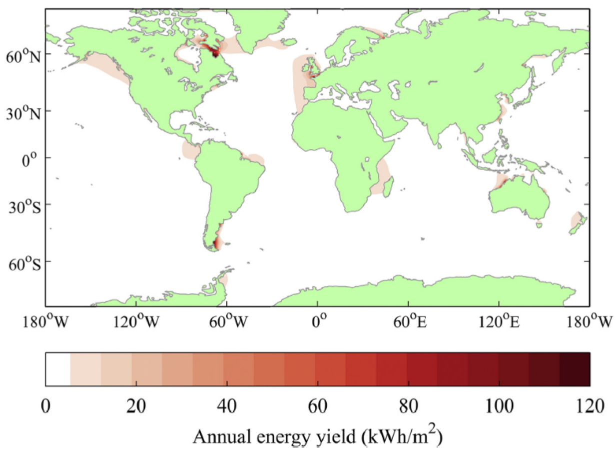

Fig. 1: The global theoretical tidal range energy resource calculated as annual energy yield (kWh/m^2) per model grid cell (1/16° x 1/16°) [4], licensed under a Creative Commons Attribution (CC BY) license.

*Corresponding author: claas.bredehoeft@fh-muenster.de.

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2 Methods

A systematic literature search was carried out for the data in this article. The Google Scholar search engine was used to search for relevant literature. Various English and German keywords were used, which are listed below:

- Environmental implications tidal range power plants
- Environmental impacts tidal power plants
- Gezeitenkraftwerk ökologische Auswirkungen
- Gezeitenkraftwerke
- Gezeitenkraftwerke Auswirkungen auf die Umwelt

The German keywords did not lead to any well-founded literature in the search. The main scientific articles on the topic under investigation were written in English. When searching for literature, care was taken to ensure that the sources were not outdated and that they addressed current developments and research into tidal power plants in order to reflect the current situation with regard to environmental impacts.

3 Results

As many tidal power plant technologies are still at the development stage, there are only a few studies on the environmental impact of such technologies [3]. In the following, the currently known environmental impacts of tidal power plants will be discussed in more detail.

3.1 Impacts on habitats and species

3.1.1 Tidal barrage generators

The construction of a tidal barrage at a bay or estuary destroys the pre-existing benthic habitat (the benthos is the entirety of all living organisms found in the bottom zone of a body of water) on the construction site. In addition, the construction and decommissioning work may have an impact on adjacent tidal areas due to the provision of caissons or staging areas. Additionally, the dam affects the habitats upstream and downstream of the facility. When the stored water from the reservoir is released during low tide phases to drive the turbines, the water level in the reservoir decreases until the tide returns. The former lower bank remains flooded. This change leads to a shift in the balance between species in the intertidal zone, with species that specialize on the upper shore potentially being displaced. The retention of water also significantly alters the exposure of mudflats for feeding birds, although the resources on the mudflats may increase in quantity and quality as they are exposed. Therefore, the availability of alternative feeding and resting sites is often crucial [5].

Downstream, the tidal range is often reduced near the dam, while it is increased in other parts of the reservoir. The outflow delays the outgoing tide from about mid-tide so that the tide flows as usual or faster from high tide until the turbines open at mid-tide, after which the outflow velocity decreases or stops. This has a potentially negative impact on birds, although this effect occurs simultaneously with the exposure of the mudflats above the dam. Power generation in dual mode (both ebb and flood tides are used to drive the turbine) reduces the changes in exposure of the intertidal zone and therefore the potential impact on the bird community. The impact on fish that feed on the tides is inverse to that of birds, as the rise in water level gives them more time to forage [5]. However, the step in the dam hinders salmonids, shad and eels from migrating to breed. They may therefore try to pass through the turbines, which increases fish mortality. The structure of the dam also creates an artificial reef on which new species begin to colonize. Despite the massive change in habitat in the bottom zone described above, a net increase in species diversity can still be observed [2].

Furthermore, the disturbance of the river can lead to a change in the turbidity and salinity of the water, which can be harmful to fish, birds and other creatures. The birds living in the estuary depend on salt marshes that grow near the mudflats and form the natural transition between land and sea. Under natural conditions, the tides bring nutrients ashore that support the growth of these salt marshes. The habitat in the intertidal zone consists of two areas. In the high marsh area, black grass (spike grass) grows in the upper area and in the lower area towards the sea, short, smooth cordgrass (salt meadow cordgrass) grows in this section. In the second section, the low marsh area, smooth cordgrass can be found. By influencing the tides as described above, the nutrient supply for these plants is reduced. As a result, the low marsh loses most of its smooth cordgrass, while in the high marsh only a few black grasses remain near the high tide line [2].

The economic viability of a tidal barrage project depends on the volume of the tidal prism (the difference between the highest and lowest water levels), which is why large estuaries and bays are preferred as locations. However, the larger the project, the more likely it is that there are no alternative feeding sites for waders in the vicinity. Fewer feeding areas are associated with increased foraging effort and have a direct impact on population size, as does lower food quality [5]. Environmental pollution from the machines used in the power plants must also be taken into account, as this can have a negative impact on the species, such as the release of hydraulic fluids, lubricants and toxic anti-fouling coatings into the surrounding water [3].

3.1.2 Tidal stream generators

The installation and operation of tidal stream generators also directly affect the benthic habitat at the chosen site by altering water currents, wave structures or substrate composition and sediment dynamics. Small pilot projects on tidal stream power generation have shown that the physical effects are reversible when decommissioned, particularly because strong currents lead to a natural disturbance of the sediments at suitable sites. However, the cumulative effect of multiple turbines must be considered in terms of the impact on the surrounding environment. The deposition of sand can affect seagrass beds by increasing mortality and reducing the growth rate of plant shoots. Conversely, the deposition of organic matter in the wake of tidal stream power plants could promote the growth of benthic invertebrate species that are adapted to this substrate. While the new habitats created by such structures may increase the abundance and diversity of invertebrates, predation by fish attracted to artificial structures may lead to a sharp reduction in the number of benthic organisms [5].

Direct mortality of fish passing through turbines can be high and the disorientation resulting from fish behavior in relation to turbines can affect species viability. However, there is extensive experience with designing sluices, cooling water intakes and turbines to reduce fish injury. These mitigation measures are a critical part of any turbine design and can help to reduce the impact of a tidal stream generator on fish [5]. Studies have observed interactions between fish and turbines, with three distinct behaviors noted. Firstly, some schools of fish feel neither attraction nor repulsion towards the turbine and therefore do not change their course of movement. Secondly, some swarms avoid the turbines by changing direction. Finally, about 5% of the fish passed the turbines directly [2].

The operation of tidal power plants differs significantly from that of tidal barrages. In the latter, a high-speed turbine is installed in a tunnel through which the water flows at high speed and high pressure. As a result, the entrained organisms have little or no chance of passing through the turbine. The system of a tidal stream generator can work without any rotating turbines at all. Some are based on the rocking oscillation of a beam with hydrofoils at both ends. When rotary turbines are used, they are mounted in the open flow field so that the rotational speed is much lower and the organisms have adequate opportunity to avoid direct contact [5]. As a result, the chance of a blade strike can be considered to be low.

No detailed information is available on the collision risk of marine mammals with tidal stream power plants. However, the likelihood of cetaceans failing to detect and avoid a large static structure is considered to be extremely low, especially for species that are echolocating, agile and fast moving. As part of risk mitigation management, the exact placement of a tidal power plant must take into account the species that visit certain areas either through site fidelity or seasonally. Furthermore, the impact of tidal stream generators on seabirds has been reported to be low. With the exception of some deep-diving species such as auks, guillemots and shags, which regularly dive to depths of 45-65 m, the risk of collisions is considered minimal. Given the slow turbine speeds compared to the agility of diving bird species, the risk of mortality is very low. However, diving birds may perceive the moving rotor blades as potential prey and therefore be attracted to their vicinity [5]. Concrete information on the probability of collision is not yet available.

3.2 Impacts on water flow and sediment distribution

3.2.1 Tidal barrage generators

The narrowing of the flow leads to turbulent currents downstream of the dam during outflow and immediately upstream during inflow, which increase mixing. Upstream, the water is static for much of the tidal cycle in the reservoir, leading to stratification and changes in phytoplankton dynamics in summer. Primary productivity is limited and reduced by high turbidity. Energy production can influence turbulent mixing and alter sediment distribution patterns. Currents with a speed of 9 to 15 km/h lead to a continuous intensive mixing process in the water column. At lower speeds, a certain degree of stratification of the water column can be expected. This can lead to increased water clarity due to reduced sedimentation [5].

According to Ref. [2], there are 5 estuaries on the west coast of the United Kingdom (UK) that have the potential for power generation from tidal barrages. Analysis has shown that these dams can increase the tidal amplitude on the east coast of Ireland, resulting in coastal flooding [2]. The impact of tidal barrages on tidal dynamics can also have a massive impact on other coastal areas that are not in the vicinity of the installation site and lead to flooding there.

3.2.2 Tidal stream generators

Tidal stream power plants increase turbulence in the water column, which in turn alters mixing characteristics, sediment transport and possibly wave characteristics. In both the near and far reaches, the extraction of kinetic energy from the tides reduces tidal amplitude, current velocities and water exchange in a region

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in proportion to the number of units installed, potentially altering hydrography and sediment transport [5]. Studies show that sediment transport depends on grain size. Furthermore, in some cases a tidal stream power plant can also cause a change in current direction [2]. In addition, tidal turbines can change the wave height by using the energy of the underlying current. The impact of structural drag on currents is not expected to be significant [5].

3.3 Noise and vibration

Tidal barrages and tidal stream power plants are all large structures whose construction and decommissioning are associated with significant noise impacts that are potentially harmful to marine life. During construction, noise and vibrations affect different species in different ways. Pile driving, blasting and seismic work, mostly required for installation, are likely to exceed nearby noise level limits for the protection of fish and marine mammals. Although the activities during the construction and decommissioning phases are short-lived, they have the potential to impact cetaceans. At offshore wind farms in Denmark, effects on the behavior and population of harbor porpoises were observed during pile driving. Fewer animals were foraging and there was a short-term reduction in echolocation activity. These effects were documented up to a distance of 15 km from the impact area. As soon as the construction work was completed, these effects were short-lived. Studies suggest that impulsive sounds at high levels have a greater impact on cetaceans than on pinnipeds. The effects on other species are not certain. Direct effects may include damage to sensory or sensitive tissues and indirect effects may include changes in behavior. When evaluating noise impacts, it is important to assess the cumulative impact of the entire system and not just the levels generated by individual elements [5].

It is considered unlikely that the operational noise from any of these facilities is ecologically significant, although very little information is available on the noise levels generated by the operation of tidal barrages and tidal stream power plants. In addition, there are very few specific studies on the response of fish and marine mammals to noise and vibration generated by operations. In the case of tidal stream power plants, operational noise from a small number of units may not exceed the thresholds, while cumulative noise generation from a large number of units may mask communication and echolocation sounds generated by aquatic organisms in the vicinity of the structures. Habituation effects must be taken into account in the behavioral responses of marine mammals to noise [5].

3.4 Electromagnetic fields

The environmental impact of electromagnetic field emissions from cables, switchgear and substations is the same regardless of the power generation facility and therefore the lessons learned from offshore wind developments are also applicable to tidal stream developments. The electricity generated by the existing tidal barrages is carried away via cables on top of the barrage and has no impact on the marine environment. For a typical industry standard cable, it has been shown that the electromagnetic field drops to a background level (approx. 50 μT) within 20 m of the cable. It has also been shown that induced E-fields of up to 91 μV are emitted from cables buried up to 1 m in the sediment [5].

High-voltage DC cables can generate fields of up to 5 μT in up to 60 m around them. Some shark species have been shown to respond to localized magnetic fields of 25-100 μT. There is also evidence that a 3-phase 130 kV cable (not buried) can be perceived by migrating European eels, but does not interrupt their migration [5].

For sea turtles, the effects of magnetic field disturbance range from minimal (i.e. temporary disorientation near a cable or structure) to significant (i.e. altered nesting patterns and corresponding demographic shifts due to large-scale magnetic field changes). In contrast, the survival and reproduction of various benthic organisms are not affected by long-term exposure of static magnetic fields. The evidence for the influence of electromagnetic fields on marine mammals is equivocal [5].

4 Discussion

The previous section presents the currently known environmental impacts of tidal power plants, some of which have already been investigated in more detail. Some of the impacts listed are based on predictions, as there is insufficient information available to the present day. These need to be investigated in more detail in order to obtain evidence. However, the majority of the environmental impacts mentioned have been proven with precise investigations and studies, so that this article provides a well-founded overview of them. The impacts that have not yet been proven are based on the assessment of technical experts and can therefore be classified as probable, as they are based on experience and deductions from other similar areas.

This article refers to the environmental impacts of conventional tidal power plants. These include tidal barrages and tidal stream power plants. Dynamic Tidal Power (DTP) technology offers an alternative to these. This is a newly developed and patented method for generating large amounts of energy from

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the tides, which promises to be cost-efficient and environmentally friendly. While DTP's energy source differs from the well-known concepts of tidal barrages and tidal stream power plants, the technical implementation is based on mature and reliable prefabricated concrete caissons containing turbines. However, DTP does not work with a closed reservoir like a tidal barrage, but catches the tidal energy as it flows through. Using a very long (>10 km) perforated dam built from the shore, Newton's second law is used as an energy source in reverse [6]. This article does not refer to this technology, which means that the environmental impacts listed cannot be transferred to DTP. DTP must be considered and examined individually.

5 Conclusion

Tidal power plants are generally located in coastal areas in bays, estuaries, inlets or straits that are characterized by strong tidal currents. In addition to the great potential for electricity generation, coastal waters also provide important near-shore habitats for many species of marine animals such as seabirds, fish and marine mammals. The construction of tidal power plants in coastal seas causes disturbance to the marine environment. First of all, tidal power plants change the habitats and thus influence the behavior and population of the species living there. In addition, the operation of tidal power plants can lead to a change in sediment distribution, a reduction in current velocities in the surrounding area, a change in current direction and a change in wave height. The construction of the power plants is also associated with noise, which primarily causes changes in the behavior of some species. The impact of operational noise on species is classified as minor. The generated electromagnetic fields can also have an impact on marine life, causing them to become temporarily disoriented in the vicinity of a structure or cable or to adapt their reproductive behavior.

How much and in what form a tidal power plant affects the environment depends on the specific location and the type of plant (tidal barrage or tidal stream power plant). As part of renewable energy, tidal power plants offer significant benefits by avoiding greenhouse gas emissions and providing a predictable and reliable energy supply. However, the impact on marine life and the limited availability of suitable sites pose challenges. Ongoing research and technological advances aim to mitigate these disadvantages and make tidal energy a more sustainable and environmentally friendly energy source. Dynamic Tidal Power (DTP) technology may be able to play a key role in this.

6 Outlook

It is imaginable that tidal power plants, as part of renewable energies, will play a greater role in the global energy supply in the future than they have done to this day. However, this share will be restricted by the limited availability of suitable sites, so that it will probably never be as large as that of wind turbines, for example, as these are better researched and developed and more potential sites are available. When deciding which renewable energies to use in the future, the environmental impact of the various technologies should be taken into account. In order to assess the environmental impact of tidal power plants in comparison to other renewable energies, further research should focus on the environmental impact of the different technologies in relation to the energy yield. The comparison can help to better understand the relative environmental impacts. When comparing the use of tidal power with the use of other renewable energy sources, it is also advisable to consider Dynamic Tidal Power (in contrast to tidal barrage and tidal stream).

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