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Governing the market entry of marine energy by symptom-adapted interventions: (i) reduction of detail complexity; and (ii) managing dynamically complex tasks

通过随症状干预来进行海洋能的市场进入治理：（一）减排细节复杂性；（二）管理动态复杂任务

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Abstract – **Governing the market entry of marine energy represents a challenging endeavour that is confronted by a series of obstacles. The harsh marine environment places considerable demands on the quality of the deployed structures and devices. Apart from technological difficulties, achieving funding is a central problem as investors show a clear preference for more mature, proven technologies. To overcome the present pre-profit phase, two different solution approaches are required: one for solving complicated technology-related or organisational tasks and another for strategic remits. In the paper, a methodology to systematically identify critical success factors is presented, and propositions to tackle detail and dynamic complexity, correlated with the commercialisation of marine energy, are made.**

Keywords – **Marine energy, market entry, detail and dynamic complexity, system dynamics modelling.**

I. Introduction

Marine energy finds itself in a decisive transition phase with operating full-scale demonstrators but an outstanding proof of the technological concept in a commercial power generation environment. Consequently, the industry goal to deliver projects of up to 50 MW by 2020 [1] requires critical evaluation, especially when considering the setbacks and delays experienced in the last years.

Managing the market entry of tidal stream and wave power represents an ambitious undertaking. In the course of a recent expert interview series, the top-ranked risks for utility-scale project implementations were identified as *uncertainty in device performance* and *achieving funding*. To ensure continuous progress on the way towards subsidy-free electricity generation, diverse problem-solving competencies are necessary. On one side, we encounter technical difficulties that require profound engineering know-how and on the other, tasks of a more strategic nature that require qualitative assessment capabilities and advanced management concepts.

The tasks correlated with the commercialisation of marine energy can be sub-divided into questions of *detail complexity* (also referred to as *complicacy*) and *dynamic complexity*. Reducing the core problem *uncertainty in device performance* is a challenging but conventional engineering task, whereas *achieving funding* is more demanding and requires the ability to cope with many interlinked impact factors at different time scales (i.e. a classic example for dynamic complexity). In this paper, the distinctly different strategies for solving detail-complex problems and appropriately managing dynamically complex tasks are described.

II. Objective of the Research

The underlying objective of this research is to de-risk and streamline the commercialisation of power generation by tidal stream and wave power technologies. The provision of problem-specific analyses and solution approaches aims to rapidly achieve a solid and sustainable market breakthrough.

The research is oriented around the hypothesis:

The market entry of marine energy can be de-risked by symptom-adapted interventions: (i) reduction of detail complexity; and (ii) managing dynamically complex tasks by qualitative feedback modelling.

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

III. Research Principle and Methodology

In the scientific literature on complexity research, the fundamental difference between detail and dynamic complexity is underlined [2,3]. Studies in the field of system dynamics revealed that in conventional management mainly aspects of detail complexity are considered, but that the real leverage lies in understanding dynamic complexity [4]. Senge [5] states, that most planning tools and analytical methods are not equipped to handle dynamic complexity.

In this contribution, a comprehensive approach to manage dynamic complexity correlated with the maturation and market entry process of marine energy has been chosen. The integration of a wide spectrum of perspectives in a systematic and transparent manner is a core principle applied in this research[1]. Different sources of knowledge are compiled to identify an optimum commercialisation strategy.

As for dynamically complex situations, a reduction of complexity can be counterproductive, qualitative feedback modelling is seen as the preferred approach [6]. In this case, expert interview information as input data and numerical modelling by system dynamics software is required.

In the course of the present research, several system dynamics models were built to fulfil the requirements of a qualitative feedback modelling process. In the initial model, the effects of dynamic complexity were considered by identifying the long-term top-level driving factors for the commercialisation of marine energy. Based on the achieved finding to focus on *showcasing commercial-scale projects/ successful demonstrators*, two further system dynamics models, concentrating on aspects of detail and dynamic complexity, were developed. In order to cross-check and substantiate the results, diametrically opposite perspectives were taken to analyse the supporting and hindering impacts on the marine energy development and maturation process.

The following chronological tasks have been performed: (i) elaboration of a target-oriented questionnaire; (ii) conduction of expert interviews; (iii) compression of information by ordering terms; (iv) configuration of system dynamics computer models; (v) calculated ranking of impact factors and determination of top-level driving factors; (vi) allocation of representative core statements; and (vii) elaboration of strategies to de-risk the technology and to govern the market entry process.

[1] By contacting 136 selected representatives from 15 stakeholder groups, we received 71 feedbacks out of which originated 11 personal and 15 telephone interviews as well as 20 filled-out questionnaires. Two questionnaires had to be discarded because they were incomplete. As a result, the knowledge of 44 managers, experts and specialists from 13 stakeholder groups was ultimately retained for the analysis. A total number of 2,129 individual replies had to be grouped in order to formulate higher-level correlations as the input for computer-based system dynamics analyses.

IV. Which Tasks are Complicated and Which are Dynamically Complex?

4.1. Large-Scale Engineering & Construction Projects

Söderlund [7] formulates that large-scale transformation projects (for which the maturation process and market launch of marine energy is an example) are characterised by involving several hundred individuals, different technologies, numerous knowledge bases, complex contractual structures and a wide range of development activities with parallel operations.

Sterman [8] demonstrates in the context of large-scale engineering and construction projects, that they consist of many *interdependent components, involve multiple feedback processes, non-linear relationships, accumulation or delay functions*, and belong, as such, to the group of *complex dynamic systems*. He emphasises that cause and effect can be subtle and *obvious interventions can produce non-obvious consequences*.

Within a research on project management, Ahern et al. [9] make the important distinction between detail-complex and dynamically complex projects. They criticise that – in line with the finding of Hayek [10] that dynamically complex tasks cannot be completely specified in advance – traditional project management privileges planning and downplays the role of learning. *Planning and problem-solving must be dealt with differently*, as summarised by Swinth [11].

4.2. Detail Complexity (Technical Complicacy)

Detail complexity is characterised by *many interacting elements and a large number of combinatorial possibilities*. The respective tasks are characterised by their high level of technical or organisational complicacy. Nevertheless, they can be planned and handled by the application of prior knowledge, skills and tools. By definition, detail-complex tasks or projects can be completely specified in advance. In the context of marine energy, questions of detail complexity arise in the framework of machinery/component design (blades, rotor, nacelle, foundations, electrical system, protection, controls), in subjects related to deployment, operation and retrieval or in multi-facetted organisational tasks (legal permits, regulatory and consenting process, finance applications).

A simplified formula to describe detail complexity is to exponentiate the number of potential states of each element by the number of elements [12]. This formula is not adequate to calculate dynamic complexity.

4.3. Dynamic Complexity

In the course of a technology convergence process, a project can change its respective characteristics. In aviation history, as exemplarily described by Ahern et al. [9], aircraft design progressed from being a complex project (when the technology was poorly understood) to a complicated project (when detailed designs are documented for production assembly). Nevertheless, as described by Snowden [13], a one-off project may not transition from being complex to becoming complicated until it is delivered and retrospectively comprehended in its entirety.

Dynamic complexity can arise even in simple systems with low combinatorial diversity and often shows aspects of counter-intuitive behaviour [14,15]. In the course of working on dynamically complex projects, continuous learning and reliable knowledge formation are paramount. Engwall [16] formulates this within a project management context by saying that it is necessary to continuously create knowledge over the complete project life cycle.

In Table 1, the most typical attributes of complex dynamic systems are presented and correlated to their appearance in the course of the commercialisation of marine energy. In this context, the term *system* refers to a set of rules that governs the *market entry and commercialisation process of marine energy*.

TABLE 1, DYNAMIC COMPLEXITY IN COMMERCIALISING MARINE ENERGY [14,17 – BOTH ADAPTED]

<table>
<tr><th>Attribute</th><th>Root cause</th><th>Form of appearance</th></tr>
<tr><td rowspan="2">On-going trans-formations in the embedding socio-technical system [18]</td><td>Innovation and change processes occur at many levels and at different time scales.</td><td>The unstable global economic situation constitutes a dynamic environment and changing strategic priorities (nuclear power phase-out, fracking) alter policy orientation.</td></tr>
<tr><td colspan="2">→ Considering a business environment in which other renewables operate price-competitive to conventional sources and the *epochal transformation of the European energy system*, the commercialisation strategy needs to be regularly adapted to socio-political developments.</td></tr>
<tr><td rowspan="2">Non-linear development and unsteady system behaviour</td><td>Non-linearity arises when (i) multiple factors interact, i.e. by complicated information pathways with many decision points; (ii) cause and effect are distant in time and space; and (iii) effect is rarely proportional to cause.</td><td>Leete et al. [19] and Wyatt [20] examined investor attitudes and found that most of them are unlikely to make any future investments in early stage device development. Venture capital investors are not closed to the industry completely, but the current level of risk and uncertainty about future revenues are discouraging them from investing.</td></tr>
<tr><td colspan="2">→ The commitment of investors is key for the commercialisation of marine energy. The present unpredictability of the costs and the length of time required to develop the technologies limit the incentive to invest and contribute to the *unsteady and non-linear progress in the sector*.</td></tr>
<tr><td rowspan="2">Counter-intuitive effects and policy resistance</td><td>The complexity of the system makes it difficult to fully understand it. The attention is often drawn to symptoms rather than to underlying causes. Many seemingly obvious solutions to problems fail or worsen the situation.</td><td>The quality of challenges that the sector faces is illustrated by the decision of Siemens to sell Marine Current Turbines (a key tidal stream device developers) only two years after its acquisition. Siemens is looking to exit marine energy, saying the development of the market and the supply chain has taken longer to grow than expected [21].</td></tr>
<tr><td colspan="2">→ The recent decision of Siemens to divest of MCT is a concern for the sector [22] and reveals the *difficulty of forecasting the pace of development* towards reaching commercial generation.</td></tr>
<tr><td rowspan="2">Adaptive characteristics</td><td>Evolution and learning lead to the selection and proliferation of the best concept(s) while others become extinct. Achieving a milestone alters the state of the system, thus giving rise to a new situation, which then influences the next decisions.</td><td>Marine energy represents a *radical innovation* and is driven by the need to de-risk the technology and achieve funding. Before becoming recognised as a mature power generation method, marine energy needs to prove a range of referenceable application cases. The attainment of this *array-scale success* will represent a major turning point and is expected to finally trigger industry-scale deployment.</td></tr>
<tr><td colspan="2">→ The economic success of marine energy depends on demonstrating market-readiness. By the game-changing *array-scale success*, competition between suppliers will shift to a new set of parameters of which the most important one is price [23]. *The development trajectory adapts.*</td></tr>
<tr><td rowspan="2">Tightly coupled</td><td>Heterogeneous stakeholders interact intensively with one another and the natural world.</td><td>Interaction of diverge stakeholders such as governments, certifiers, investors, academia, consultancies, developers, owners, operators, manufacturers and test site operators.</td></tr>
<tr><td colspan="2">→ To successfully realise the marine energy market launch, the *regularly coordinated interaction of the policy, technology and finance sectors* is necessary.</td></tr>
</table>

V. GOVERNING THE MARKET ENTRY

In the course of this research, in total, three system dynamics computer models were developed [24]. As the first model serves as a strategic indicator, all reported positive and negative impact factors on the final target of *full commercial power generation by marine energy* were coherently grouped and inter-correlated. The model was built one-on-one to the interview replies so that it directly reflects the experience and expectations of a wide range of stakeholders. Out of a total of 234 qualitative replies, directly defining the positive and negative impacts on the defined target, seven *representative* *group terms* were defined and the individual replies allocated accordingly. In a subsequent step, 16 positive (supporting/accelerating/reinforcing) and 22 negative (hindering/delaying/countervailing) *generic terms* were formulated to correlate the individual interview replies in a systematic manner according to their number of occurrences [25,26]. The calculated results of the simulations are presented in Table 2. On the left hand side, the impact factors with negative effect and on the right hand side the ones with positive effect on achieving market-competitive generation are represented. As the singular characteristics of government involvement and decisions are outside the range of this research, the highest ranked positive and negative top-level driving factors (*strong and long-term commitment from government* and *fluctuating or unclear political support*) were not examined in further detail.

TABLE 2, SPLIT RANKING OF TOP-LEVEL DRIVING FACTORS (POSITIVE AND NEGATIVE IMPACT FACTORS)

Negative (hindering/delaying/countervailing)	**Rank**	**Positive (supporting/accelerating/reinforcing)**	**Rank**
Fluctuating or unclear political support	47	Strong and long-term commitment from government	100
Lack of investor confidence	45	Showcase commercial-scale projects/demonstrators	51
Fragmented initiatives by unexperienced parties	44	Engagement industry/academia	22
Conflicts of interest (fishermen, shipping routes)	23	Cost-effective way to harvest marine energy	18
Low ability of developers to work together	17	Collaboration and consolidation between companies	15

The need to *showcase commercial-scale projects/successful demonstrators* and the identified *lack of investor confidence* are directly interdependent as investment decisions depend on track records of continuous device operation. In the centre of this area of conflict, we find the eagerly-awaited *array-scale success*, as passing this interim milestone will give confidence in the innovative sector and de-risk investments.

Subsequently, two more precisely focussed models were built to identify the top-level driving factors for achieving the *array-scale success*. In order to cross-check and substantiate the findings, diametrically opposite perspectives were taken by processing the entities of supporting and hindering impacts.

VI. SYMPTOM-ADAPTED INTERVENTIONS TARGETING ON ROOT CAUSES

6.1. REDUCTION OF DETAIL COMPLEXITY

For detail-complex (or complicated tasks), the application of complexity-reducing measures is expedient [27]. Apart from technology-related questions, detail complexity also appears within stakeholder-internal business management and in tasks of organisational nature. The following measures for complexity-reduction were identified in the course of processing the multi-disciplinary expert interview data:

(i) <u>Standardisation and certification:</u> Standards are one of the most important elements in the development of any industry [28]. A project developer's head of offshore operations emphasised, when asked for the most valuable experience gained by the early movers, the *experienced negative impact of missing standardisation*. One interviewee summed up the situation by saying *no standards, no results*. Considering the urgent need for consensus over standardisation, the over-engineering in oil and gas standards was addressed as being potentially hindering for the development of marine energy.

(ii) <u>Multi-applicable technologies and joint concepts:</u> In the course of the interviews, a power utility ocean energy manager outlined that one of the top-priority tasks in the work of academia and research should be to concentrate on *multi-applicable technologies* and *compatible devices and components* (e.g. moving parts, cable connectors, controls). To ensure compatible component design, effective supply chain management and leveraging logistics are required. Significant benefits are seen in *joint deployment and maintenance* programmes.

(iii) <u>Systems engineering:</u> When asked about the potential to reduce the cost for utility-scale project implementations, the CEO of a wave energy firm emphasised the recognition to orientate their development and research strategies at the US space-/aircraft industry and here especially on the systems engineering principles[2]. In the course of the design and deployment of marine energy converters and correlated power infrastructure, *regular system functionality checks*, focussing on operation in open sea, grid-connected, multi-device arrays, are recommended. This statement correlates with the central objective in systems engineering *to consider the finally envisaged functionality already in early project stages*.

(iv) <u>Reliability modelling:</u> As a key risk for reaching commercial generation, senior members of classification societies stressed *uncertainty about reliability* and emphasised the necessity to focus on it. In order to achieve a satisfactory technology reliability record, the experts recommended concentrating on reliability in system design and introducing *reliability engineering*.

6.2. MANAGING DYNAMIC COMPLEXITY

As a way of dealing with novel and complex tasks, Swinth [11] proposes *joint problem solving* which comprises a *common goal-orientation*, the *linkage of organisational centres* and the definition of an *overall consistent set of actions*. Within an inductive study on product innovation in continuously changing organisations (which are considered by the authors as *complex adaptive systems*), Brown and Eisenhardt [29] proclaim the importance of *extensive communication* and *design freedom* to create improvisation

[2] The term *systems engineering* can be traced back to the Bell Telephone Laboratories in the 1940s. A.D. Hall presented '*A Methodology for Systems Engineering*' (ISBN 0-442-03046-0) at Princeton University in 1962.

within current projects. They summarise that successful firms rely on *experimental products* and *strategic alliances*.

Due to on-going transformations in the embedding socio-technical system, that *encompass the co-evolution of technology and society* [18], the actual lines of strategic development of the marine energy sector need to be regularly re-adjusted. The following concepts are proposed by scholars working in the field of complex systems research:

(i) System dynamics techniques: As an initial step in approaching the characteristics of complex systems, in the mid-1950s, Forrester [30] developed system dynamics as *a methodology and mathematical modelling technique for framing, understanding and discussing complex issues and problems*. Richardson [31] defines system dynamics as *a computer-aided approach to policy analysis and design*. Wu et al. [32] introduce system dynamics as a *manner of systematic thinking that integrates a large number of causal relationships among variables and simulates real systems through high-speed computer processing power*. Forrester [33] describes the system dynamics approach as *a tool for knowledge-based decision-making*. Yim et al. [34] explain that *system dynamics methods support decision-making and enable managers to act under dynamic and non-trivial environments*.

(ii) Qualitative feedback modelling: With a focus on power projects, Groesser [35] argues that dynamic complexity is often the root cause for non-successful projects and introduces *qualitative feedback modelling* as a method to effectively deal with dynamic complexity. In the course of the present research, *qualitative feedback modelling* is not realised in the original form of working based on problem-specific relationship-diagrams, but by directly targeting the final goal of commercial power generation by marine energy. Feedback modelling is hereto realised at a more fundamental level by considering the marine energy commercialisation process as a complex system of which the dynamic characteristics are captured by semi-structured interviews with all active stakeholder groups [26]. The obvious analogy of this process with a closed-loop control circuit and its clearly defined (technical) terms helps to remove barriers [36–39].

As the presented concepts to deal with detail and dynamic complexity were successfully applied in similar environments, they are suitable to support de-risking the market entry of marine energy. The initial hypothesis is confirmed.

VII. Conclusion

There are a series of obstacles to the market entry of marine energy. Root causes for the slow commercialisation process are concerns regarding device reliability and difficulties in attracting investment. To successfully establish marine energy as a mature power generation alternative, in-depth engineering capabilities and advanced management skills are required. In order to identify optimum measures, a particular task needs to be assessed in its entirety and corresponding strategies selected. To solve machinery-related or organisational challenges, a good standard of innovation management and experience is required. Nevertheless, such specialist tasks are, in their principal characteristics, comparable to routinely executed R&D[3] activities in high-technology industry sectors.

The more comprehensive and strategically demanding tasks are to attract financing and to successfully embed the innovative generation method into the continuously changing *socio-technical environment*. To be able to adapt to such a discontinuous and non-transparent environment, systemic thinking and evolutionary steering mechanisms are required. The strategy must be flexible and re-adjustable to new trends and priorities.

The commercialisation of marine energy can be regarded as a complex dynamic system that has the capacity to change and learn from experience. There is the necessity to be mindful of the numerous time-driven impact factors and to enable learning by strengthening collaborative problem solving [40,41]. The use of cross-category expert interview data and unbiased system dynamics modelling assure the important open-integrative instead of detailed-specialist character of the research. Based on such a multi-disciplinary attempt, an all-encompassing appraisal becomes possible by avoiding concentrating in a limiting manner on stakeholder-specific views or interests.

Engwall [16] describes that *project execution is seldom a process of implementation, rather it is a journey of knowledge creation*. Reliable communication and efficient knowledge integration are seen as keys for success. The motivation for cooperative interaction to jointly de-risk the concept is given by the aim to rapidly overcome the pre-profit phase [42].

The correct strategic alignment of the sector depends on the input of all key stakeholders. The process of information gathering by *stakeholder-wide expert interviews* and the use of *system dynamics tools* to determine the currently relevant *top-level driving factors* provide a reliable foundation for governing the market entry of marine renewables.

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