Are Subsidies Required for Marine Hydrokinetic Energy Devices in Ireland? A Technological and Site Assessment

Narendran Kumar, Christopher McCallum, Gary James Britton, and John Doran

***Abstract*—To achieve the renewable energy target, it is necessary to carry out technological assessment of marine hydrokinetic energy devices. The objective of this study is to present the suitability of existing devices in the established resource sites in Ireland. The analysis is based on the technical data of the turbines and tidal current velocity profiles from the established numerical model. From this study, we conclude that there are certain locations where all kinds of marine hydrokinetic devices could be deployed, while in a few locations' technology feasibility is limited.**

***Index Terms*—Hydrokinetic energy devices, LCOE, annual energy output, EU ETS.**

I. INTRODUCTION

The main forms of ocean energy are tides, marine currents, waves, salinity and temperature gradient [1] . Harnessing energy from tides encompasses tidal range and tidal stream technologies. The tidal range technologies harness energy form the potential energy created due to the ocean surface levels. The natural barriers or the fabricated structures (barrages) are used to create this potential energy and employs simple hydropower principles to generate energy. The tidal stream technologies harness energy from the kinetic energy of the flowing water. The potential locations where the tidal streams are strong are estuaries, river mouths, tidal inlets, bays, straits, etc. In these locations, the incoming (flood) and outgoing (ebb) flow of water generates stronger currents and the hydrokinetic energy devices are used to generate energy. The tidal energy potential of 1200 TWh/year [2] or 1 TW [3] could become a large part of the energy mix to meet global electricity demand, 26700 TWh/year [4] . However, considering the constraints and limitations such as fishing sites, harbours, ports, shipping lanes, technological viability, Natura sites, human activities, siting and environmental issues, the estimated theoretical figures could be reduced substantially. Although experts have identified a huge potential in offshore renewable energy sector with regards to economic growth, job creation, energy security, reducing carbon emissions and providing sustainable energy [5], [6]. In this article potential deployment of marine hydrokinetic (MHK) energy devices in Ireland are analysed.

A. Tidal and marine Currents Energy Potential in Europe

The tidal and wave energy resource potential for EU is 100 *GW* [7]. The renewable energy directive (2009/28/EC) sets rules for the EU to achieve 20% renewable target by 2020 [8] . All member states have set their own targets of energy from renewable sources by 2020. The Republic of Ireland (ROI) target is 16% [8] and Northern Ireland (NI) had set its domestic target of 40% renewable electricity and 10% renewable heat from overall 15% share of United Kingdom (UK) [9] . So far, in ROI, 10.6% of gross final energy consumption in 2017 is from renewable sources [10]. The wind energy is the main contributing technology (84% in 2017) to achieve so far [10]. Every member state in EU has implemented respective polices, plans and consenting processes that would set the mechanism in motion to develop ocean energy installations. In the year 2016, France ranked number one in electricity generation of 501 GWh/year from marine renewable sources followed by the Republic of Korea (496 GWh/year) and Canada (18 GWh/year) [11].

In ROI the Department of Communications, Energy and Natural Resources have estimated the tidal energy development potential in ROI ranging from 1.5 to 3.0 *GW* [12] . There are a series of challenges and issues that will have to be overcome to achieve this energy potential such as Technological Readiness Level (TRL), financing, market establishments, and grid connections in remote areas. The delay in the tidal energy development is caused by significant challenges based on technology development, reduction of financial risks in deployment, operation and maintenance (O&M), and retrieval costs, engagement with manufacturers and supply chain [13].

II. DEPLOYMENTS OF MHK DEVICES IN EUROPE

Ocean Energy Europe reported that since 2010 there has been 26.8 MW of installed tidal capacity, although only 11.9 MW is still operating while the remainder has been decommissioned [14] . The recent developments has provided knowledge and experiences in the aspects of technological, economic and social aspects. Tidal devices are versatile devices as they can be deployed both inland and at water outlets at sea. The MHK energy devices are classified as axial-flow, cross-flow turbines, tidal kite, Archimedes screw device, oscillating hydrofoil [15] . Among the tidal stream technologies, large number of axial flow turbines are employed with small number of cross-flow turbines under development. Moreover, the axial-flow type is the most common and economical device in the present scenario. The additional advantage over other renewable

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energy technologies is that the resources of tidal energy is more predictable and the energy devices are effective at lower fluid flow speeds in comparison with wind energy devices.

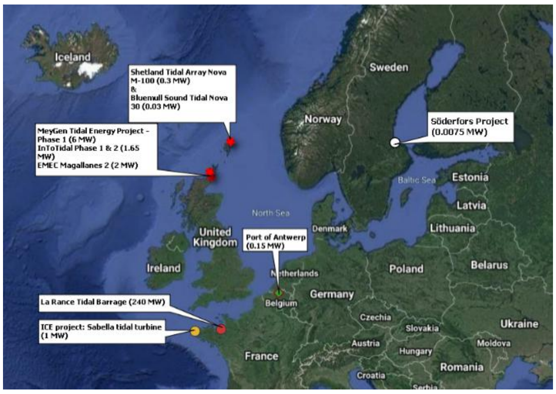


Fig. 1. MHK energy projects across Europe.

From Fig. 1, it is evident that only a few projects are currently deployed. Magagna *et al.* (2014) proposes twin-track approach such as improving the reliability and robustness of the devices through technology development and implementing appropriate mechanisms to push the sector from pilot array deployments to large-scale farms [13].

III. OVERVIEW OF THE RESOURCE IN IRELAND

The Sustainable Energy Authority of Ireland (SEAI) has calculated the theoretical tidal energy resource to be around 230 TWh/year in the island of Ireland. However, considering the practical constraints such as flow velocities, shipping lanes, military zones, etc. the estimate is reduced to 0.92 TWh/year [16] . Table I presents the MHK energy devices based on its Technological Readiness Level (TRL) [17] . The manufacturer of MHK energy devices, its rated power, rated speed, LCOE (Levelised Cost of Energy), AEP (Annual Energy Production) and TRL parameters of the devices are presented.

TABLE I: STATE-OF-THE-ART TECHNOLOGIES OF MHK ENERGY DEVICES

Device and type	Manufacturer	Rated Power (MW)	Rated speed (m/s)	LCOE (€/MWh)	AEP (MWh)	TRL [17]
AR1500	Atlantis	1.5	3-5 [18]	-	5256	9 [19]
E35 Evopod	Ocean Flow Energy	0.035	2.3	-	91.98	5 [20]
Oceade 18	Alstom	1.4		-	2452.8*	7 [19]
T200	Tocardo	0.2		-	201.48	7 [19]
SR2000	Orbital	2	3.0 [21]	-	5956.8	7 [19]
HS1000	Hammerfest	1	2.8 [22]	-	4029.60	7 [19, 20]
SeaGen S-2	Marine Current Turbines (MCT) Ltd	2	2.5	146 [23]	10336.8	7 [20]
Sabella D10	Sabella	1	4.0 [24]	-	1752*	6-7 [19, 20]
SIT250	Sustainable Marine Energy Ltd.	0.062		-	108.62*	6 [19]
M100	Nova Innovation	0.1 [25, 26]	2.0	477-786	175.2*	5-7 [20]
Deep Green Tidal kite 500	Minesto	0.5		100 [27]	1686.30	5 [20]
CoRMAT 500	Nautricity Ltd	0.5	2.5 [28]	-	876*	5 [20]
TidGen	ORPC	0.7	3.0 [29]	$540^{\dagger}$	3985.8	5 [20]
P154	Guinard energies	0.02	2.5 [30]	130-260	100	Unknown

*capacity factor is assumed as 20% [31], †private communication with ORPC

TABLE II: ANNUAL ELECTRICAL CONSUMPTION IN PRACTICAL RESOURCE SITES [16]

S. No.	Site	Capacity (*GWh/year*)
1.	Inishtrahull Sound	514
2.	Bulls Mouth	6
3.	Shannon Estuary	367
4.	Dursey Island	4
5.	Gascanane Sound	1
6.	Tuskar Rock	420
7.	Arklow	791

Table I shows the MHK energy devices starting from AR1500 has the highest TRL, 9, followed by other devices with relatively lower TRL. The suitability of these devices in the established practical resource sites of ROI is discussed. The LCOE and capacity factor (CF) of certain devices are available and the corresponding AEP is estimated. For some devices, the CF is assumed to be 20% as suggested by [31] . The assessment of technology resources is conducted on the sites suggested by SEAI report [16], tabulated in Table II. The objective of this study is to present the suitability of existing devices in the established resource sites. The capacity values provided in the Table II represents the theoretical estimation of annual energy generation in GWh based on the tidal array spacing, water depth and tidal current velocity greater than 1.5 m/s. In this study the velocity of all the sites are taken from the numerical model, discussed in the next section.

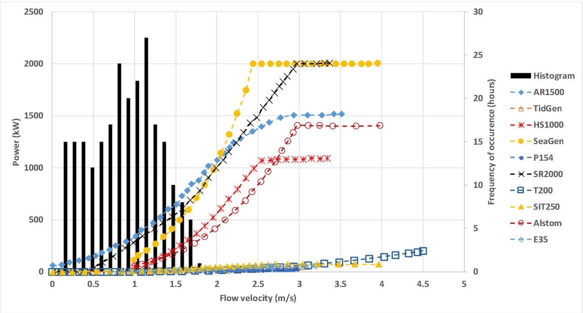


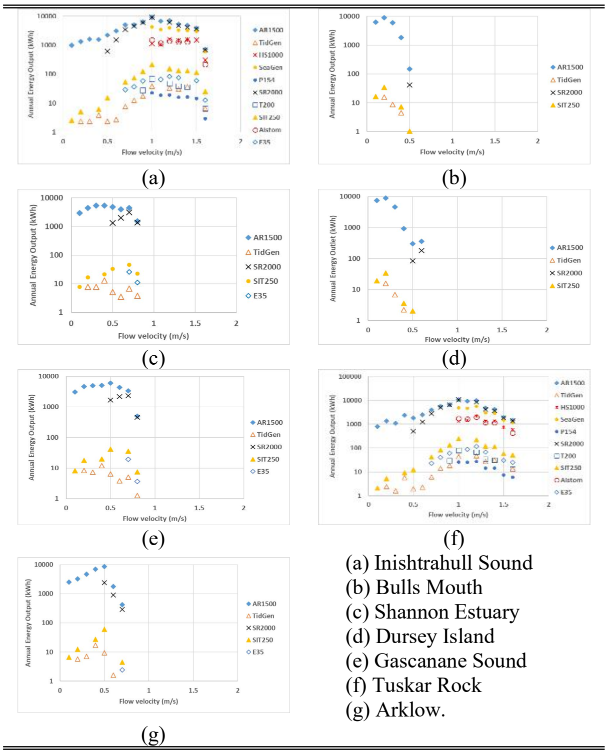
Fig. 2. Histogram of tidal current velocity and power curves of hydrokinetic energy devices.

Fig. 2 consists of a histogram of tidal current velocity and power curves of MHK energy devices considered with corresponding values presented in right and left y-axis respectively. For Inishtrahull Sound the velocity distribution ranges from 0.1-1.6 m/s, with 1 m/s as the maximum number of occurrences in a given time. Where the power curves are above the histogram this the area of "useful" energy which the device can generate energy from, this is multiplied to make an Annual Energy Output (AEO). The suitability of the MHK energy devices are proposed for potential sites from the estimated AEO value ranges as shown in Table III. The ordinate of Table III is in log-scale in order to show the AEO values for all devices regardless of plate capacity.

IV. ASSESSMENT OF TECHNOLOGY RESOURCES IN IRELAND

For Inishtrahull Sound, we have observed that all the hydrokinetic devices considered in this study could be deployed to generate useful power as shown in Table IIIa. The power curves of all the MHK energy devices are presented in Fig. 2 except for CoRMAT, M100, Deep Green 500 and Sabella in due to the unavailability of its power curve data. Therefore, the assessment of these devices could not be made in this study. In the Bulls Mouth site as shown in Table IIIb, the appropriate devices which could be deployed are AR1500, TidGen 8, SR2000 and SIT250. While the power curves of other devices such as HS1000, SeaGen, etc., does not fall within the projected tidal current velocity regime, therefore these devices could produce no energy in Bulls Mouth site. Similarly, we observe that the appropriate devices which could be deployed in Shannon Estuary, Gascanane Sound and Arlow are AR1500, TidGen, SR2000, SIT250 and E35 as shown in Table IIIc, e and g. In Dursey Sound Table IIId, AR1500, TidGen, SR2000 and SIT250 could be deployed. Table IIIf presents the technology suitability in Tuskar Rock, which has velocity distribution similar to Inishtrauhal Sound, therefore all the MHK energy devices is feasible to be deployed.

TABLE III: ANNUAL ENERGY OUTPUT (AEO) OF THE HYDROKINETIC ENERGY DEVICES FOR THE RESPECTIVE RESOURCE SITES



(a) Inishtrahull Sound
(b) Bulls Mouth
(c) Shannon Estuary
(d) Dursey Island
(e) Gascanane Sound
(f) Tuskar Rock
(g) Arklow.

V. CASE STUDIES

This section investigates the projected cost of electricity from natural gas, on/offshore wind, nuclear and MHK energy. The price of energy from gas from 2018 to 2035 is based on the price reported by by the UK Department for Business, Energy and Industrial Strategy (BEIS) [32]. The price of wind energy (onshore and offshore) is based on the latest report on energy prices in Ireland [33]. The price of nuclear energy was calculated from £$_{2012}$ price from Hinkley Point C [34] using a 17.11 % increase [35] and exchange rate of £1 = €1.16. The carbon tax scenarios, reported in Table IV, are applied to the 0.37 tonne CO_2/MWh generated from gas, according the IPCC [36].

TABLE IV: SCENARIOS FOR PRICE DETERMINATION

Scenario Number	Scenario	Conditions
1	Business as usual	• Energy continues to be generated from gas with electricity prices tracking the increase in gas price [32] • No significant form of carbon taxation is placed on energy generated from natural gas
2	EU Recommended Price (Low Price)	• Energy continues to be generated from gas with electricity prices tracking the increase in gas price [32] • From 2020 a USD$ 40/tCO_2 (€ 36.40) is added with USD$ 50/tCO_2 (€ 45.50) from 2030 [37]
3	EU Recommended Price (High Price)	• Energy continues to be generated from gas with electricity prices tracking the increase in gas price [32] • From 2020 a USD$ 80/tCO_2 (€ 72.80) is added with USD $ 100/tCO_2 (€ 91.00) from 2030 [37]
4	Real Price of Carbon	• Energy continues to be generated from gas with electricity prices tracking the increase in gas price [32] • An additional cost of USD$ 200/tCO_2 (€ 182.00) is added from 2020 [38]

The prices of tidal devices were initially set at €340/MWh. [39] the projected prices were determined via the potential growth of the tidal capacity as projected by the European Commission [40] applied via (1).

$$\text{Difference in Price} = €340 \times \frac{1}{\text{Expected Capacity in year 20XX/Capacity of tidal in 2017}} \tag{1}$$

The prices for alternative technologies are (€70/MWh) onshore wind [33], offshore wind (€80/MWh) [33], nuclear power (€125.65/MWh) [34]. Figure 3 reports the various prices of electricity prices from a variety of energy generation sources, if the gas price follows the central expectation of the BEIS.

Fig. 3 reports the prices for the central BEIS price changes for gas, and tidal prices. Although there is an initial decrease in electricity generation from natural gas in this model without carbon taxation, as shown in Scenario 1, until 2021 the ability to tax the carbon can make the price of generation from natural gas competitive with that of tidal as early as late 2024. Without carbon taxation tidal energy would not be competitive with gas generation until 2026. If tidal turbine capacity followed the pessimistic model then tidal energy would not be competitive with gas until at least 2030 and that would require a carbon tax of €182/tCO_2 which hasn't been put forward by any country to date. With respect to other renewable or carbon neutral technologies tidal energy can also remain competitive. Unless the pessimistic scenario is followed the energy generated will be equal to nuclear by 2027 or 2024. A competitive price with the more established renewable energy of wind will be the larger challenge as even in an optimistic scenario the price wouldn't be equal until 2029 at the earliest.

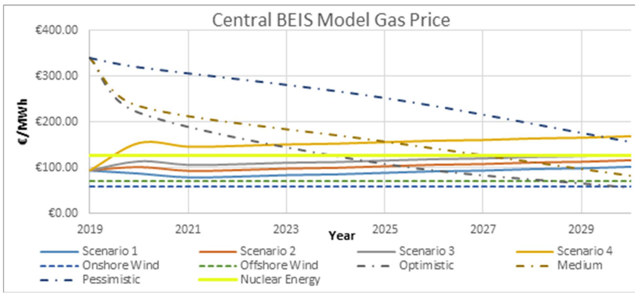


Fig. 3. Central BEIS price of gas model.

VI. CONCLUSIONS

From this assessment, we propose the most common and appropriate MHK energy devices considered for the sites in Ireland are AR1500, TidGen8, SR2000, SIT250 and E35. At present, the LCOE of MHK energy devices are higher but eventually will decrease as the TRL increases along with mass production, innovations, improved CF and lower operation and maintenance (O&M) costs. The issue with carbon taxation is it will cause people who cannot afford costly capital for renewable generation sources to pay higher energy prices. Instead, subsidies usual placed on fossil fuels, estimated at €112 billion per year (2014-2016) across the EU [41] , and should be diverted to subsidize renewable energy installation, operation and generation. In doing so need for carbon taxation isn't required while also securing energy for the future of countries in a sustainable manner which reduces climate change. From the existing MHK deployments, it is clear that these devices present an economically viable LCOE where site specific constraints on other energy generation devices exist. Research and Development supports, alongside renewable electricity feed in tariffs or similar, are key enablers in lowering the LCOE of these devices, which will play a major role in a wider renewable energy mix.

DISCLAIMER

The views and opinions expressed in this paper do not necessarily reflect those of the European Commission or the Special EU Programmes Body (SEUPB).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

The first and second authors produced results and wrote the paper. The third and fourth authors helped in analysing the results, checking the facts and proofreading. All authors had approved the final version.

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