Technical Report

External forces influencing the development of wave energy technologies for power markets

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ABSTRACT

Understanding wave energy requirements is paramount to the development of any successful technology. However, wave energy development cannot be entirely isolated from the wider context in which the technology is designed to operate, since multiple external forces influence its conception, development and operation. The external drivers and the stakeholder groups are the two main forces that define this overarching context. External drivers are tightly connected to the intended market application, whereas the stakeholder groups define the technology performance expectations. Each intended market application may call for a different combination of external drivers. In turn, the ranking of those external drivers to each stakeholder group will ultimately dictate the importance of the wave energy requirements.

This report aims to assess the relative importance of the main forces influencing the development of wave energy technologies, namely external drivers and stakeholders in two power markets, the utility-scale generation and powering remote communities. This assessment has been carried out through a survey to international wave energy representatives consisting of a varied mix of both geographical origins and background.

The analysis of results found that the ranking of wave energy drivers considerably differs for the utility-scale generation market and the powering remote communities' counterpart. Furthermore, two broad clusters of stakeholders arise. The main implication is that the development of wave energy technologies will be primarily influenced by the needs from the Owner and the Government for utility-scale and the remote community projects respectively. The knowledge of the overarching context should lead first to a better assessment of the stakeholder requirements, then evaluation of technology-agnostic capabilities and finally quantification of technical performance for the physical embodiment.

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ABBREVIATIONS

EPCI	Engineering, Procurement, Construction and Installation
O&M	Operation and Maintenance
PESTLE	Political, Economic, Social, Technological, Legal and Environmental
PPA	Power Purchase Agreement
SE	Systems Engineering
SPV	Special Purpose Vehicle
SWOT	Strengths, Weaknesses, Opportunities and Threats
WEC	Wave Energy Converter

1. INTRODUCTION

Nations all over the world are setting ambitious decarbonisation targets as a means to fight against climate change [1]. However, despite the need to increase the share of electricity generation from renewable sources, ocean energy, and particularly wave energy, still remain a largely untapped resource [2]. Wave energy is abundant, predictable, widely distributed and indigenous for a large proportion of the populations living in coastal areas [3]. Together with tidal stream, wave energy has the potential to satisfy up to 10% of the electricity demand [4]. Moreover, with a high penetration of renewable energies in the energy system, wave energy can play an important role in balancing the grid due to its complementarity to other renewable energy sources such as wind and solar [4].

All in all, the path to developing effective wave energy technologies has been poised with many challenges [5]. The ocean is a very harsh environment wherein technologies must demonstrate long-term reliable performance to be able to compete with more mature alternatives [6]. At present, various technologies are in different stages of development, but none of them has achieved commercial readiness [7]. Designing wave energy technologies is a long and intricate process in which a large set of decisions must be made. Multiple design parameters need to be assigned at an early stage, which have a significant influence in its ultimate cost and performance expectations [8]. Failure of the wave energy industry to deliver on those expectations has more than once delayed the commercial scale development of wave energy [3].

The engineering complexity coupled with the large diversity of concepts asks for a comprehensive development approach [9]. Hence, defining the full set of requirements for the design problem from start is paramount to developing a successful wave energy technology [10]. Furthermore, a clear and early understanding of the overarching context and its potential impact on system requirements and dependencies will provide a solid basis for developing wave energy technologies that meet stakeholders' expectations [11]. Attention to context is not new to Systems Engineering (SE), but its consideration has increased hand in hand with the sophistication of engineering problems. The system context comprises multiple external forces that have no direct interaction with the wave energy system, but may influence decisions related to its conception, development and operation [10]. A structural view of the system should consider the multiple value dimensions of the technology (or drivers) together with the various stakeholders that have an interest in the technology [12]. Drivers that are associated with a stakeholder groups are often called concerns.

So far, the most comprehensive analysis of the wave energy requirements has been produced within the Wave-SPARC project [13]. This work led to a complete and agnostic formulation for a utility-scale wave energy farm through application of SE and stakeholder analysis. However, the definition of system context is only partially addressed. The authors present a context diagram used to define the external systems that can directly influence the success of a grid-connected wave energy farm. It is pointed out that this overarching context can influence the design of the technology and the success of the farm, but these factors are not specifically analysed. On the other hand, the commercial viability of wave energy for off-grid applications was also analysed in [14]. The authors investigated the various external forces acting in the system context. Furthermore, they acknowledged that the external factors discussed may not affect the viability of off-grid systems in the same way as in grid-connected systems. Finally, the review of literature reveals very diverse classifications of stakeholders for wave energy projects such as [15], [16], [17] and [18]. Although there is underpinning research to assist in the identification of wave energy stakeholders, to the best of our knowledge, there is no public reference on stakeholder prioritisation in this sector.

The state of the art summarised above shows that external drivers and stakeholder groups are the two main forces that define the system context of wave energy technologies. External drivers are tightly connected to the intended market application, whereas the stakeholder groups define the technology performance expectations. Each intended market application may call for a different combination of external drivers. In turn, the ranking of those external drivers to each stakeholder group will ultimately dictate the importance of the wave energy requirements.

This report aims to assess the relative importance of external forces influencing the development of wave energy technologies in two power market applications, the utility-scale generation and powering remote communities. The utility-scale generation is the most attractive market for wave energy technologies owing to its size. Besides, powering remote communities present an appealing opportunity to decarbonise smaller-scale generation through the exploitation of an abundant and indigenous wave energy resource.

The knowledge gained from the analysis of the overarching context comprising the market application, key drivers and stakeholders' concerns will provide a solid basis for the objective evaluation of wave energy technologies against the systems requirements. The ranking of wave energy drivers considerably differs for each market application and so the stakeholder influence.

The outline of this article is as follows. First, section 2 presents the theoretical framework based on sound SE approaches and survey research. The assessment of external forces has been carried out through a consultation to international wave energy representatives consisting of a varied mix of both geographical origins and background. Section 3 analyses the external forces. It characterises the two electricity markets, as well as identifies the external drivers and main stakeholder groups. Results are presented in section 4 and discussed in section 5. An interpretation of the results and main implications of this study are provided in the conclusions. Finally, the Annex presents the questionnaire sent out to wave energy representatives.

2. METHODOLOGY

2.1. Theoretical framework

SE approaches have been successfully implemented in many industrial sectors to develop complex products to meet very demanding stakeholder requirements [19]. The body of knowledge of SE has developed many specific methods and tools over the years. Within the existing approaches for system analysis, it is worthwhile mentioning the Axiomatic Design technique [20], which introduced the concept of design domains for the first time. This framework is quite useful to systematise the design process of wave energy systems by creating boundary lines between different types of design activities. The world of design is made up of several domains and the wave energy problem is expressed in different ways depending on the design domain into question. Each design domain has an associated model, which acts as a framework for capturing domain-specific information.

An appropriate mapping of design information across domains should be performed to ensure full traceability and consistency of design requirements [21] as shown in Figure 1. In fact, the two first engineering domains define the main forces and attributes influencing wave energy technology development. Together with the intended market application, they delimit the overarching context. The environmental domain accounts for the exogenous components that affect the wave energy system. It is characterised by system drivers and their interactions [22]. On the other hand, the stakeholder domain identifies the interested parties in the wave energy technology and lead to the definition a set of desirable characteristics that the final solution should satisfy, which are represented by the stakeholder requirements [23]. The remaining engineering domains transform these general requirements into more actionable features, i.e. functional, technical and manufacturing requirements [8].

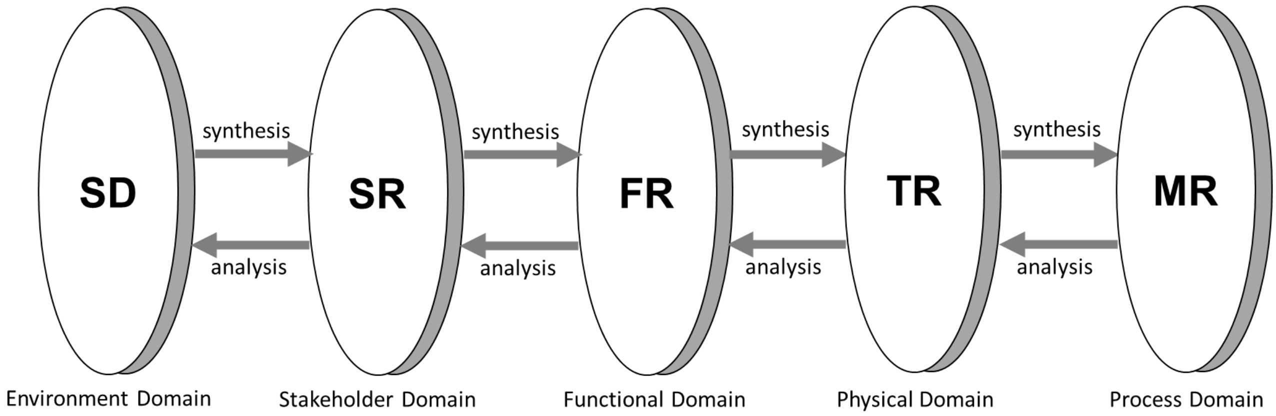


Figure 1: Domains of the design world (adapted from [20])

As it was pointed out in the introduction, a clear and early understanding of the context and its potential impact on system requirements and dependencies will provide a solid basis for developing wave energy technologies meeting stakeholders' expectations [11]. The analysis of the external forces influencing wave energy technology development has been done through a state-of-the-art review. Their prioritisation of key drivers and stakeholders however has not been addressed in wave energy literature, and an *ad hoc* consultation was needed to bridge this gap.

2.2. Survey research

A survey is a market assessment tool used as a way of quickly gaining some general information about a target audience. The survey benefits lie in its versatility, cost-effectiveness and ability to generalise results. However, as with other data collection methods, survey research presents a few disadvantages such as its potential rigidity and validity of results [24]. The present survey aimed to assess the relative importance of external forces influencing the development of wave energy technologies. Moreover, assuming the primary product for wave energy is likely to be electricity generation, two market applications are investigated, namely utility-scale generation and powering remote communities. Data for the identification of external drivers and stakeholder groups was collected from various sources such as reviewed articles, reports, technology news reports. Section 0 provides an analysis of the external forces acting in wave energy.

An anonymous survey was designed to prioritise the external forces. It was conducted by sending it out to various experts in the wave energy sector via email, which ensured that every question was asked in the same way from every respondent. Also, respondents are more likely to provide open and honest feedback in a more private survey method. In total, 120 participants were selected based on their extensive experience in the wave energy sector. Care was taken to include a varied mix of age, gender, origin (i.e. 14 countries from Europe and the Americas), and background (i.e. Academia, Research, Technology development, Industry, Associations, Test sites, Certification bodies, Consultancies, Utilities and Public investors). Answers were mainly provided on an individual basis and may not represent their organisation's position.

A total of 64 questionnaires were completed during the realisation of this survey (53% response rate). This number represents about 6% of the 1,100 full time jobs in the nascent ocean energy estimated by IRENA [25]. An online calculator [26] was used to find that the number of responses would ensure a confidence level of 90% with a 10% margin of error. These values can be considered acceptable when working with small populations and original research topics without previous studies. Survey results will only suggest a significant effect that deserves further investigation.

Survey design takes a great deal of thoughtful planning and often a great many rounds of revision. The short structured questionnaire was designed following the principles outlined by Cowles and Nelson [27]. According to these principles, good survey questions are characterised by specificity, clarity and brevity. These principles constitute a solid guideline to increase validity and reliability of responses. The two questions included in the survey are as follows:

1.- Which are the key drivers of wave energy projects for each market application?

2.- Which of the above drivers concerns each wave energy stakeholder group more?

Respondents were asked to rank the two set of factors using a Likert scale. A free text input box was also provided after each question, where the respondents were prompted to add any missing factor, reasoning behind their ranking choices or any other comments. Responses were collected in a spreadsheet and later processed for graphical representation. Participation in the survey was voluntary. The questionnaire was first distributed on 22nd November 2021, following a reminder on 27th November 2021 and finally closed on 13th December 2021. The survey questionnaire is shown in the Annex.

3. ANALYSIS OF EXTERNAL FORCES

3.1. Wave energy markets

The intended market application drives the development of innovations, since new technologies are created to address existing or unexploited market opportunities and problems [28]. Knowledge about future markets is vital at all stages of the innovation process [29]. Therefore, defining the target market(s) is the first logical step to characterise the overarching context.

Wave energy technologies harness the movement of ocean and sea waves to produce any usable form of energy. However, the primary product for wave energy is likely to be electricity generation due to the important contribution of this energy carrier to the decarbonisation of the global energy system [30]. Although some technology developers are targeting other products such as freshwater or hydrogen, most wave energy technologies are being developed to produce electricity. At least, the progress of the sector to-date has been driven mainly by electricity generation.

Owing to its size, large scale grid-connected electricity generation is the most attractive market for wave energy technologies [31]. Wave energy presents an opportunity to meet the international decarbonisation targets. However, integration of wave energy technologies into the utility scale market is challenging since these emerging technologies must struggle to compete in cost with more mature renewable energies such as wind or solar.

Alternatively, non-utility markets may present an appealing opportunity for wave energy technologies to be exploited at a smaller scale in a less competitive setting. In particular, islands and other off-grid markets could provide a steppingstone supporting the deployment of wave energy technologies while providing environmentally friendly energy to coastal communities. These territories experience a much distinct reality than their continental fellows and therefore may require bespoke solutions [32]. Consumers mainly depend on diesel power generation, they pay high electricity prices compared to mainstream markets and are more vulnerable to fluctuations in the tariff.

Other niche applications for wave energy systems have been proposed given their co-location nature. Among them, it is worth mentioning the energy supply to offshore oil & gas platforms, marine aquaculture and ocean observation and navigation [33]. However, these markets will not be investigated in this report because of their lesser size, great variety of requirements and lack of consistent information.

Table 1 summarises the main characteristics of the two application markets that are analysed in this report, namely utility-scale generation and remote community generation.

Table 1: Market characteristics.

Market	Characteristics
Utility-scale generation	• Attractive but also very competitive • WEC design mainly driven by this market • Increasing demand for renewable electricity • Legal obligations to meet decarbonisation targets
Remote community generation	• Narrower span of competition (sometimes just one option - diesel) • Low energy security and quality • Consumers vulnerable to price fluctuation and high energy costs • Simplified market and regulatory conditions

3.2. Wave energy drivers

Wave energy drivers are an essential part of the context where the wave energy system operates. Drivers are exogenous forces outside the system boundaries that can constrain, enable or alter the design solution [22]. The context includes the political, economic, social, technological, legal and environmental factors. The existence of favourable conditions in the intended market will certainly stimulate the development of wave energy technologies.

PESTLE analysis is a common tool used by companies to track the context they are operating in or are planning to launch a new project, product or service [34]. This tool can be combined with SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis to provide an excellent framework to investigate wave energy drivers from many different angles and dimensions [35]. PESTLE is an acronym which in its expanded form stands for:

- P for Political. Political drivers determine the extent to which a government may influence a certain industry.
- E for Economic. Economic drivers comprise factors that directly impact the economic viability.
- S for Social. Social drivers scrutinise social trends and attitudes.
- T for Technological. Technological drivers pertain to key knowledge and technologies that affect the industry.
- L for Legal. Legal drivers include regulations that affect the business environment.
- E for Environmental. Environmental drivers allude to factors that are determined by the surrounding natural environment the wave energy system is placed.

Attributes that characterise wave energy drivers are fairly covered in literature such as [14], [36], [37] and [38]. Table 2 provides a summary of wave energy drivers per main category.

Table 2: Wave energy drivers

Category	Attributes
Political	• Favourable policies (e.g. energy security, finance, sustainability, job creation) • Market support mechanisms • Political stability and low bureaucracy
Economic	• Access to finance, credit & insurance • Energy price and/or volatility
Social	• Growing energy demand • Social acceptance
Technological	• Technology maturity and certification • Infrastructure readiness • Supply chain availability
Legal	• Simplified procedures (e.g. consenting, environmental assessment) • Standards and certification
Environmental	• Stricter environmental protection (e.g. pollution, natural disasters, climate change) • Suitable site and resource conditions

Nevertheless, the prioritisation of wave energy drivers is still to be investigated. The authors of this work have conducted a survey to wave energy representatives to establish the importance ranking of wave energy drivers for each application market. Respondents were asked to grade the political, economic, technological, legal and environmental factors using a Likert scale, being 1 the highest importance and 6 the lowest.

3.3. Wave energy stakeholders

A stakeholder is an individual, group or organisation with interests or concerns relative to a system's development and operation [39]. Key stakeholders are those who can significantly influence the system design or are important to its success [40]. Together with wave energy drivers, the stakeholders define the overarching context where the wave energy system operates.

Stakeholder analysis encompasses the identification and prioritisation of stakeholder groups [41]. Stakeholder identification is often an overlooked activity but essential to achieve an effective system. As it was pointed out in Section 1, the review of literature reveals very diverse classifications of wave energy stakeholders. Due to this lack of consensus, clarity might be gained by describing how stakeholders are expected to interact.

It is fairly common that renewable energy projects set up of Special Purpose Vehicle (SPV) company to develop, build, maintain, and operate the system for its lifetime [42] [43]. The SPV becomes the project owner and central administrative entity tasked with acquiring funds, hiring a developer, organising power purchase agreements, and maintaining overall responsibility for the profitability of the project and for meeting obligations stipulated by regulators in the site lease. The shareholders of this company invest capital and secure funds to pay the construction mainly with loans. Additionally, the national, regional or local government can provide incentives to develop the project. Common support mechanisms in renewable energy projects are feed-in tariffs, feed-in premiums, auction schemes, quota obligations based on tradable green certificates, investment support, tax incentives or exemptions, and loan interest loans [44].

The owner hires a project developer to plan and develop the wave energy farm, often from the initial site assessment through the final commissioning stage. The project developer acquires project rights for siting and permitting, whilst independent bodies will assess the conformity of the project with regards to national and international standards. In the course of the consultation procedures, pressure groups such as marine users may set further conditions for approval. Besides, project developers may freely engage with organisations (e.g. environmentalists, political parties, community bodies, trade associations, unions, media) that can support or oppose to wave energy. The owner transfers risks by means of contract agreements with specialised firms for the construction, operation and maintenance of the farm. In turn, the main contractors rely on low-tier suppliers to provide various goods, equipment and services for the project, including certification. A crucial supply is the technology for harnessing wave energy. An insurance company is chosen to provide coverage during the construction and operation phases.

In the operational phase, the SPV will charge end-users for the energy produced, collect payments, and use that revenue to cover its costs. The broader consumer body includes individuals and organisations that consume energy and/or pay taxes. In some cases, a Power Purchase Agreement (PPA) is signed with an off-taker, often a utility company, who ultimately sells it to consumers [45]. Financing is easier to obtain if lenders can see the company has a purchaser of its production.

Considering the interactions of the concerned parties, wave energy stakeholders play four main roles:

- **Financiers**. They provide economic resources or incentives to develop the project: equity (owner), debt (lenders) and incentives (government).

- **Developers**. They provide key resources, advice, services, or assets and have a direct interest in how things are managed on the project during its lifetime: project development (owner), construction and end of life (EPCI[1] contractor), as well as operation (O&M provider).
- **Condition setters**. They impose conditions and influence the direction of the project: national, regional and local policy makers (government), independent bodies that have an administrative or regulatory role (regulators) together with environmentalists, trade associations, community bodies, political parties, unions and media (pressure groups).
- **Energy users**. They participate in the flow of energy: seller (owner), grid operator and final users (consumers).

As seen before, wave energy stakeholders can have different roles and responsibilities. For this research stakeholders have been grouped in eight broad categories depicted in Figure 2 and briefly described in Table 3.

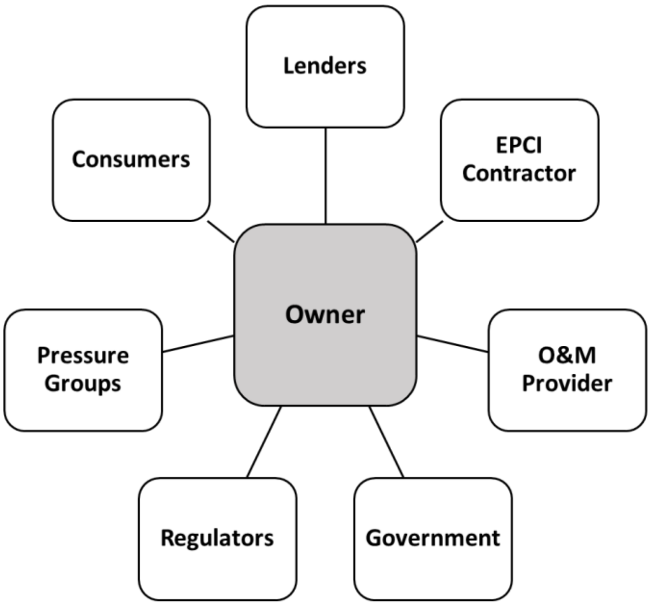


Figure 2: Wave energy stakeholder groups.

Table 3: Wave energy stakeholders

Stakeholder	Main responsibilities
Owner	• Initiate the project and design the farm • Provide equity • Set return on investment targets • Manage project risks • Sell electricity to consumers
Lenders	• Provide debt • Set interest rate • Assess financial risk
EPCI contractor	• Manage farm construction and installation • Provide insurance during construction • Select suppliers • Manage end of life recycling

[1] EPCI stands for Engineering, Procurement, Construction and Installation

Stakeholder	Main responsibilities
O&M provider	• Provide spare parts and services • Perform (un)scheduled maintenance • Provide insurance during operation • Select service suppliers
Government	• Develop and implement sectoral policies • Review compliance • Provide investment and generation incentives
Regulators	• Establish permitting requirements • Review project use of ocean space • Provide concession
Pressure groups	• Lobby for or against the project • Improve the well-being of the community
Consumers	• Set power quality requirements • Purchase generated electricity

Stakeholder prioritisation is as important an activity as stakeholder identification. The aim of stakeholder prioritisation is to focus on the needs and expectations of those stakeholder groups who have more power to and interest in influencing the wave energy technology [46]. However, wave energy stakeholder prioritisation has not been properly analysed in literature. To this purpose, the authors of this work have conducted a survey to wave energy representatives to establish the importance ranking of stakeholders for each wave energy driver. Again, respondents were asked to grade the following stakeholder groups using a Likert scale, being 1 the highest importance and 8 the lowest.

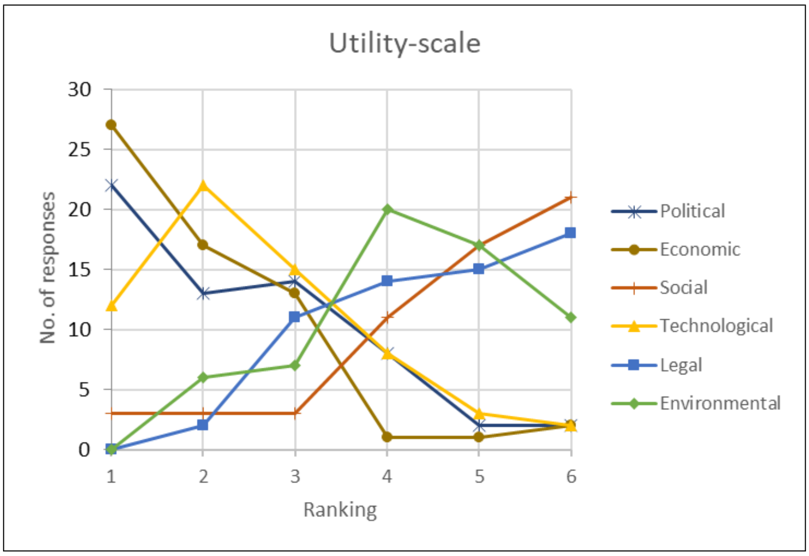
4. SURVEY RESULTS

This section presents a series of graphics summarising the prioritisation results obtained from the consultation to wave energy representatives for the application markets, key drivers and stakeholder groups. The first set consists of line graphs showing the distribution of responses, whereas the second set of bubble charts displays the most frequent ranked factors (also known as mode in statistics) together with the standard deviation from the mean value. The size of the bubbles is proportional to the number of responses.

4.1. Key drivers of wave energy projects

4.1.1. Utility-scale generation

The distribution of priorities per driver in a utility-scale generation market and the most frequent ranked factors are presented in Figure 3.



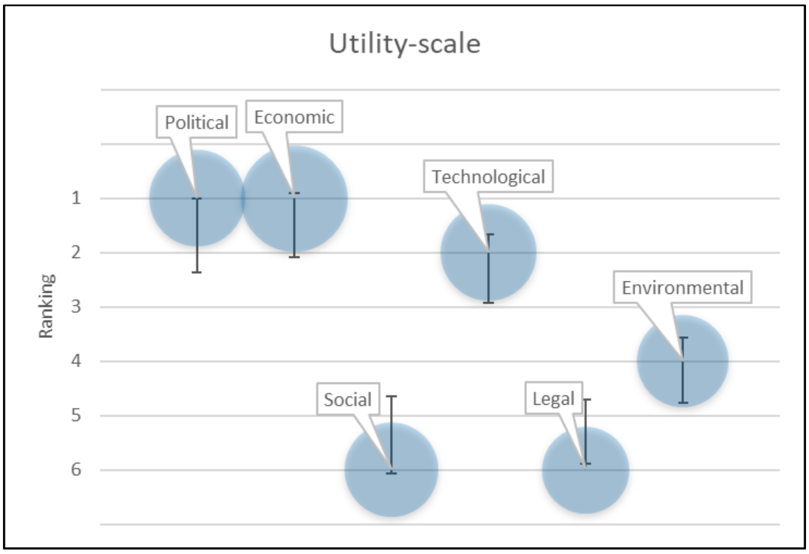


Figure 3: Key drivers for utility-scale generation.

Even though the survey did not allow to assign the same priority to the factors, it can be noted that both Economic and Political drivers did receive the highest score. Similarly, the Social and Legal drivers scored the lowest for the utility-scale generation market. In both cases, the size of the bubble can be used to disambiguate between drivers if needed. A closer analysis of the scores per driver yields a sharp rank distribution. Responses show a significant level of agreement (34-44%). The prioritisation according to the mode is not sensitive to the margin of error in the sample.

4.1.2. Remote community generation

Likewise, the distribution of priorities per external driver and the most frequent ranked factors are presented in Figure 4. This time, the focus is on the application of wave energy technologies in a remote community generation market.

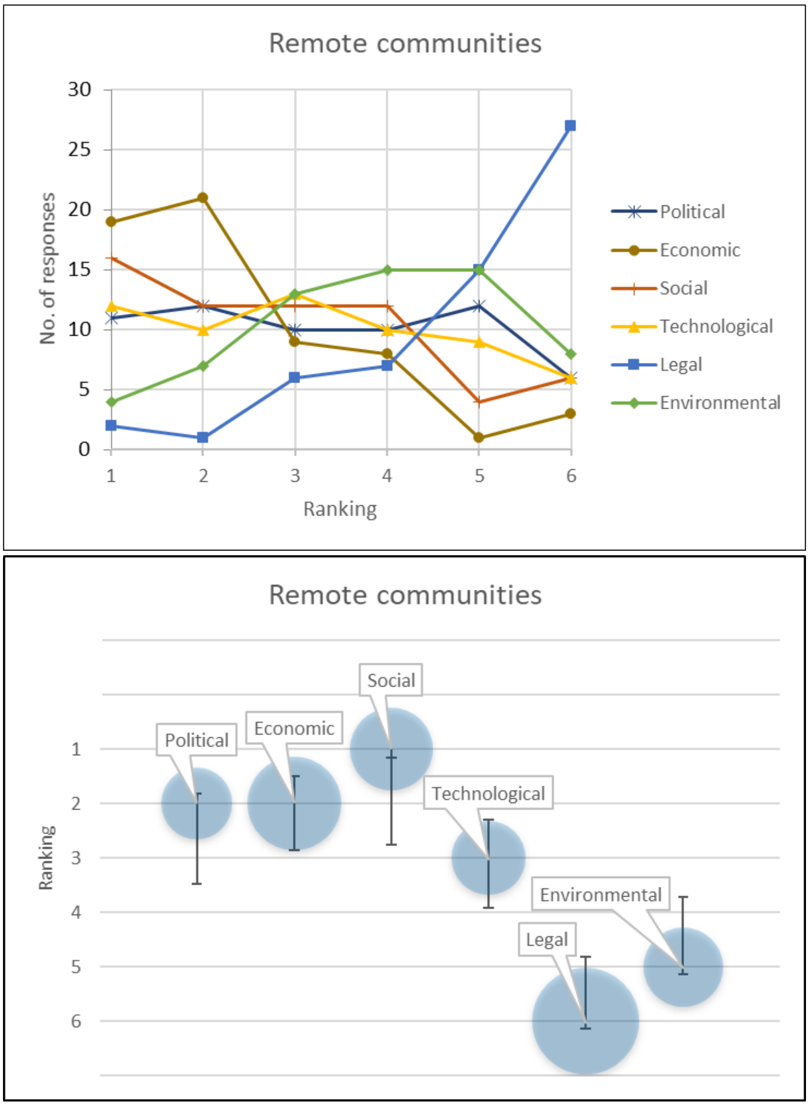


Figure 4: Key drivers for remote communities generation.

It can be observed that the Social drivers have now the top priority with 26% of responses, whereas the Legal drivers score last. The Economic and Political drivers are ranked second. The level of agreement in the responses is not so marked for all drivers as for the utility-scale generation. This means that the prioritisation of Political (20% of responses), Technological (21%) and Environmental (25%) drivers may be sensitive to the sample size. In fact, the distribution of responses is much flatter for these three drivers. Prioritisation of Political drivers has a higher degree of uncertainty as it can get a higher rank (1) or a much lower rank (5) with minor changes in the responses.

4.2. Drivers interrelationship with wave energy stakeholder group

4.2.1. Political factors

The importance distribution of Political concerns per wave energy stakeholder group and the most frequent ranked stakeholders are presented in Figure 5.

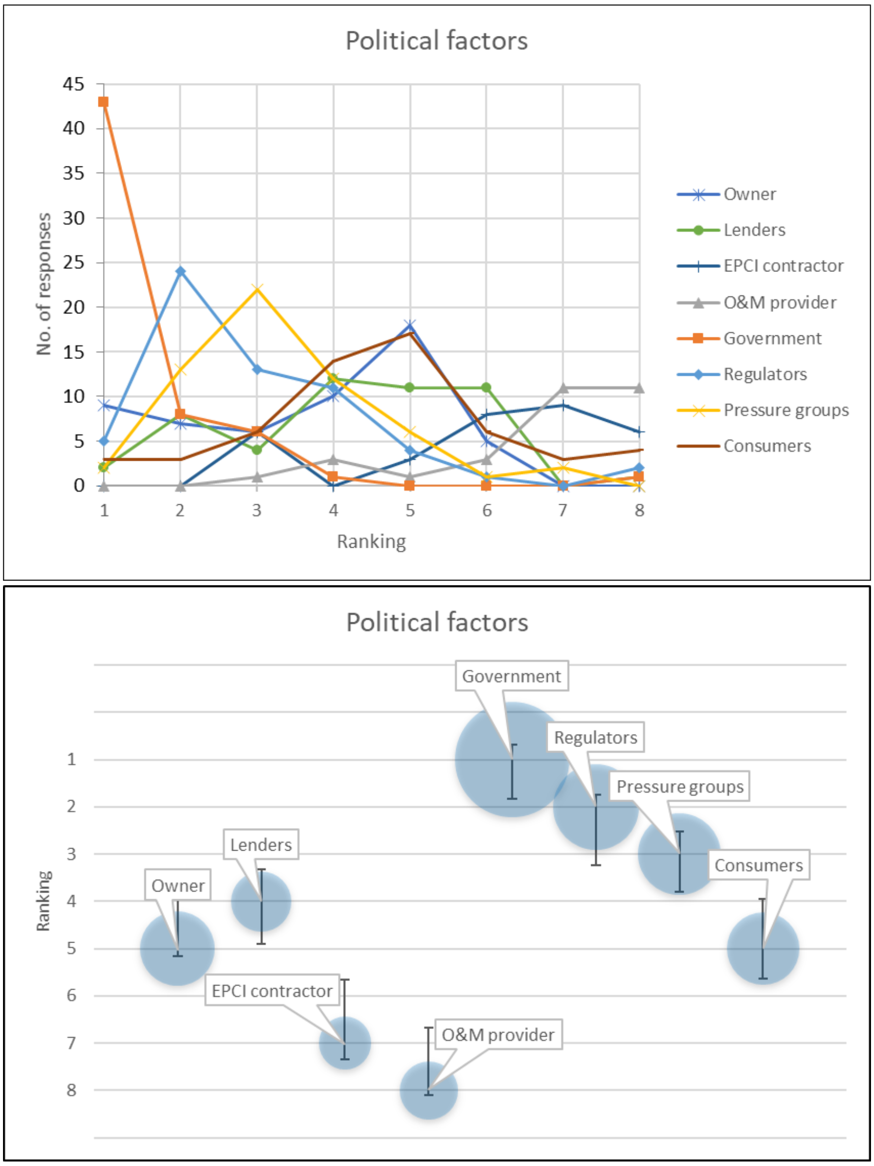


Figure 5: Political concerns for the wave energy stakeholders.

Government clearly shows up in first position with 70% of responses. The EPCI contractor and O&M provider are the least important stakeholders in terms of political concerns. These two drivers have also received the fewer number of responses (15% and 18% respectively). They could step up one position accounting for the margin of error in the sample, which is not sufficient to alter the overall prioritisation. Lenders display the greatest degree of uncertainty. They can either be ranked 4, 5 and 6 with minor changes in the responses.

4.2.2. Economic factors

The importance distribution of Economic concerns per wave energy stakeholder group and the most frequent ranked stakeholders are presented in Figure 6.

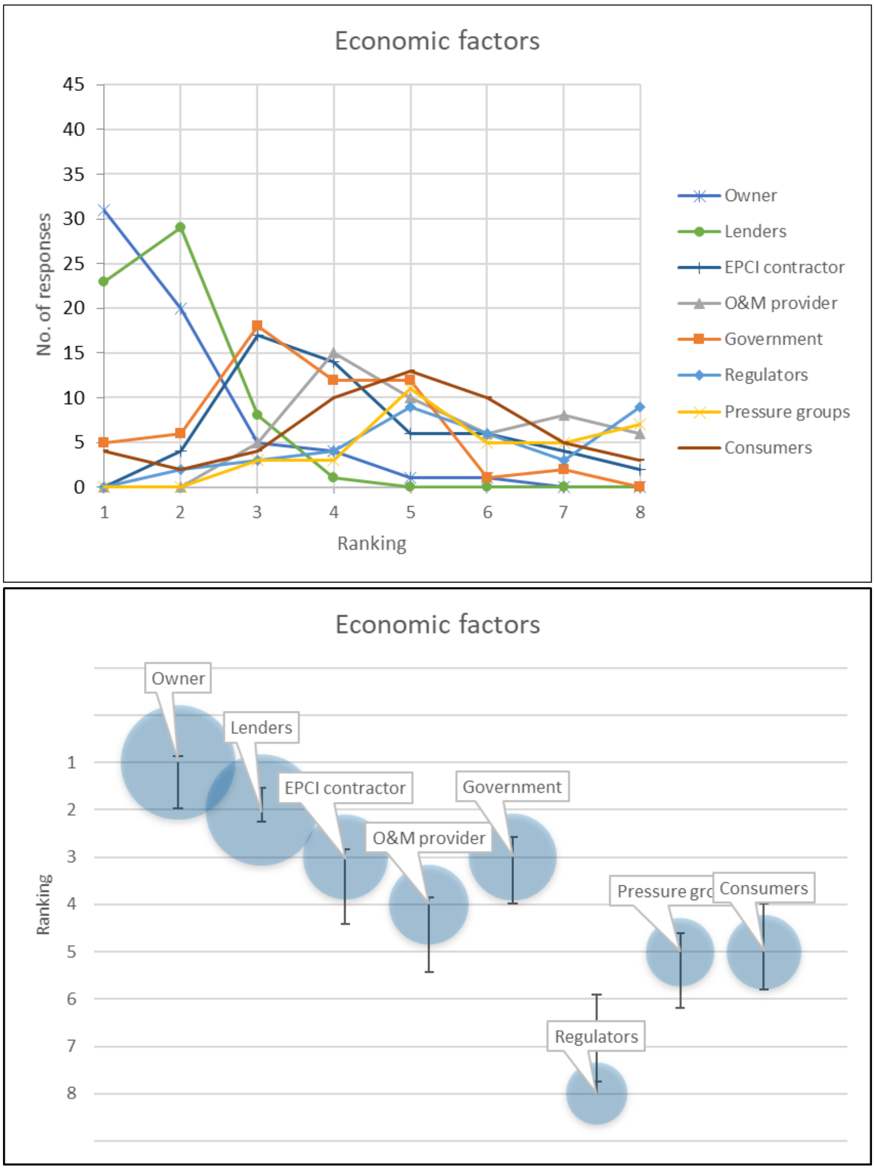


Figure 6: Economic concerns for the wave energy stakeholders.

The Owner stands out in first position with 51% of responses. There is a high level of agreement in the prioritisation of stakeholders according to Economic factors. Given the margin of error in the sample, the only uncertainty is for the Regulators who could step up to the same position as the Consumers and the Pressure groups. However, as Regulators score in the last position with just fewer number of responses (15%), this does not change the overall ranking.

4.2.3. Social factors

The importance distribution of Social concerns per wave energy stakeholder group and the most frequent ranked stakeholders are presented in Figure 7.

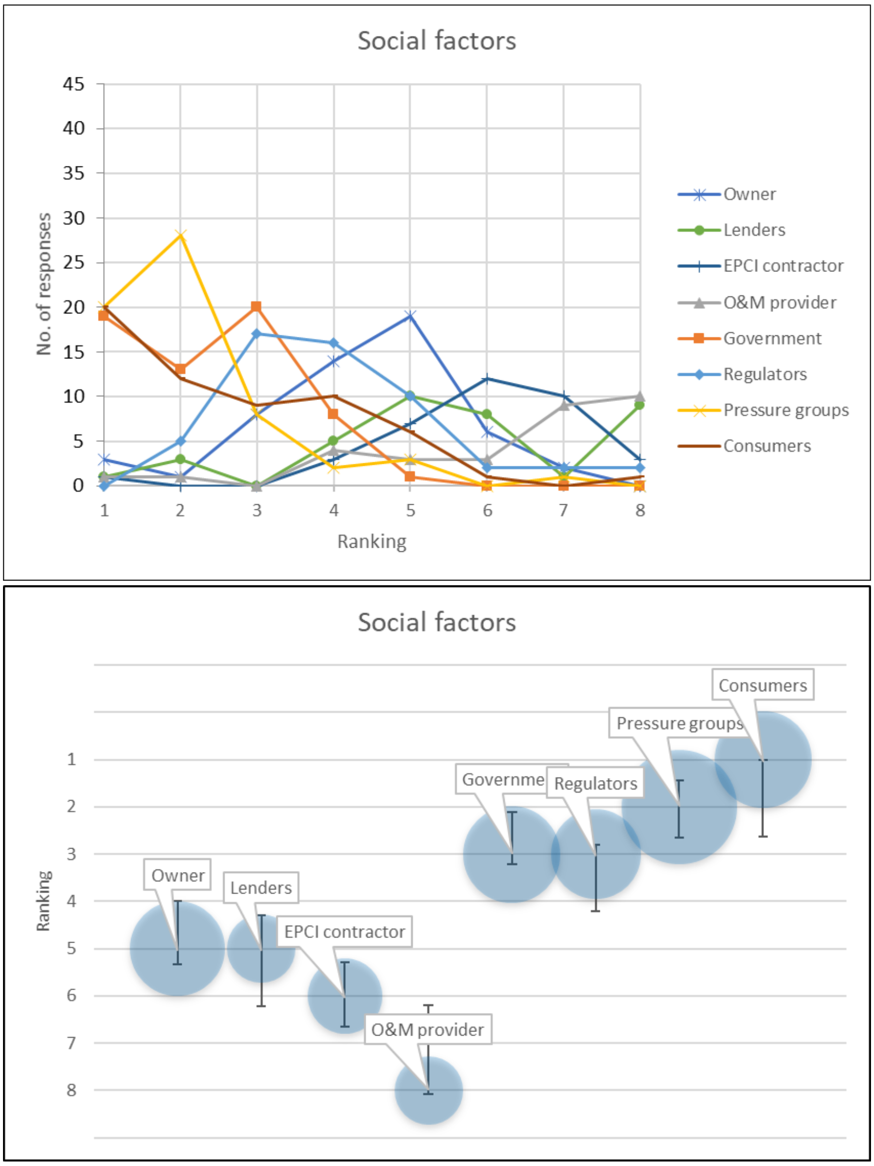
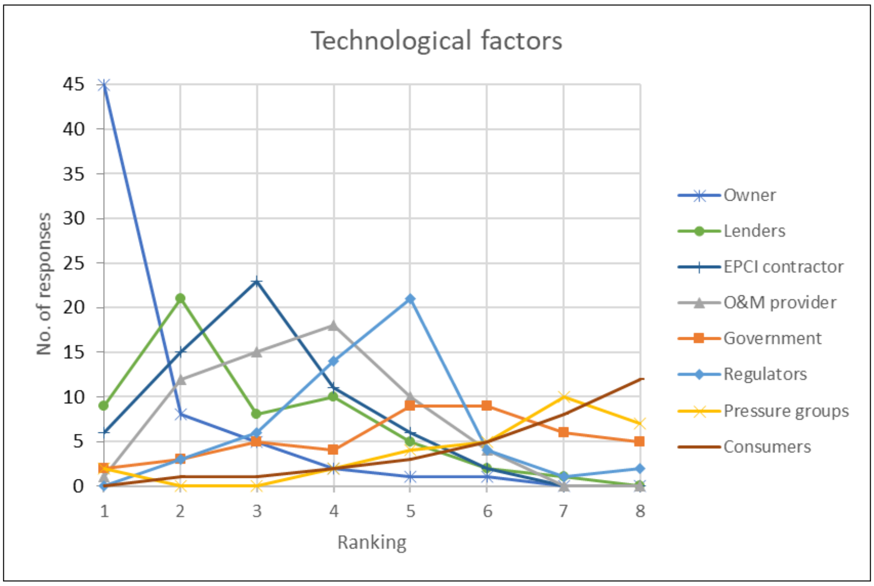


Figure 7: Social concerns for the wave energy stakeholders.

In this case, Consumers are ranked first according to Social factors with 33% of responses. There is a strong agreement with regard to the importance of Pressure groups (46%), the Owner (33%) and Regulators (28%). However, the Government can swap from the third to the first position considering the margin of error in the sample. Finally, the EPCI contractor, Lenders and the O&M provider get the fewer number of responses (16-20%). Their ranking however is unaffected by this level of uncertainty.

4.2.4. Technological factors

The importance distribution of Technological concerns per wave energy stakeholder group and the most frequent ranked stakeholders are presented in Figure 8.



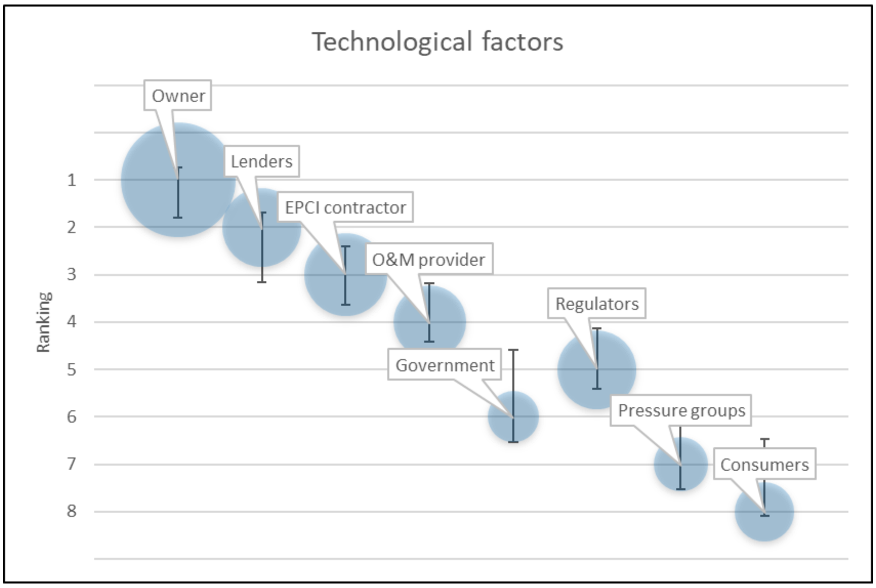


Figure 8: Technological concerns for the wave energy stakeholders.

As per the Economic drivers, the Owner jumps again into the first position, but in this case with the highest number of responses (74%). There is a high level of agreement in the prioritisation of stakeholders according to Technological factors. Given the margin of error in the sample, the only uncertainty is with the Government who could step up to the same position as Regulators. However, this does not change the overall ranking as the Government has fewer number of responses (15%). Finally, Pressure groups and Consumers close this ranking.

4.2.5. Legal factors

The importance distribution of Legal concerns per wave energy stakeholder group and he most frequent ranked stakeholders are presented in Figure 9.

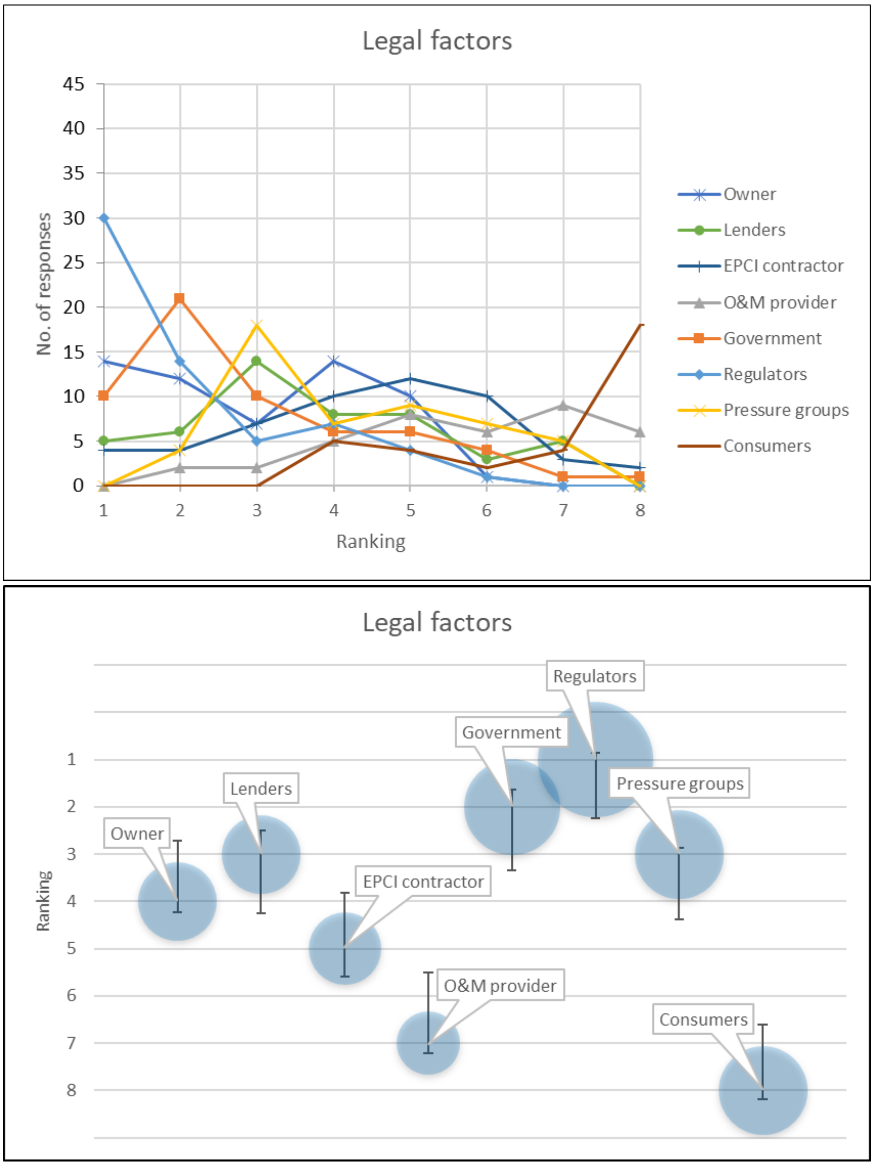


Figure 9: Legal concerns for the wave energy stakeholders.

Regulators present the highest priority with 49% of responses and Consumers the lowest with 30% of responses. There is a significant level of agreement in the ranking of stakeholders despite the margin of error in the sample. The only uncertainty remains with the position of the Owner that can be swapped from 4 to 1.

4.2.6. Environmental factors

Finally, the importance distribution of Environmental concerns per wave energy stakeholder group and the most frequent ranked stakeholders are presented in Figure 10.

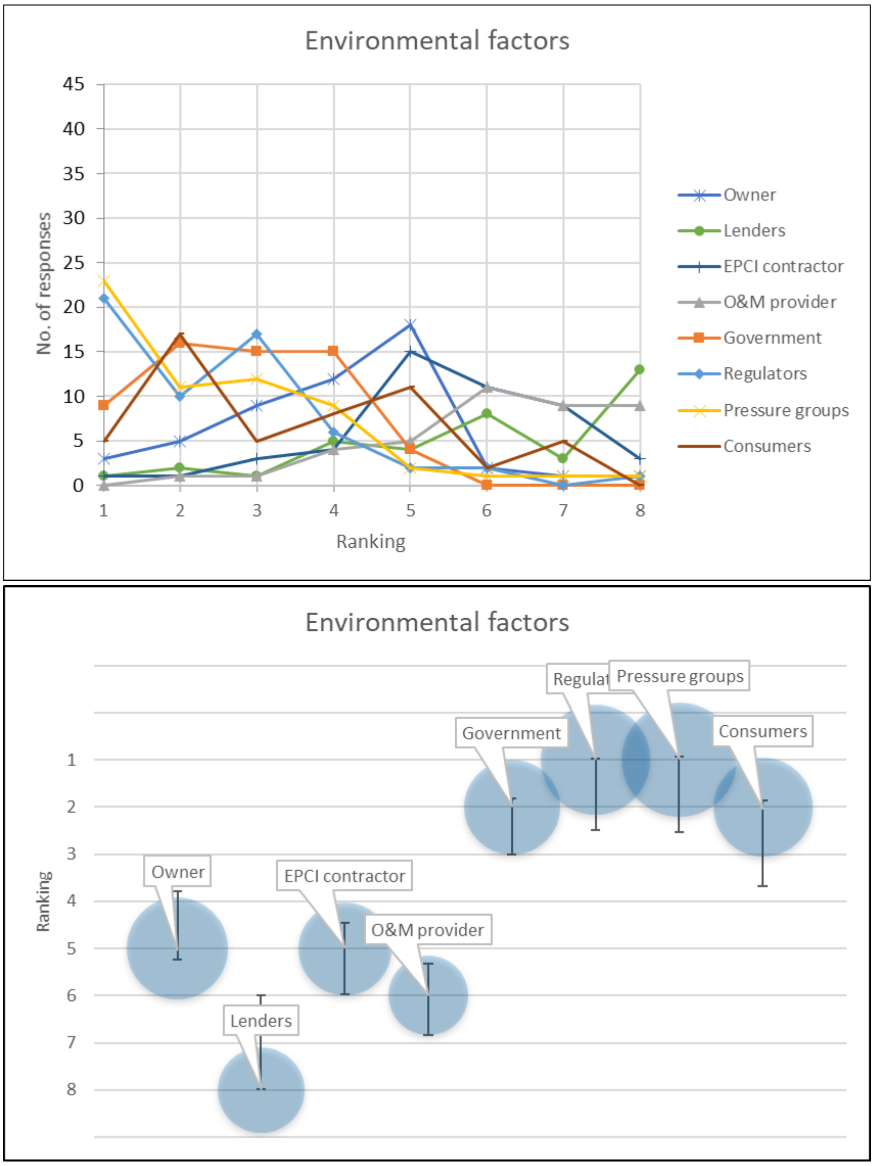


Figure 10: Environmental concerns for the wave energy stakeholders.

Both Pressure groups and Regulators share first position with 38% and 34% of responses respectively. Lenders are ranked last. The overall ranking is not sensitive to the margin of error except for the Government that can take either the third or fourth position. However, the Government accounts for fewer number of responses (26%) than the Consumers (28%), which make the obtained prioritisation still reliable.

5. DISCUSSION

5.1. Key drivers of wave energy projects

According to the survey results, the ranking of wave energy drivers considerably differs for the utility-scale generation market and the powering remote communities' counterpart. Economic and Political factors are the main motivations for developing utility-scale generation projects, whereas the Social drivers stand out on top in a remote generation market. This result is in line with the market characterisation presented in section 3.1 and the qualitative feedback collected from the consultation to wave energy representatives. In other words, utility-scale generation is a very competitive market, whilst the remote community generation is driven by the energy demand and public acceptance.

Wave energy utility-scale projects are clearly not at the commercial stage. They still require technological development, particularly to demonstrate the necessary reliability levels and cost-effectiveness. This circumstance creates important barriers to access the required financial and insurance support. Hence, public funding is needed to develop wave energy to the point that it can be picked up by the private sector. In this sense, a key political driver is long-term revenue support from governments. Additionally, investment decisions may hinge on available political targets in relation to climate change, energy transition and security of supply. Consequently, utility-scale development of wave energy technologies will largely depend on an attractive economic support and a favourable political framework.

In contrast, the maturity of existing wave energy technologies may be sufficient to provide energy at a smaller scale in a remote community project. Remote communities already bear a high cost of energy, opening the way to make wave energy technologies competitive with respect to other energy sources. In this sense, the growing energy demand and social acceptance of the local communities are crucial drivers. Moreover, local populations are much more engaged and have a closer appreciation of nearby environmental and economic benefits. The economic and political factors score second in a remote community market application and they are highly determined by the social concerns. It is worth noting that whereas social factors stand out as the main driver for remote community projects, they rank in the last position in a utility-scale application of wave energies.

Technological factors are second for the utility-scale projects and third for the remote community generation. This reflects that technology maturity is somehow assumed to be in place before any significant technology roll-out can be conceived. Besides, grid infrastructure may be critical but, being out of the hands of the technology developers, needs for stronger pushes in the economic political and social drivers.

Legal and environmental aspects are the less important concerns. There are normally perceived as barriers instead of drivers. Many procedures are partially in place and data gathered on the potential environmental impacts is limited or poorly validated because of the short deployment times of current technologies. It will be important to address these uncertainties in the future. However, it is considered that if wave technology is proven to work, then the legal and permitting side will eventually follow. Factors relating to competing uses of resource areas might also be impactful to decision making. Stricter environmental protection will speed up the transition to renewables for energy companies. The legal factor is normally equalised once the political factor is in place and sets the legal environment.

The previous results point out that there is a central issue for each application market but also that drivers are somehow interlinked. Finance is connected to a suitable political framework. Limited support will delay technology maturity, but if the technology is proven then the legal side will follow. The political factors will contribute to setting the legal framework. Environmental concerns may be the motivator for the political and social factors. Finally, job creation is a political aspect but can also improve social acceptance.

The authors acknowledge that this research has some limitations. Whereas this prioritisation is not sensitive to the margin of error in the sample for the utility-scale market, it contains a certain degree of uncertainty for the remote community generation. In fact, the Political drivers can vary the rank from 1 to 5 with minor changes in the responses. This is due to a much flatter distribution of responses. Additionally, the prioritisation exercise shows the current global landscape but lacks the local perspective and potential evolution in time. Regarding the local perspective, the number of responses received did not allow a reliable segmentation of results per each country of respondents surveyed. The ranking might be sensitive to geographical and economic development considerations, particularly for remote coastal communities.

5.2. Drivers interrelationship with wave energy stakeholder group

The wave energy problem is expressed in terms of stakeholders' expectations. The different importance ranking of these stakeholders for each key driver and market application will hence determine the system requirements for the development of wave energy technologies that is tailored to each specific use.

According to the survey results, two broad clusters of stakeholders arise. On the one hand, the Owner, Lenders, EPCI contractor and O&M provider are the most important actors for the Economic and Technological factors. On the other hand, the Government, Regulators, Pressure groups and Consumers are mainly concerned with Political, Social, Environmental and Legal factors. This result is in line with the few references in literature [13] [14] and the qualitative feedback collected from the consultation to wave energy representatives.

Political factors are of primary concern to the Government and Regulators. It is worth noting that although the Political drivers are directly steered by the Government and Regulators, the Pressure groups and the Consumers also have certain degree of influence on the Government.

Economic and Technological factors share a similar profile of stakeholders' concerns. The ranking starts with the Owner followed by the Lenders, EPCI contractor and O&M provider. However, the Government is slightly more concerned with the Economic drivers than Technological aspects. At the current stage of development, Economic and Technological drivers are crucial for both Owners and Lenders as it is their return on capital that is at stake. EPCI contractors and O&M providers will try to reduce their exposure due to technology immaturity.

Social and Environmental drivers are aspects more connected to the public and therefore are vital for the Government, Regulators, Pressure groups and Consumers. These four stakeholders score high for the Environmental drivers. However, Consumers and Pressure groups stand out for the Social drivers. Lastly, Legal factors are driven by those who can support and define the boundaries of the legal framework, namely Regulators, the Government and Pressure Groups.

These results show that the Owner and the Government are lead players in each of the two stakeholder clusters. We have seen earlier that the utility-scale generation is dominated by Economic and Political factors whilst powering remote communities is mainly motivated by Social drivers. Accordingly, it can be inferred that the development of wave energy technologies will be primarily influenced by the needs from the Owner and the Government for utility-scale and the remote community projects respectively.

In the same way it has been discussed before for the key drivers of wave energy projects, this research has some limitations. The prioritisation of concerns contains a certain degree of uncertainty due to the sample size and corresponding margin of error. A different sample can reduce the concerns of Lenders with respect to the Political factors and the Environmental factors. Similarly, Regulators, the Government and the Owner can have greater concerns in relation to the Economic, Social and Legal factors respectively.

6. CONCLUSIONS

The development of effective wave energy technologies is a complex and long process in which many decisions must be taken. A firm foundation for developing a successful technology that meets the stakeholders' expectations requests an early definition of systems requirements and a clear understanding of the potential impact/dependencies of the overarching context where the technology will operate.

The system context comprises multiple external forces that may influence decision making. This report has analysed the relative importance of key drivers and stakeholders influencing the development of wave energy technologies in two power market applications, namely the utility-scale generation and powering remote communities. The assessment of external forces has been carried out through a survey to international wave energy representatives consisting of a varied mix of both geographical origins and background.

Results from this prioritisation exercise suggests some interesting global trends. The ranking of wave energy drivers considerably differs for the utility-scale generation market and the powering remote communities' counterpart. Economic and Political factors are the main motivations for developing utility-scale generation projects, whereas the Social drivers stand out on top in a remote generation market. Besides, two broad clusters of stakeholders arise. On the one hand, the Owner, Lenders, EPCI contractor and O&M provider are the most important actors for the Economic and Technological factors. On the other hand, the Government, Regulators, Pressure groups and Consumers are mainly concerned with Political, Social, Environmental and Legal factors. Moreover, the Owner and the Government are lead players in each stakeholder cluster. The implication is that the development of wave energy technologies will be primarily influenced by the needs from the Owner and the Government for utility-scale and the remote community projects respectively.

These results are in line with the available literature and qualitative feedback collected from the consultation to wave energy representatives. However, the authors acknowledge that this research has some limitations. The number of responses received did not allow to segment the results per each country and category of respondent surveyed. The ranking might be sensitive to geographical and economic development considerations, particularly for remote coastal communities that has a much flatter distribution of responses. Additionally, the prioritisation of concerns contains a certain degree of uncertainty due to the sample size and corresponding margin of error. Higher statistical significance may be obtained by replicating the study with a larger sample size. Moreover, the segmentation per stakeholder category could add further insight to the prioritisation. In which to future evolution is concerned, it would be interesting to repeat this consultation in 2/3 years' time with the increased knowledge in the sector. Once some uncertainties have been removed, the key drivers might show a more stable picture.

Further research should encompass the detailed analysis of wave energy requirements. Traceability of the design information through the different engineering domains will be crucial to avoid any inconsistency with the formulation of requirements. The knowledge of the overarching context should lead first to a better assessment of the stakeholder requirements, then evaluation of technology-agnostic capabilities and finally quantification technical performance measures for the physical embodiment.

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ANNEX: SURVEY

1.- Which are the key drivers of wave energy projects for each market application?

1.a.- Please rank the following factors in order of importance (**1-highest; 6-lowest**)

- **Political factors**: Supporting policies such as energy security, finance, sustainability and job creation.
- **Economic factors**: Access to finance, credit & insurance.
- **Social factors**: Growing energy demand and social acceptance.
- **Technological factors**: Technology maturity and infrastructure readiness.
- **Legal factors**: Simplified procedures such as consenting and environmental impact assessment.
- **Environmental factors**: Stricter environmental protection (e.g. pollution, natural disaster recovery, climate change).

Table cells have drop-down menus to provide your choices. You are kindly asked to select **a minimum of 4** drivers per market application.

Ranking	Sample response	Utility-scale	Remote communities
1	Economic	[Select]	[Select]
2	Political	[Select]	[Select]
3	Technological	[Select]	[Select]
4	Environmental	[Select]	[Select]
5	Social	[Select]	[Select]
6	Legal	[Select]	[Select]

1.b.- Please feel free to use the box below to provide further comments on driver prioritisation. Do you miss any key driver in the above list?

2.- Which of the above drivers concerns each wave energy stakeholder group more?

2.a.- Please rank the following stakeholder groups in order of importance (**1-highest; 8-lowest**)

- **Owner**: Initiates the project; designs the farm; provides equity; sets return on investment targets; manages project risks; sells electricity to consumers.
- **Lenders**: Provides debt; sets interest rate; assesses financial risk.
- **EPCI contractor**: Manages farm construction and installation; provides insurance during construction; selects suppliers; manages end of life recycling.
- **O&M provider**: Provides spare parts and services; performs (un)scheduled maintenance; provides insurance during operation; selects service suppliers.
- **Government**: Develops and implements sectoral policies; reviews compliance; provides investment and generation incentives.
- **Regulators**: Establishes permitting requirements; reviews project use of ocean space; provides concession.
- **Pressure groups**: Lobbies for or against the project; improves the well-being of the community.
- **Consumers**: Sets power quality requirements; purchases generated electricity.

Table cells have drop-down menus to provide your choices. You are kindly asked to select **a minimum of 5** stakeholder groups per driver.

Ranking	Political	Economic	Social	Technolog.	Legal	Environm.
1	[Select]	[Select]	[Select]	[Select]	[Select]	[Select]
2	[Select]	[Select]	[Select]	[Select]	[Select]	[Select]
3	[Select]	[Select]	[Select]	[Select]	[Select]	[Select]
4	[Select]	[Select]	[Select]	[Select]	[Select]	[Select]
5	[Select]	[Select]	[Select]	[Select]	[Select]	[Select]
6	[Select]	[Select]	[Select]	[Select]	[Select]	[Select]
7	[Select]	[Select]	[Select]	[Select]	[Select]	[Select]
8	[Select]	[Select]	[Select]	[Select]	[Select]	[Select]

2.b.- Please feel free to use the box below to provide further comments on stakeholder prioritisation. Do you miss any key stakeholder group in the above list?