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1 CREATION OF INVESTOR CONFIDENCE:

2 THE TOP-LEVEL DRIVERS FOR REACHING MATURITY IN MARINE ENERGY

3 R. Bucher^{a,*}, H. Jeffrey^a, I.G. Bryden^b, G. Harrison^a

4 ^a *University of Edinburgh, Institute for Energy Systems, Mayfield Road, Edinburgh, EH9 3JL, UK*

5 ^b *University of the Highlands and Islands, Ness Walk, Inverness, IV3 5SQ, UK*

6 * Corresponding author.

7 E-mail addresses: r.bucher@sms.ed.ac.uk (R. Bucher), henry.jeffrey@ed.ac.uk (H. Jeffrey),
8 ian.bryden@uhi.ac.uk (I.G. Bryden), gareth.harrison@ed.ac.uk (G. Harrison).

9 10 ABSTRACT

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

33 **Keywords**

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

35

36 **Highlights**

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

41

42 **1. INTRODUCTION**

43 Marine energy is arising in an era of global interest in low-carbon electricity generation and is
44 confronted with a market environment in which other renewables are struggling to be cost
45 competitive with non-renewable sources. Even though there are significant public support
46 programmes, the commercialisation of marine energy represents a major technical and
47 financial challenge. Since 2003, the European Commission has allocated up to €140m
48 towards marine energy development and industry investment of more than €700m in the last
49 8 to 10 years has triggered significant progress [1].

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

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

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

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

71 **2. LITERATURE REVIEW**

72 **2.1 Investors' attitudes towards wave and tidal**

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

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

91 **2.2 Can marine energy compete on cost?**

92 According to the UK Department of Energy & Climate Change [5], the projected levelised cost
93 of electricity generation (LCOE¹) for marine energy in the year 2020 will range between 20
94 and 42 c€/kWh. Spain expects LCOE for that period of time of 21 to 33 c€/kWh [6]. Previsic
95 et al. [7] have similarly suggested commercial opening costs of electricity for wave power
96 between 20 and 30 c€/kWh. LCOE for onshore wind in the UK are projected of 9 to 15 c€/kWh
97 by 2020 and for offshore wind of 13 to 22 c€/kWh [5]. RenewableUK [8] believes that the
98 current LCOE for leading tidal current devices is around 36 c€/kWh, compared with 48 c€/kWh
99 for wave power devices. As onshore wind energy represents the reference for cost-
100 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.

101 19 c€/kWh in 1992 to 6 c€/kWh in 2014 [9]. Offshore wind farms at very good locations
102 currently achieve LCOE of 11 to 19 c€/kWh [10]. Presently, the kWh-costs in marine energy
103 are far too high to compete with other renewable or even non-renewable generation options
104 [11]. Taking into consideration the projected LCOE in the UK for 2020, the cost for tidal current
105 might touch the upper end of the offshore wind range. For the forthcoming years,
106 governmental support programs will be indispensable to further drive research and
107 development [12]. In offshore wind – with a global installed capacity of 5.4 GW [13] – it is
108 expected that a further 15 years of subsidies will be required [14].

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

116 **2.3 Protected spaces for innovation**

117 Carlsson et al. [15] identified in the course of innovation studies, that market-linked
118 technological systems are not static but need to evolve continuously to be able to survive.
119 Due to regular transformations in the embedding socio-technical system, which encompasses
120 the co-evolution of technology and society, the lines of technology development need to be
121 regularly re-adjusted [16]. Alkemade et al. [17] explain from an innovation studies perspective,
122 that new technology often has difficulty in competing with embedded technologies and
123 suggests that most inventions are relatively inefficient at the date when they are first
124 recognised as constituting a new innovation. Negro et al. [18] hereto formulated more
125 specifically, that renewable energy technologies find it hard to break through in an energy
126 market dominated by fossil fuel technologies that reap the benefits from economies of scale,
127 long periods of technological learning and socio-institutional embedding. If the gap between
128 new and established technology is very large and if there is a “paucity of nursing” or missing
129 “bridging segments” that allow for a gradual generation of increasing returns, a new
130 technology may never have the chance to rectify the initial disadvantages [19]. Scholars in
131 evolutionary economics have highlighted the importance of “niches” that act as “incubation
132 rooms” for radical novelties, shielding them from mainstream market selection. Such protected
133 environments are enabled to overcome conventional organisational (i.e. socio-technical)

134 inertia (e.g. [20], [21]). Bergek et al. [22] confirm that technology development can best take
135 place within specially created learning spaces that allow a new technology to develop a
136 technical trajectory (for reaching maturity or even a dominant design). Erickson and Maitland
137 suggest that “nursing markets” need to be created to support the technology breakthroughs,
138 taking advantage of windows of opportunity that drive adjustments in the socio-technical
139 regime [23,24].

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

144 **3. OBJECTIVE OF THE RESEARCH**

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

157 **4. MATERIALS AND METHODS**

158 **4.1 Research design**

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

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

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

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

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

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

191 **4.2 Hypothesis**

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

195 The research is oriented around the hypothesis:

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

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

201 **4.3 Questionnaire**

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

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

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

222 **4.4 Expert interviews**

223 By contacting 136 representatives from 15 stakeholder groups, 71 feedbacks were received,
224 leading to 11 personal and 15 telephone interviews, as well as 20 filled-out questionnaires. 2
225 received questionnaires had to be discarded because they were significantly incomplete. As
226 a result, the knowledge of 44 managers, experts and specialists from 13 stakeholder groups
227 (see Table 1) was retained for the analysis, corresponding to an effective return rate of 32.4 %,

228 which is higher than usual for studies of this nature [3]. A total number of 2,129 individual
 229 replies were grouped to formulate higher-level correlations as basis for the computer-based
 230 system dynamics modelling. All semi-structured single person interviews were conducted
 231 either face-to-face at the premises of the interviewee or by telephone between June 2012 and
 232 April 2013. No follow-up interviews were carried out.

233 **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).

234

235 **4.5 System dynamics computer modelling**

236 The information gained by the expert interviews was compressed by the use of ordering terms
 237 based on which a total of three system dynamics² computer models were configured. For the
 238 basic model, all positive (reinforcing) and negative (countervailing) influences on the pre-
 239 defined target of “full commercial power generation by marine energy” were grouped and inter-
 240 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”.

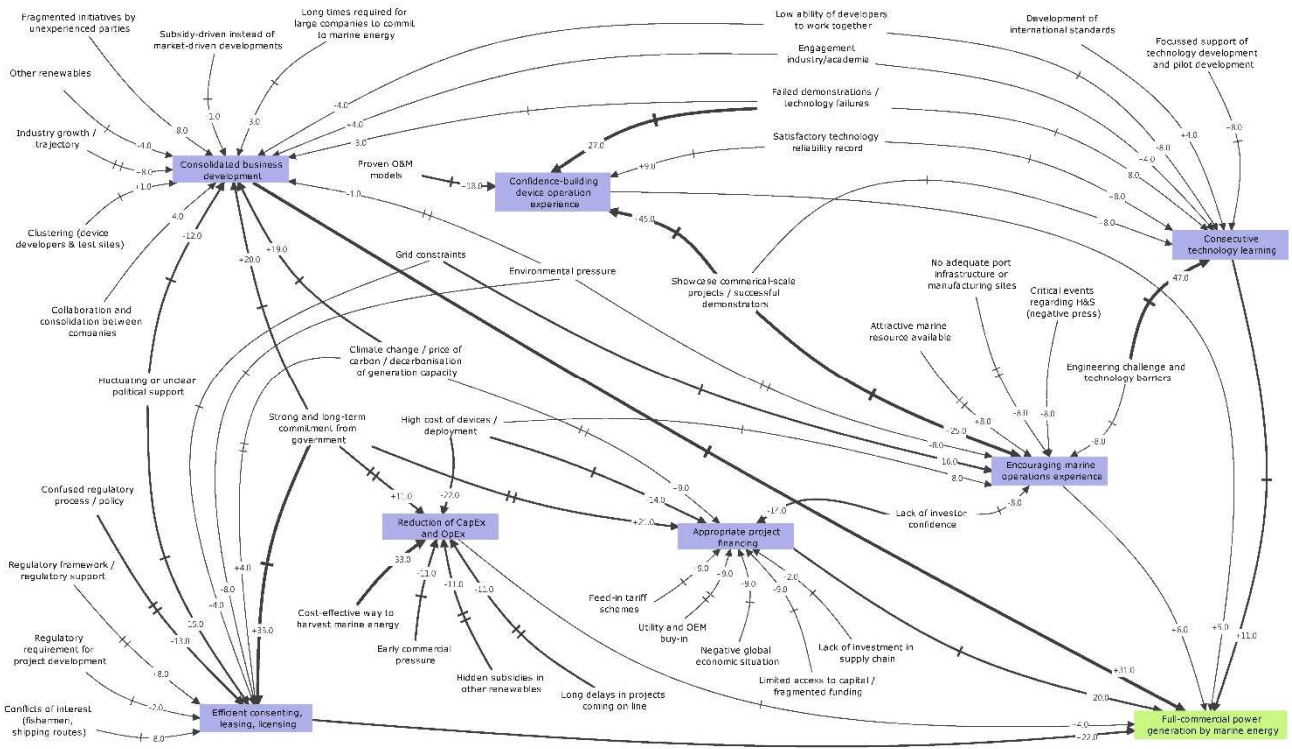


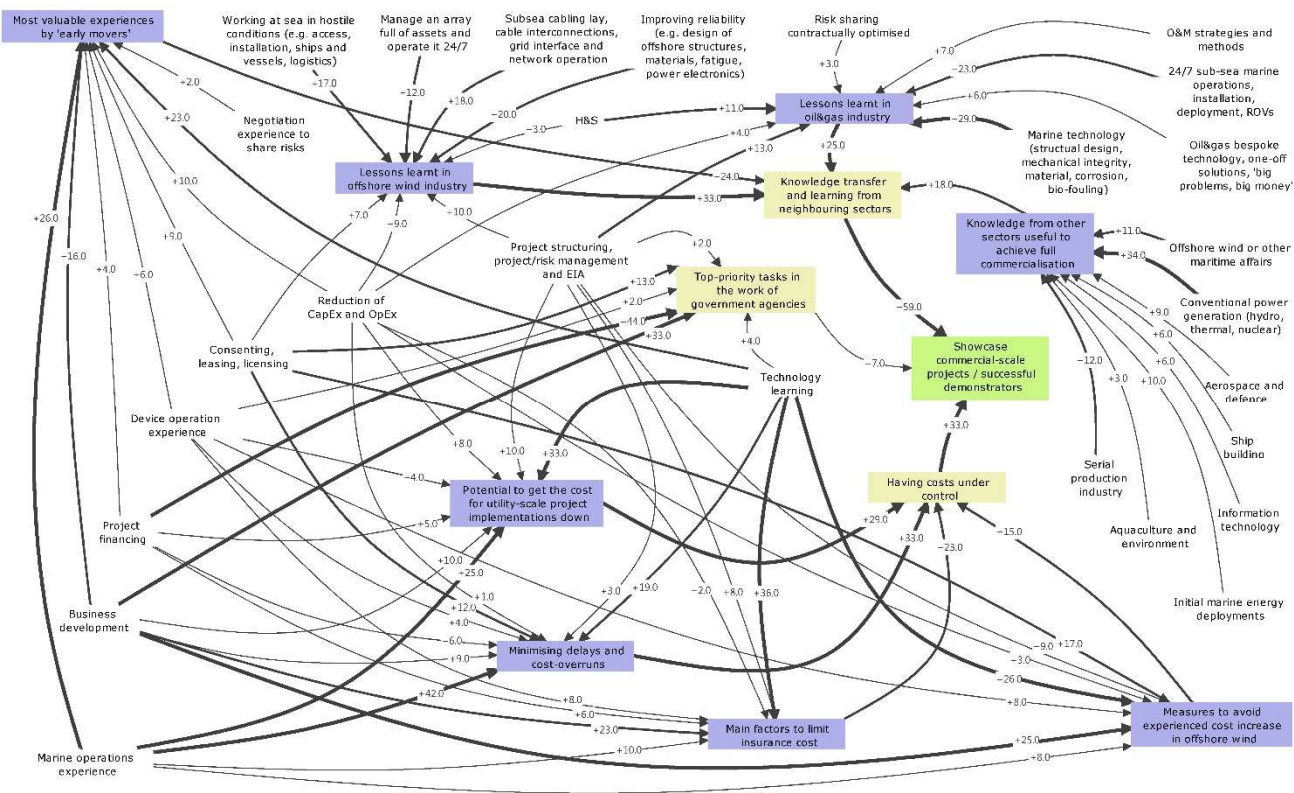
Fig. 1. System dynamics model: “Full-commercial power generation by marine energy”

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.

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



264

265 **Fig. 2. System dynamics model: “Showcase commercial-scale projects”**

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

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

276

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

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

282 **5. RESULTS**

283 **5.1 The game-changing “array-scale success”**

284 Reliability is an important factor of success for all emerging technologies. In marine energy,
285 the reliability proof remains a major challenge, as most devices to date have been in the water
286 only for short periods of less than one year. In the course of the expert interviews, the

287 importance of focusing on “array-scale activities” and the need to “to get pilot farms built” was
288 repeatedly stressed. Most answers to the question “In which areas are research most required
289 to accelerate the development of marine energy?” referred directly to multi-device
290 arrangements such as “array-scale design”, “hydrodynamic modelling of arrays”, “array-scale
291 maintenance”, “the need for design tools to facilitate cost-effective array-scale development”
292 and “to see first arrays progress through FID³”.

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

301 **5.2 Strategic drivers for reaching maturity and creating investor confidence**

302 Systems engineering

303 The interview participants identified reliability concerns as the top-ranked non-commercial
304 risk. On the opposite side, poor reliability was mentioned as the key operational risk. The
305 widespread perception of high cost and unproven reliability was mentioned as negatively
306 influencing the sector. Representatives from a UK financial firm and a Canadian project
307 developer emphasised that concerns regarding delays and cost-overruns mainly relate to
308 reliability and durability as well as the performance of marine energy converters. A US
309 academic named the need for longer baselines for system reliability and an R&D vice-chair
310 outlined that reliability is more important than efficiency. According to a Scottish government
311 employee, the failure of devices was the most fundamental and greatest single reason for
312 projects being delayed or costs increased. Reasons why the marine energy sector has not
313 developed more rapidly were repeatedly identified as due to the uncertainty of device
314 performance. The need to demonstrate equipment reliability at utility-scale was mentioned by
315 a machinery expert of a global maritime classification society. When asking for significant
316 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)

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

325 Standardisation

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

336 Knowledge sharing

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

346 Maximising collaboration and minimising competition

347 In line with the findings on the limited sharing of knowledge, a lack of collaboration was
348 reported. The artificial competition with on-/offshore wind was criticised by an Irish marine
349 energy development manager as negatively influencing an uninterrupted progress. The

350 interviewed head of development of a wave converter manufacturer underlined the
351 attractiveness of exploring the prospects by co-locating wave and wind power devices.

352 Offshore deployment experience

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

360 Risk management and risk sharing

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

370 **5.3 Result summary**

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

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

382 **6. DISCUSSION**

383 **6.1 Overcoming the pre-profit phase**

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

394 **6.2 Technology-oriented stakeholders**

395 Competitive collaboration

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

404 Detail and dynamic complexity

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

411 a) Detail or combinatorial complexity (also referred to as complicity), which is characterised
412 by many interacting elements and a large number of combinatorial possibilities. Apart from
413 technology-related questions, detail complexity also appears within stakeholder-internal

414 business management and in tasks of organisational nature. The application of complexity-
415 reducing measures is expedient [33] and might favour: (i) applying systems engineering; (ii)
416 forcing standardisation and certification; and (iii) using multi-applicable technologies.

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

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

430 Competitive technology qualification routine

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

441 **6.3 Financing sector**

442 Apart from the support for technologies with declared synergies toward off-shore wind, the
443 financing sectors are expected to focus on stimulating the cross-interaction between the
444 different forms of renewable energies and on strengthening design convergence. The cost of
445 marine energy is seen as high compared to existing generation with hidden subsidies. As cost
446 of energy was identified to be more relevant than capital expenditure, efforts are required to

447 identify the techno-economic optimum way for the harvesting of marine energy. With regard
448 to a mentioned need to compromise reliability and cost, the insurability of the projects must
449 be ensured. In feasibility studies, it is important to consider that the cost of energy production
450 is dependent on the capacity deployed [40]. In the course of a project planning, it is necessary
451 to foresee extreme engineering and to consider the likelihood of test or early-stage failures.
452 Pilot projects with availability records will provide confidence in the performance of the core
453 technologies. Generally, it is required to keep in mind that realism is requested when it comes
454 to the (global) scale of the industry and to recognise the differences to offshore oil & gas with
455 regard to design, manufacturing and logistics.

456 **6.4 Policy framework**

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

470 **7. CONCLUSION**

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

474 The two major risks for multi-megawatt projects (funding and device performance) are directly
475 interlinked and co-ordinated action is required to overcome this circular relationship (“chicken
476 or egg causality dilemma”). As funding is required for improving device performance (and
477 vice-versa), showcasing an array-scale success was identified as the interim milestone on the
478 way towards commercial generation. This game-changing event will simultaneously mitigate

479 both mentioned risk complexes. With the near-future prospect of realising profits in a new
480 power market segment, there should be a strong motivation for cooperative industry
481 interaction aimed at jointly de-risking the technology.

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

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

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

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

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