The environmental effects of utilising tidal current energy devices for energy output

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Abstract— **Ocean renewable energy has become a necessary alternative to the currently adopted renewable energy systems. Tidal current turbine technology is still at an early stage of development. Environmental effects, and a deficiency in the understanding of the environmental concerns, has become one of the significant obstacles to overcome to enable full commercial development. However, there is a growing body of work describing and evaluating the most significant environmental aspects of tidal current turbine technology. At the forefront of this research is the development of comprehensive environmental impact assessment methodologies. This review provides an overview of the literature that discusses the environmental effects of operating tidal current turbines. This paper focuses on life cycle analysis, environmental stressors and environmental receptors of the tidal current turbine technology. This important work also discusses the implications of the environmental effects on marine wildlife, and near and far field environmental stressors. Finally, this paper presents details on some of the most significant challenges facing tidal energy technology development.**

Keywords—**Tidal current turbine, life cycle, environmental stressor and receptor, horizontal-axis tidal current turbine.**

I. Introduction

TIDAL energy has the potential to provide an addition to commercially available renewable energy technologies, such as solar and wind energy systems. However, tidal energy offers greater reliability than solar and wind energy and it is predictable over large time-scales. Similar to the technological advances of wind turbine design, emerging developments on tidal turbine designs are making the installation of tidal current turbines increasingly viable and economically feasible. However, the risk to the marine environment and marine organisms, from tidal energy systems, has not been extensively studied. Poor understanding of environmental effects are one of the top barriers that prevents the tidal energy industry and energy regulators from commissioning turbines in the most energetic tidal sites [2].

In 2016, the Ocean Energy Strategic Roadmap by the Ocean Energy Forum 2016 was released together with the Strategic Research Agenda for Ocean Energy released by Technology and Innovation Platform for Ocean Energy (TPOcean 2016) which proposed a number of actions to identify gaps and barriers that have been hindering the sector [3]. According to Magagna [4], horizontal axis turbines have reached a technology readiness level (TRL) of 8, which indicates that tidal energy has reached a high level of maturity. However, the key bottlenecks for the ocean energy sector is financing of projects and the concern regarding unknown environmental impacts which, in turn, slows down consenting and licensing of projects [4]. Critical knowledge and information gaps hinder the development progress of evaluating environmental impacts. Understanding the extent of ecological impact of marine renewable energy device as part of an environmental impact assessments is fundamental for the conservation of marine mammals at tidal energy sites [5].

It is important to differentiate between environmental effects for the purpose of evaluating an environmental impact. Furthermore, the environmental risks of the technology require greater consideration and demand detailed comprehension [7]. Environmental effects are the broad range of potential measurable interactions between tidal energy devices and the marine environment. Environmental impacts are effects that, with high certainty, rise to the level of deleterious ecological significance [7].

There exist 3 main types of tidal current turbine, namely: horizontal axis turbines, vertical axis turbines, and oscillating hydrofoil [8]. It is important to note that this paper refers to a horizontal axis turbine when tidal current turbine is mentioned.

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This paper references to some pilot tidal energy projects. A well-known tidal current turbine SeaGen is located in Strangford Lough, Northern Ireland and another in the Bay of Fundy, Canada. The SeaGen tidal current turbine was one of the world's first grid connected commercial tidal current turbines and the company behind it is Marine Current Turbine Ltd, now currently known as Atlantis Resources Ltd. Other well-known tidal companies include OpenHydro Ltd with two successful commercial-scale turbine projects that were successfully retrieved from tidal sites in April and July 2017 for maintenance. Another familiar name is the MeyGen project by Andritz Hydro Hammerfest (UK), which it has the largest planned tidal farm project worldwide [8].

The main objective of this paper is to provide an overview of the literature that discusses the environmental effects of operating tidal current turbines on the surrounding marine environment. This works is structured as follows: Section 2 provides an overview of tidal turbine life cycle and the main energy and carbon intensities; Section 3 discuss the environmental stressor (environmental effect) of tidal current turbines; the concerning stressor will be related to each environmental receptor in Section 4; Section 5 discusses the challenges for further technological development; the critical gaps in the knowledge and recommendations are discussed in Section 6; Section 7 concludes by summarising the key aspects of each of the described environment effects.

II. Life Cycle

One of the best ways to assess the environmental impact of a tidal current turbine is to consider the life cycle analysis of the product. The life cycle analysis for a tidal current turbine evaluates the raw materials, manufacturing, transportation, installation, operations, maintenance, decommissioning and disposal.

According to Uihlein [9], tidal current turbine design and manufacture demand more materials per installed capacity compared to other renewable energy technologies. The high-power density nature of ocean energy allows for higher efficiency devices; however, it also demands for higher materials input for reliability and survivability. Results obtained by Uihlein [9] supports a study by Douglas et al. [10] which states that the main environmental impact from tidal energy devices is due to the use of materials. Douglas et al. [10] analysed the 20 years life cycle of the 1.2 MW SeaGen tidal current turbine. The paper states that the gross embodied energy without the recycling credit is 25,903 GJ, and the materials and manufacturing stage accounts for 86% of gross energy consumption and 1,924t of CO_2 with the same approximate proportions. The respective energy and carbon intensities are comparable with large wind turbines at 214 kJ/kWh and 15 gCO_2/kWh respectively. The energy payback period is approximately 14 months and the CO_2 payback is around 8 months.

Walker et al. [11] compared the life cycle for four different tidal current turbines, namely OpenHydro, Flumill, ScotRenewables and TGL devices. The analysis is based on the turbine's functional unit of 10 MW over 100 years. The CO_2 intensity of the devices ranges from 18.5 to 34.2 gCO_2/kWh. The values are positioned alongside more established renewable energy sources such as solar PV and biomass. The energy payback period ranges from 7.2 years to 11.2 years and the CO_2 payback periods ranges from 3.5 years to 5.9 years. The results yielded the same conclusion with the total embodied energy and CO_2 concentrated in the materials of the devices.

Environmental effects can be reduced as tidal current turbine technology is still being developed. Improvements on increased efficiency, durability and reliability as well as better mooring systems will not only reduce installation and operation cost, environmental effects will be reduced as a result. For example, a 50% increase in the device lifetime could reduce the life cycle environmental impact of tidal current turbines by 33%, as all significant impacts stem from the manufacture, assembly, installation and end of life and not during the operational stage [9].

Life cycle analysis on a tidal current turbine in general concludes that better turbine design and improvements in material technology will potentially reduce environmental impact of tidal turbine even further [10], [11]. However, Uihlein [9] provided another approach in reducing the environmental impact by installing tidal current turbines in arrays or farms, since components can be shared and efficiencies increased.

III. Environmental Stressors

In 2010, a workshop in Seattle on the environmental effects of tidal energy development has conceptualised the environmental effects of tidal current turbines into terms of stressor and receptor interactions for ease of discussion and focus. The approach used in this paper provides an encompassing framework. According to Polagye et al. [7], stressors are those factors that may occur as tidal energy systems are installed, operated or decommissioned.

A. Presence of Devices: Static and Dynamic Effects

Tidal energy devices have to be secured to the seabed using either a monopile or gravity foundation with the necessary cables and anchors which will be static for the duration of the device's operational life cycle. These static structures are associated with near-field physical environment such as habitat and ecosystem interactions.

The severity of static stressor effects is dependent on the structure types as well as the geographical and habitual nature of the installation site. In a suitable condition, the static structures may act as an artificial reef, affecting scour and deposition, and providing a new habitat for reef friendly species. The change in ecosystem might attract new predators. Decommissioning the devices and cables might have a greater effect, as it would remove a habitat used by resident marine life [7].

B. Blade Strike

As oppose to tidal barrages that limit the passageway of fish to pass through, tidal current turbine does not have a physical wall that constraints the passage through the tidal domain. However, placing tidal turbines randomly on the ocean floor where fish and marine mammals populate still warrants a study to assess the risk involved. Romero-Gomez and Richmond combine computational fluid dynamics (CFD) with Lagrangian particle tracking methods to provide a realistic representation of blade strike mechanisms for fish [12]. The results from the simulation with a specific turbine with blade thickness (10 mm to 150 mm) and two fish species (juvenile Salmonid and adult Atlantic sturgeon) representing large and small fish size, indicated a mortality rate of less than 4%. The main factor for low mortality rate is the lack of supporting structure that produce contraction of the fluid flow through the runner which yields lower flow velocities than conventional hydro-turbines which directly reduce the impact velocities of tidal current turbine collisions. Nevertheless, this conclusion cannot be generalised due to the variety of designs of tidal energy devices.

The potential for marine mammals to collide with a tidal current turbine exists. Harbour seals are usually chosen as test subjects that represent the marine mammal collision experiment. The reason being major tidal development in the UK and the northern Irish Sea, are deployed in areas where harbour seals occupy. However, harbour seal population is in decline and afforded a high level of protection therefore increasing the level of scrutiny by the regulators in the UK. This has led to extensive monitoring around the SeaGen tidal current turbine, amassing extensive datasets of seal movements before deployment, during construction and after deployment.

According to Copping et al. [13], a hypothetical example of three tidal current turbines (10 m blades) with a 15 m hub height. The turbines are placed at intermediate depths in the water column. According to UK telemetry data, seals typically occupy this rotor swept area 25% of the time. The turbines are placed in a tidal channel with a width of 1 km and a depth of 30 m. It is assumed that the seal acts as a point traversing the blade. The results show that the probability of a seal entering the blade swept area of the tidal current turbine is 79%. The probability of the seal encountering the blade is 0.05%. The probability of the seal sustaining a serious or fatal injury is 0.005%.

The overlap in depth distribution between the tidal current turbine and the seals is small which significantly reduce the risk of blade collision [13]. Additionally, this experiment on seals and their behaviour may be site-specific and the behaviour around different tidal sites may vary.

C. Pressure difference

The effect of the pressure difference caused by the operation of tidal current turbines on marine mammals and on the surrounding environment are usually classified as not significant [14]. Moreover, this is due to comparisons made with hydroelectric turbines (e.g.: Kaplan Turbine). For a hydroelectric turbine, the head difference before and after the turbine presents the biggest issue regarding the interaction between the turbine and fish, however tidal current turbines do not suffer from this problem.

According to Zangiabadi et al. [14], the swim bladder in fish is the main organ that is affected by rapid pressure changes. It is typically assumed that the swim bladder obeys Boyle's law which reduces complexity when developing numerical models to determine the pressure difference in the swim bladder and potential impacts.

Another reason tidal current turbine pressure change has less effect on fish mortality is the exposure time. In comparison, the pressure spike in conventional hydroelectric turbines occurs, typically, for a period of 0.2 s, while tidal current turbines occur for a period of 0.5 - 1 s.

Although the effect of pressure change is not significant compared to hydroelectric turbines, the sudden changes in pressure experienced by fish whilst traversing a tidal current turbine will have some effect, some fish rely on their swim bladder to regulate gases to adjust their depth in the water, thus post traversal of a tidal current turbine may affect the fish's ability to regulate their swim bladder which will affect their basic biological functions, i.e. feeding, locomotion, and reproduction. It is also important to note that this particular issue only applies to fish that have a swim bladder.

D. Energy Removal

Energy removal became a high priority area of concern when various modelling studies had shown that large-scale arrays of tidal current turbines have the potential to significantly impact the hydrodynamics in the surrounding area [1], [8], [15]–[18]. Unlike other environmental effects which are device specific, energy removal effects are broadly similar across all devices. According to Nash et al. [15], changes to the hydrodynamics may effect water quality, such as sediment transport impacts, impacts on bacteria levels, salinity and temperature, flushing times and primary production. A few examples are given where tidal current turbine arrays were modelled on tidal site locations, for example Severn Estuary/Bristol channel, and Muskeget Channel, New England, USA [15]. The results show that suspended sediment levels strongly correlate with velocity changes. Reduced sediment levels occur in areas of reduced velocities inside, upstream and downstream of the array. Sediment levels rise in high bypass velocities to the sides of the array. Changes in sediment levels can travel up to 15 km from the tidal current turbine arrays and erosion streams are expected adjacent to arrays.

Another impact on the water quality is bacteria levels and salinity. There is a direct correlation between levels of suspended sediments and bacterial concentrations [15]. Tidal current turbine arrays with smaller spacings between turbines have the greatest effect on the change in bacteria levels.

Energy extraction also significantly effects the flushing time and it increases non-linearly with respect to the number of turbines in the array. Based on a study that looked at the effect of arrays of different densities on local flushing times in the Shannon Estuary, Ireland. Lower density arrays (more spacing between turbines) significantly reduces the flushing time even for large numbers of turbines.

E. Benthic and Habitats

A more direct effect of tidal current turbine wakes is friction with the seabed which may lead to the formation of benthic boundary layer [19]. A benthic habitat is the ecological region at the base of the ocean floor [1].

O'Carroll et al. [20] assess the effect of an operational tidal current turbine wake on epifaunal boulder reef communities (benthic habitats) adjacent to the SeaGen tidal current turbine. The author uses an Artificial Neural Network (ANN) and a Generalised Linear Model (GLM) to predict the distribution of Ecological Status (ES) of the benthic habitat. The ecological status is based on a Water Framework Directive compliant multimeric index which is the High Energy Hard Substrate (HEHS) index. According to the HEHS index, the SeaGen tidal current turbine has negative influence on benthic communities immediately between and adjacent to the device quadrat legs. However, the negative effects dissipate quickly beyond the device quadrat legs. A single tidal current turbine is unlikely to have a large-scale impact. It is safe to assume a tidal current turbine is unlikely to have a negative impact on the benthic communities [1], [20], [21].

F. Chemical Effects

A tidal current turbine is a large mechanical structure that is engineered to operate for decades in the ocean, which means potential release of pollutants like lubricating oil and antifouling paints into the ocean. Nevertheless, the impact to the environment is miniscule. According to Sangiuliano et al. [1], SeaFlow's tidal current turbine operation has no known leaks and only required minimum amounts of lubricating oil. The author also states that antifouling paint used for a tidal current turbine are usually the most environmentally friendly due to environmental regulation. A tidal current turbine that is submerged in shallow waters will potentially be affected by the photic zone and thus subjected to higher risk of bio-fouling [22]. Long exposure to ocean bed debris may also risk bio-fouling.

Another aspect of chemical pollution is from the installation and decommissioning phase of the tidal current turbine. Attention should be cautioned regarding leaking and discarding of harmful chemical substances from decommissioned plant and transportation vessels [23].

The environmental effects from chemical to-date is purely speculation due to the lack of evidence from a decommissioned turbine with recorded environmental field data.

G. Acoustics Effects

The acoustic effects are separated into the installation and decommissioning phases and operational phase of the tidal current turbine. Tidal farms are major civil engineering structures that might involve pile driving or seismic work which will likely exceed the protection threshold values for fish and marine mammals [16]. Operational noise of tidal current turbines are expected to be insignificant and is unlikely to have negative impacts on marine wildlife [1]. For example, an experiment on Chinook Salmon by exposing sample noise from an operating 6-m-diameter OpenHydro turbine, shows that the Chinook Salmon have low risk of injury from a tidal current turbine in or near their migration path. However, the author concluded that other variables like Auditory Evoked Potential (AEP) thresholds should be considered in order to obtain a proper data analysis [24].

Several studies have presented a direct impact (e.g. auditory related injuries) of tidal current turbine noise emissions to species specific marine wildlife [16], [23]–[26]. However, few studies have considered the ecological impacts of empirical turbine noise emissions. For example, although long exposure to a simulated turbine noise does not have significant internal or external injuries to Chinook Salmon [24], the masking effects of low frequency noise emitted by a tidal current turbine may affect harbour seals behaviour. This is because a breeding harbour seal's call is typically between 40 and 500 Hz, which in turn may impose permanent change to nearby ecological environment [5]. The ambient sound condition and yearly seasons also have substantial influence on the extent of masking [5].

In addition, the cumulative noise production from an array of turbines have the potential to mask communication and echolocation of aquatic organisms around the tidal farm [16]. Lloyd et al. [17] concluded a case study which modelled the sound field of an array of 10 tidal current turbines with a turbine diameter of 23 m reveals that the most significant influence is likely within a distance of 2 diameters from the array. The influence is in terms of temporary threshold shift (TTS), which generally means 75 dB above the respective hearing thresholds, in comparison to permanent threshold shift (PTS) which is 95 dB above hearing thresholds. The authors have recommended further work to account for mechanical noise which has significant potential for radiated noise reduction.

Temporary threshold shift (TTS) studies from 1996 to 2015 concludes that critical gaps exist in which exposure frequency affects the resulting patterns of TTS growth and recovery. The author also suggests that the data are available only for a few species and methods of extrapolation for other species remains uncertain [27].

H. Electromagnetic Fields (EMF) Effects

Laying technologies and related effects for offshore wind, wave or tidal energy development are generally the same [26]. Marine wildlife that has the ability to sense and respond to EMF are elasmobranchs (sharks, skates and rays), crustacea (lobsters and prawns), Cetacea (whales and dolphins), bony fish (sturgeons) and marine turtles [26]. Field studies showed that associated EMF from alternating current (AC) cables of marine renewable energy devices are emitted into the marine environment and the measured levels were higher than predicted which are detectable by sensitive species. However, marine wildlife reaction with the emitted EMF is unknown due to significant knowledge gaps [26]. Baring-Gould et al. [28] states that direct current (DC) (0 Hz) compared to alternating current (AC) (60Hz) is more likely to be detected by sensitive species due to the lower transmission frequency of DC cables.

Similar to most environmental effects discussed in this paper, the siting of large tidal current turbine arrays may impose a greater effect on marine wildlife, and consideration of EMF-sensitive species mentioned for migration, foraging, and reproduction should be taken into account [1].

There are extensive studies that document the specific species that may be affected by EMF, however to-date, little scientific research has been done to understand the impact of EMF to the marine environment and the relevant ecological impact.

IV. Environmental Receptors

Environmental receptors are those elements of the marine environment that may be affected by stressors [7]. This section discusses the relevant receptors that are influenced by the stressors mentioned above. The construction, operation and decommissioning of a tidal current turbine all affects marine environmental receptors. The effect of interaction of each stressors and reactors are usually rated in either simple confidence assessment charts [26] or receptor matrix [7] with low, medium and high in terms of uncertainties based on key findings and evidence. However, this paper focuses on the types of stressors that have potentially significant effects on each specific receptor. Those stressors are: static effects, dynamic effects, chemical effects, acoustics, EMF, and energy removal.

I. Physical Environment: Near-Field

Near-field involves elements of the immediate environment of the tidal current turbine for which specific direct effects of the turbine can be detected [29]. The related stressor that will affect the near-field physical environment are: water quality, tidal elevation, noise, EMF, sedimentation.

The tidal elevation effect from a large-scale tidal current turbine array in the near-field have a larger effect compared to far-field. The tidal elevation near the tidal farm may increase by 5 to 7 cm, and in some cases up to 18 cm in very localised areas [18].

A tidal current turbine may generate complex particle velocity fields in the near-field that cause the seabed to vibrate. This may affect some marine species that are sensitive to particle motion instead of acoustic pressure variations [30].

EMF-sensitive marine species migration routes may be affected in the very near-field with little impact [1]. Reducing tidal current velocities in both near and far field will ultimately result in sediment deposition.

J. Physical Environment: Far-Field

Far-field environmental effects involve the area in which the disturbance from machinery cannot be easily distinguished from other natural or anthropogenic disturbances [29]. From a physical perspective, this field is defined as the area surrounding the machines beyond which the specific character of the tidal current turbine array is not directly discernible.

In the far-field, according to Dominics et al. [18], a theoretical tidal current turbine array studies for the Pentland Firth, tidal elevation increases upstream of a large-scale tidal current turbine array and tidal elevation decreases downstream of 2cm. This is due to the energy dissipation of the incoming stream from the Atlantic through the tidal current turbines in Pentland Firth. It is also found that the effect on current in the far-field is smaller than the local area, the reduction is only 1 cm/s both upstream and downstream of the Pentland Firth, while current reduction of 0.5 m/s occurs in the vicinity of the local area and increased velocities occur where the flow is diverted through gaps between turbines [18].

The far-field effect of the tidal current turbine array also includes changes in bed shear stress, which may affect primary production, sedimentation effects and seasonal conditions. The seasonal hydrodynamic change is evident when during summer there is increase in water column stratification, which may trigger phytoplankton bloom. However, during winter the energy extraction does not have significant influence on well-mixed waters [18].

The density of tidal current turbine arrays also has a significant effect on the far-field environmental impact. High density tidal current turbine arrays may reduce the size of the tidal range in an estuary environment, with the highest density tidal current turbine array reducing the tidal range by 42.14%. Tidal current turbine arrays may also affect the self-purification rate of the waters in the area (flushing studies), the highest density tidal current turbine array may increase the residual time by approximately 70% (15.3 day), due to the blockage effect. This may have several water quality implications as the bacteria may reside unnaturally for a significantly longer time. This paper modelled the far-field hydro-environmental effects of tidal current turbine arrays in the Shannon Estuary. [31]

Hypothetically, a tidal current turbine operates for 18 to 20 hours per day, while a passing boat is heard for approximately 8 minutes. Therefore, the overall noise level emitted by the tidal current turbine may be comparable to noise produced by 135 to 150 passing boats at a particular location. According to Lossent et al. [25], a single tidal current turbine may induce behavioural disturbances within a maximal area of 3.141 km^2 which is up to 1.5 km from the tidal current turbine. The implication might increase significantly based on the number of tidal current turbines in the area, thus installing tidal current turbine arrays have raised concerns of lost habitation.

K. Marine Ecosystem (Fish, Mammals, Birds)

Introducing huge turbine structures to extract energy is expected to have implications to the surrounding ecosystems. Stressors such as energy reduction, tidal elevation, water quality, acoustics and EMF effects have the potential to deter marine wildlife from their routine resulting in a change of the surrounding ecosystem.

Tidal current turbines are perceived to have implications on wetland-birds due to the tidal range reduction that reduces the size of mudflats and marshes affecting reproduction of migratory birds. However, according to Garcia-Oliva et al. [33], a numerical model simulating hydrodynamic conditions of the Solway Firth and the Shannon Estuary show that the impact of tidal current turbine arrays on wetland-birds are expected to be low, and large losses of important habitat should be avoided. The authors also state that tidal barrages with similar installed capacity would have a far greater habitat loss.

Fraser et al. [34] investigated fish distributions for behavioural change due to renewable energy devices in a tidal stream. The results show that the presence of a tidal device induces behavioural change, the change includes increased attraction rate from the normal 1.10 schools / hour to 1.91 schools/ hour. The work also details disruption of the natural diurnal patterns, while at peak flow velocities there was evidence of avoidance behaviour. The change of distribution of schools is likely to encourage foraging behaviour of predators such as marine mammals and seabirds which may influence risks to protected species.

Marine mammal investigations usually involve harbour seals. This is a result of the research conducted on pilot tidal current turbines most of which are located at habitats of harbour seals. Joy et al. [35] studied the potential risks to harbour seals posed by the SeaGen tidal current turbine in the Strangford Narrows. The results show that the blade strike probability is 9.7% by incorporating seal dive behaviour and that seals are adapting their behaviour to the presence of the tidal current turbine. The seals are also avoiding the turbine with 68% spatial avoidance within 200m of the tidal current turbine. However, this does not represent all marine mammals, tidal current turbine design as well as array layout. It is clear that diversity of marine species studies is important to better understand the overall environmental implications of tidal current turbines to marine mammals.

V. CHALLENGES

The main challenges associated with the studies of environmental effects of tidal current turbines is the lack of critical field data due to expensive environmental monitoring procedures. In addition, there are only a small number of full-scale devices installed or being installed. Most of the designs of tidal current turbines are based on a similar principle of operation compared to wave energy converters for example. However, the array configuration for tidal current turbines have more environmental implications in comparison to wave energy converters. The challenge of array configuration lies with the fact that arrays with high local density configuration provides better energetic performance but have more significant environmental implications compared to array configurations with lower tidal current turbine densities [8]. Importantly, tidal current turbine array optimisation should include hydro-environment consideration for optimum efficiency without risking important ecological impact. , in turn,

VI. DISCUSSION

The number of studies in this domain of research has grown rapidly over the past 5 years. However, most of the studies are not conclusive due the lack of measured field data, the complexity of species, location and design specific factors. Installing and monitoring a greater number of pilot tidal current turbine projects like the SeaGen tidal current turbine in locations that have different operational conditions will contribute more to the development of a detailed environment impact assessment for commercial tidal current turbines. Measured data will also help to eliminate speculative environment stressors and focus on stressors that have real potential for environmental impact.

Among the number of environmental effects discussed, far-field environmental effects such as sedimentation, tidal elevation, acoustic effects and water quality have long-term environmental impacts that should not be overlooked by immediate physical environmental effects, such as mooring, pile driving, and blade striking of marine wildlife.

From this work, it is evident that many modelling techniques are being improved upon [12], [14], [17], [31] and there are several models of environmental impact levels [9], [23], [29], [35], this shows that the tidal current turbine environmental impact assessment and standards are still in the development stage.

VII. Conclusion

Tidal current turbines compared to tidal barrages have significantly less potential for blade striking of marine fish and mammals, pressure differences are insignificant and there are fewer effects on wetland-bird populations. The environmental effects of EMF from tidal current turbine cabling has the same implication as offshore wind turbines and wave energy converters. The environmental effects that may lead to permanent change of the ecosystem or have the greatest environmental impact is mooring, chemical and biofouling effects, pile driving, decommissioning of the device, and energy removal from long-term operation of a tidal current turbine. Water quality (bacterial aggregation, sedimentation, flushing rate) effects are of particular importance, however, the severity of these effects is still unclear. Further detailed evaluation of the water quality at tidal energy sites is required. Acoustic effects from the operation of a tidal current turbine does not directly impinge on marine wildlife (tissue damage), however the masking effects may impact population growth or may even cause a decline in population numbers.

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