Creation of Investor Confidence: The Top-Level Drivers for Reaching Maturity in Marine Energy

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CREATION OF INVESTOR CONFIDENCE:

THE TOP-LEVEL DRIVERS FOR REACHING MATURITY IN MARINE ENERGY

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ABSTRACT

Electricity generation by tidal current and wave power arrays represents a radical innovation and is confronted by significant technological and financial challenges. Currently, the marine energy sector finds itself in a decisive transition phase having developed full-scale technology demonstrators but still lacking proof of the concept in a commercial project environment. After the decades-long development process with larger than expected setbacks and delays, investors are discouraged because of high capital requirements and the uncertainty of future revenues. In order to de-risk the technology and to accelerate the commercialisation process, we identified stakeholder-wide balanced and realisable strategic targets. The objective is to name the top-level drivers for facilitating technology maturation and thus achieving market acceptance. Our analysis revealed that the two major risks for multi-megawatt projects (funding and device performance) are directly interlinked and that co-ordinated action is required to overcome this circular relationship. As funding is required for improving device performance (and vice-versa), showcasing an "array-scale success" was identified as the interim milestone on the way towards commercial generation. By this game-changing event, both mentioned risk complexes will be simultaneously mitigated. We observed that system dynamics modelling is appropriate for an unbiased analysis of complex multi-level expert interview data. The applied research model was found to be efficient and allows a regular re-assessment of the strategic alignment thus supporting the adaptation to a complex and continuously changing socio-technical environment.

Keywords

Marine energy commercialisation, strategic drivers, investor confidence, system dynamics

Highlights

- Key risks for commercial projects (funding & device performance) are directly interlinked
- Decisive investor confidence will be created by the game-changing “array-scale success”
- System dynamics was applied to identify the top-level drivers for the market breakthrough
- The knowledge of 44 experts was integrated to identify the commercialisation strategy

1. INTRODUCTION

Marine energy is arising in an era of global interest in low-carbon electricity generation and is confronted with a market environment in which other renewables are struggling to be cost competitive with non-renewable sources. Even though there are significant public support programmes, the commercialisation of marine energy represents a major technical and financial challenge. Since 2003, the European Commission has allocated up to €140m towards marine energy development and industry investment of more than €700m in the last 8 to 10 years has triggered significant progress [1].

To become recognised as a mature generation alternative, marine energy needs to prove a range of referenceable application cases in commercial project environments. Managing the market entry process represents an ambitious undertaking that requires the unbiased identification and stakeholder-wide application of harmonised strategic principles. To tackle this problem, comprehensive expert interviews and system dynamics techniques were used to identify the top-level drivers. Representative interview statements, correlating with the determined strategic drivers, are put into context.

It was identified that, drawing on expert interviews, the two top-ranked risks for multi-megawatt tidal current and wave power array projects are "achieving funding" and "device performance". Both are interlinked and will be mitigated simultaneously when achieving the "array-scale success". As investor confidence mainly depends on proof of continuous grid-connected operation, attainment will represent a major turning point for the global marine energy business and is expected to finally trigger new investment required for large-scale deployment.

To efficiently pass the present "pre-profit" phase and to head towards commercial-scale projects, coordinated interaction within and between the stakeholder groups is required. A conclusive strategy to orientate the marine energy development process must integrate the dynamic and complex interplay between the different stakeholders.

The focus of the research is on de-risking the technological concept and thus attracting investment to finally establish marine energy as a competitive generation alternative with commercially viable projects implemented on a regular basis.

2. LITERATURE REVIEW

2.1 Investors' attitudes towards wave and tidal

Leete et al. [2] report that investors engaged in marine energy venture capital funding were unlikely to make any future investments in early stage device development. They found that venture capital investors are not closed to the industry completely, but the current level of risk and uncertainty of future revenues are discouraging them from investing. It is underlined that a track record of continuous device operation of at least 6 months is a pre-requisite for further engagements. Investors profiled by Masini and Menichetti [3] showed a clear preference for more mature, proven technologies with only 3 of 93 investors analysed having any exposure to wave and tidal energy. Given the relatively small scale of today's marine energy developments, investors are able to achieve similar or greater returns on larger developments of more proven energy technologies. Magagna and Uihlein [4] describe that high costs associated with marine energy, combined with the unproven status of the technologies, hinder investors' confidence.

These studies clearly describe the present investment climate and investor attitudes based on experience. As improvement measures are rarely proposed, this paper intends to name effective strategies to overcome the present locked-in situation and to provide arguments for investors to direct their financial engagements. The required efforts for putting corresponding measures into practice can be justified by the long-term benefits after the market breakthrough.

2.2 Can marine energy compete on cost?

According to the UK Department of Energy & Climate Change [5], the projected levelised cost of electricity generation (LCOE[1]) for marine energy in the year 2020 will range between 20 and 42 c€/kWh. Spain expects LCOE for that period of time of 21 to 33 c€/kWh [6]. Previsic et al. [7] have similarly suggested commercial opening costs of electricity for wave power between 20 and 30 c€/kWh. LCOE for onshore wind in the UK are projected of 9 to 15 c€/kWh by 2020 and for offshore wind of 13 to 22 c€/kWh [5]. RenewableUK [8] believes that the current LCOE for leading tidal current devices is around 36 c€/kWh, compared with 48 c€/kWh for wave power devices. As onshore wind energy represents the reference for cost-competitive renewable power, it shall be noted that the global average LCOE dropped from

[1] LCOE is defined as the ratio of the net present value of total capital and operating costs of a generic plant to the net present value of the net electricity generated by that plant over its operating life.

19 c€/kWh in 1992 to 6 c€/kWh in 2014 [9]. Offshore wind farms at very good locations currently achieve LCOE of 11 to 19 c€/kWh [10]. Presently, the kWh-costs in marine energy are far too high to compete with other renewable or even non-renewable generation options [11]. Taking into consideration the projected LCOE in the UK for 2020, the cost for tidal current might touch the upper end of the offshore wind range. For the forthcoming years, governmental support programs will be indispensable to further drive research and development [12]. In offshore wind – with a global installed capacity of 5.4 GW [13] – it is expected that a further 15 years of subsidies will be required [14].

Although there is the perspective for continuously decreasing LCOE for marine energy, we see the need to concentrate on rapidly achieving a multi-company based market breakthrough. If the first commercial array projects do not deliver good returns for investors, the significant industry investment of the last years might not be compensated and the focus of interest would finally move to other technologies. It is evidently in the interest of all engaged stakeholders to make use of the available window of opportunity in order to overcome the current pre-profit phase and to establish a new and innovative industry.

2.3 Protected spaces for innovation

Carlsson et al. [15] identified in the course of innovation studies, that market-linked technological systems are not static but need to evolve continuously to be able to survive. Due to regular transformations in the embedding socio-technical system, which encompasses the co-evolution of technology and society, the lines of technology development need to be regularly re-adjusted [16]. Alkemade et al. [17] explain from an innovation studies perspective, that new technology often has difficulty in competing with embedded technologies and suggests that most inventions are relatively inefficient at the date when they are first recognised as constituting a new innovation. Negro et al. [18] hereto formulated more specifically, that renewable energy technologies find it hard to break through in an energy market dominated by fossil fuel technologies that reap the benefits from economies of scale, long periods of technological learning and socio-institutional embedding. If the gap between new and established technology is very large and if there is a "paucity of nursing" or missing "bridging segments" that allow for a gradual generation of increasing returns, a new technology may never have the chance to rectify the initial disadvantages [19]. Scholars in evolutionary economics have highlighted the importance of "niches" that act as "incubation rooms" for radical novelties, shielding them from mainstream market selection. Such protected environments are enabled to overcome conventional organisational (i.e. socio-technical) inertia (e.g. [20], [21]). Bergek et al. [22] confirm that technology development can best take place within specially created learning spaces that allow a new technology to develop a technical trajectory (for reaching maturity or even a dominant design). Erickson and Maitland suggest that "nursing markets" need to be created to support the technology breakthroughs, taking advantage of windows of opportunity that drive adjustments in the socio-technical regime [23,24].

For a decade, we have seen that significant development in the marine energy sector is taking place within such "protected incubation rooms" in the form of marine energy test facilities or subsidised pilot projects. Research, however, recognises an underlying time pressure, as artificially created learning environments can be maintained only for a limited time.

3. OBJECTIVE OF THE RESEARCH

The referenced primary literature describes the difficulties which the marine energy sector faces and makes investors' restraint evident. Although ideas for improving the investment climate are outlined, the presentation of a conclusive set of measures that can be implemented by the stakeholders in order to advance the commercialisation of marine energy was not found. The current literature lacks well-founded arguments and coordinated strategies to work stepwise towards market acceptance. This contribution is intended to close the gap in literature by qualifying the mid-term goals and by providing a coherent strategy to overcome the pre-profit phase. The focus is on presenting methods to de-risk the technology and to govern the market entry process in order to create investor confidence. The identification of a directed and concise strategy for the market launch in one single attempt is crucial. If stakeholders realise their individual benefit by the subsequently presented measures, their willingness to implement them will increase.

4. MATERIALS AND METHODS

4.1 Research design

The research includes a combination of qualitative and quantitative methods, which divide the study into three phases. In phase one, a target-oriented questionnaire was presented, which formed the basis of expert interviews to obtain a broad-perspective image of the current situation and plans. In phase two, the interview data were systematically processed and formed the input for the configuration of representative system dynamics computer models.

In phase three, milestone events on the way towards commercialisation were determined and corresponding strategic principles to achieve them identified.

A basic principle applied in this research is to create new insight by compiling different sources of knowledge for the elaboration of an optimum strategy towards achieving market competitive generation. Okhuysen and Eisenhardt [25] describe in a study in the field of experimental behavioural science, that new knowledge is generally created by applying multiple perspectives to the same information. Huang and Newell [26] underline in their research on cross-functional projects with multiple stakeholder groups, that it is vital to understand the dynamics of organisational learning and strategic change initiatives.

In order to follow the principle of multiple perspectives, experts from all stakeholder groups were invited to contribute with their individual experience and know-how. Based on this multi-disciplinary attempt, an all-encompassing appraisal became possible by avoiding concentrating in a limiting manner on stakeholder-specific views or interests only. Special attention was dedicated to include a wide spectrum of stakeholders and the performance of data compression in a transparent and fact-based manner.

To master the amount and complexity of the cross-category information and to systematically identify the fundamental drivers, all data were uniformly consolidated to form the basis for the configuration of detailed cause-effect relationship diagrams. The final system dynamics models emerged from "iterative cycles of data gathering, feedback analysis, implementation of measures and result evaluation" as described by Formentini and Romano [27] in a knowledge management context.

The use of system dynamics modelling techniques assures an open-integrative, instead of detailed-specialist, character of the research. Based on this multi-disciplinary approach, an all-encompassing appraisal becomes possible by avoiding concentration in a limiting manner on stakeholder-specific views or interests. The methodology applied enables a dynamic interplay between knowledge creation, knowledge compression and targeted knowledge diffusion.

4.2 Hypothesis

Regular commercial marine energy projects will be realised under institutional financing and according to international procurement principles. To ensure investor engagement, the reliability of the technological concept has to be proven in advance.

The research is oriented around the hypothesis:

The unbiased processing of expert interview data by system dynamics computer modelling allows the identification of stakeholder-wide applicable strategies that create investor confidence and thus facilitate the marine energy market breakthrough.

The long-term focus is on establishing marine energy as a market competitive generation alternative with commercially viable projects implemented on a regular basis.

4.3 Questionnaire

For the survey, a questionnaire with a total of 90 questions was prepared, out of which 48 were yes/no questions and 42 were qualitative, referring to stakeholder-related experience. With the aim of harmonising and uniformly directing the research, the interviewed experts, in a first set of questions, provided estimations of the characteristics of future tidal current or wave power projects (capacity ~40 MW, implementation ~2025, investment ~120 m€). The next set of questions was directed towards knowledge transfer by asking “Which are the most valuable experiences gained by the early movers in the marine energy sector?” and “Which lessons learnt in the offshore wind and oil & gas sectors can be transferred to marine energy?”. In a further section, focus was put on achievements and planning by asking “What do you consider as main reasons why the marine energy sector has not developed more rapidly?” or “Which should be top-priority tasks in the work of the other stakeholder groups to reach full commercialisation?”.

Cost aspects were examined by asking “Where do you see the greatest concerns for delays and cost-overruns in marine energy projects?” or “Where do you see significant potential to get the cost for utility-scale project implementations down?”. The question defining the basic system dynamics model was of qualitative nature by focusing on positive and negative impact factors for reaching “full-commercial marine energy”.

Finally, a quantitative assessment of the risk levels in commercial-scale marine energy per project phase was carried out by rating a total of 40 risk types out of four risk categories (strategic, financial, technological, operational).

4.4 Expert interviews

By contacting 136 representatives from 15 stakeholder groups, 71 feedbacks were received, leading to 11 personal and 15 telephone interviews, as well as 20 filled-out questionnaires. 2 received questionnaires had to be discarded because they were significantly incomplete. As a result, the knowledge of 44 managers, experts and specialists from 13 stakeholder groups (see Table 1) was retained for the analysis, corresponding to an effective return rate of 32.4 %, which is higher than usual for studies of this nature [3]. A total number of 2,129 individual replies were grouped to formulate higher-level correlations as basis for the computer-based system dynamics modelling. All semi-structured single person interviews were conducted either face-to-face at the premises of the interviewee or by telephone between June 2012 and April 2013. No follow-up interviews were carried out.

Table 1 – List of participating stakeholders

Government (associations) & trade organisation: The Scottish Government, Marine Scotland, Energy Technologies Institute, Carbon Trust, Department of Energy and Climate Change, The Crown Estate, Scottish Natural Heritage, Centre for Environment, Fisheries & Aquaculture Science, RenewableUK, Technology Strategy Board.
Certifying authorities: Det Norske Veritas, Lloyd’s Register.
Investors & lenders: Green Giraffe.
Law firm: Eversheds International.
Academia & research: University of Washington, University of Edinburgh, National Taiwan Ocean University, Irish Marine Institute.
Engineering consultancies: Natural Power, Xodus Group, Tecnalia Research & Innovation, South West Renewable Energy Agency, Royal Haskoning.
Project developers: Emera, EDF, Electricity Supply Board, Iberdrola.
Owners & operators: ScottishPower Renewables, Ente Vasco de la Energía.
Transmission system operator: Scottish and Southern Energy Renewables.
Device manufacturers: Marine Current Turbines, Pelamis Wave Power, Wavebob, Siemens, Wave Star, Ocean Renewable Power Company.
Offshore contractors: 6 contacted (no feedback).
Test site operators: European Marine Energy Centre, Fundy Ocean Research Centre for Energy, National Renewable Energy Centre, Minas Basin Pulp & Power, France Energies Marines.
NGO: Greenpeace.
Offshore wind industry: Dong Energy Power.
Oil & gas industry: 4 contacted (no feedback).

4.5 System dynamics computer modelling

The information gained by the expert interviews was compressed by the use of ordering terms based on which a total of three system dynamics[2] computer models were configured. For the basic model, all positive (reinforcing) and negative (countervailing) influences on the pre-defined target of “full commercial power generation by marine energy” were grouped and inter-correlated (Fig. 1).

[2] As an initial step in approaching the characteristics of complex systems, in the mid-1950s, J.W. Forrester developed system dynamics as “a methodology and mathematical modelling technique for framing, understanding, and discussing complex issues and problems”.

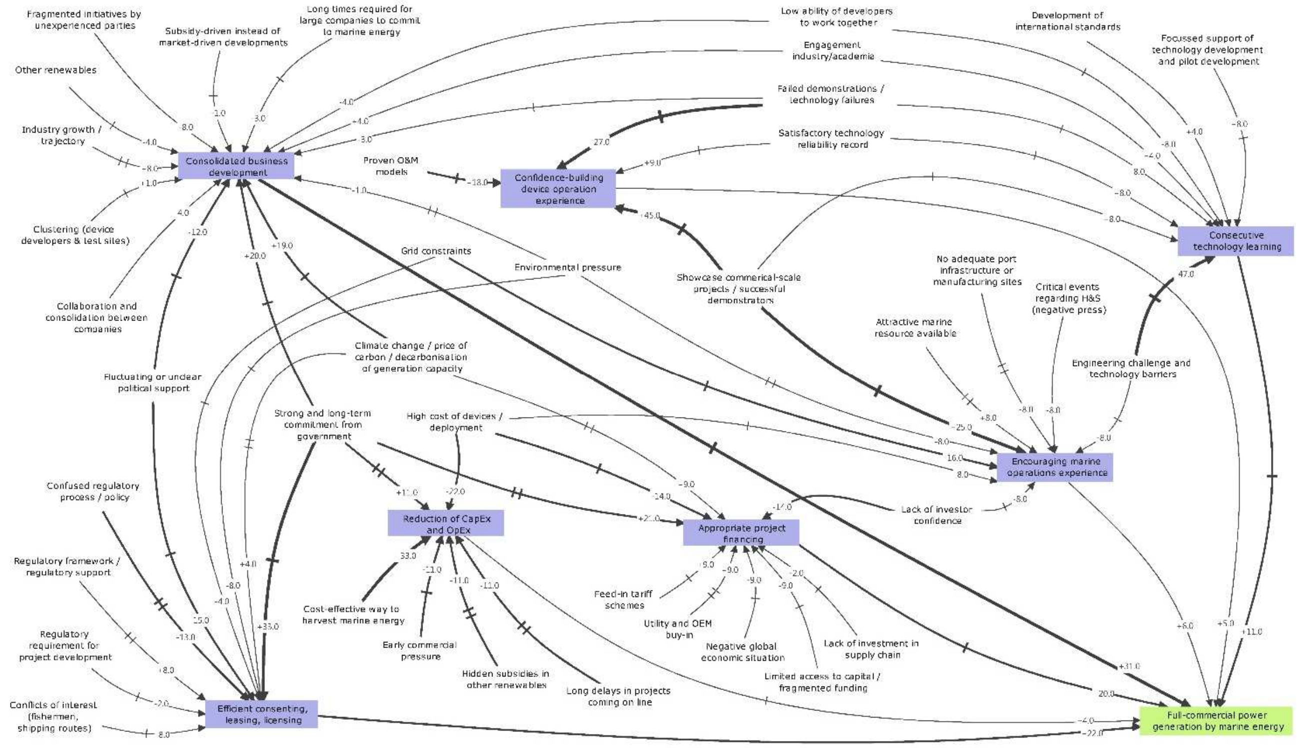

Fig. 1. System dynamics model: "Full-commercial power generation by marine energy"

The model was built one-on-one to the interview replies, so that it directly reflects the experience and expectation of all interviewed stakeholders. Out of a total of 234 individual replies, 16 top-level driving factors, essential for achieving commercial power generation, were identified and concentrated into three milestone terms:

(i) Government support: The long-term commitment from government represents the basis for progress of the sector. Early stage developments depend on coordinated funding mechanisms and fiscal measures as well as an efficient consenting process.

(ii) Array-scale success: The 2nd ranked top-level driving factor (showcase commercial-scale projects / successful demonstrators) forms the essential element of this interim milestone that triggers further development.

(iii) Cost reduction: After having successfully demonstrated the array-scale success, the cost of energy will decline due to serial manufacturing and technology convergence.

As the singular characteristics of government support are outside the range of this paper, the context around achieving the second milestone term "array-scale success" is examined in detail by identifying the respective reinforcing and countervailing impact factors. Based on the findings suggesting the prioritised focus on showcasing commercial-scale projects, a second (see Fig. 2) system dynamics model was developed.

This new target was examined in detail by analysing 671 correlated interview replies. After calculating the ranking of impact factors and the determination of top-level driving factors, representative core statements from the interviews were allocated. Subsequently, strategies for de-risking the technology and governing the market entry process were elaborated.

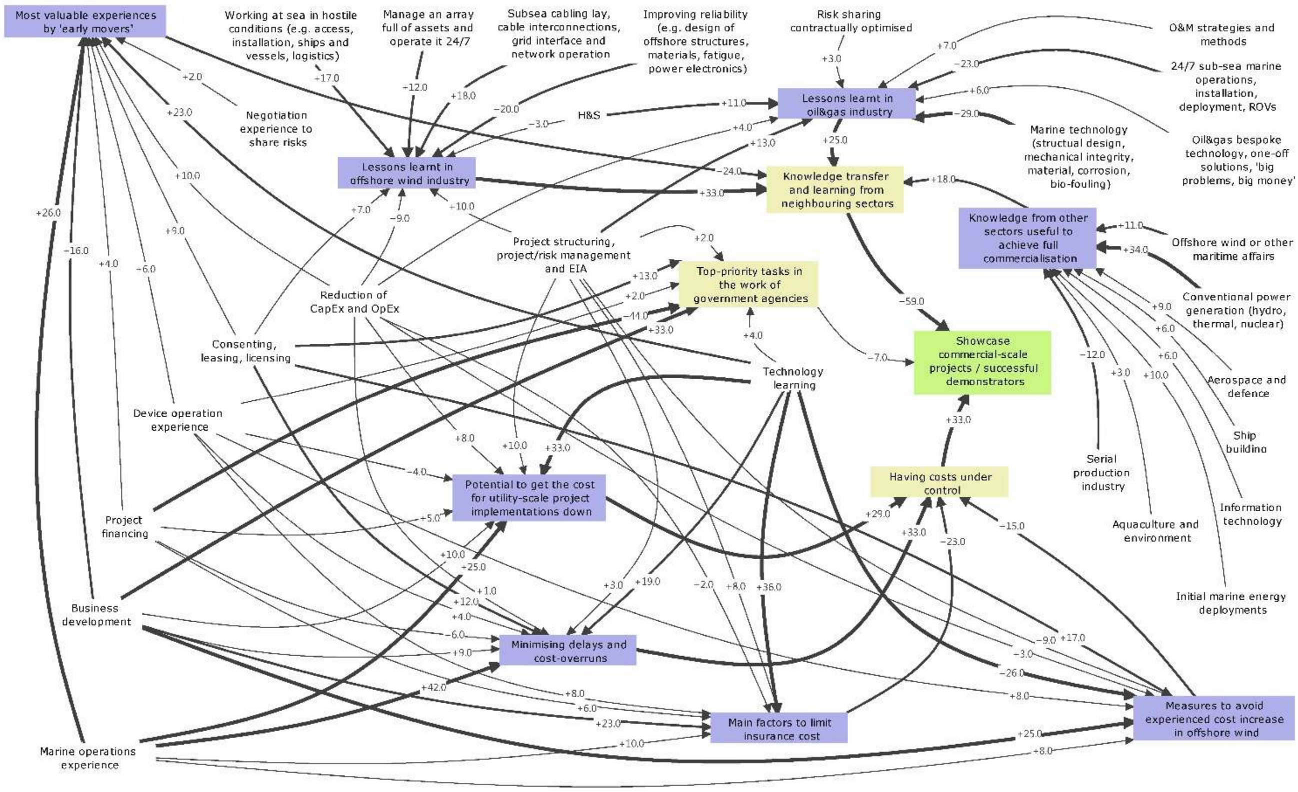

Fig. 2. System dynamics model: "Showcase commercial-scale projects"

To make full use of the insight gained in the course of the interviewing process, the negative impact factors (generated from 1,712 replies) hindering, delaying or countervailing the development of marine energy were examined in a third system dynamics model [28]. The target factor was set as "negative impact on the development of marine energy". Consequently, the central cluster of impact factors acting on the interim milestone "array-scale success" was tested by processing the negative impacts. By taking this diametrically opposite perspective, the research findings were further substantiated and balanced.

In Table 2, the most relevant recommendations and support options identified for sector-specific orientation are given. They are based on the prioritisation calculated by the system dynamics software and the compression of corresponding interview statements.

Table 2 – Strategic orientation for the marine energy stakeholder groups

Technology
Adopt systems engineering principles inspired by the space-/aircraft industry
Consider that extreme engineering is required with a focus on survivability and reliability
Reduce the number of technological concepts (technology convergence)
Develop multi-applicable technologies (standardisation of components) and joint concepts
Design for installation and maintenance purposes
Minimise the lack of collaboration and improve knowledge sharing
Gain offshore deployment experience with full-scale devices
Move from device testing towards array-scale activities under open sea conditions
Integrate risk management into project management
Consider the need to restructure and commit to the supply chain
Policy
Facilitate consenting, leasing, licensing (i.e. with a single point of handling the process)
Promote cross-interaction between renewables
Stimulate appropriate risk sharing between the stakeholders
Encourage initiatives to bring in expertise from offshore oil & gas marine operations
Focus on availability of qualified personnel and heavy marine services
Underline the importance of knowledge sharing (central bottleneck)
Improve collaboration and alignment between industry, utilities, academia and developers
Support grid-connected test facilities and pilot zones
Support strategies for grid operation with significant wave and tidal power in-feed
Simplify access to the international (out of Europe) market
Financing
Recognise that pilot projects with availability records provide confidence in core technology
Support technologies with declared synergies towards off-shore wind
Consider the likelihood of early-stage failures and the failing in unexpected parts of project
Keep in mind that realism is required when it comes to the (global) scale of the industry
Focus on cost of energy and not on capital expenditure
Consider that the cost of energy production is dependent on the capacity deployed
Evaluate the insurability of projects
Recognise differences to offshore oil & gas with regard to design, manufacturing, logistics
Realise the advantage of working with the already existing companies in the market
Encourage contract structuring and contract standardisation as in onshore wind

The system dynamics computer models were designed and configured exclusively based on the empirical data obtained through expert interviews. The result ranking calculated by the simulation software represents superordinate knowledge and correlates to information usually available to management.

5. RESULTS

5.1 The game-changing "array-scale success"

Reliability is an important factor of success for all emerging technologies. In marine energy, the reliability proof remains a major challenge, as most devices to date have been in the water only for short periods of less than one year. In the course of the expert interviews, the importance of focusing on “array-scale activities” and the need to “to get pilot farms built” was repeatedly stressed. Most answers to the question “In which areas are research most required to accelerate the development of marine energy?” referred directly to multi-device arrangements such as “array-scale design”, “hydrodynamic modelling of arrays”, “array-scale maintenance”, “the need for design tools to facilitate cost-effective array-scale development” and “to see first arrays progress through FID[3]”.

The prevailing top-ranked risks (“achieving funding” and “device performance”) are directly interdependent as investor confidence depends on track records of continuous device operation – and vice versa. In the centre of this area of conflict we find the “array-scale success” because passing this milestone will give confidence in the industrial sector and de-risk investments in commercial projects. As the preparation and management of array-scale success is of central relevance for the continuous development of the marine energy, effort was put in identifying the top-level strategic principles of technical-organisational nature for being considered to be implemented by the key stakeholders.

5.2 Strategic drivers for reaching maturity and creating investor confidence

Systems engineering

The interview participants identified reliability concerns as the top-ranked non-commercial risk. On the opposite side, poor reliability was mentioned as the key operational risk. The widespread perception of high cost and unproven reliability was mentioned as negatively influencing the sector. Representatives from a UK financial firm and a Canadian project developer emphasised that concerns regarding delays and cost-overruns mainly relate to reliability and durability as well as the performance of marine energy converters. A US academic named the need for longer baselines for system reliability and an R&D vice-chair outlined that reliability is more important than efficiency. According to a Scottish government employee, the failure of devices was the most fundamental and greatest single reason for projects being delayed or costs increased. Reasons why the marine energy sector has not developed more rapidly were repeatedly identified as due to the uncertainty of device performance. The need to demonstrate equipment reliability at utility-scale was mentioned by a machinery expert of a global maritime classification society. When asking for significant potential to get the cost for utility-scale project implementation down, the emphasis from a

[3] Final Investment Decision (see “FID enabling for renewables” by The Department of Energy & Climate Change, UK)

wave energy converter firm representative was on the orientation of development and research strategies at the US space-/aircraft industry and here especially on the systems engineering principle. To achieve a satisfactory technology reliability record, experts recommend more focus on reliability in system design and the introduction of reliability modelling. In the course of the design and deployment of marine energy converters, regular system functionality checks, focusing on the final operation in open sea, grid-connected, multi-device arrays, are recommended. Senior members of classification societies stressed the uncertainty about reliability as a main risk factor and emphasised the need to focus on it.

Standardisation

When being asked about the most valuable experience gained by the "early movers", a project developer's head of offshore had "experienced negative impact by missing standardisation". Considering the urgent need for consensus over standardisation, one interviewee referred to the detected over-engineering in oil & gas standards (with regard to marine energy purposes). Another interviewee summed up the situation by saying "no standards, no results". According to the opinion of a utility's marine energy project manager, one of the top-priority tasks in the work of academia and research should be to concentrate on multi-applicable technologies, standardised devices and system components. A utility's representative underlined the expectation to reduce the cost for commercial-scale project implementations by the positive impact of technology convergence.

Knowledge sharing

The limited sharing of knowledge in the industry and between project developers is seen by the strategy manager of a public-private partnership and the head of energy of UK's innovation agency as one main reason why the marine energy sector has not developed more rapidly. A senior policy officer emphasised the need to transfer lessons learnt in the offshore wind industry in order to avoid duplication of time and effort. The project manager for the implementation of the world's first commercial breakwater wave power plant underlined the need to improve the sharing of bad experience and testing data. To support progress, he suggested conferences be used to explain why things went wrong and to display the finally implemented solution.

Maximising collaboration and minimising competition

In line with the findings on the limited sharing of knowledge, a lack of collaboration was reported. The artificial competition with on-/offshore wind was criticised by an Irish marine energy development manager as negatively influencing an uninterrupted progress. The interviewed head of development of a wave converter manufacturer underlined the attractiveness of exploring the prospects by co-locating wave and wind power devices.

Offshore deployment experience

As the programme director of a leading centre of sustainable energy expertise outlined, with the aim of demonstrating the viability of electricity generation by marine energy, it is necessary to provide transparency to investors and to focus on “bringing some 10 MWs in the water”. The importance of design for installation and maintenance purposes was emphasised by the representative of a wave energy device manufacturer. As an example of lessons learnt in the offshore oil & gas industry being transferred to marine energy, a senior manager at a Canadian utility mentioned their focus on reliability and survivability.

Risk management and risk sharing

The development manager of a wave energy converter firm explained that their company approach towards risk management is to collaborate with a multi-national oil & gas exploration corporation. He stressed the requirement to share risks by collaboration and to integrate risk management into project management. A law firm’s contract expert highlighted that risk sharing should be contractually optimised to identify the most appropriate risk owners. Apart from the need for contract standardisation and collaborative contracts (contracts that allow purchasing goods, services and works collectively to achieve favourable contract terms), he recommended contract splitting as practised in offshore wind. An owner’s representative mentioned that engineering consultancies should share risk with project developers.

5.3 Result summary

Considering a business environment in which other renewable energy technologies operate in price-competition with conventional sources, the market entry of marine energy is seen as a one-off chance. Consequently, it is in the elementary interest of the manufacturing firms and related stakeholders to make best use of the pre-commercial period through an extraordinary level of sharing knowledge with competitors and by enforcing cooperative interaction. As noted by Jay and Jeffrey [29], support and transfer of generic knowledge is currently limited by early-stage commercial competition.

Major power projects are usually realised by institutional financing and under the terms of international competitive bidding. Consequently, in marine energy, a number of equally competent manufacturing firms will be required at the time of the wholesale market-rollout to ensure realistic pricing and to avoid single bidder dependency.

6. DISCUSSION

6.1 Overcoming the pre-profit phase

Array-scale success represents the key interim milestone and has to be seen within the larger picture, characteristic for the power industry. For a marine energy technology breakthrough, positive and transparent feedback from a variety of longer term grid-connected and commercially operated multi-megawatt arrays is required. After concept maturity has been demonstrated by grid-feeding schemes, new potential for cost reduction will be tapped by serial manufacturing processes and learning effects forced by the routine implementation of projects under global market competition. The identification of yet undiscovered low-cost strategies is a natural element of technology convergence processes. In the course of the research, we identified the need to join forces and to strengthen stakeholder interaction to make use of the singular chance to establish marine energy in a commercial environment.

6.2 Technology-oriented stakeholders

<u>Competitive collaboration</u>

Competitive collaboration is a form of strategic alliance between two or more independent firms that interact to pursue a set of agreed goals to contribute and share benefits on a continuing basis in one or more key strategic areas [30]. Hull and Slowinski [31] demonstrate that cooperative relationships in high technology between large industrial conglomerates (with strong market positions) and small firms (providing innovative technology) brought innovations to market that neither firm alone could have accomplished. If the marine energy industrial competitors accept the great significance of jointly achieving a long-term-oriented market success, then the motivation for entering into strategic alliances will rise.

<u>Detail and dynamic complexity</u>

To ensure continuous progress towards competitive electricity generation, diverse problem-solving competences are required. In order to identify an optimum strategy before making a decision, the apparent problem complex needs to be analysed and categorised. There are technical difficulties that require profound engineering expertise, whereas other tasks – of more strategic nature – require qualitative assessment and tactical skills [32]. The complexity correlated with the market launch of marine energy can be sub-divided into:

a) Detail or combinatorial complexity (also referred to as complicacy), which is characterised by many interacting elements and a large number of combinatorial possibilities. Apart from technology-related questions, detail complexity also appears within stakeholder-internal business management and in tasks of organisational nature. The application of complexity-reducing measures is expedient [33] and might favour: (i) applying systems engineering; (ii) forcing standardisation and certification; and (iii) using multi-applicable technologies.

b) Dynamic complexity, which is characteristic for large-scale engineering and construction projects with multiple feedback-processes and non-linear relationships with accumulation or delay functions. Cause and effect can be subtle and obvious interventions can produce non-obvious consequences [34,35]. Concerning the process of marine energy commercialisation, dynamic complexity becomes apparent when looking at the long-term development history of the sector and the experienced setbacks. As a reduction of complexity can be counter-productive for dynamically complex tasks, qualitative feedback modelling is seen as the preferred approach [33]. Within the present study, this was realised by means of system-dynamics-backed analyses of semi-structured expert interview data.

Research revealed that in conventional management, mainly aspects of detail complexity are considered but that the real leverage lies in understanding dynamic complexity [36]. Most industrial planning tools and analytical methods are not equipped to handle dynamic complexity [37].

Competitive technology qualification routine

As years will pass before full maturity is reached, the introduction of a competitive technology qualification routine was proposed for early commercial projects in order to achieve the required safety for investment [38,39]. The principal idea is to complement the execution of large projects with a qualification process in the course of which different manufacturers' power conversion devices are deployed and operated under real-sea conditions in the final project area for a defined period of time. The individual device performance is independently assessed and the manufacturer of the best-ranked system is awarded the main supply contract. Non-successful competitors are compensated. Competitive technology qualification routines would facilitate a transparent and evidence-based selection process to identify the most suitable technology for a specific site.

6.3 Financing sector

Apart from the support for technologies with declared synergies toward off-shore wind, the financing sectors are expected to focus on stimulating the cross-interaction between the different forms of renewable energies and on strengthening design convergence. The cost of marine energy is seen as high compared to existing generation with hidden subsidies. As cost of energy was identified to be more relevant than capital expenditure, efforts are required to identify the techno-economic optimum way for the harvesting of marine energy. With regard to a mentioned need to compromise reliability and cost, the insurability of the projects must be ensured. In feasibility studies, it is important to consider that the cost of energy production is dependent on the capacity deployed [40]. In the course of a project planning, it is necessary to foresee extreme engineering and to consider the likelihood of test or early-stage failures. Pilot projects with availability records will provide confidence in the performance of the core technologies. Generally, it is required to keep in mind that realism is requested when it comes to the (global) scale of the industry and to recognise the differences to offshore oil & gas with regard to design, manufacturing and logistics.

6.4 Policy framework

With regard to policy-related aspects, a key topic is to enable efficient consenting, leasing and licensing by ensuring a single point of handling. The close and regular adaptation of public support programmes and incentive mechanisms to actual requirements is crucial for accelerating the marine energy maturation process. The need to bring in existing skills from the oil & gas sector, to improve knowledge sharing and to strengthen collaboration between industry, utilities, academia, device manufacturers and project developers was identified. The implementation of appropriate risk sharing mechanisms between the stakeholders is relevant for achieving common progress. In order to prepare the move from device testing towards array-scale activities under open sea conditions, grid-connected test facilities and pilot zones are of high value. Considering future large-scale deployments, the importance of transmission infrastructure investments and support strategies for grid operation with significant wave and tidal in-feed cannot be underestimated. With regard to the global scale of the industry, simplified access to the international (out of Europe) markets is important.

7. CONCLUSION

The approach of using cross-category expert interview data to create system dynamics computer models is seen as a powerful method to keep track of the sectorial development and thus to advance strategy finding.

The two major risks for multi-megawatt projects (funding and device performance) are directly interlinked and co-ordinated action is required to overcome this circular relationship (“chicken or egg causality dilemma”). As funding is required for improving device performance (and vice-versa), showcasing an array-scale success was identified as the interim milestone on the way towards commercial generation. This game-changing event will simultaneously mitigate both mentioned risk complexes. With the near-future prospect of realising profits in a new power market segment, there should be a strong motivation for cooperative industry interaction aimed at jointly de-risking the technology.

To fulfil both requirements, i.e. (i) to achieve the market breakthrough; and (ii) to establish a new industry with a variety of manufacturers, extraordinary concessions between natural competitors are required. The (temporary) joining of forces in the form of competitive collaboration is necessary to pass the singular hurdle of getting market acceptance and to create investor confidence. It shall be remembered that the available incubation rooms were created with the goal of developing the technology to the level of reliability required to compete in the energy market. A special level of collaborative behaviour in a test field environment is beneficial to the sector.

Referencing to the initial hypothesis, the paper makes the following contribution:

The presented target-oriented measures are suitable to support the commercialisation of marine energy on a fundamental level. The combination of expert interview data and system dynamics modelling allows the identification of effective and practically implementable strategies.

The most comprehensive and strategically demanding task is to attract financing and to successfully embed the innovative generation method into the energy infrastructure. To be able to adapt to a continuously changing socio-technical environment, evolutionary steering mechanisms and systemic thinking are required. The chosen strategy must be flexible and re-adjustable to new trends and priorities.

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