Irish renewable energy policy: encouraging the wave energy sector?

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Abstract—**Governments in Europe and around the world, have agreed to take action to make drastic reductions to greenhouse gas emissions and, with added impetus due to heightened energy security concerns, national renewable energy policies must adapt to keep pace in order to support this sector. This study examines the changes to renewable energy policy in Ireland in general, and offshore renewable energy policy in particular, and analyses whether these changes are robust enough to support a nascent Irish wave energy technology development sector. This study provides a comparison to successful wind energy policy measures implemented in Denmark and with examples being set by international institutions in Europe. This study will look at relevant legislation, test facilities, consenting procedures, feed-in tariffs, environmental impact, intellectual property protection and government financial support and will discuss how the focus on offshore wind by policy architects will effect wave energy technology development. Conclusions will show that many policy elements vital for the growth and support of the wave energy sector, formerly lacking, have been addressed. It will be shown that the changes have largely come about due to internationally-prescribed obligations, and the perceived demand for offshore wind, and that wave energy technology developers in Ireland will potentially both benefit and lose from this. Further analysis and the passage of time are required to determine whether the new policies are fully embraced and enforced.**

Index Terms—**Wave energy, renewable energy policy, technology development**

I. Introduction

SINCE the ratification of Ireland's Climate Action Act 2021 [1], the country is now legally committed to achieving carbon neutrality by 2050. This, along with energy security concerns and economic growth potential, provides motivation for increased focus on renewable fossil fuel alternatives. Ireland has one of the strongest wave energy resources on the planet estimated at around 525TWh [2], and has a significant, globally recognised technical expertise in both fundamental research and wave energy device prototype development and testing. The advantages of wave power are significant and include an energy density 10 times that of solar or wind at a latitude of 15°N (northeast trades), the solar insolation is 0.17 kW/m^2. However, the average wind generated by this solar radiation is about 20kn (10 m/s), giving a power intensity of 0.58 kW/m^2 that, in turn, has the capability to generate waves with a power intensity of 8.42 kW/m^2. [3]. This is in addition to high availability, complementarity with other renewable resources and predictability [4]. With significant investment in wave energy research and development and support at policy level, Ireland has the potential to become a world leader in wave energy technology development.

Denmark has an exemplary record in wind energy development and exploitation [5]. This study will use Denmark's wind energy experience as a benchmark, with Denmark having a similar demographic profile to Ireland, and where wind technology is now mature with continuing technology development and global dominance. If policy elements implemented successfully in Denmark were applied by Ireland to wave energy technology development, this could encourage Ireland to accelerate wave energy technology development for global exploitation.

In 2023, wave energy technology development in Ireland lags behind other renewable energy sources, particularly with support for ocean-based renewable energy directed largely to offshore wind [6]. This is due to various factors, including a lack of convergence on a design, the comparatively high Levelised Cost of Energy (LCoE) [7], and wave energy company liquidations affecting investor confidence [8].

However, wind and solar suffer from a variability gap [9], which is currently plugged by fossil fuels, but, if net zero is to be achieved, a market will exist for a renewable energy source that, in combination with wind and solar, can reduce overall renewable energy variability.

Ireland has the potential to develop wave energy technology to service a global market need, but it is not currently in a position to do this. In fact, the International Renewable Energy Agency estimates 29,500 TWh/year of electricity could be produced per year from waves, which exceeds global electricity consumption in 2018 [10].

Danish companies own 38.5% share of the global wind energy market (Vestas alone owns 20% of the market) [11]. It is geographically and demographically similar to Ireland, both have similar climates and GDPs [12], [13]. This study will take a comprehensive look at Danish wind energy technology development, to determine the factors that have led to a vibrant wind energy development sector, and to determine how these could be applied to Irish wave energy technology development.

Objectives include:

This work was supported by the Centre for Ocean Energy Research, Maynooth University and by The Maynooth University Engineering Department

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Digital Object Identifier: https://doi.org/10.36688/ewtec-2023-154

- To review offshore renewable energy policy in Ireland, having particular regard to recent changes, including a review of international policy,
- to determine whether new wave energy policies in Ireland have embraced the policy elements that led to the success of the wind energy industry in Denmark,
- to determine whether ocean energy policy changes are sufficient to support an indigenous wave energy technology development sector in Ireland.

Contributions include:

- A review of renewable energy policies in Ireland,
- a review of previous policies effecting offshore renewable energy policy in Ireland,
- a summary of policy changes in areas of interest to wave energy technology developers including test facilities, consenting, funding opportunities, and intellectual property protection,
- a review of funding available for research and development,
- a comparison of polices in Ireland to wind energy policy in Denmark,
- a comparison of Danish wind policies to Wave Energy Scotland and Europewave's approach.

II. Wind energy policy in Denmark

Denmark pioneered wind energy technology development from the late 19th and through the 20th century, and successfully exploited it commercially to the extent that Denmark exported €8.9bn of wind energy technology in 2022 [14]. The successful growth in Danish wind power exploitation in the last 5 decades can be related to 6 factors:

1) Pioneers: Denmark has had some exceptional wind energy pioneers, dating back as far as the 1890s. These individuals forged a path inspiring future generations that led directly to politically powerful associations and lobby groups. Poul La Cour experimented with converting traditional windmills to DC electricity generating wind turbines in the 1890s. He gave courses, started associations and, importantly, received government funding. One of his students, Johannes Juul, was the first person to connect a wind turbine with an asynchronous AC generator to the electricity grid. In 1956, he built the Gedser turbine which became the pioneering design for modern wind turbines. The government sponsored efforts of La Cour and Juuls helped them to form a wind energy movement, and positioned Denmark at the forefront of wind energy technology globally and planted the seeds for a commercially successful energy sector.

2) Political and social context: The social and political context is important in terms of Danish wind energy technology development, in that the oil crisis of the 1970s, coupled with a national distaste for nuclear energy, led to a security of supply objective augmented by a Green House Gas (GHG) emission reduction objective. Successive coalition left-wing governments engendered long-term policies that provided certainty for developers, producers, and owners, and wide-spread public support. Daugarrd in 1997 [15] concluded that more than one-third of people in Denmark are directly engaged in wind schemes, or are familiar with other people engaged in such schemes.The potential impact of share ownership on public perceptions of wind farms was articulated in a study which revealed that 58% of households in the Sydthy region of Denmark owned one or more shares in a co-operatively owned wind energy turbine [16]. Examining links between share ownership and perceptions, the report found that people who own shares in a turbine are significantly more positive towards wind energy than people with no economic interest in wind turbines, and are more willing to accept further turbines in their locality.

3) Risø - a research and development hub and a guarantee of quality: The Risø Test Centre was initially established in Denmark to conduct research into nuclear power. In the early 1970s, its remit changed and it was given the role of providing 'type approval' for wind turbines and also acted as a hub for the wind energy community, by sharing research gathered from companies seeking type approval. Speculators that wanted to take advantage of the government 30% installation cost subsidy at the time, were required to seek certification from Risø, in the knowledge that findings would be shared with other developers. Certification would later come to be a requirement, regardless of subsidies.

Data gathered by Risø scientists from developers, lead to improvements in capacity, output, noise reduction and later power quality. Certification led the way to regulation and improved design and quality, and Denmark quickly gained a reputation for producing high quality turbines essential for its success globally, particularly during the Californian wind rush in the early 1980s. [17]. According to an OECD/IEA survey, a total of USD 2363 million was spent on wind-energy related R&D from 1976 to 1995 in Denmark, demonstrating the level of political commitment.

4) Open innovation: The type approval certification requirement in order to receive the 30% capital subsidy, ensured that Risø test centre scientists had access to the designs of every wind turbine that was planned to be installed in Denmark. This lead to a climate of trust and open communication between technology developers, policy makers and industry, and has proved to be a pragmatic, long-sighted means by which Danish turbines became world leaders for quality production.

5) Incremental, bottom-up, trial and error approach to development: Most of the wind turbines installed in Denmark were private, not-for-profit 10-15kw turbine projects based on Juuls' Gedser turbine; in 2010 25% were owned by cooperatives and 63% by farmers [18]. These were generally rural co-operatives attracted by the secure government supports consisting of 1 turbine, although Riisager built 30 machines in the 1980s, becoming the first Danish person to commercialise wind energy [19]. This engendered innovative design and sparked the interest of politicians dealing with a fuel crisis and popular opposition to nuclear power.

An incentives plan, in the form of capital grants for installation, was launched in the late 1970s, and small investors were encouraged by the guaranteed purchasing price and helped by capital grants. Eventually large

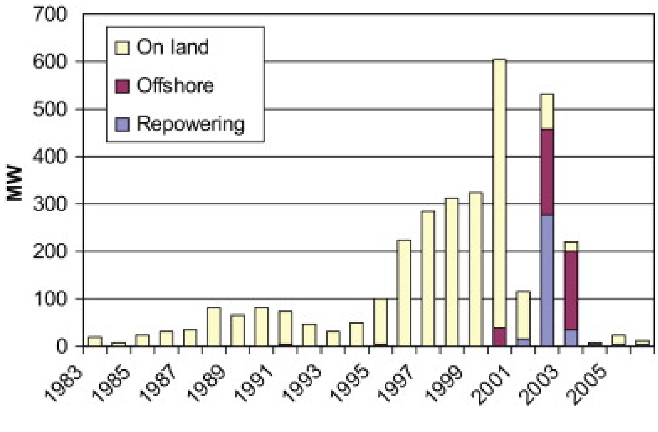

Fig. 1. Turbine installation in Denmark
Turbine installation in Denmark Munksgaard 2008

Manufacturers – Vestas, Nordtank Bonis Nordex, and later Micon, would notice the success of Riisager and diversified from agricultural equipment manufacturing, to wind turbines. These companies now reside in the top ten wind turbine producers internationally.

6) Long-term policies: The Danish government has been willing to commit to long-term, stable policies and interventions, which have provided certainty for developers, producers, and owners, and has played an important role in fostering the commercial success and longevity of Danish wind energy technology development. This has been bolstered by enthusiastic public and industrial support leading to support from the government through a process which Hvelplund calls *innovative democracy* [20]. Quantitative targets were introduced for the first time in Energie81: 60,000 turbines to supply 10% of Danish electricity by 2000. Even though the number of turbines only reached 5000 in 1997, the supply target was met by 1998. More targets were set in 1990 (100MW) and in 1996 (200MW). Agnolucci [21] maintains that quantitative targets provided certainty to the Danish wind industry, impossible to achieve without investment and production incentives.

In 1979, investors received 30% of their initial capital investment. During the 1980s 30% was reduced to 10%, and eventually abolished in 1989. From 1979 to 1989, approximately €38 million was granted under this capital investment scheme. Funding was also available for for test centres to disseminate knowledge. Income from wind turbines was taxed favourably until 1996. Further incentives were available, including tax deductions up to a certain generation capacity threshold, and a 10-year agreement with (not-for-profit) utilities guaranteeing turbine owners feed-in rates amounting to 70-85% of retail electricity prices. When the market had matured, the Danish government would introduce green certificates, and Danish consumers were obliged to buy at least 20% of their electricity from renewable sources. During periods of uncertainty, installation stalled, highlighting the need for long-term, substantial and stable policy initiatives [22].

Denmark ranks as the world's largest manufacturer and exporter of wind turbines and has the third largest installed wind energy capacity in the world. Almost 60% of the world's wind turbines are manufactured in Denmark. The Danish government has set substantial targets for growth in wind-powered electricity generation and expects it to account for 50% of domestic power generation by 2030 [23]. As a country similar to Ireland in size and potential, it might prove useful in assessing the efficacy of Ireland's wave energy policy, by comparing it to Danish wind energy policy.

III. Renewable energy policy in Ireland

Ireland cannot unilaterally create its own unique regulatory framework, but rather is is influenced and bound by international and European Union (EU) policies. International policies have a direct effect on the renewable energy sector, with Ireland having signed up to the Paris Agreement [24] and the European Green Deal [25]. In the Climate Act 2021, the Irish government agreed to reduce green house gas emissions by 50% in 2030, and to net zero by 2050. The 2030 target was subsequently increased to 51% [26]. The EU has an ambitious offshore renewable energy target which has supported the growth of offshore wind energy development across Europe [27].

In 2015, 193 countries signed up to the 17 UN Sustainable Development Goals (SDGs), as a concerted effort to overcome global challenges, including damage to the environment [28]. Part of the vision for Ireland is to transition to a competitive, low carbon, climate-resilient, and environmentally sustainable economy by 2050, supported by investment in renewable energy. The SDGs led to the legally binding Paris Agreement in 2015, which was signed by 193 countries and the EU. Article 2, commits to strengthening the global response to the threat of climate change, and has set a limit for climate temperature increase to 1.5°C above pre-industrial levels. Governments are held to account by the UN's annual Conference of the Party (COP) summits. At COP26 in 2021, 200 countries set new emissions targets at which the COP26 president Rt Hon Alok Sharma MP stated "It is up to all of us to sustain our lodestar of keeping 1.5 degrees within reach". The EU's response to the Paris Agreement was the Green Deal. This was reworked in Energy Directive 2018/2001/EU which is the current overall EU policy for the production of renewable energy [29]. It set a new target for energy from renewable sources of 32% by 2030. In July 2021, the Commission revised the directive (COM/2021/557 final) with a 40% target. Less than a year later, in view of the Russian conflict in Ukraine, the Commission proposed, in its Communication on the REPowerEU plan (COM/2022/230 final), to further increase this target to 45% by 2030. On 30 March 2023, the European Parliament set a binding renewable energy target of a minimum 42.5%, but aiming for 45%, for 2030 [30]. EU member states were required to draft National Energy and Climate Plans for 2021-2030, detailing how they would meet the new targets.

The goal of the Climate Action Act, 2021, Ireland, was to articulate a legally binding, coherent set of policy actions to get Ireland to a net zero carbon energy system. It was unanimously endorsed by the Oireachtas (Irish Parliament), as a climate emergency was declared. Ireland is likely to be 25% off target for the next 2021-2030 accounting period, due to increases in emissions, with the Environmental Protection Agency (EPA), stating in March 2022, that ”the current pace of implementation will not achieve the change required to meet the Climate Act targets”. Despite this, Ireland has agreed to meet net zero emission goals by 2050. The stated aim of the Climate Act is to pursue the pathway with the least burdens and greatest opportunities. Electricity targets defined by the Act, include an increased reliance on renewable energy sources for Ireland's electricity needs, taking the market share from 30% to 70% supported by a streamlining of the consent system, connection arrangements, and funding supports for new renewable technologies on and offshore.

The Plan recognises that achieving 70% of electricity from renewable sources, including at least 7GW of offshore renewables, will require building significant infrastructure and increasing the capacity to integrate new technologies. This will be a significant challenge as the transition accelerates in the 2030-2050 period.

The (Irish) Intergovernmental Panel on Climate Change was established in 1988 and has created a climate action fund, including a fund for renewable sources of electricity of €77m under the first call. Other funding opportunities exist for renewable technology developers: Enterprise Ireland and Science Foundation Ireland have a new research priority theme focusing on energy climate action and sustainability and the EPA has established a national research coordination group. The Sustainable Energy Authority of Ireland released its statement of strategy, establishing a prioritisation of funding opportunities across all public funding bodies including EU funding leading to commercialisation and innovation arising from research funding, to ensure that Ireland is favourably positioned to benefit from new and emerging global opportunities in addressing climate change. The SEAI stated that renewable generation is intermittent and unpredictable and therefore needs a range of technologies and solutions. The SEAI further said that increased energy efficiency is not enough to meet climate targets. There is a need to increase renewable generation capacity [31].

Ireland's Offshore Renewable Energy Development Plan (OREDP) [32] established a framework for the sustainable development of Ireland's offshore renewable energy potential exploitation. The OREDP has identified Ireland's coast as one of the most energy productive in Europe, with a long-term potential of 70GW of ocean energy opportunity for wind, wave and tidal within 100km of the Irish coastline. The development of offshore renewable energy sources will be planned, led, and aligned with the National Marine Planning Framework (NMPF). This will allow Ireland to balance its significant renewable energy potential with security of electricity supply and develop long-term ambitions to export its offshore renewable resources.

The plan recognises a need to support the ocean energy research, development and demonstration of floating wind, tidal and wave technologies, including maximising supply chain and enterprise opportunities and associated test infrastructure. The OREDPII draft is available and is due to be published in 2023 following public consultation. It has promised to recognise the ”immense potential for wind, wave and tidal energy that can aid in the delivery of our long-term climate goals [33], OREDPII has increased focus on offshore wind. Wave energy is discussed in terms of potential rather than concrete plans.

Until very recently, there was no dedicated legislation dealing with offshore renewable energy resources and, as a result, there has been a reliance on existing foreshore, environmental and maritime jurisdiction legislation which was not designed for the development of offshore renewable devices. It became apparent that Ireland needed to implement effective and efficient policies [34]. Before the enactment of Ireland's new regulatory framework, in relation to the consenting process for offshore development, adherence to the existing legislation was considered to be a major non-technical barrier to ocean energy development leading to what O'Hagan called “legal ambiguity and administrative uncertainty” This labyrinthine consenting process could take up to 10 years, had no dedicated legislation, and involved several regulatory authorities with actors lacking in expertise in offshore energy. Ireland lacked a licensing architecture that included statutory consenting time-frames and evidence of a structured process [35]. It is clear that greater integration in the decision-making process was required with appropriate resources to back it up, in addition to knowledge building. In 2021, Ireland enacted the Marine Area Planning Act [36] (MAPA) in an attempt to streamline the process.

The consenting process could take up to 10 years in Ireland, compared to 18 months in Portugal and 2.5 years in Spain [37]. Scotland offer a one stop shop for project consent established by the Marine (Scotland) Act 2010. It comprises a highly consultative scoping process which takes 9 months. Their procedure is based on knowledge sharing and the principles of “survey, deploy and monitor”. The Scottish Parliament have also established Marine Scotland Science which provides economic and technical advice for marine renewable energy and evidence building, enforcement, and policy. Developers in Scotland can be assured of a one stop shop, built on experience with oil and gas exploration. Dalton et al [38] recommend a one stop shop for planning permission, foreshore licences, and grid connection for Ireland, and cited Danish wind energy as an exemplar, suggesting that the focus should be on innovation, deployment and manufacturing. Gaps in the Irish consenting procedure before 2022 can be compared to progress in Scotland in offshore wind. From 2005 to 2022 in Ireland, there are no new offshore wind developments since the Arklow Bank demonstration project in 2004. Scotland has been forging ahead with fully commissioned sites including the European Offshore Wind Deployment Centre, Hywnd Scotland, Robin Rigg, and “Beatrice” [39].

The gaps in offshore renewable energy policy in Ireland, before MAPA, can be summarised as:

- Lack of dedicated legal frameworks
- Procedures designed for other sectors that regulators see as unknown or uncertain, prompting them to apply tests strictly,
- an uncertain time-frame for investors,
- stakeholders are not consulted until after the lease has been awarded or otherwise,
- too many regulatory authorities involved, who lack specific expertise,
- environmental impact is an area of uncertainty for regulatory authorities and should be amended depending on the scope of the project,
- public acceptance can cause delays [27]. Indeed, McLaghlan suggests a consultative approach, founded on expertise and knowledge sharing "beyond NIMBYism" [40].

In 2011, Klessman et al [34], note that factors for reaching EU targets include effective and efficient policies (that) can be attained by:

- Early engagement with stakeholders through a transparent system with a clear structured process,
- more integration in the decision-making process supported by resources,
- reliable time-frames,
- knowledge building and sharing mechanisms,
- increased financing mechanisms.

A. New offshore consenting procedures policies in Ireland

EU Directive 2014/89/EU [41] required Ireland to produce the National Marine Planning Framework (NMPF), Ireland's answer to EU mandated Marine Spatial Planning, which defines where different activities take place at sea. The NMPF had a number of aims:

1) To reduce GHG emissions and accelerate the transition to cleaner energy,
2) to increase the use of offshore renewable energy (ORE) in an efficient and coordinated manner,
3) to support offshore renewable energy growth,
4) to develop a robust effective and transparent consenting process to ensure environmental protections are built in,
5) to link offshore and onshore grids.

Visualisation assessments, to determine the visual impact of offshore structures, must also be included. However, up to now, visualisation assessments are not available for wave energy developers so the rather nebulous "policy and best practice" will be used. Another potential gap in the NMPF is the lack of identification of strategic locations (spatial designations). The early stage of development, level of risk and ecological significance is largely unknown for wave energy developers.

Ireland's first National Marine Area Planning Act (MAPA) was ratified in 2022, although remains to be implemented fully. It provides a new consenting process for marine development within Ireland's 12 nautical miles [42]. The new consenting process requires developers to obtain a Maritime Area Consent (MAC) before they can apply for development consent. The Act provides for a new Maritime Area Regulatory Authority (MARA) which will be responsible for administering the consent and enforcement, but as of May 2023, is not fully operational.

Wave energy was not mentioned, however, with potentially less visualisation and environmental impact concerns, wave energy and other emerging offshore renewable technologies, can potentially benefit from a more efficient system as they progress towards commercial viability and large scale testing.

The MAPA is one component of the NMPF which illustrates the vision of Ireland's maritime area (495,000 KM^2) until 2040. It provides the legal and administrative underpinning for a new planning regime in the maritime area, the MAPA replaces existing development consent regimes with a single consent principle or MAC (seabed lease), it will enable development consent, or planning permission with one Environmental Impact assessment. It will ensure that the consent complies with EU environmental assessment obligations, complies with the Aarhus Convention on Public Participation [43], and enables Ireland to deliver projects conducive to national climate targets for 2030.

Developers require MACs before applying to An Bord Pleanala which have strict time limits, indeed, a decision on a MAC must be made withing 90 days. In 2023, the first 7 MACs were announced, all for offshore wind projects. These projects (worth 2.5 GW of electricity), can apply for planning permission and take part in ORESS 1, discussed in section V below.

Quantitative targets for installed capacity were one of the elements that proved successful for Danish wind energy. The EU set a target for 1GW installed capacity of wave plus tidal energy by 2030 and 40GW by 2050, which they say will require an investment of €800bn [44]. Ireland's Climate Action Plan 2023 [45], has set targets for offshore wind 9GW onshore wind, 8 GWsolar, and at least 7GW of offshore wind by 2030 (with 2GW earmarked for green hydrogen production). It fails to mention either wave or tidal energy, however, it does outline the significant research and innovation supports available for emerging technologies.

IV. Supports for wave energy technology developers

A. Funding for wave energy technology development

The new Irish renewable policy measures discussed in section III, if fully developed, will prove useful to wave energy project and technology developers for deployment at full scale for fully-realised projects and full-scale demonstration models. Wave energy is not at this stage yet, operating mainly up to Technology Readiness Level (TRL)6 [46], and so it is useful to determine available supports for technology developers at lower TRLs in order to bring wave energy technology through the TRL scale to commercial realisation.

Weber, in 2012, [47] introduced the Technology Performance Level (TPL) metric, complementary to the TRL scale, that considered the economic performance of WEC systems early in their development. This shows that funding is required across the TRL scale (fig. 2). Weber's study described the TPL scale as a

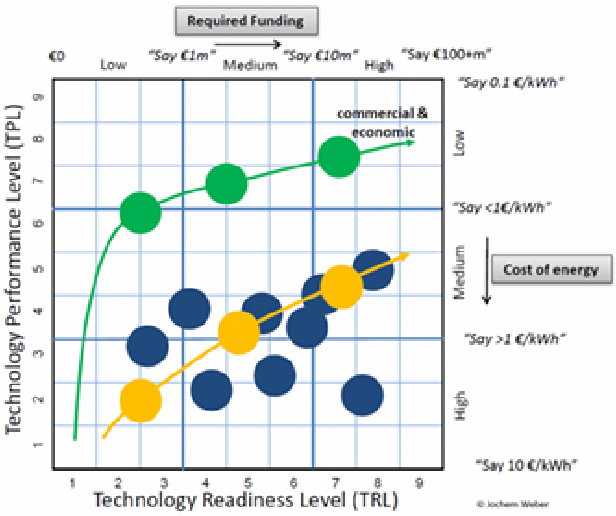

Fig. 2. Comparison of development trajectories. Weber, 2012

value map for visualisation, qualification and comparison of the technology development status with respect to overall commercial readiness and performance. The stage-gated approach adopted by Wave Energy Scotland and Europewave, discussed in section VIII below, would seem to support this approach.

The EU Commission's Clean Energy Technology Observatory's November 2022 report [48], stated that wave energy technology developers did not feel that there is a shortage of funding at lower TRLs. However, the focus on offshore wind by policy-makers, is a cause of concern for those in the wave energy sector, in that there is a sense that wave energy projects may be de-prioritised in favour of offshore wind technology development projects. Also, SEAI described a gap in funding in their 2019 report [49], stating that, as technology becomes more commercial, the risk for private investors generally decreases. This is not the case for WEC system development as the cost of development increases exponentially as the technology moves up the TRLs from controlled models to open sea conditions.

Project funding is available for wave energy technology developers in Ireland. SEAI offers funding through their RD&D programme. They have a stated interest in wave energy development, but the most recent call did not have a specific wave energy theme (although it did cater for enabling technologies for ocean energy development) and wave energy developers could apply through the open theme. SEAI did have an ocean energy prototype fund up until 2019, but this is not currently open. Enterprise Ireland provide general enterprise funding, to support companies, research performing organisations, and partnerships of both. This may be suitable for projects from TRL6 and higher. Science Foundation Ireland (SFI) fund STEM-led research and have an annual budget of around €250m. One programme of note is the €65m SFI National Challenge Fund, which offers funding under missions such as ”energy innovation” and is stage-gated, similar to the WES approach. The SFI centre for marine research and innovation (MaREI), participates in EU projects such as Horizon2020 and Interreg, as partner and coordinator, and has also funded PhD students. The Marine Institute has a PhD scholarship programme as does the Irish Research Council.

B. *Test facilities*

Wave energy is an emerging technology with little convergence on a design archetype [50]. For this reason it is essential that any country that wants to promote innovation in this area must provide adequate testing facilities at different stages of development. "testing innovative wave energy devices. . . .is an important step towards harnessing some day a reliable energy resource" (Franklin Oor US Undersecretary for science and Energy at the US Energy Department 2016 on the Pacific Marine Energy Centre test site).

Different test facilities are necessary at different stages of wave energy technology development, in order to assess the wave resource available, and to enable developers to have sufficient information to address risks, lower costs, and inform future designs to accelerate development. Ireland has developed test facilities that cover each of the TRLs. Devices can potentially progress from the Lir National Ocean Test Facility (LOTF) to the protected conditions of the 1/4 scale SmartBay Galway Bay Test Site, and ultimately to the open sea conditions of the Atlantic Marine Energy Test site(AMETS).

The LNOTF [51] on the west coast of Ireland, is designed for laboratory testing of offshore wind, wave, and tidal energy devices, for scaled testing up to TRL 4 in a controlled environment. It has an electrical laboratory to test electrical systems for sea trials. It also has 4 wave tanks: a deep ocean wave basin (for 1:15 scale testing) that can produce waves up to 1.2 metres high, an ocean wave basin for 1:50 scale testing, a wave and current flume for 1:50 scale testing and a wave demonstration flume.

The Galway Bay test site [52] is ¼ scale on 37 hectares with depths between 21 and 24m and relatively sheltered at-sea conditions. It can test operability, survivability, and performance. It is cabled for power and data and can test underwater parts. It is useful for WECs at TRLs 4-6 and data buoys. Funded by Science Foundation Ireland at a cost of €3.6 million, it was operational from 2006. Ocean Energy Buoy tested there from 2007 – 2011 as well as Wavebob and Sea Power ltd. A foreshore licence was granted to the test site in 2017 for a maximum of 3 devices at any one time for up to 18 months, however, the parameters of the licence were amended causing substantial delays. The test site awaits reopening and issuing of the lease.

AMETS [53] is situated off the coast of County Mayo, and will provide a cabled real-world test site in harsh open water conditions. It was initially seen as a grid connected facility for testing the performance of wave energy conversion technologies in real-sea conditions. To date there has been no testing activity at the site, and the cable and related infrastructure has yet to be installed. In 2018, SEAI began the process of expanding the scope of the site to include floating offshore wind technologies testing. They were awarded a licence for underwater cabling and testing of wave energy devices in 2015 and were granted planning permission in 2018. They are currently gathering environmental impact information in line with the now out-of-date marine consenting procedures. When operational, a range of floating offshore wind technologies may be tested on site, with a maximum of six installed at any one time across the two test areas while wave energy devices could be tested at the same time. In 2023, under the new regime, SEAI plan to apply for consent for floating offshore wind technologies through the Maritime Area Regulatory Authority (MARA). In 2024 MARA will decide on the floating offshore wind technologies consent application, and offshore cables will be installed. In 2025, the first offshore wind turbines are planned for deployment.

The priority for test facilities has shifted from wave energy technologies to offshore wind, perhaps being seen as low-hanging fruit for the ambitious 2030 targets. The test facilities described above would seem to be a perfect breeding ground for renewable energy technology developers. However, despite being awarded a foreshore licence in 2017, the Galway Bay test site is not open for business and neither is AMETS. EMEC [54] on the other hand, is the European Marine Energy Centre based in the UK. It describes itself as an "innovation catalyst" getting marine renewable energy to market. Remi Gruet, CEO of the trade association Ocean Energy Europe, stated the motivation: "wave energy will help smooth production peaks or dips from variable wind". It boasts 2 grid connected accredited sites and 2 scale test sites. One of its most recent devices is OE35 by Irish company Ocean Energy, which will use an EMEC site to test the largest capacity WEC in the world for 2 years. It remains to be seen whether MAPA and MARA will facilitate the operability of the test sites, and can be seen as a litmus test of how wave energy technology development in Ireland is perceived by decision makers.

C. Power purchase scheme

The ambitious renewable energy targets set by governments can only be reached with support systems that help cover the cost disadvantages faced in liberalised electricity markets [55]. For emerging technologies, this is of particular importance. States either choose a price-based Feed-in Tariff (FiT) scheme or a quantity based, tradeable quota system known as 'Green Certificates'. After the first schemes launched in Portugal (1988), the Netherlands (1989) and Germany (1990), all EU member states implemented support mechanisms for renewable energy development divided along the following lines: Feed-in tariffs where the lawmaker obliges national transmissions system operators (TSOs) to feed in the full production of green electricity at politically fixed prices depending on the source (wind, hydro etc). The TSO passes on the higher cost to the consumer. This causes a problem in that in a liberalised market, if the electricity supplier had a greater percentage of renewable energy, the cost of the electricity would be higher. Green certificates oblige producers to either produce or buy green energy. The quotas are tradeable. Green certificates are also bankable (one cert /mWh). The producer can sell their electricity or sell their green certs.

1) Renewable Energy Support Scheme: In Ireland, until recently, surplus energy was loaded on to the grid for free. However, renewable energy generators are now provided with a minimum price for each unit of electricity exported to the grid over a 15 year period.

In 2018, to encourage investment in renewables, the Irish government approved the design of the Renewable Energy Support Scheme (RESS) to replace REDFIT2 based on the emergence of energy commitments as a key function of the Renewable Energy Directive with the EU Clean Energy Package.

RESS was described by SEAI as a "competitive auction based, cost effective, framework" and claims that it will help deliver community ownership and partnership and increase technology energy diversity. Interestingly, all successful projects must provide a community benefit fund e.g. Dooleg More windfarm. This would have the advantage of encouraging community buy-in, potentially deflecting negative publicity.

RESS auctions are held at frequent intervals throughout the lifetime of the scheme, in line with targets identified in Ireland's National Energy and Climate Plan. RESS allows Ireland to take advantage of falling technology costs, and avoids locking in higher costs for consumers. RESS establishes an auction system for wind farms and solar farms, so that companies from different renewable industries will compete. This would seem to have negative connotations for emerging technologies including wave energy, as higher costs are to be expected with newer technologies.

RESS is not index linked, which means that whatever a potential provider bids is the price they will get for the next 15 years regardless of inflation. Only projects with planning permission and a grid connection offer can bid in to the auction. Under RESS there is a provision of 300 gigawatts for solar as it is more expensive than wind, suggesting that this might be possible for emerging renewable energy sources in the future. The first 7 projects due to go for auction in 2023 are offshore wind projects.

In 2014 68 countries applied the FiT scheme [56]. The FiT rate is determined by each government based on the operational capital and investment costs of each renewable energy source. Typically FiT schemes have contracts from 10-25 years and vary depending on maturity of the technology, capacity size, resource quality and location of project. [56].

In Spain, the support scheme for solar photovoltaics stopped in 2012 due to over-generous tariffs, overcapacity and tariff deficits. Denmark moved from FiT to green certificates for wind in 2001, creating a reduction in new installations that lasted for seven years. [57].

Wave energy technology developers need to promote their technology to project developers. Project developers are likely to establish in a country that has attractive financial supports. It will be interesting to watch offshore wind projects as they progress through the RESS auction and planning permission process to determine whether changes to the financial support system are conducive to wave energy project development.

D. Intellectual property protection

Ireland has a well-developed and notoriously strict patent protection system. New inventions can be granted protection in law through patent registration. A patent translates technology to legal writing in order to protect technological advances. New or improved products or processes are eligible. A patent confers the right to exclude others from making, using, selling or importing the patented invention in a particular jurisdiction. This 'industrial property' can be assigned, transferred, licensed or used by its owner [58]. This is important for emerging technologies, such as wave energy, particularly when there is no design archetype.

Novelty is necessary for patentability. Disclosure, including your own, may compromise novelty. There can be no sales, publication or verbal disclosure until the patent filing date. This may be difficult for academic researchers, who may want to publish widely.

In general, patents give the inventor the right to object to someone's use of your patent. It also gives potential investors reassurance and confidence that your invention has been legally vetted and protected. Commercialisation gives value to possible spin-out companies and can form the basis for licensing deals.

There is very little patent infringement litigation in relation to the number of patents in force at any one time and, despite relatively similar legislation in different jurisdictions, outcomes in can differ widely, largely due to local procedural differences.

Patent infringement litigation is relatively rare in Ireland, and is mostly seen in the pharmaceutical industry as several international pharmaceutical companies base their manufacturing headquarters in Ireland. Irish patent litigation will be resolved not just by reference to the Irish Patents Act, but also from relevant case law precedent due to its common law status. This differs from most European countries which have civil law jurisdictions which rely more heavily on legislation.

According to the EU Commission's Clean Energy Technology Observatory's 2022 report [48] globally, between 2010 and 2019, 3561 patent applications involving ocean energy were submitted with 1677 granted, 710 of which were high value (of potentially significant economic value to the patent holder). China made 49% of applications, with 76% of those applications emerging from universities and government organisations.

Inventors from the EU were responsible for 12% of applications with 73% of submissions made by companies. The EU submitted most high value inventions in wave energy at 34%. According to the report, in terms of international protection, International activity inventions originating from the EU account for 18% of the total international inventions. Around 15% of EU inventions are protected internationally, while for China, only 1% of their inventions are internationally protected (see Fig. 2). Trends in patenting show that the number of high value inventions is steadily decreasing in the European Union and increasing in China.

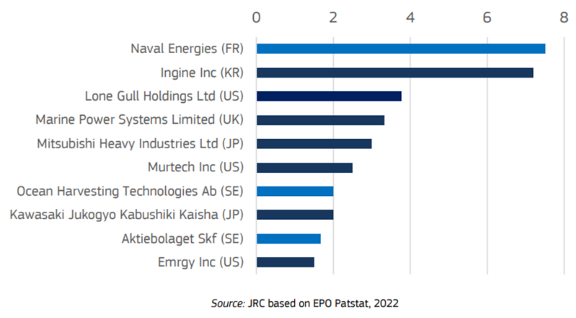

Fig. 3. Top 10 Companies with high value inventions 2017-2019 Source: European Patents Office stats.

Looking at the legislation, the trends and qualitative data gathered, it appears as though wave energy technology developers do not feel the need to patent, until and unless, they are part of a company with plans for an open-sea project. Publishing and trade secrets seem to be the norm for developers at lower TRLs.

V. Offshore Wind Energy and its Impact on Wave Energy Development

Irish policy makers see wind energy as the means by which Ireland will reach its initial 2030 targets. Offshore wind will play a significant role in this and the government have recently increased the target from 5GW to 7GW of offshore wind energy to be produced by 2030. The importance of offshore wind is evident in the first Marine Area Consents approved under MAPA, all 7 being offshore wind projects. It is safe to assume that MAPA and the establishment of MARA are primarily for the use of offshore wind developers. However, more efficient consenting procedures and planning permission may prove beneficial to wave energy technology developers as they near commercial viability and at-sea deployment.

In addition to the advantages that policy changes might have for wave energy technology developers, it is useful to consider the benefits of a diverse portfolio of energy sources for the country. Fusco et al [59] describe the power output variability and lack of predictability of wind energy, particularly in Ireland and how the variability is reduced through a mix of wind and wave or wind/wave devices.

VI. International Institutions

How have other international institutions reacted to the new international policies in the areas described above namely: consenting procedures, test facilities, power purchase schemes and intellectual property protection that have significant repercussions for wave energy developers? This section will look at Wave Energy Scotland (WES) and EuropeWave's experience.

A. Wave Energy Scotland

WES was established in 2014 to ensure that "Scotland maintains a leading role in the development of marine energy". [60]. It has funded 132 contracts

TABLE I
RISØ, WES AND EUROPEWAVE COMMONALTIES

Topic	Risø	WES	Europewave
Demonstration models	Yes	Yes	Yes
R&D	Yes	Yes	Yes
Public funding	Yes	Yes	Yes
Consent time limits	Yes	Yes	Yes
Open innovation	Yes	Yes	Yes

and committed £50million to marine energy projects. WES purchased the intellectual property of Pelamis Wave Power in 2014 and Aquamarine Power in 2015, capturing the learning gained in their development [61]. The funding scheme employed by WES involved pre-commercial procurement, the objective being to stimulate innovation. It also uses a stage-gate approach to funding, with the most effective projects gaining the final prize. There is promotion of collaboration across the supply chain by WES entities (eg. between Arup and Mocean) and use of the test facilities at EMEC. [54]. Projects have been funded in areas covering different elements of WECs, including control, power take off, materials and manufacturing, connection systems, and novel WECs. Developers AWS Ocean Energy and Mocean Energy Ltd have received funding of £7.7million, having developed devices to TRL5 through WES.

B. Europewave

EuropeWave describes itself as an innovative research and development programme for wave energy technology. It commits to combining almost €20 million of national, regional and EU funding to drive a competitive Pre-Commercial Procurement (PCP) programme for wave energy. As with WES, PCP is a phased service agreement leading the winning projects to open-sea deployment, and testing where public procurers buy R&D from competing suppliers, and the suppliers retain the intellectual property ownership rights, while procurers keep some usage and licensing rights [62].

The PCP programme has been taken from the WES model, highlighting openness, collaboration, and a spreading of risk between public and private investors. Europewave cites the importance of large scale demonstration models, to provide certainty to potential investors and funders. Europewave projects use the EMEC test site in the Orkney Islands as well as the BiMEP test site in the Basque Country. Five wave energy projects are currently at the design and modelling phase. The projects are Arrecife Energy Systems S.L. (Trimaran) AMOG Consulting Ltd (Sea-Saw WEC), CETO Wave Energy Ireland Ltd (ACHIEVE), IDOM Consulting, Engineering and Architecture S.A.U. (MARMOK) and Mocean Energy Ltd (Blue Horizon 250), (a company also funded by WES), who will share €3.6million over the next 9 months.

Table 1 shows some of the elements that Risø, WES and Europewave have in common.

VII. DISCUSSION AND CONCLUSIONS

Although the 2030 targets loom large over policy makers, the consequent policy changes in Ireland are very recent and are not yet fully operational. In determining whether the new policy changes will be helpful to Irish wave energy technology developers, we can look at successful elements from wind energy in Denmark and from WES and Europewave (Table II).

TABLE II
IRISH WAVE ENERGY POLICY COMPARED TO RISO, WES AND EUROPEWAVE

Topic	Current Irish policy
Pioneers	No - due to the emphasis on offshore wind
Political motivation	Yes - climate targets provide a call to action - but wave energy is seen as less urgent as it is a new technology
Social context	Yes - new RESS auctions require investment in community projects
Research and Development hub	No - MARA is an administration vehicle for consent, there is no policy incentive for collaboration
Capital investment	No - more funding is needed to bring WEC devices to full-scale demonstration stage
Long term policies	No - the new policies will benefit offshore wind as low-hanging fruit to meet targets until wave energy progresses through the TRLs
Streamlined consenting procedure	Yes, however, most WECs are at maximum of TRL 6 and are not ready for full-scale deployment. There is also uncertainty about environmental impact and planning permission
Test facilities	No, Galway Bay and AMETS test sites remain non-operational
Intellectual property protection	Yes - although some developers at early TRLs prefer to maintain trade secrets rather than register patents
Quantitative targets	No - Wave energy is not mentioned in the Climate Action Plan 2023

Table II shows that, although many elements necessary for wave energy technology energy, previously lacking from Irish offshore renewable energy policy, have now been addressed, some elements such as test facilities and the establishment of MARA are not fully operational, and some have yet to be enshrined in Irish policy, notably the lack of a high level champion and a central R&D hub. Most importantly, looking at supports across the TRLs, technology developers can access funding at the lower TRLs (although specific funding calls related to wave energy seem to be decreasing in availability), technology developers in partnership with project developers should be able to avail of the new policy changes at the higher TRLs, particularly benefitting from a more streamlined consenting procedure, but there seems to be a gap for those developing wave energy technology at the middle TRLs where significant government investment and demonstration models are needed to attract industrial investors to bring the technology towards commercial realisation and where costs increase exponentially as devices move from a controlled environment. Policy makers in Ireland in recent years, have focused on offshore wind, seen as most likely to offset 2030 emissions targets. However, due in part to the variability of wind power, diversity will be necessary in Ireland's renewable energy supply. Wave energy is not yet commercially viable, but Irish policy changes might help to expedite this if policy makers look beyond 2030 towards the 2050 targets, and decide to champion wave energy, recognising burgeoning technologies as worthy of support, given Ireland's technical expertise and substantial resource. Analysis and observation are required over the coming years, as MARA is fully established, and RESS matures, to determine how and whether wave energy will be served by Irish offshore renewable policy.

ACKNOWLEDGEMENT

The Authors would like to thank the Centre for Ocean Energy Research and the Electronic Engineering Department at Maynooth University.

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