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Exploring Capabilities Driving SME Development of Technological Readiness Within the Marine Sector

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Declaration

“This is to certify that the work I am submitting is my own and has not been submitted for another degree, either at University College Cork or elsewhere. All external references and sources are clearly acknowledged and identified within the contents. I have read and understood the regulations of University College Cork concerning plagiarism and intellectual property.”

Abstract

SMEs contribute to the economy along with industrial expansion. However, there are challenges for SMEs in the present environment to keep pace with the turbulent technological advances, and most new technologies fail to traverse the gap between the proof-of-concept and prototype demonstrated in the relevant environment (valley of death between TRL 3 to 7). This requires detailed real-time information on the challenges of SMEs through the chronological evolution path and required capabilities to develop their technology and bring it to the market. Given the vast quantities of untapped renewable energy, the strategic importance of the sector and the emergence of a cluster of such SMEs, this exploratory study focused on how technology-based SMEs can develop technological, organisational, and managerial capabilities through their technology development to move from proof-of-concept to scalable prototyping through the technology readiness spectrum. For this purpose, the research started with a survey of the existing population for a broad understanding of the subject through 33 quantitative questionnaires. Then, three explorative interviews were conducted to delve into issues raised in questionnaire results, and finally, an in-depth analysis was carried out to assess the issues raised in questionnaires by nine qualitative case studies. The results showed that technology development programs do not only rely on technological capabilities and must prioritise organizational and managerial capabilities and outsource the capability gaps through partnerships with academic institutions, SMEs, large companies, and the customer market. In this regard, consistent learning from prior experiences and knowledge transfer between SMEs and large companies in the marine energy sector and other sectors is crucial for developing technological capabilities. Besides, experimental analysis and testing at test facilities and sites require a robust, scalable idea regarding the facilities' technical specifications. Furthermore, the findings highlighted the crucial role of financial resources, which can be achieved by writing convincing grant proposals or creating a cash flow in the firm. This can be achieved by increasing the focus on commercialization even at earlier TRLs by finding intermediary markets. All this can lead to developing organizational capabilities in a firm. Moreover, the results showed that besides technological and organizational capabilities, managerial capabilities and human skills could help SMEs through the valley of death, which requires training in management and business for technology developers. Finally, the networking and partnership capability is particularly significant to fill the capability gaps, which should be facilitated by government assistance. The research findings will contribute to improving the ability of SME marine renewable energy firms to develop their technology and bring it to the market for societal benefit. Implications for theory, marine energy technology developers and policy offer a deeper understanding of how we can better nurture marine-based SMEs in traversing across the valley of death (TRL3-TRL7) by developing technological, organizational, managerial, and external capabilities.

1 Chapter One - Introduction

In recent decades, due to the energy crisis, financial crisis, and global warming concerns, high-technology development has been gaining worldwide attention (Nugroho *et al.*, 2017). A rigorous technology development plan leads to the manufacture, commercialisation and sale of a robust product (Adam *et al.*, 2017). This evolution path toward market readiness can be described as a technology life cycle (Tassey, 2013). However, emerging technologies are not always developed enough to be deployed effectively and efficiently in operational activities and may require more research before integrating into the existing manufacturing environment (Greitemann *et al.*, 2014).

The technology readiness level (TRL) has been considered as one of the most promising approaches for addressing technological maturity (Lezama-Nicolás *et al.*, 2018) and is used for tracking progress and supporting the technology development process through the early stages of the technology development (TRL1) to actual system demonstration (TRL9) (ARENA, 2014). Technology readiness measures the risk associated with introducing new technologies into existing systems and standard operating procedures and measures the extent to which a technology is suited for deployment in a real operational environment (Engel *et al.*, 2012). For technologies that are not ready for providing technological products or services in the market, the consolidation of the supply chain depends on the reliability of the technology and its progress towards a higher level of technical and investment readiness as a measure of the maturity of the technology (Ariffin and Arof, 2020). For example, ocean energy technologies are still in a prototype testing stage, and there has been little commercial deployment to date due to the non-competitive cost of energy produced by wave and tidal energy devices compared to other alternative renewable energy sources such as wind (de Andres *et al.*, 2017; Saint-Jean *et al.*, 2020; Clemente, Rosa-Santos and Taveira-Pinto, 2021). In this regard, every company has a unique need to define the path forward to advancing the technologies to increasing maturity levels. Large companies have well-developed and enhanced R&D systems and have sufficient resources to invest in innovation (Wagner and Hansen, 2005). However, small high-tech firms need to find innovative ways to generate revenues, define value propositions for customers, suppliers, and partners, and conduct marketing to leverage the firm's capabilities and limited resources (Mansour and Barandas, 2017).

SMEs need to improve their digital intensity level, including addressing skills and technological gaps to prepare them for the digital economy demands (OECD, 2019). The fastest-growing start-ups are those who transform plans and policies into action in the form of research and development (R&D), innovation, and training, devote great emphasis on hiring skilled and motivating employees, and balance the augmentation of their capabilities in different areas (Kang, Baek and Lee, 2018).

1.1 Context and research gap

Many industries use TRL to determine the development status of their technology and what is required to bring it to a level of maturity sufficient to enable operational "in-service" applications. Due to the significant role of the marine sector in the transition towards a global blue economy, TRLs are a widely used metric of technology maturity and risk for high-tech devices (Weller *et al.*, 2015). Ocean-based economic sectors with various emerging industries and significant growth potentials and capabilities, which increasingly implement national and regional ocean economies, lead to higher value-added products (OECD, 2016). Managing interactions between ocean economic sectors is a crucial component of blue growth (Klinger *et al.*, 2018). Blue Growth – a driver to harness the untapped potential of Europe's oceans, seas, and coasts – "can contribute to the EU's international competitiveness, resource efficiency and job creation, all while maintaining biodiversity and the marine environment, thus conserving the services that healthy and resilient marine and coastal ecosystems provide" (European Commission, 2012).

In the case of enhancing our marine scientific knowledge, we should be better prepared to adapt current and future maritime activities since maritime activities will have fewer adverse environmental impacts and provide more sustainable alternatives in comparison with their land-based counterparts (European Commission, 2019). Also, due to unique wave, tidal and offshore wind energy resources, creating a national network of facilities covering all TRLs along the Atlantic coast should not be underestimated (Noé, 2013). However, to date, many proposed marine energy concepts have reached the early validation levels of development (TRL1-3). Only a few mature designs have attained pre-commercial development status following prototype sea tests (TRL7-8). New technologies should be de-risked in terms of component durability and reliability in order to traverse through the aptly labelled "valley of death" (TRL3-7) on their way to commercialization (Weller *et al.*, 2015). Although innovative and emerging sectors, such as renewable wind energy and biotechnology, have grown exponentially in recent years, these sectors are also encountering challenges. The primary challenges to the development of high-growth SMEs are market failures in acquiring funding investment (Pasumarti and Patnaik, 2020), government regulations in the development and functionality of SMEs

(Pasumarti and Patnaik, 2020), indirect labour costs (Pasumarti and Patnaik, 2020), access to foreign markets (Knight and Cavusgil, 2004; Ramon-Jeronimo, Florez-Lopez and Araujo-Pinzon, 2019), and challenges in attracting qualified staff and skilled labour (Sandelowski, 2000), etc.

One of the main issues in the development of marine energy concepts is the high investments required to demonstrate the concept's suitability and gain confidence in the technology through expensive prototype demonstrations (Penalba and Ringwood, 2019). Addressing these challenges in marine-based SMEs needs greater use of economic analysis and economic instruments, better use of innovations in science and technology, and innovation in governance and stakeholder engagement (OECD, 2016). Along these challenging paths, start-ups and SMEs need to boost the TRLs relying on existing maritime industries (Johnson, Dalton and Masters, 2018). TRL metrics will help us select the technologies that are considered technically and commercially promising and realistic in the long-term.

1.2 Research Questions

This study aims to examine the capabilities driving marine sector SMEs' technological development that support development across the 'valley of death' from TRL3 to TRL7. Based on the above background, we seek to address this overarching research question:

What capabilities enable technology-based SMEs in the marine sector to support the advancement of their technology from proof of concept to scalable prototype for market adoption?

To help answer this general question, we have identified three sub-questions:

1. What challenges do SMEs (start-ups and established) encounter when developing technologies from proof of concept to scalable prototype development within the marine sector?
2. What technological, organizational, and managerial level capabilities enable SMEs to develop technologies from proof of concept to scalable prototype development within the marine sector?
3. Do SMEs seek external support? How are externally controlled resources and capabilities leveraged by SMEs to support technology development from proof of concept to scalable prototyping within the marine sector?

1.3 Motivation for this Research

On a global level, major challenges arising from climate change and resource use have created a global marketplace for innovative products and solutions in the energy sector. However, early-stage development can be difficult to fund, the returns can be difficult to forecast, and the innovation "landscape" is frequently complicated and unclear (McIntyre, 2014). High-tech SMEs are capable of leveraging innovation practices to advance their core technology toward market adoption (Barrett, Dooley and Bogue, 2021). However, because of the unpredictable and ambiguous nature of the technology development phase, most R&D activities fail to demonstrate the innovation process (Tiryaki, 2020). This point in the process, called the "Valley of death" (McIntyre, 2014), is the gap between the technical invention or market recognition of an idea and the efforts to successfully commercialize it. Crossing the Valley of Death is highly rewarding but is not without risk and complexity and requires resources and capabilities to carry it off.

Ireland is bounded by the Atlantic Ocean in the west and north-west, the Celtic Sea in the south and the Irish Sea in the east, with one of the best offshore renewable energy resources in the world (KPMG, 2018). Hence, developing ocean energy can contribute to meeting Ireland's growing demand for renewable energy and to developing an export industry for ocean energy devices. Therefore, directing R&D towards **how we can better nurture marine-based SMEs in traversing across the valley of death (TRL3-TRL7)** can significantly impact Ireland's energy policy by directing marine sector SMEs toward developing internal and external capabilities for successful technology development.

Moreover, there has been little research about the wave, tidal stream, and ocean thermal energy conversion technologies. Hence, tracing the development process across the technology readiness levels (TRLs) spectrum is of great importance for marine-based firms (Mankins, 2004; European Commission, 2014). Understanding the chronological evolution path of multiple marine technology companies, together with the managerial response to critical incident challenges experienced, will contribute to both the strategy and innovation literature by deepening understanding of technological, organizational, and managerial capabilities that SMEs develop for the transition from proof of concept to scalable prototype development. Correspondingly, a significant contribution to improving marine renewable energy technology development processes is envisaged towards a higher level and performance.

In addition, despite a vast array of research in this field, there are few studies concerning the challenges start-ups and SMEs face within the marine sector. In this study, we analysed technical and commercial challenges for marine sector SMEs, in the TRL3-5, as a way to enhance the level of technology readiness. In this regard, we have also made recommendations that can be used by SME owners in improving their organizational skills and managerial capabilities that underpin the progress to the technical and commercial maturity level of early-stage (TRL3-5) for such marine sector companies.

Consequently, there is a question of **what capabilities enable marine-based SMEs to advance their technology from proof of concept to scalable prototype** and whether those capabilities are unique for each particular start-up or some similarities can be identified within the same industry (Ambrosini and Bowman, 2009), and whether they originate internally or are sought externally.

Thus, it is important to explore how and what capabilities are linked to the growth of SMEs. Using such an approach, we will be able to capture some evidence of the technological, organizational, and managerial capabilities of enterprises, how they are deployed, how they can affect organizational growth, and how they might vary in different firms.

1.4 Methodology

This research employs a mixed-method (quantitative-qualitative) approach (Creswell, 2009) involving secondary data, questionnaires, explorative interviews, and semi-structured interviews to examine the underlying challenges and capabilities of advancing technology by SMEs from proof of concept to scalable prototype for market adoption. This is considered the most suitable research method when there is a lack of prior research in an area (Yin, 2017).

Based on this rationale, we hypothesize as follows:

Hypothesis (1): Marine-based SMEs encounter challenges other than technological in developing market-ready offerings.

Hypothesis (2): Technological capabilities at the organizational level enable a transition from TRL concept to scaled prototype.

Hypothesis (3): Organizational capabilities enable a transition from TRL concept to scaled prototype.

Hypothesis (4): Management capabilities enable a transition from TRL concept to scaled prototype.

Hypothesis (5): Capability gaps within the venture (internals) are addressed by seeking externally controlled resources.

The objectives and research questions have been summarized in Table (1-1) with their respective research hypothesis.

Table (1-1) Research Objective, research questions and hypothesis

Objective	Research Questions	Hypothesis
To determine the challenges of technology development (TRL 3 to TRL7)	What challenges do SMEs (start-ups and established) encounter when developing technologies from proof of concept to scalable prototype development within the marine sector?	***Hypothesis (1):*** Marine-based SMEs encounter challenges other than technological in developing market-ready offerings
To determine the capabilities that enable technology development (TRL 3 to TRL7)	What technological, organizational, and managerial level capabilities enable SMEs to develop technologies from proof of concept to scalable prototype development within the marine sector?	***Hypothesis (2):*** Technological capabilities at the organizational level enable a transition from TRL concept to scaled prototype
		Hypothesis (3): Organizational capabilities enable a transition from TRL concept to scaled prototype
		Hypothesis (4): Management capabilities enable a transition from TRL concept to scaled prototype
To determine the role of externally controlled resources in technology development (TRL 3 to TRL7)	Do SMEs seek external support? How are externally controlled resources and capabilities leveraged by SMEs to support technology development from proof of concept to scalable prototyping within the marine sector?	***Hypothesis (5):*** Capability gaps within the venture (internals) are addressed by seeking externally controlled resources.

Our focus group are classified as small and medium-sized enterprises (SMEs)[1] (following EU recommendations) in the maritime sector as SMEs are the backbone of the European economy and the drivers of growth and innovation.

The data for this study was mainly generated through 33 online surveys from awarded marine sector SMEs of the Marine Energy Alliance (MEA)[2] project in Ireland, the UK, France, Netherlands, Denmark, Norway, and Sweden, three explorative interviews and nine semi-structured interviews with founding-owners/entrepreneurs of SMEs from the Republic of Ireland and the United Kingdom. The data were complemented by secondary sources, such as information from websites and third-party information (i.e. MEA resources), which were used both to select the participants and contribute to findings, thus assisting data triangulation (Guion, Diehl and McDonald, 2011).

The collected data during the interviews was assessed using thematic analysis, resulting in a mix of deductive (from the literature, reflected in the interviews) and inductive ('emerging' from the data) themes that helped answer the study's three research questions. The analysis of the qualitative interviews was an iterative process, as the researcher moved between data analysis and data collection while also referring

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[1] *The category of micro, small and medium-sized enterprises ('SME') is made up of enterprises which employ fewer than 250 persons and which have an annual turnover not exceeding €50 million, and/or an annual balance sheet total not exceeding €43 million. Within the SME category, a small enterprise is defined as an enterprise which employs fewer than 50 persons and whose annual turnover and/or annual balance sheet total does not exceed €10 million while a micro-enterprise is defined as an enterprise which employs fewer than 10 persons and whose annual turnover and/or annual balance sheet total does not exceed €2 million.*

[2] For more information: https://www.offshore-energy.biz/companies/marine-energy-alliance/

to the extant theory that guided the study. Ideas were refined as the data was generated, analysed, and compared to extant research simultaneously.

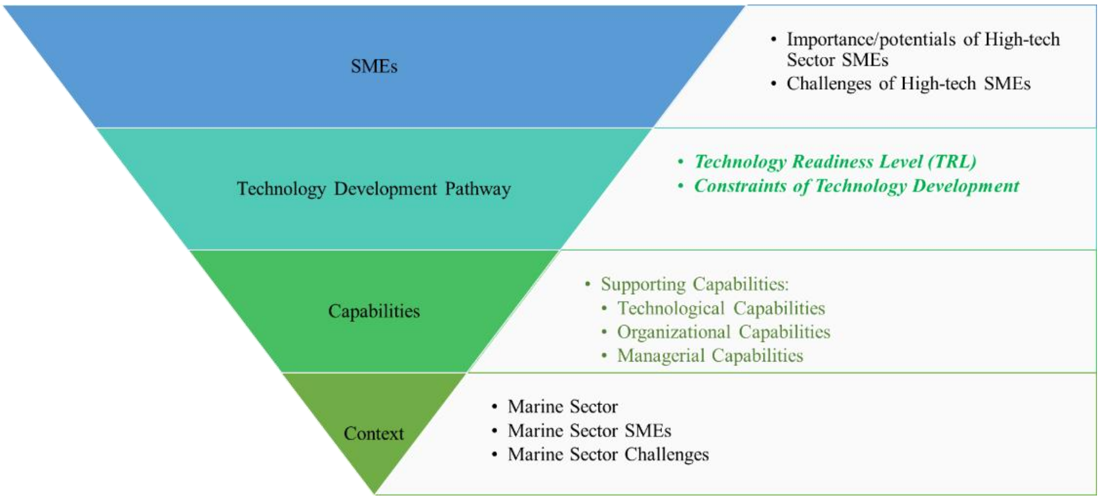
1.5 Format of the Thesis

Following this Introduction, Chapter 2 reviews the literature on capability deployment and development, along with previous research in the marine energy sector. Chapter 3 outlines the methodology used in the study, including the research approach and case study design. Chapter 4 describes the data, while Chapter 5 summarizes the research outcomes and recommendations arising from this research, and topics for further research are suggested. Chapter 6 concludes.

2 Chapter Two - Literature Review

This literature chapter discusses the current state of research in a wide range of related fields, including technological, organizational, and managerial challenges and levels of technological maturity. First, we explore the literature on small and medium-sized enterprises due to the challenging evolution path of SMEs and start-ups compared with MNCs. We then move on to technology development trajectories and maturity requirements. Then, in order to find which capabilities are of higher priority for entrepreneurial ventures, we explain how and what general and technological, organizational, and managerial capabilities underpin the technology development from proof of concept to scalable prototyping. Finally, considering the recently introduced concept of blue growth, we explore the literature on SMEs and technology development in the marine context. A visual overview of Chapter Two is illustrated in Figure (2-1).

Figure (2-1) Flowchart of Literature Review



2.1 Small and Medium Enterprises (SMEs)

SMEs are noteworthy drivers of economic development in most economies across the world, particularly in developing and emerging nations (Gamage *et al.*, 2020; Gherghina *et al.*, 2020).

SMEs are vital drivers of economic growth, job creation and technological development (Al-Haddad *et al.*, 2019; Gherghina *et al.*, 2020). As drivers of economic growth, SMEs should benchmark their assets, processes, and performance and seize opportunities to maintain their competitiveness (Singh, Garg and Deshmukh, 2008). The evolution of the global economy has created both challenges and opportunities for SMEs (Dominguez and Mayrhofer, 2017). With the emergence of globalization and the knowledge-based economy, SMEs must constantly innovate to remain competitive (Raymond *et al.*, 2018). The size of enterprises does not guarantee the availability of adequate technology as a tool for doing business and remaining competitive. However, in an increasingly saturated and competitive market, SMEs handle changes and decision-making easier because of their flexibility, innovation, and agility (Haq, Hameed and Raheem, 2020; Miroshnychenko *et al.*, 2020). Consequently, compared with larger firms that implement plans slowly, small enterprises can introduce innovative, new products and proceed along that path if they are successful.

SMEs account for 99% of all enterprises in the European Union (EU) and have created about 85% of jobs in the last five years, ensuring two-thirds of the region's total private sector engagement (European Commission, 2016). Although SMEs, compared to large companies, possess insufficient funding, which restricts them from investing significant funds for technology, they demonstrate more flexibility to technical shifts and better adaptability to market fluctuations and new customer demands, whilst their organizational structure allows for faster decision-making. Nevertheless, to achieve this potential, SMEs need a continued source of longstanding funding (Gherghina *et al.*, 2020). The European Commission designed a set of measures alongside a modern and coherent policy for the practical development of innovative concepts to support the growth and development of SMEs in close relation to the employment market (Commission of the European Communities, 2008). Hence, SMEs play an essential role in poverty reduction, job creation, international trade promotion, and technological innovations and contribute significantly to the growth of developing economies (Luo, Wang and Yang, 2016).

On the one hand, SMEs in high-tech industries are the new entrants to markets, and they often conduct entry strategies and innovation activities, such as new product development (NPD), to pioneer new categories (Liu and Wang, 2020).

2.1.1 High-Tech SMEs

High-tech SMEs are SMEs based in the high-tech sector, which helps to improve economic performance by expanding markets and increasing productivity and industrial competitiveness (Wu, 2008). High-tech companies aim to maximize their potential by acquiring market share in their domestic market and internationally (Mejri and Ramadan, 2017). Jo and Kim (2018) aimed to determine the factors that contribute to the success of technology-based start-ups by defining success as innovative performance through technology innovation actions and then suggesting strategic directions for increasing the competitiveness of technology-based start-ups.

However, the high-tech sector might be subject to capital market imperfections because of the low probability of R&D project success, the uncertainty of returns on investment, and the need for special knowledge to evaluate (information asymmetry exists between insiders and investors (Ghazinoory and Hashemi, 2021). Hence, SMEs in high-tech sectors must be more creative and innovative in order to survive, compete, and grow. This is because technologically-driven firms that operate in a vibrant internal and external competitive environment are characterized by rapid technological change and reduced product life cycles (Gu, Jiang and Wang, 2016).

Therefore, high-tech SMEs are facing many problems, such as high operating costs, lack of talent, and difficulty in financing, which significantly restrict the innovation capacity of the high-tech SMEs in the long run (Corsi and Prencipe, 2017; Schoonmaker, Solomon and Rau, 2017; Senaratne and Wang, 2018; Ghazinoory and Hashemi, 2021).

2.1.2 Challenges of High-Tech SMEs

Technological-based SMEs prioritize technology research and development, as well as capital, human resources, and material resources, in the process of enterprise growth and development. Through technology development, investment accounts for a large proportion as technology-based SMEs need to develop and test production (Chang, 2019).

Firms often fail to sustain themselves long enough to reach the market. The gap or valley of death within TRL3 to TRL7 from demonstration to scaling is where public-funded ideas fail to transit to private-funded solutions (Warrian and Wolfe, 2017).

Access to financial resources is a key impediment to SMEs' growth because information asymmetry exists between financial institutions and SMEs (Iqbal *et al.*, 2018). Besides, the high cost of innovation is also an inhibiting factor for high-tech SMEs. Mugogo and Midala (2020) refer to the inability to hire and purchase necessary skilled human power and equipment, failure of enterprises to acquire external competence, and no budgeted money for innovation activities as barriers for SMEs to engage in technological innovation.

Crossing the valley of death for new technology developments as a gap between federally-funded basic research and industry-funded applied research and development requires partnerships between universities and firms (Hartley and Medlock, 2017). Collaborative R&D partnerships among partners are becoming increasingly common, but they come with their own set of problems in terms of the R&D context and the ever-changing environment (Lee *et al.*, 2017). Therefore, SMEs have no choice but to integrate internal knowledge and technical skills with outsourcing advanced technical expertise and networking by developing viable technological capabilities in terms of activities and strategies to stand out differently in the changing business environment (Salisu and Bakar, 2019).

2.2 Technology Development Pathway

Globalization and climate change might pose significant challenges for European countries but may also generate new opportunities. Provided that, environmental concerns increasingly guide customer preferences and technological development (Pihlajamaa *et al.*, 2013). Assessing the evolution of new technologies and their readiness path has long been a focal part of future studies discipline (Watson *et al.*, 2019). Over recent years, a debate over maturity models has developed to maintain a maturity model that helps firms develop capabilities and become more mature (Harmon, 2009; Khoshgoftar and Osman, 2009; Mettler, 2011; Poeppelbuss *et al.*, 2011). The main advantage of a maturity model is that it allows firms to recognize strengths, weaknesses, and benchmarking information for projects and organizations (Jugdev and Thomas, 2002). Although some maturity models guide capability development by proposing improvement measures, most maturity models only contain a set of capability areas and descriptions of capability and maturity levels and leave the identification of improvement measures to the model user (Curtis and Alden, 2007).

It is clear from available studies that the transition from technology availability to technology uptake in a product or system cannot be achieved using current technologies' evolutions. Poor technology selection and management can lead to significant financial losses and, in the long-term, can result in the organization being unable to compete in markets where it used to thrive.

Based on Bonnin et al. (2020), the reluctance of the private sector to invest in technologies that are perceived as immature is the main reason for the gap between the proof of concept and development phase. However, uncertainty about regulatory frameworks may also significantly affect private sector investments. Upadhyayula et al. (2018) described that academic researchers often lack the motivation to seek entrepreneurial opportunities. There is a lack of a systematic framework at many academic institutions to bridge the gap between primary research and viable product. In order to avoid getting stuck in the Valley of Death and persuade investors to take the risk with the up-scaling of promising technologies, governments need to attract private investors—their capital, knowledge, and networks—to further the growth of the marine sector. Hence, taking a closer look at technology characteristics in value creation and acquisition opportunities can help companies better select and choose technologies for development. Development time and commercialization capacity, efforts achieved in R&D outside the laboratory, and the advantage of technology rivalry can all be used to determine the maturity phases of any technology (Altunok and Cakmak, 2010).

Moreover, firms use Technology Readiness Assessment (TRA) framework to determine the maturity of new technology and/or capability. TRA is a systematic, metric-based assessment of how far technology development has progressed (Yasseri and Bahai, 2018). TRA is an essential procedure for firms managing resource allocation for technology development programs as it leads to the identification of gaps in testing, demonstration, and knowledge of the technology's current readiness level, and also the information and steps needed to reach the required readiness level for successful inclusion in the project, as well as the identification of at-risk technologies that require proper management (European Commission, 2020). For this purpose, several milestones should be defined during the life cycle of new technology and new systems through technology development progress (Mankins, 2009):

a) Systems analysis and conceptual design studies
b) Decision from among several competing design options
c) Beginning of full-scale development

Webster and Gardner (2019) argued that TRA, as a technology management tool, is used at various steps to assess the technical and economic costs, future economic potential, and possible risks of developing a technology system. So, there is an urgent need for ventures to exploit TRA to determine the maturity of a new technology and/or capability (Ahlskog, Jackson and Bruch, 2015) as well as products and services full-span commercialization using the 9-stage technology readiness levels (Mankins, 2009).

A plethora of TRA studies shows that the readiness of technologies would lower the risk of technology transition and adoption (Engel *et al.*, 2012). Therefore, the main barriers, practices, methods, and knowledge management tools need to be identified because firms with higher maturity in innovation, solution development, and scalability development display higher utilization of knowledge management practices, methods, and tools (Oliva and Kotabe, 2018). There are few advanced metrics and tools to measure how ready technology is. The most universally accepted methodology is the *Technology Readiness Level (TRL)*.

2.2.1 Technology Readiness Level (TRL)

The Technology Readiness Level[1] is a measurement used to assess technology maturity before its inclusion in a system. The TRL scale is a helpful communication and risk management tool to support policy and funding decisions about technology development and transitions since it provides a consistent reference for assessing development status across the full spectrum of new technologies (Rackley, 2017). The technology readiness level (TRL) implemented by NASA during the 1980s was later

[1] Technology Readiness Levels are further described in Appendix 1.

defined and expanded in other industries by John Mankins (2004). Mankins (2004) developed a helpful framework for measuring maturity between different technologies oriented towards technology and innovation. Also, Collins and Pincock (2010) outlined the steps to determine technical readiness and map the path forward to advance readiness systematically. The roadmaps identify precise project objectives and requirements; create a consensus vision of project needs; provide a structured, defensible, decision-based project plan; and minimize project costs and schedules. However, planning and decision-making represent significant challenges for all projects and the technology development pathway of SMEs and need to be investigated.

2.2.1.1 Constraints of SMEs

A major source of risk in the process of technology development is the uncertainty about the development of the concept, the development of the model, and the development and verification of the prototype in real working conditions (Belina *et al.*, 2015). Based on Krawczyk-Dembicka (2017), it is essential to conduct a market analysis of the available technologies and find those that could significantly impact its development. Research and development (R&D) is related to investigative activities a business conducts to improve existing products and procedures or to develop new ones by focusing on applied aspects of technology development, not basic research of the research institutions or universities (Okkonen, 2017). Research and Development and technological capabilities need to be converted into actual market opportunities to achieve intended economic growth and support new product introduction (NPI) (Betz, 2011; Ardito, Ernst and Messeni Petruzzelli, 2020). Technology innovation and research have frequently been stimulated and funded by different public organizations and are usually limited to TRL1-3 (Andronchev *et al.*, 2020). This is where most new technologies fail, and a more significant part of these technologies never leaps over the private sector (Valley of Death) (McIntyre, 2014).

Although this phase is critical to realise the commercial viability of products and creates a bridge between research and new technology development, it is often overlooked (Ardito, Ernst and Messeni Petruzzelli, 2020). Even if many studies have attempted to analyse the prerequisites of new technology introduction (e.g., organizational, human, and environmental factors), making handoffs from ideas to commercialization is one of the biggest challenges for companies (McKinsey & Co, 2010). So, firms need to demonstrate that the technology is ready for testing in a practical use condition, as well as identify key manufacturing processes (including tooling and machines) before product development (Wong, Beiter and Ishii, 2008).

Technology Readiness metric includes fundamental limitations: inability to assess multiple technologies, i.e. how do the individual parts affect the whole, lack of consideration of the criticality of each technology, i.e. which parts can be safely substituted, inability to assess the applicability, i.e. how does the technology under development suit its intended application context and lack of consideration of life-cycle aspects, i.e. what happens with the readiness as the product is modified or competing technologies become more mature (Hicks *et al.*, 2009).

After defining the technology readiness path, SMEs need to reflect on more specific aspects of planning and implementation; otherwise, they will face challenges concerning market analysis and feasibility (Sefton, Ronkko and Bellgran, 2020). In comparison, the practice-oriented literature focuses on how companies struggle to develop plans that justify their investments (McKinsey Digital, 2016) and how these challenges become even more complex due to the need to plan a technology readiness path (Schneider, 2018). Although almost all investment-ready projects have addressed market readiness, they suffer mainly from deficient competition analyses, insufficient engagement with potential customers and imperfect marketing and sales plans (Mion *et al.*, 2015). A creative sales plan or some improvement in the manufacturing process can help SMEs design their financial plans (Havlíček and Roubal, 2014). At the early stages of commercialization readiness, the funding gap as the hindrance in accessing the required capital to grow the business by all SMEs makes it challenging to get the financing required to grow a business in the start-up period (Das, Hui and Sha, 2018).

The first reason for this issue is supply-side problems, such as information asymmetry and a lack of track record among small businesses, limiting the amount of funding available for investment. The second reason has to do with demand issues, in which the planned use of capital is not a profitable investment for the external party, so the business will not be funded (Abraham and Schmukler, 2017). Generally, through the shift from public funding to private funding in the innovation process for high-tech companies, companies become less able to receive public funding for research. In contrast, the chance of obtaining private investments for commercialization is low (Nemet, Zipperer and Kraus, 2018). However, technology commercialisation requires significant investments and a commercial product is created when high-tech companies can obtain revenue from their innovation (Tassey, 2014).

Moreover, business success requires partners, suppliers, and clients within a cooperation network where companies can compete and cooperate to create innovative products and services and provide value to clients (Freixanet *et al.*, 2020). However, entrepreneurial firms confront challenges in leveraging their partners' limited resources and managing the tension between learning and protection (Jee and Sohn, 2020). Working with partners to leverage a broader set of skills, ideas, resources, and relationships than any company could do independently can be essential to long-term success and sustainability (Unido, 2004). So, business model designs identify how SMEs and their partners create and capture value and support the successful commercialization of sustainable technologies (Zott, Amit and Massa, 2011; Bidmon and Knab, 2018). Besides, in most cases, regulatory requirements are not well-streamlined, generating a lot of stress for entrepreneurs who want to establish their firms (Nyarku and Oduro, 2018).

Transparently, there is a strong relationship between a firm's strategic capabilities, business model innovation, and performance (Pucci, Nosi and Zanni, 2017). That is why business model innovation has received remarkable attention from scholars (Foss and Saebi, 2017; Zhu, Zhang and Lin, 2017; Anwar, 2018; Pucihar *et al.*, 2019; Vaníčková and Szczepańska-Woszczyna, 2020; Walaszczyk and Dingli, 2020). For instance, according to Gambardella and McGahan (2010), firms innovate in their business models to take advantage of new markets, enjoy unprecedented opportunities, and commercialize their underlying assets toward a sustainable competitive advantage in the long-term (Annarelli, Battistella and Nonino, 2019; FIRMAN *et al.*, 2020). In another study, Sefton et al. (2020) stated that in case of not adapting and developing a prototype from the validated market area with its related requirements and regulations, the development of the prototype would be more difficult, and the risk of recasting the prototype several times increases or due to lacking a good feasibility study, the price on the product might be too high resulting in a limited sales volume.

Although new technology ideas are quite attractive in the high-tech sectors, market unwillingness leads to the danger of failure. Hence a genuine gap in the market for the company’s value proposition leads to much more successful commercialization (Johnson, Dalton and Masters, 2018). Supporting this claim, Zott et al. (2011) argued that a company should develop a distinctive business model to fully realize its commercial potential. High-tech firms in the marine sector need to create a suitable innovative business model for new product commercialization to consider all internal and external factors.

Clearly, value proposition is a prevalent topic in literature as there is no business without a clear value proposition (Morris, Schindehutte and Allen, 2005). In this regard, the ideal situation would be to select items or services that provide the highest technical performance at the lowest cost, or at the very least, to seek the best technical and economic compromise (Mallard, Debusschere and Garbuio, 2020). Financial profitability is usually assessed with the Levelized cost of energy (LCOE) which provides insight into the value proposition for the various technologies investigated (Robertson, Bekker and Buckham, 2020). SMEs encounter challenges in accurately estimating the LCOE model. For this purpose, Johnston et al. (2020) reviewed the challenges of evaluating LCOE for offshore wind outlining different approaches to calculate LCOE, influential factors, and the impact of variation in LCOE calculation. Lee and Yang (2018) claim that changes in future energy technologies can be predicted using the LCOE foresight model based on the learning curve, market share, and interaction. Therefore, the LCOE model provides information about technological trends and provides beneficial information for decision-making by governments regarding R&D investment (Lee and Yang, 2018).

So, firms need to possess the ability to embrace and use new capabilities to bridge the valley of death. A path to technical feasibility and technology development requires addressing capabilities literature.

2.3 Capabilities

Entrepreneurial firms face challenges in leveraging their limited resources and managing the balance between learning and ownership (Jee and Sohn, 2020). Therefore, how firms address these challenges is key to their success and warrants further investigation. A series of resource-based research was conducted in the early nineties to link firm resources and sustainable competitive advantage with valuable, rare, imitable, substitutable organizational resources and capabilities (Barney, 1991). *Resources* are defined as all existing assets, processes, management information, etc., utilised by a firm to effectively reach final products or services (Barney, 1991; Amit and Schoemaker, 1993), which can be tangible (financial, e.g., cash, securities; physical, e.g., plant, equipment, land, buildings, raw materials, etc.), intangible (technology, e.g., patents, copyrights, trade secrets; brand, company reputation, culture) and human (skills, know-how, motivation, capacity for communication and collaboration) (Grant, 2016). In contrast, *capability* refers to the firm's ability to implement resources through the organisational process toward the desired purpose (Amit and Schoemaker, 1993).

The Resource-Based View (RBV) suggests that the pathway to profitability and growth depends on exploiting differences, not doing the same things as other firms. A firm routinely generates and modifies its functional routines to improve efficiency and effectiveness through structured and stable sort of actions (Eisenhardt and Martin, 2000; Zollo and Winter, 2002; Tran and Nguyen, 2019). Similarly, according to capabilities literature and the dynamic capability view (DCV), operational capabilities generate profitability, but dynamic capabilities control the rate at which operational capabilities change in response to changes in the firm's environment (Ambrosini and Bowman, 2009). Although in some ways, the definition of dynamic capabilities is similar to the previously defined concept of operational capabilities, some researchers refer to it as the capability of an organization to modify processes and improve its resources effectively and responsively (Helfat *et al.*, 2007). Teece (2009) suggested a comprehensive definition of dynamic capabilities and claimed that organizational and managerial processes are the subset of sensing, seizing, and managing threats/transformation.

Since firms' capabilities are limited and difficult to be built within a short period, academics can exert their unique skills and resources to make up for firms' internal resources through cooperation (Kang, Baek and Lee, 2017) and evolve in tandem with the level of network engagement (McGrath *et al.*, 2018). O'Dwyer and Gilmore (2018) showed that the desire of SMEs to increase their capabilities and capture value to tackle the competitive landscape with a partner would lead them to access the alliance resources that they cannot internally generate.

Among scholars, Penrose (1996) highlighted the importance of differences in their firm-specific experiences as a critical source of innovation, especially in transforming organisational resources into a critical innovation source that fosters organisational growth. The firms' different kinds of innovation capabilities create the potential to generate innovative outputs (Neely *et al.*, 2001; Wallin *et al.*, 2011; Popa, Soto-Acosta and Martinez-Conesa, 2017).

Innovation capability is defined by Romijn and Albaladejao (2002) as the necessary skills and knowledge to absorb, master, and improve existing technologies effectively and create new ones. Therefore, innovation capability is crucial to SMEs aiming to compete with their larger and more resource-possessing competitors (Saunila, 2019). Innovation capability is a multi-faceted concept that includes various qualitative and systemic, internal, and external factors and different innovations require different approaches (Francis and Bessant, 2005; Hauser, Tellis and Griffin, 2006).

Various studies have also pointed out that organizational factors help in creating open innovation culture and increasing the innovation performance of SMEs (Martinez-Conesa, Soto-Acosta and Carayannis, 2017; Pustovrh *et al.*, 2017; Bereczki, 2019; Freitas, 2019; Ojaghi, Mohammadi and Yazdani, 2019; Santoro *et al.*, 2019; Ul Hameed *et al.*, 2019; Enkel, Bogers and Chesbrough, 2020). Thus, innovation is regarded as the capability that firms use to gain more and better competitive advantages (Barney, 1991; Neely *et al.*, 2001; Ticha and Tichá, 2010; Hart, 2012; Maldonado-Guzmán *et al.*, 2019), reach a higher business performance (Neely *et al.*, 2001; Singh, Garg and Deshmukh, 2008; Forstner, Kamprath and Röglinger, 2014; Hilman and Kaliappen, 2015; Sawaean and Ali, 2020), and enhance the productivity of their resources (Helfat and Peteraf, 2003; Nandakumar, Ghobadian and O’Regan, 2011; Lee, Kwon and Pati, 2019; Jones, Gold and Devins, 2020).

For SMEs with a limited resource base, it is costly and time-consuming to develop relationships with many actors, so they should seek open innovation partners (customers) that can take multiple roles and contribute to the whole innovation process (Tobiassen and Pettersen, 2018). In particular, open innovation is capable of reducing a lack of personnel skills and qualifications, limited know-how, restricted R&D capabilities, capital, funding, and growth and scaling challenges (Mitsios and Kechagias, 2017).

The firm’s ability to innovate, grow in size, develop new unique capabilities to develop technology, establish partnerships, and find new growth dimensions and linkages such as, for example, environmental sustainability, level of internationalization, or organizational effectiveness is of great importance. Size growth is measured by increasing the number of employees, year by year, averaged (Cliff, 1998; Audretsch, Santarelli and Vivarelli, 1999; Lotti, Santarelli and Vivarelli, 2001; Capelleras and Hoxha, 2010; Lawless, 2014). King et al. (2003) suggested that firm size is strongly associated with the evolutionary technology development process that a firm chooses to enter. Smaller firms enter the innovation process at earlier stages and require fewer resource requirements. However, larger firms enter the innovation process at later stages of the commercialization process in which the resource demands to support manufacturing and marketing are much higher.

Deriving from definitions, capability growth and size growth are somewhat overlapped dimensions arguing that as a firm increases its size, it automatically augments its endowment of capabilities. Therefore, innovation can be regarded as a significant capability for every firm, especially SMEs and start-ups, which require an efficient application of their existing resources and the abilities of all their staff to add more value to their products (Grant, 1996; Yang, Rui and Wang, 2006; Sáenz, Aramburu and Rivera, 2009; Ramon-Jeronimo, Florez-Lopez and Araujo-Pinzon, 2019). However, the firm does not just grow in size but also in network and capabilities. McKelvie and Wiklund (2010) argued that cooperation between firms in its various forms (Strategic alliances and joint ventures) leads to firm growth. Zahoor and Al-Tabbaa (2020) underscored the importance of networks that can guide resource and knowledge exchange in domestic networks for SMEs.

Consequently, firms can remain small in size but grow by creating a network of business partners. Firms get complimentary resources and assets by forming alliances and partnerships with local businesses, which helps them accelerate their commercialization process. Through partnerships with companies and universities, they can acquire access to funds, market, knowledge, property rights, and opportunities. This connection can also be used to create a reputation, bring a product to market, and boost productivity (Ojaghi, Mohammadi and Yazdani, 2019).

2.3.1 Capability Gaps

Depending on the sector, Technology Transfer starts between TRL3 and 5 (valley of death). The gap between the proof-of-concept and prototype demonstrated in the relevant environment or the gap between academic-based innovations and their commercial application in the marketplace represents a lack of structure, resources, and expertise (Markham, 2002). SMEs face more significant financing obstacles than larger enterprises. Especially newly established and smaller SMEs or those requiring rather a small financing are faced with a structural financing gap due to information asymmetries, lack of credit history and disproportionate transaction costs. SMEs rarely have the internal funds they need and consequently seek external financing. This market environment results in an access to finance gap for SMEs (Fi-compass, 2019). As a result, most successful technology-based firms devote high R&D efforts to support NPI in order to ensure a sustainable competitive advantage (Ardito, Ernst and Messeni Petruzzelli, 2020). However, technology development programs absolutely have restrictions and limitations in resources, management skills, design, and manufacturing capabilities.

So, capabilities other than technological (organizational and managerial capabilities) must be tracked and improved continuously for the sustainable success of the technology development program to accelerate cost reduction and market uptake of key low-carbon technologies. This includes a commitment to the need for de-carbonization of energy systems to meet climate change obligations and maximise the economic benefits.

The key solutions to overcome the development challenges in the technological readiness spectrum from concept to prototype are addressed in the next section under the lens of technological, organizational, and managerial capabilities.

2.3.2 Supporting Capabilities for Technology Development

SMEs possess limited capabilities to access and manage information, inefficiencies in their internal management, disadvantages caused by the small scale of their businesses, and a lack of qualified human resources and access to finance (Ruengsrichaiya, 2012). Firms should focus on acquiring technological capability that offers the required human skills, e.g., entrepreneurial, managerial, and technical, on efficiently setting up and operating industries to develop innovation and achieve competitiveness (Khefacha and Belkacem, 2016).

Companies can reduce the time to market by obtaining some of the required capabilities from the business partners rather than building them in-house to reduce financial asset commitment and enhance their flexibility (Von Hippel and Von Krogh, 2006). Also, collaboration with partners can be an essential source of learning for the firm by transferring and pooling technological know-how and resources to expand their knowledge bases and competencies (Pellikka and Malinen, 2014). Since start-ups generally lack resources, they can only enter markets by forming partnerships with other players by aligning resources to the partnership's capabilities (Ta *et al.*, 2020). Companies that fail to respond strategically to challenges such as a lack of finances and various capabilities for technological commercialization will fail (Barr *et al.*, 2009). The literature on technological, managerial, and organizational capabilities is discussed in more detail below.

2.3.2.1 Technological Capabilities

Technological capacity is linked to exploration and exploitation activities in order to persecute innovative processes and achieve organizational ambidexterity in SMEs (Senaratne and Wang, 2018). Technological capabilities play an essential role in determining the success of new ventures or SMEs because they enable companies to gain market acceptance and achieve long-term competitive advantage through continuous innovation in improving existing products and/or creating new products in the market (Hasan and Uthamaputhran, 2020). Aderemi et al. (2009) discuss that technological capabilities are determined and influenced by either external factors (e., g. competition, technological change, and government policy), or internal factors (e. g., R&D, working experience and on-the-job training).

Some studies discuss the effect of technological capabilities on competitive advantage (Zheng and Liu, 2010; Huang *et al.*, 2012; Al-Mamary, Shamsuddin and Hamid, 2015; Anwar, Khan and Ali Shah, 2018; Al-Mamary *et al.*, 2020; Khan, Rathore and Sial, 2020). For example, Filho and Moori (2018) adopt an interdisciplinary approach by combining the strategic orientation of supply chain management with technological capabilities. Rahim and Zainuddin (2019) used interviews and the survey method to discuss technological innovation capabilities, competitive advantage, and firm performance. Their results show that R&D capability, networking capability, manufacturing capability, and human resource capability influence competitive advantage and firm performance differently.

The positive effect of technology capability on organizational performance and a mediating role of knowledge management have been revealed by examining the mediating role of knowledge management between information technology capability and organizational performance in SMEs (Hamdoun, Chiappetta Jabbour and Ben Othman, 2018; Małecka, 2018; Zahra *et al.*, 2019; Ghezali and Boudi, 2020).

2.3.2.2 Organizational Capabilities

Helfat and Peteraf (2003) argued that the *capability life-cycle* concept is a useful tool to bring the concepts of resources, path dependency, routines, and capabilities together. An organised team with a specific objective for creating a new capability and any other existing resources brings a history and path dependence to the team at its birth. Combining individual resources can develop *organisational capabilities* to deploy resources for the desired result (Grant, 2016). The overall ability of an enterprise to operate more efficiently can vary dramatically within and across different enterprises. To invest in successful organisational development, experts need to promote ownership and responsibility of organisational development strategies (EuropeAid, 2010; Datta, Shaxson and Pellini, 2012; Jessica and Gordon, 2016).

Winter (2003) defined organisational capability as a set of high-tech routines and decision options to achieve a particular output type. This view is in accordance with Teece et al. (1997), who pointed out that organizational capabilities are a firm's capacity to exploit internal and external capabilities to cope with changing environments. Technology innovation activities help new ventures enter markets effectively while allowing established companies to adapt to new technology and improve their organizational capabilities (Cefis and Marsili, 2006).

2.3.2.3 Managerial Capabilities

In general, SMEs fail during their early stages of development due to poor management. Having a proper risk management technique is a challenge within the SME environment due to a lack of risk management knowledge, insufficient resources, poor control environment and risk management skills by management in capitalizing on available funds for the well-being of the business (Jobo and Phyllis, 2020). Among specific internal capabilities that could help the innovation processes of SMEs, team organization, in terms of composition and roles, are vitally important for crossing the valley of death (Otto, 2020). People with experience in entrepreneurship and financial investments are essential for the team to obtain financial resources while the company is in the valley of death (Fisher, Kotha and Lahiri, 2016). Ekwere (2016) revealed that despite government reinforcements such as enabling financial access for SMEs, risk management knowledge and application in SMEs had received minimal attention. Ali et al. (2017) shed light on the conceptualization of managerial capabilities considering four dimensions: decision-making, management style, people development, and succession planning.

TRLs would help firms manage their R&D funding better and attract more funding opportunities, manage, and decrease the risk levels in R&D, allowing decision-makers to act more quickly, making it easier to communicate with different stakeholders and making it easier to assign responsibilities to people. TRLs would also make it easier for managers to align their R&D to the overall strategy by understanding a technology's nature and development path (Lavoie and Daim, 2017).

2.4 Marine Energy Context

Like all high-tech sectors, "Marine" and "Green technologies" are sectors where untapped potential can contribute to job creation and sustainable economic growth targets. The new concepts of "Blue Growth" and "Blue Economy" have propelled the development of new maritime sectors to the frontline of the political agenda (van den Burg *et al.*, 2019). The concept of blue growth can be traced back to the conceptualization of sustainable development (SD) and has been widely used and has become necessary in aquatic development in many nation-states, regionally as well as internationally (Eikeset *et al.*, 2018). Based on EU, the financial sector is a key partner in bringing about the transition to sustainable consumption and production. That is why van den Burg et al. (2017) examined investor behaviour, investors' motives, and conditions and criteria relevant to investing in Blue Growth sectors. Blue Growth Focus Areas (BFA) to deliver both sustainable growth and job creation include blue energy (Stuiver *et al.*, 2016; Zanuttigh *et al.*, 2016; Sangiuliano, 2018), aquaculture (van den Burg *et al.*, 2016; Weiss *et al.*, 2018; Yarkina and Logunova, 2021), maritime (Calado *et al.*, 2019; Kyvelou and Ierapetritis, 2019), coastal and cruise tourism (Dwyer, 2018), marine mineral resources (Johnson, Dalton and Masters, 2018), blue biotechnology (Rotter *et al.*, 2021). These areas are still in development, and various risks reduce the willingness to invest.

The European Union has also identified Ocean Energy as a sector with high potential for sustainable jobs and growth in its Blue Growth strategy. In this regard, testing and modelling across the TRL spectrum include a focus on cost reduction to ensure that marine renewable energy technologies can compete with other low-carbon energy technologies that will constitute the energy system's backbone (Marine Institute, 2017). Soukissian et al. (2019) aim to present and discuss in depth the key issues for Marine Renewable Energy (MRE) cluster development in the Mediterranean and show its necessity for the commercial and sustainable development of Blue Energy in the area, given that Blue Energy development in the Mediterranean is still in its early stages. Pisacane et al. (2018) describe that the marine energy sector adds up to the many different traditional maritime activities and the new ocean-related industries developing, potentially aggravating the competition for the use of marine spaces in the

Mediterranean region and threatening its environmental status. Achievement of effective protection of the marine environment against the negative effects of their installation, operation, and removal is as significant as promoting marine renewable energies (Salvador, Gimeno and Sanz Larruga, 2019). Although the ocean has always been acknowledged as a source of sustainable and renewable energy, the development of a self-sufficient and mature sector has yet to emerge. Economic viability requires minimizing the cost of electricity instead of simply maximizing the converted energy at the early design stages (techno-economic optimization) (Sirigu *et al.*, 2020).

2.4.1 Marine Sector SMEs

Like all SMEs, firms in the maritime sector are trying to drive innovation in the industry to discover a commercial application for the technology and a business model that can be financially viable in the long-term (Chubb and Zangrando, 2019). New Technology Introduction is considered riskier as they are based on exploiting new concepts in the market. However, NTIs are praised for their innovativeness despite their vulnerability (Fudickar and Hottenrott, 2019). Since technology-based firms rely on their staff's technical expertise to create, detect, and exploit commercial opportunities, they tend to have a specialized collection of technical knowledge related to their field of activity, which is expanded and enhanced by employees, specialized in research and development (R&D) (Saemundsson and Candi, 2017). Expanding SMEs can help countries identify the reasons for low productivity growth and widening income gaps, as developing SMEs significantly impact competitiveness, innovation, and employment (OECD, 2018). Although the maritime industry is traditional and reluctant to adopt changes, the major players have realized that innovation is an urgent need.

Similarly, a few studies have explored the role of capabilities in the context of marine start-ups. SMEs, the most active generators of innovation, bridge the gap between public sector R&D and the commercialization of products in the marine sector (Johnson, Dalton and Masters, 2018). The marine energy sector should follow the market and technology trends to develop ideas into new products and services (OECD, 2019). For this purpose, SMEs – which form the maritime industry's backbone – play a pivotal role in performing studies of the state-of-the-art market, increasing understanding of business plans, and identifying potential partners and competitors.

Therefore, SMEs in the marine sector encounter various ways to commercialize their ideas. Thus, SMEs should operate like an entrepreneur or a start-up company, doing things cheaply, being innovative, and searching for innovative approaches to address customer problems; analyse the markets and customers for new opportunities; seek customers' problems and the root causes of the problems; explore the hidden assets (capabilities, knowledge, personnel, etc.) of the enterprise to solve the customer problems; and so on (Ferry, 2009).

2.4.2 Challenges of Marine Sector SMEs

Despite 40 years of development, Wave and Tidal Technologies are still at an early stage TRLs and wave energy has failed so far to achieve a potentially commercial power take off (PTO) technology. Thus, the "valley of death" scenario is increasingly becoming a significant barrier for the sector, where financial investors either will not fund or withdraw funds when ocean technologies reach this stage. In the light of these difficulties for the sector, ocean energy is diversifying and seeking other partners in

Blue Growth to add to its value proposition and help reduce costs and risk (Dalton *et al.*, 2019).

The main challenge for most ocean energy technologies is to reduce costs and increase system reliability and performance in order to demonstrate a long-term economically sustainable performance. The very limited site availability, high capital investment and the potentially significant ecological impacts for large scale utility projects in all but a couple of locations cause challenges (Mofor, Goldsmith and Jones, 2014). The sector needs to overcome challenges and barriers related to the transition from basic research to technology development, funding and market establishment, management and environmental issues and the availability of grid connections, especially in remote areas (Acciaro and Sys, 2020). Developing devices for harnessing these sources is technologically challenging as they must operate in harsh environments with widely varying conditions (Villate *et al.*, 2020). This gives rise to a range of interdisciplinary challenges which must be addressed: the technical challenges to generate optimum energy, at the lowest cost, with the least environmental impact; managerial challenges associated with educating a workforce who have the ability to effectively manage the multiple uses of the marine environment, while enabling a supportive framework for an emerging industry, and commercial challenges where policy uncertainty has hampered development and uptake of both mature and immature renewable energy technologies (Hemer *et al.*, 2018). To enable maturity, the direction of the funding requires funding on a research project of significant scale, providing a stable research leadership, and leveraging the partner's facilities to attract inward investment in the deployment of renewable energy technologies and services in the marine sector.

2.5 Gaps in the theoretical background

High-tech SMEs experience various challenges, including limited financial access, lack of business skills and an unpleasant business environment (Bymolt *et al.*, 2015). Similarly, in the maritime sector, SMEs face barriers to growth and continue to experience a variety of challenges. Nevertheless, SMEs' contribution to the development of marine technologies and services toward the "Blue Growth Strategy" (Sheil, 2013; European Commission, 2017, 2018; Eikeset *et al.*, 2018) needs investments in research and innovation (Andusaitis *et al.*, 2016). Innovation projects by focusing on innovation activities such as demonstration, testing, prototyping, scaling-up, miniaturization, design, and market replication are able to address the specific challenge of Blue Growth and demonstrate their potential in terms of competitiveness and growth underpinned by a strategic business plan (Horizon 2020, 2014). However, marine energy sector SMEs and start-ups would face financial challenges in different life cycle stages (Bass and Ernst-Siebert, 2007; Schultze, 2016), e.g., lack of access to finance to develop their innovative activities (Karadag, 2015; Mallinguh, Wasike and Zoltan, 2020).

Also, there is a perception gap between industry and higher education and education providers as employers of SMEs require industry-ready graduates who can immediately contribute to their business with minimum training. The issue becomes even more crucial when some universities fail to actively engage with the changing needs of the industry, as well as the industry as a whole, demonstrating little interest in working with universities to structure graduate programmes (MatchTech, 2015). Thus, higher education systems and training institutes of the countries as external sources of knowledge play a specific role in stimulating the innovative activities of

SMEs and start-ups to face competitive challenges and maintain their technological capabilities.

Moreover, compared to MNCs, SMEs do not have sufficient resources and knowledge to implement structured risk management. Thus, lack of risk management knowledge, insufficient resources, poor control environment and risk management skills, tedious labour laws, unskilled workers, poor infrastructure as well as environmental and economic changes are serious challenges within SMEs (Jobo and Phyllis, 2020) where the entrepreneurial risk management becomes crucial. Hence, the poor selection and management of technologies can lead to serious financial losses and, in the long-term, weak competitiveness in markets.

Successful transition of research from an idea to a laboratory experiment and finally to a real operational application need a sufficient level of technology readiness due to the challenges associated with technology transition and adoption (Engel *et al.*, 2012). Technology gaps are usually considered in technology readiness assessment frameworks like TRL. So, we accept that technological challenges are evident through the technology development process, and other challenges need further investigation. Therefore, this study has proposed the following hypothesis:

Hypothesis (1): Marine-based SMEs encounter challenges other than technological in developing market-ready offerings.

A practical and informative technological readiness assessment requires a clear understanding of the performance objectives for the new technology and/or system capability and an understanding of the current, well-established readiness level for the technology and/or system capability in question, as well as for any key supporting technologies (TEC-SHS, 2008). Universities, publicly financed organizations, and research institutes are mainly responsible for TRL1-4. However, R&D attempts will be considered a failure if they do not result in outputs such as patents or proof-of-concept prototypes. Firms' research and development (R&D) and technological capabilities are critical. However, capabilities need to be turned into actual market opportunities to achieve the desired economic outcomes.

Hypothesis (2): Technological capabilities at the organizational level enable a transition from TRL concept to scaled prototype

Entrepreneurial leaders are able to develop new organizational capabilities that foster innovative solutions and new business models directed at the next challenge (Schoemaker, Heaton and Teece, 2018). The ability to design and develop new technologies and processes based on both R&D and continuous innovation efforts becomes vital (UNCTAD, 2005). SMEs need to focus on R&D capabilities to help secure their own growth and drive the industry forward. Without funding, SMEs will not be able to invest in technology to innovate or even update their manufacturing processes or products. So, constant investment in technology is often necessary to acquire future market opportunities to compete in global markets and meet international (UNCTAD, 2005). Hence, due to SMEs' significant role in emerging and mature economies (Mallinguh, Wasike and Zoltan, 2020), we examine the role of organisational capabilities in acquiring new technologies. Having different capabilities is a crucial asset for developing breakthrough innovations for many ventures. Besides, firms might not have been able to develop their first prototype without investment in technological capabilities (Farhana and Swietlicki, 2020). Therefore, this study has proposed the following hypothesis:

Hypothesis (3): Organizational capabilities enable a transition from TRL concept to scaled prototype

A good management plan accelerates the transition of new technologies into acquisition to become an operational capability. For this purpose, data and/or knowledge management systems in a laboratory environment assure the system's fidelity and environment (Mankins, 2004). Also, implementing innovation and new business practices leads the firms toward lean operations and projects. Accordingly, innovative management skills make firms resourceful and responsive to multiple and sudden changes (UNCTAD, 2005). Identifying, analysing, and understanding factors that influence the firm from the internal and external environments are essential for the strategic management of a firm to know its capabilities in product/service development, plan on how to attack markets and manage its technology and product (Lavoie and Daim, 2017). Later, Lavoie and Daim (2018) investigated the implementation of TRLs and R&D management in achieving a competitive advantage for organisations. Gryger et al. (2010) considered leadership development or lean operations and projects and talent management a top priority for most companies in building capabilities through the Mckinsey survey.

On the other hand, emerging technologies such as artificial intelligence, digitalization, automation, cybersecurity, etc., creates skill gaps. Hence, identifying skills gaps and understanding the maritime sector's future skill requirements and technological development needs further analysis. Considering the challenges of finding and retaining talented employees, talent management has become a strategic priority since employees play a crucial role in creating competitive advantage (Guthridge, Komm and Lawson, 2008). Therefore,

Hypothesis (4): Managerial capabilities enable a transition from TRL concept to scaled prototype

Entrepreneurs should focus on analysing the external macro-environment to identify gaps and deficiencies where there might be exploitable needs/problems in a new venture. Such analysis helps the entrepreneur learn and discover further information and develop innovative approaches to identify problems or requirements in the marketplace (McKelvie, Wiklund and Short, 2015). Innovative firms tend to be more open to external knowledge sources and more able to absorb the knowledge from external sources (Love, Roper and Zhou, 2016) because a lack of external cooperation and exchange of ideas leads entrepreneurs to move forward without necessary inputs (Farhana and Swietlicki, 2020). Bass and Ernst-Siebert (Bass and Ernst-Siebert, 2007) argued that barriers exist for maritime SMEs to obtain access to the subsidies for innovation in the funding terms and access to external finance as a constraint on their R&D activity.

As a result, technology-based start-ups must be able to leverage external resources to overcome the challenges created by a serious lack of management resources, allowing them to enhance their performance by employing other resources (Slotte-Kock and Coviello, 2010; Newbert and Tornikoski, 2012). Therefore,

Hypothesis (5): Capability gaps within the venture (internals) are addressed by seeking externally controlled resources.

2.6 Summary

This chapter has presented a critical literature review, including the theories that underpin this research and the practical context. To conclude, while marine energy sector SMEs play a significant role in the coherent growth of the marine energy industry (Marine Energy, 2019), more research is needed on such emerging industries (Roche *et al.*, 2016; Hussain, Arif and Aslam, 2017).

There are gaps and barriers within current technology development and planned project deployment in the emerging ocean energy sector (MacGillivray *et al.*, 2013). Hence, studies that analyse challenges through SMEs' technology development trajectories in this sector are required. For many firms, translating their scientific research into marketable products and the road to TRL 9 is technologically challenging and capital intensive, putting pressure on the technology developers (Pisacane *et al.*, 2018). Hence, there is a leading question to explore:

"What capabilities enable technology-based SMEs in the marine sector to support the advancement of their technology from proof of concept to scalable prototype for market adoption?"

Companies might successfully cross the valley of death by their internal capabilities (Markham *et al.*, 2010; Pollok, Lüttgens and Piller, 2019). However, new firms with limited internal resources require input, such as funding, industry-specific expertise, access to potential customers, technology competence, etc., to bring their technology towards commercialization. In this regard, firms are also compelled to combine their resources and capacities with their collaborators' specific competencies, such as through outsourcing and consulting to enhance firm competence (Brandl, Jensen and Lind, 2018).

Chapter 2 contained the conceptual framework that served as a lens in the study. The gaps in the body of knowledge provided justification for this study. Marine technology developers might be able to use the findings to provide an understanding of challenges between proof of concept and full-scale development and an understanding of internal and external capabilities to cross these barriers. One way of looking at this issue is by considering technological, organizational, and managerial challenges.

Nevertheless, as discussed in this chapter, existing literature provided context and background for the study. The synthesis of the literature discussed in this section was also used to identify categories and themes, as well as to establish a preliminary coding framework for use in the study's inquiry. The next chapter will present the methodology in which the research has been conducted.

3 Research Methodology

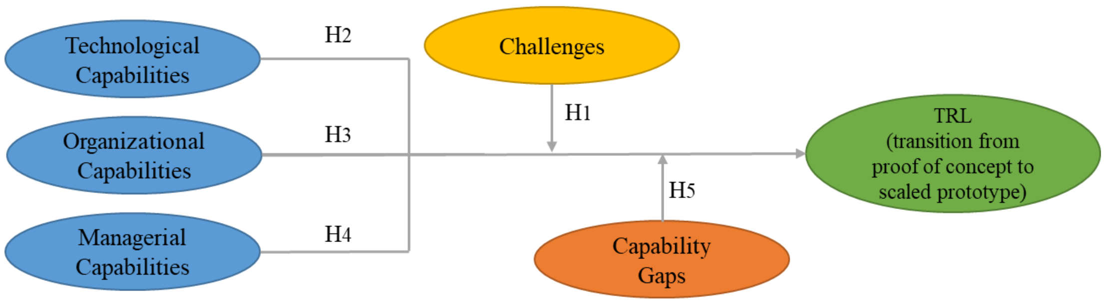
This chapter includes information on the research methodology and design of the study, which are aligned with the problem statement, purpose statement, and research question. Additionally, the logic behind the selection process for the research participants, instrumentation, procedures for recruitment of participants, data collection, and data analysis are discussed.

3.1 Introduction

In this study, the specific problem was that most SMEs in the marine sector are not adequately prepared to advance their technologies from proof of concept to scalable prototyping. The purpose of this exploratory multiple case study was to gain an in-depth understanding of how SMEs' owners can develop capabilities to cross the valley of death for market adoption.

Based on the theoretical discussion in chapter two, Figure (3-1) reflects the relationships between different concepts and theories. The theoretical framework will function as a guide for utilizing the selected theories in our research to test the hypotheses and answer the research questions.

Figure (3-1) Theoretical framework of the study



In this study, a mixed-method was used to describe relationships between theory and research, help understand the social world by examining the interpretation of that world by its participants or analyse social properties that are the outcomes of interactions between individuals (Bryman and Bell, 2019). The mixed research method meets the need of this study as it ensures that study findings are based on respondents' experiences.

Research methodology is used to determine the degree of authenticity of a piece of research as well as establish data collection, data processing, and analysis techniques (Balnaves and Caputi, 2001) and contains information about alternative approaches to a topic and determines which approach is most appropriate to answer a research question (Maylor and Blackmon, 2005). This research seeks to explore three related questions, and each research question is asked in the context of technology-based SMEs within the marine energy sector. The research questions signify the aspects of inquiry that we want to study in identifying and guiding the data collection process (Lewis, 2015).

3.2 Research Map

Several sequential tasks were followed and completed to conduct this study. These steps are defined in the following order:

- Literature review of SMEs' challenges and required capabilities to transverse in the technology readiness spectrum
- Review and synthesize existing knowledge
- Finding the right positioning within the literature and recognizing the research gap
- Developing the research purpose and designing relevant research questions (RQs)

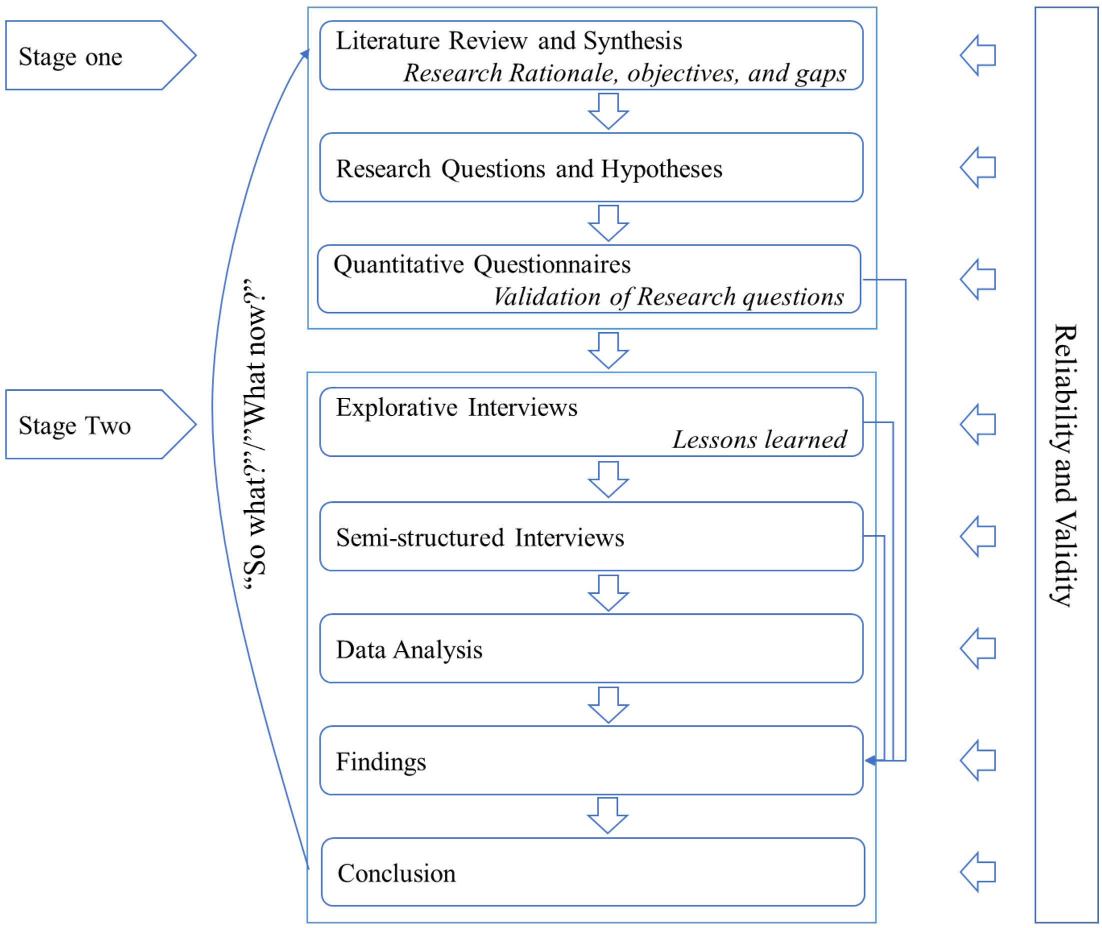
- Developing a theoretical framework for understanding SMEs' challenges and the required capabilities to transverse in the technology readiness spectrum
- Developing a methodology appropriate to the research questions
- Research design (type of research, research strategy, data collection and data analysis methods, reasoning style)
    - Survey of the existing population for a broad understanding of the subject by quantitative questionnaires
    - Explorative interviews to delve into issues raised in questionnaire results
    - In-depth analysis of issues raised in questionnaires by qualitative multiple case studies (case selection, finding respondents, data collection, and data analysis)
- Research discussion and conclusion

Obviously, all these tasks are inextricably linked, and they were assessed at each level of their execution during the research. Initially, identifying context, key questions, and themes leads to identifying associated research gaps and developing the research purpose and research questions. Hence, specific questions to investigate can be determined based on the literature, quantitative questionnaires, and the context. Then, explorative interviews with experts can validate the taken steps and shed light on the next steps.

One of the noteworthy points is finding an answer to "so what?" through research to connect back to reality and make something useful from research (Maylor and Blackmon, 2005). In this study, this point is considered by targeting the main question of how we can better nurture marine-based SMEs in traversing across the valley of death (TRL3-TRL7) and how this research will be useful for all stakeholders, policy makers and researchers in the maritime energy sector.

The research quality has been assured by controlling the research process's reliability, validity, and related data at each stage. All explanations above are shown as follows (see Figure (3-2)).

Figure (3-2) The process of the research



3.3 Research Design

The research design is the general approach of how we went about answering the research question and guarantees that the evidence gained through the research process appropriately addresses the research problem because inappropriate use of methods cannot address the research question posed by the study (Bryman and Bell, 2019). The research designs considered for this study on capabilities of marine sector SMEs for technology development included case study, ethnography, phenomenology, narrative, grounded theory, and mixed-method. An ethnographic design is appropriate for understanding a phenomenon through a group's shared beliefs, behaviours, and experiences in its environment over a prolonged period (Willgens *et al.*, 2016). This research approach was considered inappropriate because ethnographic strategies entail the researcher immersing themselves in the participant's paradigm for an extended period of time to thoroughly investigate, observe, and document the participant's paradigm. Getting extended access to the individuals and businesses chosen for the research study would be difficult and unlikely to be granted (Saunders and Lewis, 2018). The phenomenological design was not selected because it involves exploring a phenomenon based on participants' lived experiences and the meaning they ascribe to the phenomenon (Saunders and Lewis, 2018). However, the goal of this research was to explore the owners-managers' experiences and not the meanings they assigned to the phenomenon of this study. The narrative design was unsuitable too, since narrative research design involves exploration through the chronological narration of individuals' life stories and experiences (Willgens *et al.*, 2016). The aim of this study was not to report the personal stories of owners-managers. The grounded theory approach was rejected because there was no need to attempt to establish a new theory to address the study problem (Saunders and Lewis, 2018). Capability theories exist which describe capabilities in general; however, there was not enough information to determine if new theories are needed for technology-based SMEs in the marine sector or not.

Therefore, we applied a two-phase, sequential, mixed-methods approach to this research. This mixed-methods approach permits triangulation of data and findings, confirming and interpreting themes disclosed by prior investigation (Guion, Diehl and McDonald, 2011). These methods are further described below.

3.3.1 Questionnaires

The questionnaire method intends to collect data from a large set of subjects with carefully structured questions derived through testing and iteration to elicit reliable responses from the sample. The questionnaire aimed to collect structured data to verify the significant impacts of the factors derived from the secondary data and literature study and add new information to the research projects in terms of perception of different factors. Because of practical constraints such as cost and time, a non-probability sampling approach, purposive judgment sampling (Saunders and Lewis, 2018), was regarded as the only viable choice because the population is unknown or requires extensive resources to establish. The chosen method determines the sample according to fixed criteria and accurately represents the population.

3.3.2 Exploratory Multiple Case Study Research

Based on the selection of qualitative methodology, an exploratory design approach was selected to determine the capabilities of SMEs for technology development (Saunders and Lewis, 2018). There is a need for more academic articles to concentrate on building a deeper understanding of the specific challenges of the marine environment and the required capabilities to support the advancement of technology. Many studies do not discuss the skills and knowledge needed to minimize the risks and ensure effective movement across the TRL spectrum, especially for the SMEs in the marine sector which perform in hostile environments. This is because many explorations mainly adopt a quantitative approach to examine large-scale data with very generic and pre-determined criteria.

3.3.3 In-Depth Analysis of Particular Cases

An interview-based case study design is selected to obtain comprehensive details about the phenomenon through interviews and observations with owners-managers of SMEs. Choosing the multiple case study design facilitated the acquisition of detailed information from research participants and provided insight for obtaining answers to the research question. The multiple case study design provided an extensive understanding of the issues from a broader perspective with data from various sources, and it was based on the premise associated with the purpose of the study and the data collection method.

3.4 Research Approach

Due to a lack of prior research related to the capabilities and challenges of technology-based SMEs in the marine sector, this research employs a mixed method of quantitative and qualitative case-based approach (Hinkin, Tracey and Enz, 1997). This approach facilitates a comprehension of the key informant’s perceptions to gain insights into something not yet entirely understood (Belli and Waters, 2014), namely what capabilities empower technology-based SMEs of the marine sector to pass the valley of death between TRL3-7.

The research approach provides various means of answering research questions by outlining different starting and conclusion points; various steps between these points; the use of concepts, theories, and styles of explanation or comprehension (Blaikie, 2019). Deduction, induction, and abduction are the three main approaches applied by researchers in business and management studies (Saunders and Lewis, 2018). Each of these approaches has its own research process that differs in starting point, aim, and the point that the conclusion is drawn (Kovács and Spens, 2005).

In deductive reasoning, the conclusion is deduced from the operationalization of the developed hypothesis or propositions (derived from existing theories). In other words, it starts from a general truth to infer a particular fact. In contrast, the inductive reasoning style starts from the empirical level (real-life observation) and leads to a theoretical conclusion. On this basis, a general proposition is inferred from a particular fact (Dubois and Gadde, 2002). In abductive reasoning, the researcher is simultaneously involved in the theoretical and empirical levels. In this regard, the theory matching operation is done in a back-and-forth direction between the observed data and theories to achieve new insights and conclusions. A real-life observation is the starting point for much abductive research. However, in some cases, the theoretical level is the starting point for other researchers. The main outcome of this analytical approach is theory development rather than theory generating (Dubois and Gadde, 2002). Abduction as the systematized creativity or intuition in research to develop "new knowledge" (Kovács and Spens, 2005) addresses the weaknesses of the deductive and inductive approaches adopting a pragmatism perspective.

This research first follows a deductive approach in six consecutive steps below (Blaikie, 2019):

1. A hypothesis, idea, or premise is presented to develop a theory.

2. Using current literature, a verifiable proposition or number of propositions is concluded by reasoning.
3. Examine the hypothesis and the rationale of the argument, compare, and critique this hypothesis with current theories to analyse if it provides a deeper level of comprehension.
4. Assess the hypothesis by gathering the relevant data to measure the concepts and examine them.
5. If the findings are not similar to the hypothesis, the theory is not supported and is considered false and must be rejected, altered, and the procedure must be re-established.
6. If the findings are consistent with the hypothesis, the theory is supported.

Then, inductive strategies were implemented to answer 'what' questions yet are constrained to dealing with 'why' questions[1].

3.5 Sample Selection

As this research is part of the marine energy alliance project, the sample includes 45 high-tech SMEs in the marine sector with characteristics pre-defined for SMEs. The non-probability, purposive sampling approach is best suited for this study since all samples are chosen for a specific reason and are considered to reflect the population based on the researcher's judgment. Purposeful sampling also entails selecting participants who can provide detailed descriptions of their perspectives, experiences, and behaviours in relation to the research problem (Koch, Niesz and McCarthy, 2014).

[1] Abduction is a research approach that alternates between deduction (theory to data) to induction (data to theory) and vice versa

In purposive sampling, it is essential to be clear on the informants' experience and qualifications (Patton, 2014). In this regard, the interview informant must be a management team member like the founder or co-founder, CEO, project manager, or director of SMEs. The capabilities and challenges of SMEs can be clearly documented by interviewing the members of the board, who are expected to have in-depth knowledge of the firm's operational process and general strategies (Teece, 2019).

Also, there are no rules for sample size in qualitative research. However, sample size depends upon what you want to know, perspectives, considerations of representativeness, generalizability (Creswell, 2013), and what can be achieved with available time and resources. Yin (2017) suggests that sample logic and the typical criteria to determine sample size should not be utilized due to the complexity of defining the sample size in qualitative research. Instead, one should think about this decision as a reflection of the number of case replications. Nevertheless, on the basis of ontology, Yin (2017) suggests a small-N number, no more than 30), Creswell (2013) proposes four to five participants, and Bryman and Bell (2019) loosely between 20 and 30. The sample for this study was chosen based on their availability and the required information.

3.6 Data Collection

Data collection in qualitative research includes a variety of methods: observations, textual or visual analysis (books, photos, or videos) and interviews (semi-structured or open interviews (individual or group)), group discussions (focus groups, group discussions, joint narratives, or group interviews) (Iphofen and Tolich, 2019). So, there are many available choices in business research when choosing an appropriate method. The methods used in this research study include both primary (semi-structured interviews) and secondary research methods.

3.6.1 Secondary Data

Before questionnaires and semi-structured interviews, secondary data were collected on 42 case companies by MaREI Centre for the MEA project. This data was to inform the researcher of the intricate details of the company and the interview participants and give the researcher a more comprehensive understanding of the organization's position. These documents were crucial in the thesis writing process because they allowed for a more thorough triangulation process to verify the data collected during the company interviews, thereby increasing data credibility, as well as allowing for the identification of similarities and differences between cases (Yin, 2017). MEA's purpose was to advance the technical and commercial maturity of early-stage (TRL 3–4) marine energy technology firms, with the ultimate goal of lowering the chance of device failure during future demonstration phases.

3.6.1.1 Target Population

The target population[1] of SMEs are located in the European Union, including Ireland, United Kingdom, Netherlands, France, Norway, Sweden, and Denmark and have been chosen from marine energy technology SMEs engaged in fields of wave, tidal, floating offshore solar, and floating offshore wind are at TRL3 or 4. Selected technologies are considered technically and commercially promising and realistic in the long term.

[1] Further description of the target population is brought in Appendix 2.

3.6.1.2 Selection Criteria

The selection criteria for marine energy technology firms consisted of firms that satisfy the following criteria: firms that employ less than 250 employees have a maximum annual turnover of €50 million and a maximum annual balance sheet total of €43 million. All firms develop marine renewable energy device/technology concepts in tidal, wave, offshore floating wind, offshore floating solar and other maritime energy sectors.

The sample SMEs were brought onto the project via two open calls, one in 2019 and the other in 2020. The launch date of call one was December 18, 2018, and the close date was February 15, 2019; the second call started on January 1, 2020, and closed on February 14, 2020. In Call 1, 49 SMEs applied, and 22 were selected, and in Call 2, 43 SMEs applied, and 20 were selected. Based on micro, small and medium-sized enterprises (SMEs) categorization, all awarded companies were SMEs. Company profiles have been drawn up in Table (3-1), providing an overview of the 42 case studies of MEA.

Table (3-1) SME profiles

	SME	**Location**	**Field**	**Position in the company**	**N of employees**
Call 1	1	Ireland	Wave	Chairman	6-10
	2	Ireland	Wave	Program Director	1-2
	3	Netherlands	Wave	Owner	1-2
	4	Australia/UK	Tidal	Director	1-2
	5	France	Tidal	CEO	6-10
	6	France	Offshore floating wind	CEO	3-5
	7	France	Wave	CEO	1-2
	8	Netherlands	Tidal	Representative	3-5
	9	Ireland	Tidal	CEO	1-2
	10	France	Offshore Floating Solar	Founder and CEO	1-2

	11	Ireland	Wave	Technical Lead	1-2
	12	UK	Wave	Managing Director	3-5
	13	Netherlands	Wave	CTO	3-5
	14	Ireland	Tidal	Mechanical Engineer	3-5
	15	Ireland	Wave	Technical Director	1-2
	16	Ireland	Wave	CEO	1-2
	17	UK	Wave	CEO / CTO / Inventor	1-2
	18	Ireland	Wave	M-D	3-5
	19	Netherlands	Wave	COO	6-10
	20	Ireland	Wave	CTO	11-20
	21	Netherlands	Tidal	Manager R&D	1-2
	22	Ireland	Wave	CEO	3-5
Call 2	1	France	Offshore Floating Wind (platforms)	Senior Commercial Manager	11-20
	2	Ireland	Offshore Floating Wind (mooring component)	Technical Director	3-5
	3	France	Offshore Floating Wind	Head of Operations	11-20
	4	France	Tidal (Hydrokinetic turbine vessel)	CEO	3-5
	5	UK	Offshore Floating Wind	Director / Lead Project Engineer	1-2
	6	UK	Tidal	Project Engineer	6-10
	7	UK	Tidal	CEO	3-5
	8	UK	Wave	Managing Director	3-5
	9	France	Power-To-Gas conversion of offshore wind energy	Project Manager	11-20
	10	Sweden	Wave	Founder & CEO	3-5
	11	Netherlands	Offshore Floating Solar	Financial Controller	6-10

	12	Ireland	Wave	Vice President Of Product Development	3-5
	13	France	Wave	CEO	3-5
	14	Netherlands	Offshore Floating Solar	Co-Founder and Board Member	3-5
	15	Netherlands	Offshore Floating Solar	Chief Strategy Officer	11-20
	16	France	Offshore Floating Solar	R&D Engineer	3-5
	17	Denmark	Offshore Floating Wind (foundation)	CEO	6-10
	18	Norway	Wave	CEO	1-2
	19	UK	Wave	CEO	1-2
	20	UK	Power harvester (water, sea, river, tidal & subsea)	Co-Founder & Director	6-10

The target companies were invited to participate in the research study. Within these companies, the target interviewees were at least one member of the upper-level management team. This group of individuals were selected because they have a holistic view of how organizational-level capabilities enable companies to achieve higher TRL. The collected data by MEA included information about:

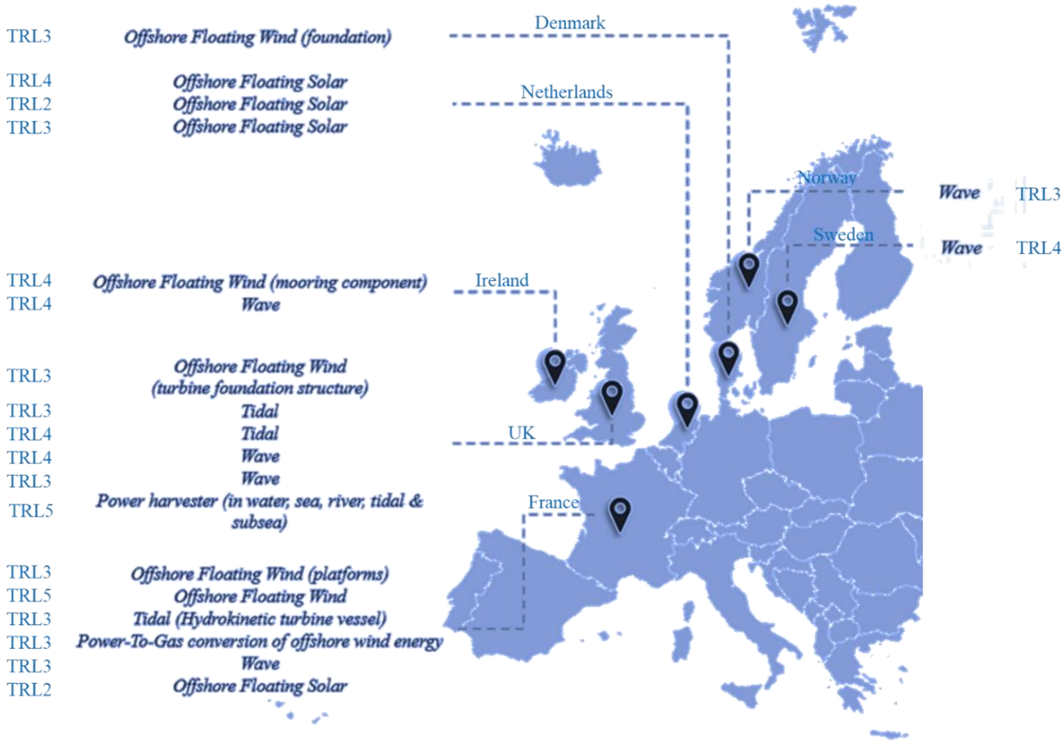
- Details of the companies' marine renewable energy device/technology concept,
- Achieved technical/commercial milestones in terms of Principle of Operation, Analytical Modelling, Experimental Modelling/Validation, System Integration & Design, Manufacturing, Installation & Operation, Commercial Value, and Risk Management,
- Technology Readiness Level of the marine energy concept
- Technical and commercial maturity level of the marine energy concept

- Innovative element(s) of your marine energy concept are and provide a clear technical rationale for the concept having techno-economic advantages over existing marine energy concepts at a higher TRL.
- The key milestones in marine energy concept development
- The technical and commercial challenges
- The technical and commercial support categories demanded from MEA partners

Figure (3-3) and Figure (3-4) show the marine energy concepts and their TRL of case studies based on their location.

Figure (3-3) Marine energy concept of call 1 based on their location

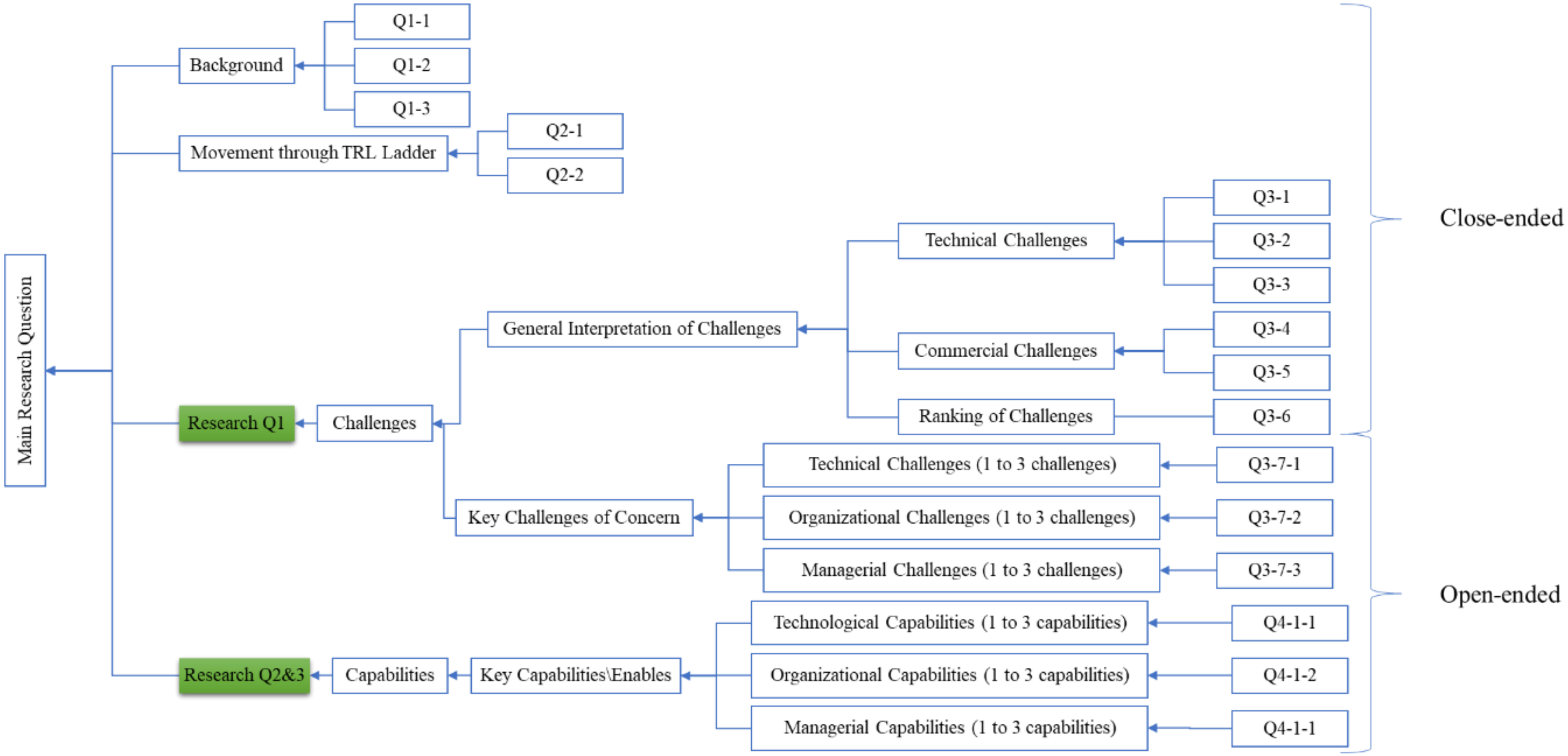
Figure (3-4) Marine energy concept of call 2 based on their location



3.6.2 Questionnaire

For this purpose, structured questions were derived through testing and iteration to elicit reliable responses from the sample. A questionnaire with both closed-end and open-end questions (Figure (3-5)) was designed based on the study of data from the literature. The questionnaire contained questions about the respondents, technology development stage (TRL), challenges experienced at different stages of development of your marine technology, the key challenges of concern, and key capabilities\enablers that have facilitated marine technology development. In this regard, questionnaires utilized text responses and five-level Likert scale questions techniques to gather information about companies' technology development experience in terms of technological, organizational, and managerial challenges. The full questionnaire can be found in Appendix 3. This survey led to an in-depth analysis of particular cases for further analysis.

Figure (3-5) Quantitative questionnaire structure



3.6.2.1 Questionnaire Distribution

The questionnaires were distributed online by the preferred method of an email with a link to the survey on Google Forms[1]. Google Forms is a survey administration software included as part of the free, web-based Google Docs Editors suite offered by Google. Surveys as an attachment as a word document include a more cumbersome process for the respondent to download the attachment, complete and save it and then re-attach it to the email to send it back to the researcher. Hence, the method of embedding the survey was preferable, given the volume of information within the survey and the convenience of the approach.

3.6.2.2 Email System[2]

The advantages of using email systems include accessing large sample sizes, quick turnaround, and quicker results. However, there is a risk of the email being termed junk due to the increased volume of email traffic and information overload. Emailing was used to enhance a more significant response rate from SMEs across the vast geographical area of the European Union. An emailing strategy was developed to maximize the response rate, with careful thought given to the content, delivery, and follow-up stages of the process. The email subject line included the name of the project and our expectation: **[MEA] Marine Energy Insight**. It is essential to increase credibility by choosing an appropriate subject as it influences the first impression of communication, gains the respondents' attention, and is not deleted. Information was clear and precise to prevent communication barriers. Contact details of the researcher were clearly visible, and respondents were encouraged to contact in the case of uncertainty or confusion about completing the survey.

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[1] https://www.google.com/forms/about/

[2] See Appendix 4, 5, and 6.

3.6.2.3 Online Surveys[1]

An online survey was considered an appropriate and convenient tool to gather data to reach a large number of respondents across a large geographic area with the researcher's minimum involvement in data collection and analysis. The survey results can be collected automatically in a database and exported as tabular data, which can subsequently be imported into Microsoft Excel and SPSS software. When respondents provide an invalid response, such as selecting multiple tick boxes when only one should be marked, they can be automatically prompted. The online survey instrument was chosen over alternative techniques such as postal or telephone distribution due to time and financial restrictions, the benefits of convenience for both the researcher and the respondent, sampling control, and ease of data entry and analysis.

3.6.2.4 Lessons Learned

In order to double-check the results obtained from questionnaires and in-depth analysis issues raised in questionnaires, we designed explorative interviews.

3.6.3 Explorative Interviews

Exploratory research is used to explore an issue that was not clearly defined, is conducted to better understand the existing problem and test assumptions raised from the literature review and questionnaire but will not provide conclusive results. Hence, it has started with a general idea and used the research as a medium to identify issues that can be the focus of future research. In terms of collecting detailed and accurate

[1] See Appendix 3.

data, the interview technique is the most efficient. The researcher can also record interviews in case he or she has to go back and double-check specific information.

So, this phase has been particularly valuable at the early stages of a project to become familiar with the field terminology and practices on technology-based SMEs in the marine energy sector. In particular, the aim was to discuss the trajectory of the sector, the challenges and how SMEs (existing and start-ups) can develop technologies within the area.

The explorative interviews were divided into the following main parts: general challenges of technology development in the marine energy sector, specific challenges of technology development in the marine energy sector, the most challenging phase of TRL, and capabilities and resources to cross the valley of death.

3.6.4 In-Depth Analysis with semi-structured interviews

In order to probe the issues raised by questionnaires and explorative interviews, a qualitative approach was required to gather rich data about the challenges and capabilities of marine energy SMEs and start-ups. We would provide a qualitative understanding of the issue because there is a lack of study on qualitative and contextual variables in this field. Therefore, semi-structured interviews were used as a method of data collection.

This type of interviewing requires curiosity about what the interviewees tell to collect a rich set of data. It also requires the interviewer to listen, understand, and be reflective, to be able to follow up statements with more detailed questions. Such interviews also need to be well planned (Qu and Dumay, 2011). Since our research involved direct interaction with human participants for the purpose of data collection with interviews, we had sought ethical approval from University College Cork before commencing the survey. Then, an approved interview protocol was used as support so that the same questions were asked at each interview with an opportunity to ask follow-up questions to confirm, reflect on, and get a deeper understanding of the participants' stories.

3.6.4.1 Ethical Approval process[1]

The ethical orientation of this research is directed by guidelines set out by the University College Cork and Social Research Ethics Committee[2] (SREC). Ethical approval was sought and gained from the SREC due to involving human participants.

A research consent form (Appendix 10) was collected from all participants as part of the ethical procedure. A copy of the information sheet, to which all participants had to agree, is presented in Appendix 9. The information sheet was provided in written format to allow participants to consider the various elements of the research and to sign if they consented to the information being collected. Full anonymity was offered to all participants involved in the study, and, consequently, no firm names or individual participants were referred to.

3.6.4.2 The Interview Protocol

After a broad study and general analysis of technology-based firms in the marine sector, we narrowed our focus and conducted an interview protocol to answer the research questions.

[1] Research Ethics | University College Cork (ucc.ie)
[2] Social Research | University College Cork (ucc.ie)

The interview protocol (see Appendix 11) outlines the format that the semi-structured interview will take. Questions in the interviews are divided into six topics: Introductions of participants, Company Background, Challenges, Capabilities, Movement Across TRL3, and Future TRL stages. Informant respondents were members of the board, CEOs and managers of R&D, marketing, and production, as well as other key people who had rich experience and knowledge of technology development in each SME.

The interview protocol for each interview is adjusted to fit the company's context, but inquiries about the research concept using main questions and probes that open up informative conversations rather than direct conversations to predictable ends. The questions are open to change which means that the researcher may reword, drop, or add questions. Changing the sequences or diverging from questions to pursue details is also possible. According to Francis (2010), studies with a small number of interviews can lead to incomplete results. As a result, the goal of this study is to conduct a minimum of 7 interviews for thematic analysis. The interview guidelines ensure data collection for the research question of this study and verify the same information collected for all cases.

How to retrieve, record, and rely on interview data is a matter of personal preference. Based on Patton (2014), a tape recorder is indispensable since recordings have the advantage of capturing information more faithfully than hurriedly written notes might, and they can help the researcher focus on the interview. In this research, all transcribed interviews were reviewed by this researcher. Additionally, notes were taken during the interview and were added to the interview material, and the company's secondary data in the form of brochures, PowerPoint presentations, photos, and artefacts were collected and complemented with the company's web information.

3.6.4.3 Participants

Since the target population is vital for enhancing credibility and coherence, it comprises owners-managers from nine marine sector SMEs located in Ireland/UK. The selection criterion for participants in this study was owners-managers, 18 years of age or older, who have more than 5-year experience leading a SME. As the potential participants, the owners-managers received a letter of invitation to participate in the study after granting permission to conduct the study in their organizations. The letter of participation included a request for the participants' consent to participate in a face-to-face or interview or using MS Teams using institutional ID and a brief statement about the process.

During the initial telephone conversation, potential participants were also given an overview of the process, their voluntary participation, and their ability to withdraw from the research at any moment. Before starting the interview, the participants were informed again about the purpose of the study and the interview process and were allowed sufficient time to ask questions and peruse and sign the consent form. A mutual understanding of the purpose of the research between researcher and participants is essential to encourage trust and full participation in the interview. Allowing the participant to become familiar with the interview process was another strategy for establishing a relationship and building trust (Castillo-Montoya, 2016).

This can also facilitate the provision of accurate data that are useful in answering the research question and ensuring the validity of the research findings.

3.6.4.4 Our Focus: Irish/UK Companies

For in-depth analysis, we chose SMEs and start-ups in Ireland (one country) due to easy access, shared language (English), and consistent economy to secure comparability in the sample cases; thus, legitimate claims to external validity with respect to the core findings (Miles and Huberman, 1994). The nine companies were selected considering three characteristics:

1) they were a small or medium-sized enterprise

2) they developed marine energy concepts locally in Ireland,

3) they were at TRL 3 or 4 at the initial step of the research

3.6.5 Limitations

Data collection of this study has limitations associated with semi-structured interviews since they are constructed to facilitate the capture of an individual's perceptions and ideas. However, the answers provided in these interviews are not always reflective of their actions in reality. Also, because of lack of structure, in open-ended questions, the interviewee might provide a comprehensive answer to the question or provide information that initially came to mind, thus potentially failing to collect valuable data. To avoid this problem, triangulation is used to reduce the limitations of any particular data collection technique. Although even secondary data may not be impartial and cast doubt on the validity of research outputs, scholars accept these limitations on the basis that implicated data is more valuable than no data. In each case, conducting several interviews facilitated the triangulation (Guion, Diehl and McDonald, 2011) of the information collected, ensuring the research's credibility and validity and preventing individual bias.

3.7 Data Validity and Reliability

In case study research, there are three major concerns to consider when it comes to research quality assurance: reliability, validity, and generalizability (Vinet and Zhedanov, 2011). The degree to which a set of findings may be considered dependable is referred to as reliability, and how effectively the results can be justified and regarded as a true and accurate depiction of reality is referred to as validity. It is essential to ensure both construct and internal validity. The generalizability of a study's findings measures how effectively the research can be applied to the whole population. In case studies, generalization is based on analytical generalization, in which the researcher attempts to generalize a set of results into a border theory. Generalizability is sometimes referred to as external validity, too. Several tactics should be taken to address each measure to ensure the quality of the research (Uwe Flick, 2009; Vinet and Zhedanov, 2011; Creswell, 2013). Applied tactics for each component of research quality are separately presented in Table (3-2).

Table (3-2) Measures taken to ensure the quality of this research in different stages of the research process

Construct validity	- **Based on a clear research map (process), a chain of evidence was established (e.g., the theoretical framework of challenges of technology development and required capabilities to transverse the valley of death, data collection and research findings)**

	- **Multiple sources of evidence were used (Survey, in-depth interview, etc.)** - **Different respondents from various functions were interviewed for the cases using a similar semi-structured interview, which led to data triangulation** - **To minimize the risk of errors and misunderstandings, key informant respondents were asked to review the case study reports**
Internal validity	- To minimize interpretation bias, the collected data is presented, when possible, based on exactly what the respondents said. Furthermore, direct quotations of interviewees are used. - To avoid conclusion bias, the interviews' results were checked by supervisors.
Generalizability or External validity	- The research context and associated characteristics for the studied marine sector SMEs are described. - To perform analytical generalization, several propositions for future studies were generated based on an explored research area for future research (to be generalized). - Multiple-case units were used to address replication logic - Empirical data were compared with theoretical findings.
Reliability	- Research procedures were documented. - An interview guide was prepared. - All interviews were recorded, transcribed, and documented.

	- Collected data were documented and archived. - To avoid influencing interviewees, open-ended questions facilitated an appropriate condition to obtain the respondents' own words and opinions (this was also important to eliminate bias). - To avoid incorrect interpretation and likely bias, the author's interpretation was checked by supervisors. - The author's past interviewing experience was utilized.

Adapted from Saeedi (2014)

Therefore, assessing the above measures ensures the collection of genuine, credible data, leading to reliable results. The questions must be structured in a way that they measure and meet the study objectives. The respondents must thoroughly comprehend the questions to convey their responses, and the responses must then be comprehended and interpreted during the data analysis phase.

3.8 Methodology for Qualitative Data Analysis

In a qualitative study, data analysis includes working with research data to identify significant patterns and themes to address the core research question (Miles, Huberman and Saldaña, 2014). The primary goal of data analysis is to understand the significance of the information obtained and its relation to the research topic (Gelling, 2015).

In this research, the data is analysed using the methodological triangulation process of scrutinizing and comparing data from questionnaires and semi-structured interviews (Bekhet and Zauszniewski, 2012). The use of many sources of evidence, known as multi-source analysis, enhances the value of data obtained from a single source (Vinet and Zhedanov, 2011). In addition, the triangulation procedure was used to guarantee the completeness of the data during the analysis stage of this study (Vinet and Zhedanov, 2011).

The aim was to corroborate the evidence from participants' responses and their observed behaviour regarding the research question of challenges, capabilities, and capability gaps of marine-based SMEs. Commencement of the data analysis process involved familiarization with reading the expression of Interest (EoI) survey results (secondary data) related to company profiles and their marine energy concepts.

This phase is essential for understanding, interpreting, and collating the themes and meanings within and across cases (Donges, 2015). The data reduction stage of the analysis process aims to compress the collected data into a more manageable format. Simultaneously, the data need to be rich and extensive enough to allow for an adequate account of contextual information. To handle so much data, it is recommended to use text-analysis software such as NVivo[1], a qualitative research tool that makes it possible to store any kind of document and organize it by information source and content. Through the process of selecting, clustering, abstracting, and transforming, the documented transcriptions change into a usable form.

It is crucial that the researcher selects relevant codes to analyse the collected qualitative data, as these play a central role in bridging qualitative data to the theory and literature review. This bridging role took place by reducing codes into different

[1] https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home

themes, categorizing themes, and linking these themes to the relevant concepts rooted in the theory section.

3.8.1 Thematic Analysis

Thematic analysis is a method for analysing data in primary qualitative research that is increasingly being accepted for its importance in facilitating effective and suitable policy and practice by synthesizing qualitative data based on the evidence (Braun and Clarke, 2006). It is systematic because it allows qualitative data to be analysed logically and organised. That is why it can be used to analyse large qualitative data sets, as well as smaller ones, leading to detailed descriptions, explanations, and theorizing (Saunders and Lewis, 2018).

The analysis of the qualitative interviews was an iterative procedure in which the researcher switched between data analysis and data collection while also referring to the study's underlying theory. At the same time, ideas were refined by data generated, analysed, and compared to existing research (Eisenhardt and Graebner, 2007). Given the challenges of working with a massive amount of data, the analytical process moved from initial familiarization to organization, identification of themes, exploration of relationships between categories, and concluded with the development of theoretical insights. Benefiting from multiple cases, the researcher progressed from each case as an analytical unit to case study analysis, in which structures and relationships were replicated, contrasted, and expanded, allowing for considerably richer theoretical elaboration (Eisenhardt and Graebner, 2007). The steps of thematic analysis are further described in Appendix 12.

3.8.2 Qualitative analysis – the software tool NVivo

NVivo, as a qualitative software tool, was used to organize, store, and accurately code the interviews. NVivo was necessary since the coding process was required for a total of 103 pages of single-spaced text across nine transcripts. Coding and data analysis are not synonymous, however, coding is a crucial aspect of the qualitative data analysis process (Wong, 2008) and the software tools have to be viewed as an aid in this process. In practice, the transcripts and documents from the interviews are imported into NVivo as PDF files and then coded. The codes under each node are assessed and revised to discover the codes that are most connected to the research questions.

The analysis of transcribed interviews and notes using NVivo is not a linear process, where you go by the data and move on to the next stage data set. With readings and reviewing, but also moving "back and forth" consistently within the transcribed data, an exercise had to be followed with all, inductively coding, moving from the specific to the general, as a recursive process. Figure (3-6) shows the thematic coding process, which models the coding process. With respect to this coding schematic, the next stage of topic coding entailed assembling interview data to appropriate locations under the associated sub-sections.

Figure (3-6) Thematic coding process

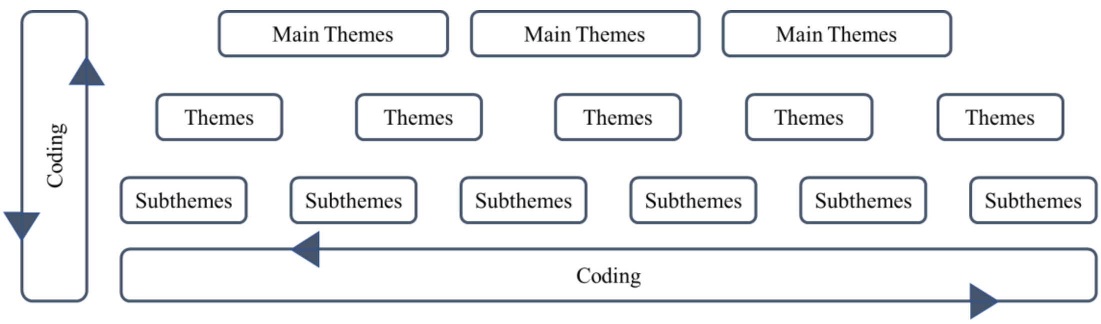
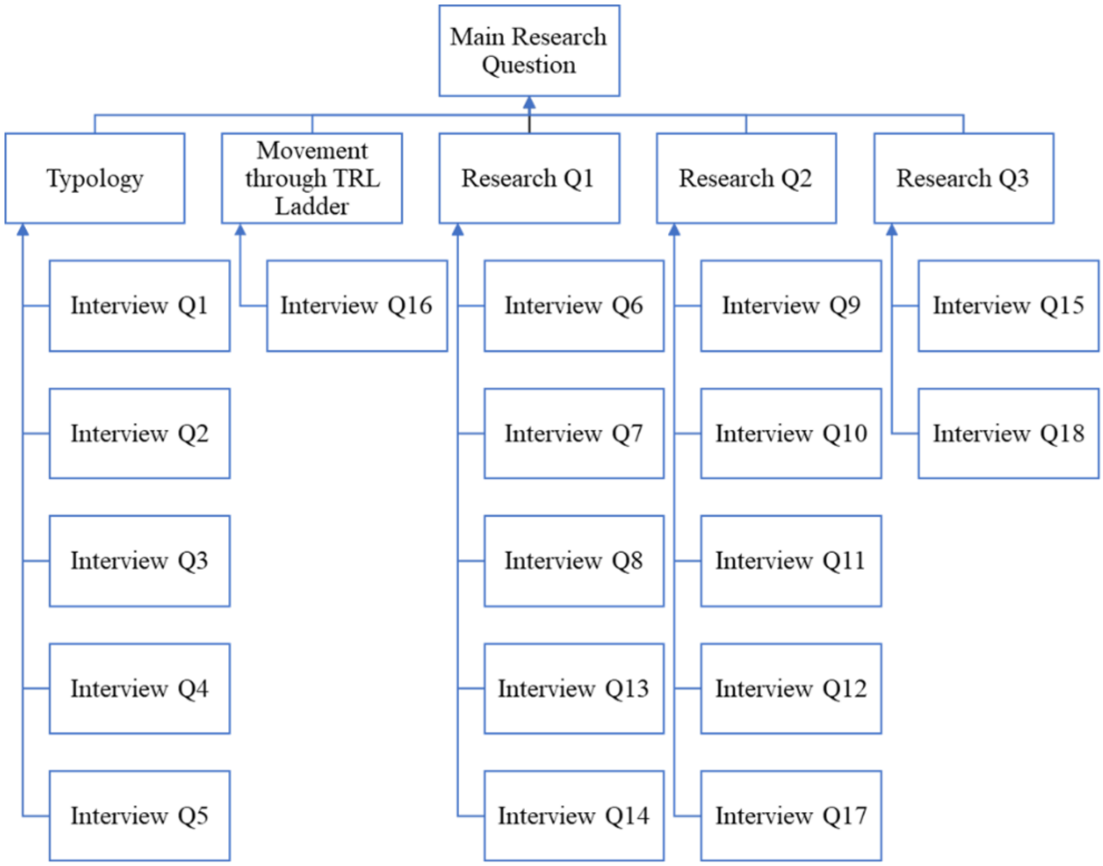


Figure (3-7) depicts the progression of the topic coding, whereby pertinent interview data to answer the central, top-level research question moves upward through researcher filtering and synthesis. Ultimately, the most relevant data emerge into the holding location for the central research question, ready for data analysis and summation. The interview data essentially flowed from siblings to parents through a progression of topic coding steps. In addition, these relationships emulate the strategy for the research study, reflecting how meaningful data emerged from structured interview sessions. This movement and filtering of information ensured that the central research question of the study remained the focal point of the data exploration.

Figure (3-7) Data coding progression



The node structure in NVivo allows for several structuring regimes of the nodes by subdividing a dataset hierarchy with mother, child, and sibling nodes. NVivo is flexible, allowing for efficient recoding and un-coding of text as well as restructuring, renaming, merging, and removing nodes at any point during the process. All of these actions are stored and can be reported on, increasing the transparency of the conducted research (Crowley, Harre and Tagg, 2002). Figure (3-8) shows the first level coding of transcripts.

Figure (3-8) NVivo - First Level Coding

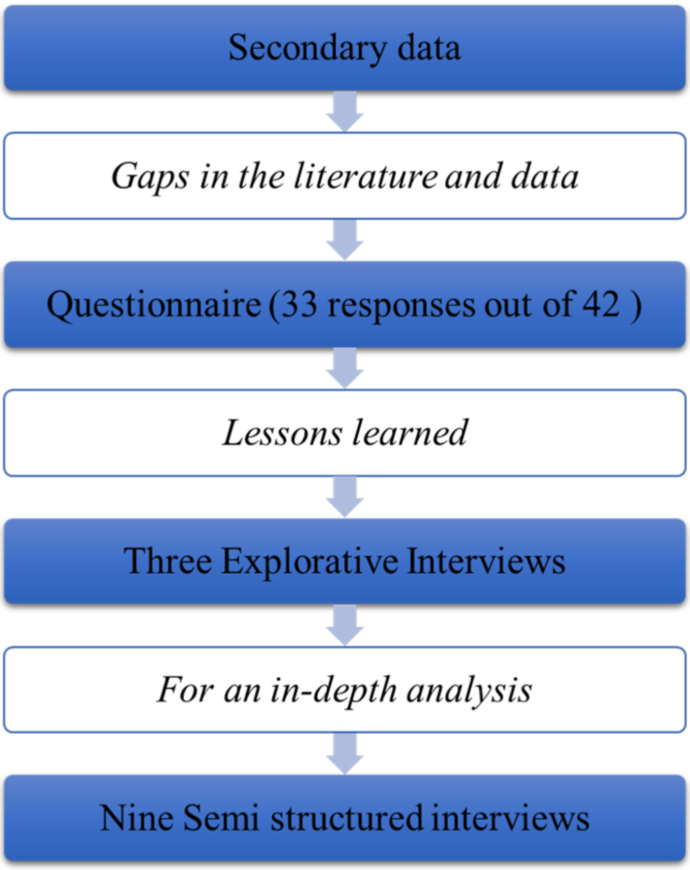
Name	Files	References
Background of Interviewee	9	23
Foundation of Company	8	10
Number of Employees	8	13
Capabilities	9	96
Internal Capabilities	9	59
Technological	4	13
Managerial	6	21
Organizational (Commercial)	9	24
External Capabilities	9	39
Products and Services	3	13
TRL Level	3	10
Start of technology	6	10
Good Points (experience)	8	15
Innovations and Uniqueness	7	12
Challenges	9	143
Internal Obstacles	9	141
Technological	9	44
Managerial	4	9
Organizational (Commercial)	9	79
Sector specific	5	15
External Obstacles	2	2

NVivo was an enabling tool for familiarization with the data and the identification of emergent themes. Initially, it was necessary to review the data in NVivo multiple times to determine preliminary themes associated with the interview questions. Such perusal was also beneficial in the creation of nodes for broad coding. NVivo was also valuable for reviewing and analysing the distribution of the themes across participants.

3.9 Concluding Remarks

To summarise, this chapter has introduced and discussed and justified the choice of mixed methods methodology as a suitable research methodology for this study. A mixed-method research design was deemed most suitable to triangulate findings and to ensure all research objectives are fully addressed. The chapter has in great detail explained the research map, and research design of the two data collection phases, including the methods used of the initial focus group followed by an online survey and then by explorative interviews to seek insights and perceptions of interviewees into something not yet entirely understood, and finally by semi-structured in-depth interviews. Figure (3-9) shows the main elements of research and the methodological choices and scale of data.

Figure (3-9) Flow diagram of methodological choices and scale of data



The data collection techniques applied included primary and secondary data sources. Primary data sources involved distributing questionnaires and conducting three explorative and nine semi-structured interviews, each guided by an interview protocol.

Secondary data sources included publicly available data sourced from literature and the MEA project.

Ethical considerations have also been fully addressed. All interviewees were sent the interview transcripts and allowed to make any amendments to the interview transcripts. Further, all data collected was reviewed by the supervisory team.

Lastly, pattern matching was used in the data analysis phase as a method of comparing theory-based hypotheses with the data collected. In sum, this chapter has comprehensively rationalised, discussed, and defended each research design stage.

4 Results

This chapter presents the research findings as mixed methods research. As mentioned in the synopsis of chapter 3 (Figure (3-9)), this study collected quantitative data with structured questions to verify the significant impacts of the factors derived from the secondary data and literature study through an online survey (questionnaire). 33 SME responses were received out of 42 targeted from the legacy project. Based on lessons learned from quantitative data, qualitative data with explorative interviews were collected to double-check the results obtained from questionnaires, and then in-depth interviews were conducted to assess the issues raised by secondary data, questionnaires, and explorative interviews. Interviews were online through MS Teams and presented findings from these complementary approaches.

To address the overall research question that aims to explore the capabilities driving SMEs and start-ups' technology development, the research seeks to explore three related questions, as previously outlined. This chapter starts with the challenges, capabilities and origin of capabilities discovered by questionnaires. Then, it shows the results of explorative and in-depth interviews. These findings were discovered using a mixed-method.

4.1 Quantitative Analysis

The data presented include response rate, sample characteristics including primary roles in the sample, size of the SMEs based on their number of employees, changes in TRLs, and a presentation of findings against each study objective. The data are analysed and presented based on the response to the items in the questionnaires. The researcher frequency tables and percentages to present data. Charts are also used, while the narrative text is used to present and analyse interview responses.

4.1.1 Response rate

Out of the 42 identified SMEs of the MEA project that had been monitoring for TRL development, a total of 33 responses returned (a 0.78% response rate) to our online survey (Appendix 3). Of those who responded, respectively, 19, 4, 5, 2, and 4 SMEs were from wave, tidal, offshore floating wind, offshore floating solar, and other marine energy sectors.

4.1.2 Sample characteristics and groups for analysis

A prerequisite for completing the survey was that only senior management team members were the respondents as it provides more robust data due to the knowledge of the businesses these roles entail. The final sample contained 33 individuals that described themselves as CEO, Managing/Program/Technical Director, Owner, CTO, R&D/Commercial Manager, COO, Project/Design Engineer, Co-Founder and Board Member, or Chief Strategy Officer. Figure (4-1) shows the complete sample of roles.

Figure (4-1) Primary roles in the sample

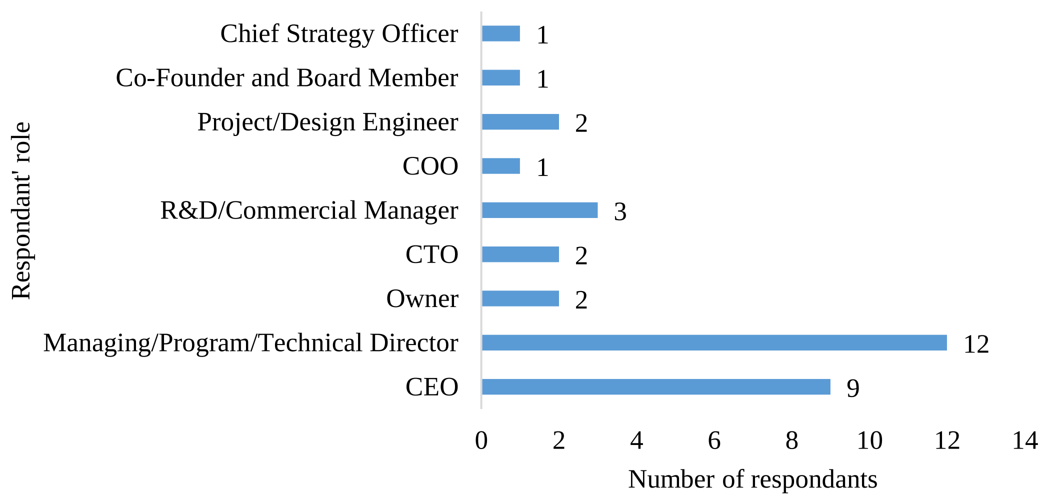
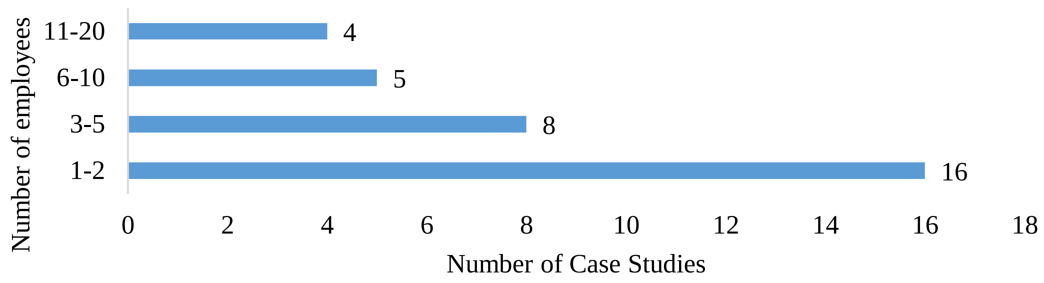


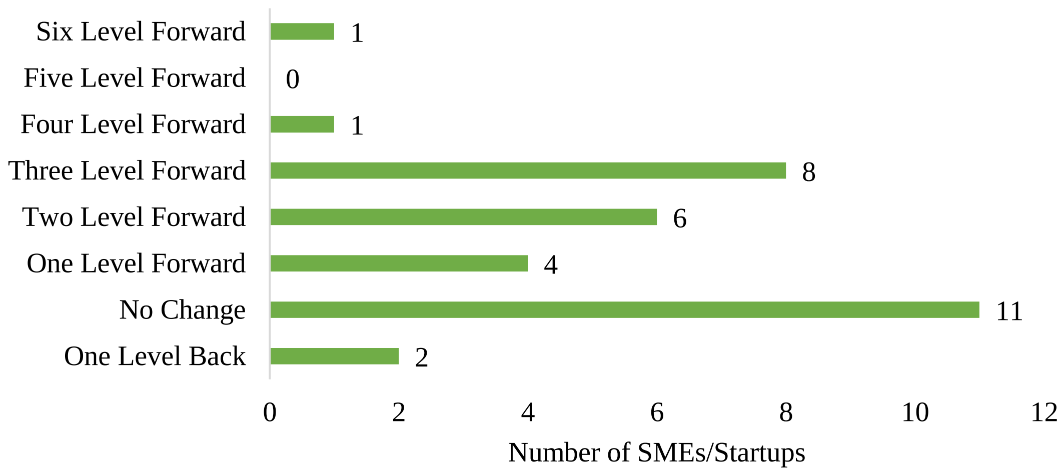
Figure (4-2) illustrates the size of the SMEs by the number of employees. Of the 33 (100%) valid responses, the majority of SMEs are micro-businesses, employing less than ten employees (87%, n=29). 13% (n= 4) can be classified as small firms having between 11 to 20 employees.

Figure (4-2) Size of the SMEs based on their number of employees



As the TRL framework was developed to check the advancement of technology, it was important to examine whether there were differences in the levels of technology readiness or not. During the initial phase of data collection, the majority of observed projects positioned themselves in the early stages of the development ladder (mainly TRL 3 and 4).

Figure (4-3) Changes in TRLs



Based on Table (4-1), among 33 case studies, firms in all offshore floating wind, solar and other concepts have climbed the TRL ladder (at least one level), and half of the tidal firms have moved up in the TRL spectrum in three years. However, just 39% of wave energy technology developers have moved up the TRL ladder.

Table (4-1) Positive change in TRL based on the marine energy concept

Marine Energy Concept	N of firms with positive TRL change	N of firms	Ratio (%)
Wave	7	18	38.89
Tidal	2	4	50
Offshore Floating Wind	5	5	100
Offshore Floating Solar	2	2	100
Other	4	4	100

4.1.3 Challenges in the Marine Energy SME Ecosystem

Despite the great potential of marine energy, it accounts for the smallest portion of renewable energy amongst the variety of renewable sources. Nevertheless, these emerging technologies still need targeted incentives to unlock their potential fully (MRIA, 2018). In order to answer the first research question, ***What challenges do SMEs (start-ups and established) encounter when developing technologies from proof of concept to scalable prototype development within the marine sector?***, participants were asked several questions about their perception of challenges through technology development.

4.1.3.1 Broad understanding of challenges

First, the participants were asked to indicate the degree of technical and commercial challenges experienced at different stages of development of their marine technology. This step helped us explore the owner-managers perspectives and experiences of this phenomenon.

➢ ***Technical Challenges***

The aim was to map out what technical challenges impacted technology development by marine energy SMEs. Figure (4-4) shows that design, system integration, scaling, manufacturing, installation, and operation have been significantly challenging for SMEs.

Figure (4-4) Technical challenges of technology development

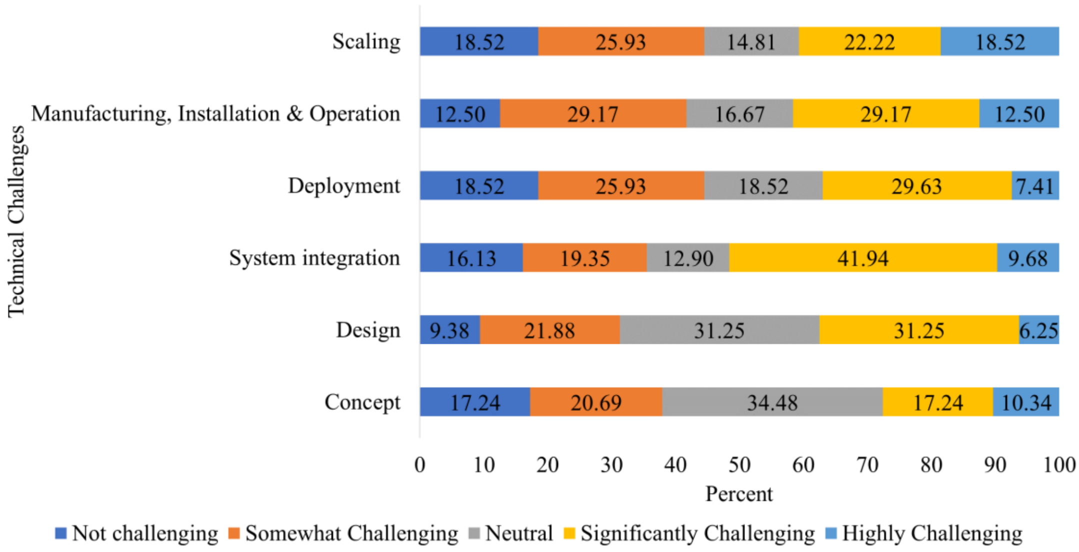
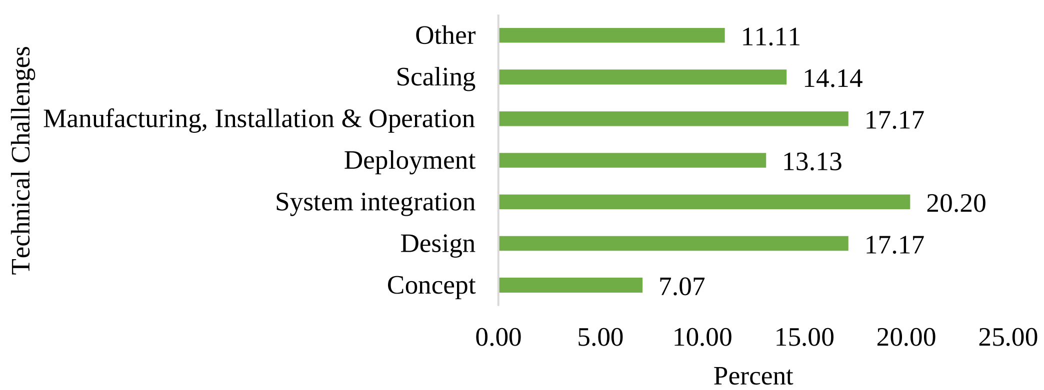


Figure (4-5) showed that design, system integration, and manufacturing, installation and operation were the most challenging technical issues until TRL 4. [1]

Figure (4-5) The most challenging technical issues of technology development



[1] The technical challenges mentioned in "Other" part were not technical. For example, some respondents mentioned finance as a technical challenge.

The most challenging technical issues are described below:

System integration

System integration is challenging based on the concept of the developed technology.

For example:

For some tidal technologies:

- Utility-scale tidal technologies have many challenges with grid connections.
- Electric Conversion is challenging.
- Significant money is needed to test and prove the system and all its components

For some wave technologies:

- Integration of subsystems and thoughtful development of a failure modes table to capture risks involved with interfaces are challenges for WEC developers as subsystems, in many cases, have been tested in isolation, and adequate planning will be required to prevent issues when subsystems are joined into the whole WEC system
- There is not enough testing data available on sub-systems, particularly PTO systems.
- Economical mooring/anchoring integration is required.
- It should be autonomous.
- The control system is not developed yet.

For some mooring components:

- The integration of the Load Reduction Device (LRD) component into the overall system is highly complex. Detailed numerical modelling of the combined mooring system, LRD, platform, and turbine is required in order to assess the overall integration impact.
- Operational environment exposes challenges for integration.

For some offshore floating solar technologies:

- o New methods had to be developed.

Design

There are many solutions for developing technology. In addition, a lot of theoretical understanding is needed for developing innovative technologies. However, technology should be designed for survivability and low cost. Hence, scaling up has challenges around building optimization by minimizing costs of materials, assembly, deployment, maintenance, and finally, building a robust system, easy to manufacture. Design challenges even increase for some technologies, for example, for some wave energy technologies:

- o Subsystems required for technical/economic viability do not yet exist, so substantial subsystem R&D is required
- o Some of the sub-systems, in particular the PTO system, might be at a low TRL
- o There is not enough information available to integrate design with WEC

Manufacturing, Installation and Operation

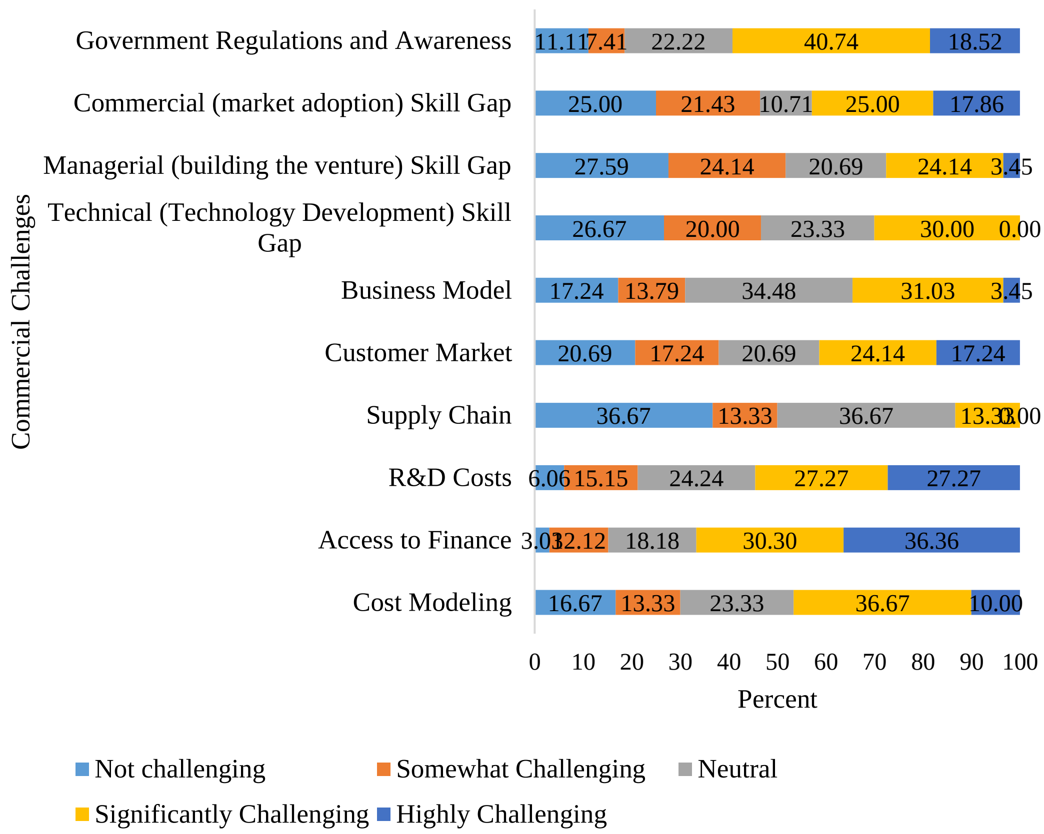
For different technologies, some parts of the device have never been constructed. Thus, getting everything together to ensure a solution demonstrating is challenging. Also, due to high subsystem R&D, high CAPEX and OPEX. Modularity, cost, and lead times for new manufacturing processes are often required.

➢ ***Commercial Challenges***

Yet, the ocean energy market is in its early stages, and the industry should overcome a variety of obstacles to prove the technology's reliability and affordability. Despite recent progress, few developed ocean energy technologies have achieved the level of technological readiness required to ensure the commercialization of the technology.

Hence, we aimed to map out what commercial challenges impacted technology development by marine energy SMEs. Figure (4-6) shows that government regulations and awareness, customer market, R&D costs, access to finance, and cost modelling have been significantly/highly challenging for SMEs.

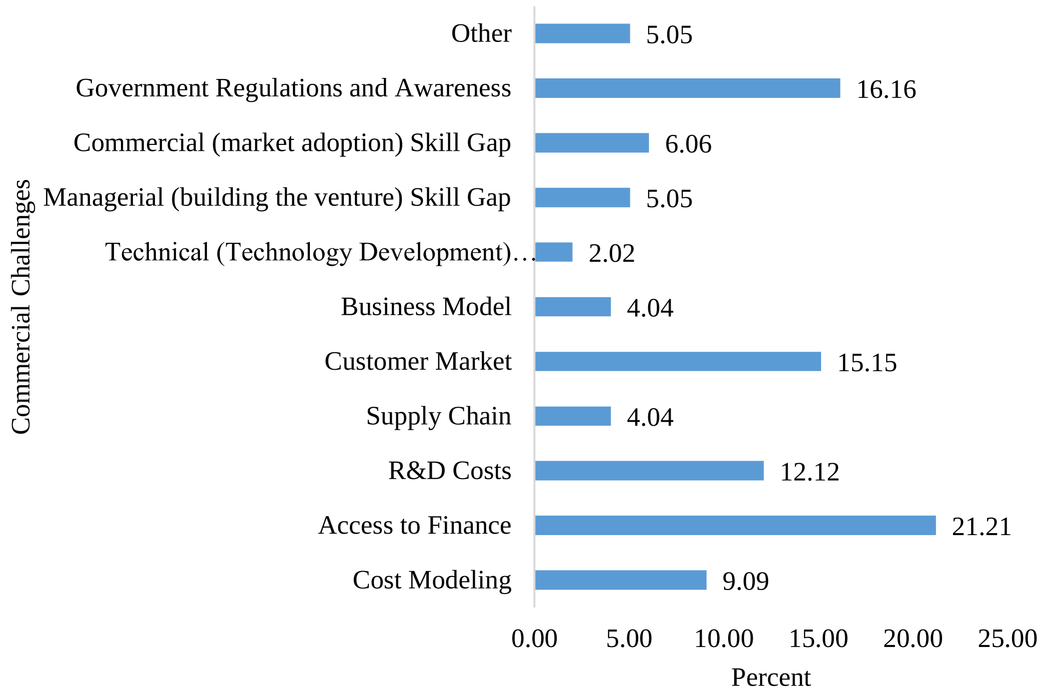
Figure (4-6) Commercial challenges of technology development



Based on Figure (4-7), access to finance, government regulations and awareness, and customer market were the most challenging commercial issues. [1]

[1] The commercial challenges mentioned in as "other" were irrelevant or could be placed in available categories.

Figure (4-7) The most challenging commercial issues of technology development



The most challenging commercial issues are described below:

Access to finance

Access to finance is usually the most significant challenge that SMEs face. Although good funding opportunities are/have been available, raising finance has a time and competence intensive application process, a challenge for SMEs with limited bandwidth. The funding bodies do not work collaboratively, meaning that understanding this ecosystem is incredibly challenging, and the scope of their support is many times insufficient. The funding calls are not conveniently structured based on TRL. For instance, in the development stage (TRL4 to TRL6), the technological risk should be reduced to an acceptable level for private investors to enable demonstration. It takes time to convince stakeholders what energy storage's value would become. Specifically, several high-profile commercial failures occurred in the wave energy sector in the past 20 years. For instance, following the collapse of Pelamis and

Aquamarine, no private sector invests in wave technologies. Also, EU funding is tough to access due to high competition and the qualitative nature of the assessment process.

Government regulations and awareness

Not all governments are aware and supportive of blue energy growth, especially in legislation. So, it is not easy to get permission for pilot projects for novel technologies. Also, the regulatory bodies are usually challenging to deal with and slow. Despite the evident efforts from governments, innovators do not have a clear pathway to innovate.

Customer market

Early utility-scale market support is usually limited for marine energy technologies at the development stage, and intermediately markets need leveraging in most cases. Also, the market is complex for some technologies and finding who the customers are.

At the deployment stage, customers want deployment data prior to thoroughly engaging. So, the market still needs to be established; but this is a problem in attracting private investors. SMEs need to convince customers that developed cost reduction technology does not introduce risk into their project.

R&D costs

With a novel system, R&D costs, especially demonstrations, are very high as building prototypes and accessing test facilities are costly, and it is impossible to justify commercially when so many uncertainties about market deployment exist.

Cost modelling

Low TRL systems are hard to project costs for, especially when manufacturing methods need to be developed. Costing the components is easy but costing the full impact they have on customers is challenging due to a wide range of CAPEX and OPEX costs being impacted, as the components change the requirements for other expenditure, installation, OPEX, and even project lifetimes.

Moreover, a LCOE model has to be built from the ground up. In order to develop this model, getting customers to share/agree on these numbers is impossible. Also, limited information is available in the public domain for marine technology projects. So, getting justifiable inputs is challenging, particularly in estimating O&M costs.

4.1.3.2 Impediment of technology development

The general interpretation of the respondents about the key technological and commercial challenges faced by marine sector SMEs was discovered using the questionnaires. Besides, respondents were asked to rank and name the challenges of their concern, looking forward to the next 18 months.

Based on results (Table (4-2)), 54.55% of respondents ranked commercial challenges as the most significant impediment to firm development, 48.48% of respondents ranked technical challenges as the second greatest impediment to firm development, and finally, 54.55% of respondents ranked managerial challenges as the third impediment to the firm development. Hence, organizational challenges are the most significant barrier for most companies for technology development. Then, the most significant impediment is technological challenges, and finally, managerial challenges had the most negligible impact on technology development.

Table (4-2) Ranking of challenges for technology development

Ranking by Respondents	Technical Challenges (% of respondents)	Commercial Challenges (% of respondents)	Managerial Challenges (% of respondents)
1	33.33	54.55	12.12
2	48.48	18.18	33.33
3	18.18	27.27	54.55

In order to realize the changes from TRL3 to TRL 7, participants were asked to mention the key challenges of concern, either technological, organizational, or managerial challenges looking forward to the next 18 months.

Technological Challenges

Technical challenges mentioned by respondents are listed in Table (4-3). Design, Demonstration, Experimental Modelling/Validation, and Scaling were the most iterated technical challenges looking to the next 18 months.

Table (4-3) Key perceived technical challenges looking to the next 18 months

Category	Challenge	Frequency	Sum of Frequency for each Category
Design	Basic design	1	6
	Sub-systems design	3	
	PTO design	1	
	Detailed design	1	
Demonstration	Demonstration of concept	2	6
	Pilot projects/demonstration spots	2	
	Access to a demonstration test site	2	
System Integration	Integration of large equipment on small offshore structures	2	2
Experimental Modelling/Validation	Validation tests at labs and open ocean	2	7
	Access to data	3	
	Optimising the design	2	
Scaling	Scaling up	5	6

	Finding the right size of the device and building the prototype	1	
Deployment	Sea trials	1	2
	deployment and installation of components	1	

Managerial Challenges

Managerial challenges mentioned by respondents are listed in Table (4-4). Creating a team and recruiting experts were the most iterated managerial challenge predicted by SMEs looking to the next 18 months.

Table (4-4) Key perceived managerial challenges looking to the next 18 months

Category	Challenge	Frequency	Sum of Frequency for each Category
Management	Lack of focus due to lack of time/money	1	6
	Building a business of the right scale	3	
	Technical and project management skills	2	
Team	Keeping key staff	1	14
	Recruitment: managerial levels roles ensuring high-quality persons will be essential to long term success	13	

Organizational Challenges

Organizational challenges mentioned by respondents are listed in Table (4-5). Access to finance was the most significant organizational challenge perceived by respondents. Then, finding a customer market and finding partners and external support were two other significant challenges perceived by respondents looking to the next 18 months.

Table (4-5) Key perceived Organizational challenges looking to the next 18 months

Category	Challenge	Frequency	Sum of Frequency for each Category
Access to finance	Availability of Finance	9	25
	R&D financial support	1	

	Financing to cover engineering resources (engineering personnel and software costs)	1	
	Finance for demonstrating the concept	2	
	Funding to develop a system for real environment deployment	1	
	Finance to build an organization/a team	1	
	Access to strategic investment	1	
	Raising money for upscale testing	5	
	Develop funding strategy	1	
	Advancing the technology when so much time is spent seeking funding	3	
Costs	High cost of full-scale demonstrators	1	3
	Certification costs	1	
	Fluctuating material and transport prices	1	
Risk Management	Too short of a time scale for much change from present	6	7
	Risk mitigation	1	
Reliability	Increase reliability of technology	1	3
	To be efficient and cost-competitive	1	
	Ensuring high-quality, robust units to sell and build in higher volume	1	
Customer market	Engagement with the customer to fit their needs	4	17
	Access to customers/market	4	
	Aligning to take advantage of commercial opportunities	2	
	Creating awareness	4	
	Market growth	1	
	Identifying short term market	1	
	Insight in market	1	
Commercialization	Verification of an acceptable LCOE	1	2
	Sales	1	
Partnership and collaboration	Finding a partner	3	10
	Gain access to decision-makers/investors	1	
	forming a reliable and expert supply chain	2	
	Government support	2	
	Offshore Legislation	2	

4.1.3.3 Capabilities of Marine Energy SMEs

In order to answer the second research question, What technological, organizational, and managerial level capabilities enable SMEs to develop technologies from proof of concept to scalable prototype development within the marine sector?, participants were asked to name key capabilities\enablers that have facilitated their marine technology development.

Technological Capabilities

Technical capabilities mentioned by respondents are listed in Table (4-6). Based on results, Knowledge of the sector and technology development was the most significant enabler of technology development. Also, respondents perceived design and scaling as the two other capabilities of great importance.

Table (4-6) Technological capabilities/enablers of technology development

Category	Capability	Frequency	Sum of Frequency for each Category
Design	Open-mindedness in design space	1	6
	Design	4	
	Flexible design	1	
Know-how	Knowledge of the sector and offshore experience	4	18
	Practical know-how of the details of the system	3	
	Experience in testing different types and scales of technologies	7	
	In house engineering capabilities	2	
	Academic background	2	
Concept	In house innovation development	1	3
	Ingenuity	1	
	Harmonious combination of knowledge and optimism	1	
Experimental Modelling/Validation	Have a small workshop to make models	1	6
	Prototyping skills	2	

	Modelling, building scale models	2	
	Access to test facilities	1	
Scaling	Scalable design	1	1

Managerial Capabilities

Managerial capabilities mentioned by respondents are listed in Table (4-7). Apparently, creating a strong and experienced team of experts is a crucial enabler of technology development. Then, management in terms of R&D, project and risk management was the second highly iterated managerial capability perceived by respondents. Finally, the ability to fill the internal expertise gap with external resources was considered an important managerial capability.

Table (4-7) Managerial capabilities/enablers of technology development

Category	Capability	Frequency	Sum of Frequency for each Category
Internal expertise	Management team being university educated in management	1	1
Management	Risk Awareness / Management	1	14
	R&D management	2	
	Management experience in all functions	3	
	Having regular meetings with the team and collaborators	1	
	Project Management	3	
	Meeting deadlines	1	
	Flexibility through sustaining a small core team while grant-dependent	1	
	EPCI project management	1	
	Being mentored by Business Gateway	1	
Team	Strong and experienced team	9	37
	Strong R&D team	5	
	Strong core IP	4	
	Multidisciplinary team	5	
	Motivated and responsible team	5	
	Friendly team	1	
	Small organisation of voluntaries	3	

	Simple organisation	1	
	Recruitment of experts	4	
External expertise*	Involvement of external expertise	1	5
	Access to an expert team of advisors	1	
	Support from a start-up incubator	1	
	Help in the earlier stages from universities	1	
	Knowing where weakness is and finding others to fill in	1	

Organizational Capabilities

Organizational capabilities mentioned by respondents are listed in Table (4-8). Obviously, having sufficient organizational resources to deliver the project was the priority of most respondents. Needless to say, access to finance and commercialization capabilities are required to traverse the technology development process.

Table (4-8) Organizational capabilities/enablers of technology development

Category	Capability	Frequency	Sum of Frequency for each Category
Access to Finance	Capability of securing grant funding	4	7
	Experience raising both public and private funding	2	
	Accelerator programs	1	
Project Delivery	Certification Support	1	14
	Manufacturing capability	1	
	Strong Engineering	5	
	LCOE-based evaluation of design options	1	
	Cost & financial modelling	1	
	Cost-effective method of storm survivability and high performance	1	
	Lean cost structure	1	
	System Engineering	1	
	Technology Roadmap Development	2	
Customer market	Market research	1	3
	Tendering for contracts	1	
	Strong market relationships	1	

Commercialization	Access to the stock market for technological and commercial development	1	7
	Creation of videos to explain with clarity	1	
	Unique selling point (USP)	2	
	Commercialization	2	
	Spread of attention to all markets	1	
Strong supply chain	Good connections with the supply chain	1	2
	Supply chain knowledge	1	
Partnership and collaboration*	Strong local network	1	4
	Collaboration with engineering companies	1	
	Certification Support	1	
	Partnering	1	

4.1.3.4 Outsourcing capabilities

Participants were not asked any specific questions in order to answer the third research question; Do SMEs seek external support? How are externally controlled resources and capabilities leveraged by SMEs to support technology development from proof of concept to scalable prototyping within the marine sector?. However, based on the results, SMEs look for external capabilities (specified by *). SMEs with limited resources need to obtain services from an outside provider. Outsourcing helps a small firm get more done and assign critical tasks and processes to professionals without significantly expanding their full-time staff. As mentioned earlier, outsourcing can help SMEs in various stages of technology development. Outsourcing technical experts that SMEs cannot afford to employ full-time can help SMEs in simulation/numerical modelling, validating technology at scale, at sea, prototype test strategy, design optimization, and finally, de-risking the design. Also, in most cases, SMEs would also like to learn more about the certification process to achieve certifications to support investment and project development.

On the other hand, an outside marketing firm can help SMEs grow quickly through advertisement design, content creation or social media posting. Additionally, these firms are usually filled with professionals who can help SMEs come up with creative ideas and helpful strategies for commercialization. So, the business experience within the group will provide valuable market insight as well as information on the identified blockers to commercialization.

4.2 Explorative Interviews

Explorative interviews were like a bridge between the quantitative and qualitative parts. The target interviewees were a Marine Incubation Manager, an Operations and Projects Director, and a Senior Technologist.

Based on the evaluation of the explorative interviews, SMEs and start-ups face major challenges in the following areas:

- Finding new funding resources,
- Recruitment and management of talent,
- Lack of business sense behind the idea, or the business analysis of the idea,
- Getting access to the market,
- National policy gaps for marine planning and development,
- Complexities of providing services for SMEs because of judicial reviews, etc.

Hence, new technologies do not get a chance to avail themselves of the test facilities; they do not function as originally intended. It is particularly difficult for SMEs working on marine energy technologies to find external funding for later technology development stages because investors are less familiar with the market opportunities and may perceive a higher risk. That is why the innovation process and the “valley of death” or the “innovation gap” occurs between TRL4 and TRL7.

On the contrary, SMEs require internal and external capabilities to cross the technology development barriers. Frequently, technology competencies are appropriate, but SMEs fail to reach out to partners to fill a gap evident to everybody from the outside looking in, in terms of business planning and market development. In this regard, funding around the project regarding grant aid and commercial venture capital or private capital is often misunderstood or poorly understood. To avoid this problem, knowledge of programs around innovation funds and commercialization funds is of great importance. Also, business capability helps developers strategically approach the start-up or technology development processes.

Therefore, exploratory interviews helped us gain insight into barriers and enablers of the technology development path and realize that some issues raised in questionnaires and interviews, such as funding challenges, lack of business sense behind ideas, policy gaps and partnership challenges, needed further investigation.

4.3 Qualitative In-depth Analysis of Cases

The timing allowed us to capture the lessons learnt from the questionnaires and conduct a deeper analysis of some issues raised in the questionnaire, such as the most significant barriers to technology development (to answer Q1), technological, managerial, and organizational capabilities to cross the valley of death (to answer Q2), and the role of outsourcing capabilities (to answer Q3). A total of 9 interviews were conducted online using Microsoft Teams between 5^{th} November and 30^{th} November 2021.

Interviews were recorded and transcribed in 103 pages[1] of text. Interviewees have been found through the network of the MEA project. The interviews ranged from 20 minutes to 50 minutes, and an interview protocol was used. The interview protocol for each interview is adjusted to fit the company's context but inquiries about the research concept by using main questions and probes. The other questions are open to change which means that the researcher may reword, drop, or add questions. Changing the sequences or diverging from questions to pursue details is also possible. The interviews included more focused questions when factors began to emerge. Several questions were added for factors when it became clear they needed more in-depth investigation. The interview protocol consisting of all main questions and some important additional questions can be found in Appendix 11. Francis (2010) claimed that studies with few interviews could result in incomplete results. Therefore, this study aims to include a minimum of 9 interviews for thematic analysis.

We delved into the most iterated challenges and capabilities through in-depth analysis, and the themes pertaining to the research questions were noted. In order to respond to research questions, four major themes were apparent from the analysis of the data in NVivo. Table (4-9) is a summary of the findings with respect to the prominent themes.

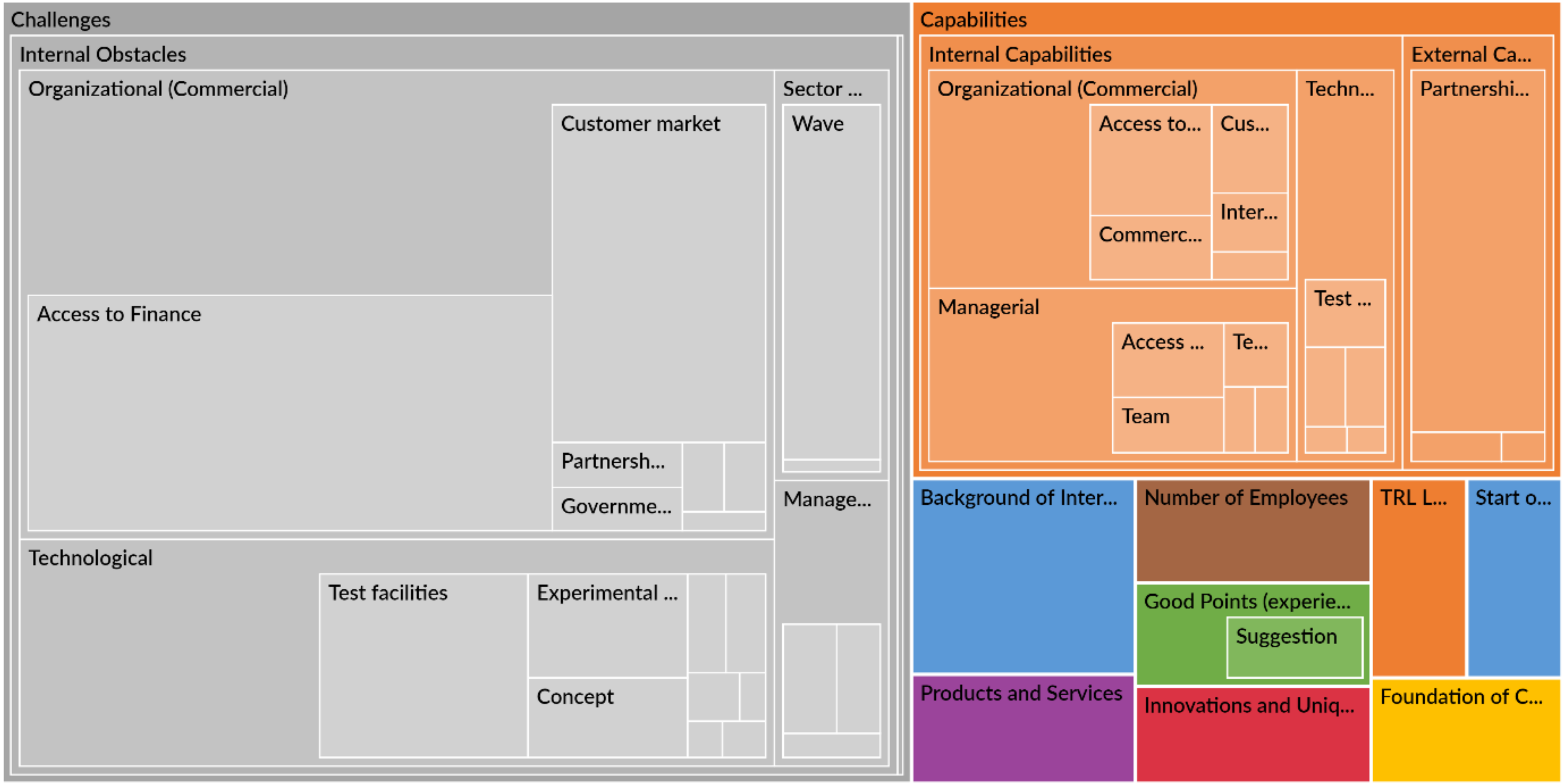
[1] See Appendix 14: A sample of a single transcript

Table (4-9) Final code structure

RQ	Themes	No. of participants	No. of references
RQ1	1. Challenges	9	143
	1.1. Internal obstacles	9	141
	1.1.1.Technological	9	42
	1.1.2.Managerial	4	9
	1.1.3.Organizational (Commercial)	9	81
	1.2. External Obstacles	2	2
	1.3. Sector-specific	4	15
RQ2	2. Capabilities	9	97
	2.1. Internal Capabilities	9	59
	2.1.1.Technological	9	15
	2.1.2.Managerial	6	21
	2.1.3.Organizational (Commercial)	9	23
RQ3	2.2. Outsourcing Capabilities	9	38
RQ2&3	3. Innovations and Uniqueness	7	12
	4. Good Points (experience)	8	15

Figure (4-8) is a treemap diagram that shows hierarchical data as a set of nested rectangles of varying sizes in which sizes represent the amount of coding at each node, e.g., the number of nodes coded or the amount of coding references. Larger areas display at the top left of the chart; smaller rectangles display toward the bottom right. Besides, colours are used to show additional information related to the data hierarchy. This means that each different parent item in the hierarchy is assigned a different colour, and the child and grandchild items are lighter shades of the parent colour.

Figure (4-8) Comparison of reference points by code



For example, as shown in Figure (4-8), the interviewees were more eager to discuss their challenges (as it includes almost half of the data) which means that challenges had the most coding references and occupied the largest area in the chart. Besides, these challenges are categorized into internal and external obstacles based on colour shades. Internal obstacles are categorized into organizational, technological, managerial, and sector-specific challenges.

4.3.1 Typology

Interviews started with informing the interviewee regarding the study. The interviews were conducted with predetermined questions with a clear and structured purpose. However, the questions were open, and additional probing was utilized besides the planned structure. Interviews started with the introduction of participants and background questions to better understand the perspective from which the answers are derived and the company's background. The core of the interview was divided into three sections: Movement across the TRL spectrum, challenges, and capabilities. The interview protocol can be seen in Appendix 11. The results of the interviews are categorized below.

In order to better understand the research context, the following general information and explanations are briefly presented for the studied cases and their relevant context. The qualitative part of the study focused on nine SMEs of different sizes in the context of the marine industry. The cases were drawn from the population of the MEA project's small and medium-sized firms. To increase control over the research design, the eligibility criteria were further constrained. The geographical scope of the study was Ireland and United Kingdom. To control the segment-specific differences, the segment was constrained to marine energy technology development. In other firms, the case firms were wave, tidal, or marine technology components such as mooring systems. The demographics of case firms are presented in Table (4-10); For anonymity, I utilized numbers, such as Cases 1, 2, 3, to 8, instead of real firm titles.

Table (4-10) Case Demographics

Case	Country	Interviewee role	Marine energy concept	N of employees	Year of establishment	Year of starting specific technology	TRL changes	
							From	To
1	Ireland	Managing Director	Wave	3-5 (3)	2012	2012	TRL 4	TRL 3
2	UK	Research Engineer	Wave	11-20 (15)	2015	2017	TRL 4	TRL 7
3	UK	Director / Lead Project Engineer	Offshore Floating Wind	1-2 (2)	2010	2018	TRL3	TRL 5
4	Ireland	Technical Director	Floating Offshore Wind mooring component	3-5 (4)	2018	2020	TRL4	TRL 7
5	UK	Program Director	Wave	1-2 (1)	2009	2009	TRL 4	TRL 4
6	Ireland	Managing Director	Wave	1-2 (2)	2008	2018	TRL4	TRL 4
7	Ireland	CTO	Wave (Other)	11-20 (14)	2005	2011	TRL 4	TRL 7
8	Ireland	Design Engineer	Tidal	1-2 (2)	2006	2004	TRL 4	TRL 3
9	Ireland	Director	Offshore Floating Wind	1-2 (1)	2010	(unknown)	TRL2	TRL 8

The case studies' background is further described in Appendix 13.

4.3.2 Subthemes

Several subthemes in relation to the major themes also emerged from the data analysis.

4.3.2.1 Theme 1: Challenges

The first major theme to emerge was technology development challenges. Based on participants' experiences, the participants advanced three areas of challenges outlined in Table (4-11). Organizational challenges were the most prominent, with 81 references among the nine participants.

Table (4-11) Coding related to technology development challenges

Subtheme	**No. of participants**	**No. of references**
1. Challenges	**9**	**143**
1.1. Internal obstacles	**9**	**141**
1.1.1. Technological	**9**	**42**
1.1.1.1. Concept	**2**	**5**
1.1.1.1.1. Idea	**1**	2
1.1.1.1.2. Knowhow	**2**	3
1.1.1.2. Demonstration	**1**	**3**
1.1.1.3. Design	**1**	**1**
1.1.1.4. Experimental Modelling-Validation	**9**	**27**
1.1.1.4.1. Modelling	1	7
1.1.1.4.2. Test facilities	**6**	**13**
1.1.1.4.2.1. Availability of test sites	3	6
1.1.1.4.2.2. Permissions for testing	4	4
1.1.1.4.2.3. Status of test facilities	3	7
1.1.1.4.3. Testing	**7**	**8**
1.1.1.4.3.1. Costs of testing	3	3
1.1.1.4.3.2. De-risking	1	1
1.1.1.4.3.3. Feasibility assessment	3	4
1.1.1.5. Manufacturing, Installation and Operation	**2**	**3**
1.1.1.6. Scaling	**2**	**2**
1.1.1.7. System Integration	**1**	**1**
1.1.2. Managerial	**4**	**7**
1.1.2.1. Internal skill gap	**3**	**5**
1.1.2.2. Finance	**1**	**2**
1.1.2.2.1. Delays in salaries	**1**	2
1.1.3. Organizational (Commercial)	**9**	**81**
1.1.3.1. Access to Finance	**9**	**45**
1.1.3.1.1. Lack of grants	**7**	21
1.1.3.1.2. Time-consuming processes	**2**	2

1.1.3.1.3. R&D Support	**2**	6
1.1.3.1.4. Risks	**3**	4
1.1.3.1.5. Scaling Costs	**6**	9
1.1.3.1.6. Testing and Validation Costs	**1**	1
1.1.3.1.7. Delays	**2**	4
1.1.3.2. Government regulations	**1**	**3**
1.1.3.2.1. Awareness	**1**	2
1.1.3.2.2. Legislations	**1**	1
1.1.3.3. Customer Market	**8**	**27**
1.1.3.3.1. Unawareness	**3**	3
1.1.3.3.2. Delays	**2**	6
1.1.3.3.3. Engagement	**3**	7
1.1.3.3.4. Market forces	**5**	9
1.1.3.3.5. Finding alternative market	**2**	2
1.1.3.4. Certifications	**1**	**1**
1.1.3.5. Partnership and Collaboration	**3**	**4**
1.1.4. External Obstacles	**2**	**2**
1.1.4.1. Delay	2	2
1.1.5. Sector-specific	**4**	**14**
1.1.5.1. Wave	**4**	**14**
1.1.5.1.1. Lack of Credibility	**3**	5
1.1.5.1.2. Mooring	**1**	1
1.1.5.1.3. Power take-off	**1**	3
1.1.5.1.4. Technology Performance	**1**	1
1.1.5.1.5. Technical know-how	**2**	3
1.1.5.1.6. Government Agencies	**1**	1

Interviews with experts in developing marine energy technologies allowed for more in-depth mapping of essential problems for SMEs and start-ups. The following sections present the most significant barriers to technology development uncovered from the information provided by the nine interviewees to answer the first question of the research:

What challenges do SMEs (start-ups and established) face in developing technologies from proof of concept to scalable prototype development within the marine sector?

The challenges were identified from the collected evidence and grouped into technical and commercial categories using the TRL spectrum. We have based it on our most robust evidence in several cases where a challenge relates to more than one category.

- ***Technological Challenges***

Among technological challenges, experimental modelling and concept were the most iterated ones. Thus, we delved into the details of these two issues.

Concept

Based on interview results, the overarching challenge is at the concept stage as most people in marine energy, especially wave energy, has little knowledge of the sea. Marine energy technologies must be designed to remain on-site for the duration of the development in an energetic environment. Also, all sub-components must be designed for rapid replacement and in-factory servicing. It is crucial to have the right idea. If the idea is not good enough, the other TRLs (e.g., 7 and 8) will become even more challenging because there is no good solution.

Experimental modelling/Validation

All participants pointed out the difficulties of modelling and testing prototypes. In the step after proof of concept, understanding the underlying physics and applying it is the challenge that has generally been solved over the last 5 to 10 years through some good open-source tools. So, that is sort of relating back to some of the challenges with the early TRLs regarding modelling.

At this stage, one of the significant challenges and expenses in moving forward with TRL is testing. Universities, compared to most places, do not work in real-time. So, all procedures are very slow and mechanistic. In order to do tests, they ask for contracts that are running to pages, and it takes a long time to get the permissions and do testing.

Also, trying to get to TRL 4 is challenging for some marine energy developers because some devices are slightly different (larger) than most devices, and there is no lab that would fit or accommodate the device. So, there is a need to treat the environment to test since such facilities just do not exist. From TRL 4, doing some system integration testing full systems becomes a critical barrier. As models get bigger, SMEs need to use bigger tanks in a very simplified sort of way. For some technologies, the test sites are not appropriate in Ireland. For example, some technologies need to be tested in deep tanks, but available test tanks are quite shallow. That is why Irish SMEs are compelled to test in test sites out of Ireland. Also, some test sites, such as AMETS Mayo on the Atlantic Coast, have a very severe condition to try the first effort at something that has been just designed.

In addition, there are not any standards for testing for seawater compatibility. So, the risk appetite for something new is a challenge, so they push the boundaries further than what something old had to do and have to work with them to define tests for seawater compatibility. So, it takes time, and time is cost because you have got a team of people.

- ***Managerial challenges***

Internal skill gap

External collaborators are not totally reliable; they deliver late or do not deliver the expected quality. Instead of asking somebody else to do some analysis, firms need to invest in their own resources, buy some software licenses, and train graduates to train graduates do the analysis themselves. Besides, it is expensive to outsource things.

- ***Organizational Challenges***

Obviously, organizational challenges were the most troublemaking issues for SMEs. For instance, all participants pointed out the difficulty in obtaining capital and getting financial institutions to invest in SMEs. Besides, the customer market emerged as vital in relation to barriers of technology development.

Using the NVivo program, Table (4-12) shows the frequency of the word 'finance' or its synonyms[1] or derivatives[2] and the frequency of the word 'customer' or its synonyms or derivatives in the interview transcripts for all the interview participants.

Table (4-12) Frequency of the words 'finance' and 'customer'

Word	**Occurrence**	**Word**	**Occurrence**
Finance	174	Customer	165

Lack of Finance

There is some sort of support and smaller grants around the earlier TRLs, which will help cover many costs once to move into real demonstrators in the sea. In the research phase, the government provides a certain amount of money every year, identifies research areas, and opens competition for proposals. They receive proposals from companies, and they fund projects. The problem is that the funding covers a range, not just offshore renewable energy. They are heavily involved in pharmaceutical

[1] Finance OR money OR capital OR fund

[2] Finances OR Financing

development or clean energy; whatever topics need research and development. Sometimes it feels a bit of an unlevel playing field when players with considerable financial backing can be winning. Besides, sometimes they create a big box instead of segmenting the research and organizing public funding grants; for example, marine energy developers compete for funding with other high-tech SMEs such as pharmaceuticals and agriculture. However, the situation is usually very isolated and fragmented. For instance, there is no full government program for launching technologies in the deep ocean.

On the other hand, they could create forums where people engaged in offshore renewable energy can meet and discuss and share ideas. In addition, in some cases, people are not responsive, and it takes a long time to hear from them. Some people are not very interested in what they are doing or have totally different approaches. For example, it is not easy to meet individuals who make the decisions from departments like SEAI.

In the early stages, SMEs are reliant on public grants. Then, it comes to moving up the scale in terms of size, and costs obviously start going up faster. The number of funding opportunities drops off, which means that in the development phase, through TRL 4 to 6, trying to get the next funding is challenging because SMEs still do not have a real product, but they do need quite a bit of fund to get a product from a model that they have tested in a lab to a big prototype that they have testing in the sea. So, it becomes hard to have continuity because the grants have their own timelines. Also, there might be gaps between grants (winning one and losing the other), or it might take a year or more to get answers because people who work for the public sector might not really understand the situation. So, technology might be good enough, but SMEs need to accelerate it to get to a qualified commercial product. Some major international companies might be interested in advanced technology, but they usually say: “You are a bit early”. In addition, costs increase with the steps up the TRL ladder, from approximately 10s of thousand at the lowest TRLs, through 100s of thousand, to a few million at TRL6 and above. The further up the TRL ladder you get, the more expensive your next step is, and the more reliant you are on getting that next set of funding aligned, whether it is a public sector, R&D support, or private support. So, one of the biggest challenges is the level of effort spent on writing applications to try and get public sector R&D support. Hence, Funding is a critical issue for the transition from development to deployment because the scale of the prototype is smaller, and if SMEs only get enough funding, they can match it to their budget and do a prototype test at a small scale in a lab to prove technical feasibility because they need to find a client who says: “I think this is a good idea here is ...£, Develop it”. However, it is not just about the money but also de-risking.

In this regard, SMEs need to farm out different aspects, design parts and get costs for a system. There are many guesstimates there, and no one can operate on guesstimates. At higher TRLs, putting something of a large scale at sea is very expensive. So, financing is a big problem as most people in charge of finance are not risk-takers. Technology developers need to have solid figures of their technology’s readiness – i.e., how qualified, or commercially ready it is as investors ask for minimizing the risk and a total deliverable cost. However, SMEs usually cannot give them a realistic cost until they develop the engineering at a certain level. So, the client should see that with a specific technology, they can make, for example, 2, 3 hundred million a year through engineering services to an oil company or an energy company.

Customer Market

For technologies at TRL 4 to 6, the challenge might be finding the right way to navigate through intermediate or alternative markets. Even when the SME is at TRL 6 to 7, which can become a huge company that can manufacture prototypes and has a market ready to buy it, which is unlikely for an SME; it is still challenging as SMEs might not become able to convince a prominent investor to say, “Yes, I believe in your validated technology in the lab, I am going to invest.”

Therefore, access to funding is linked to finding a suitable market for the end use of the work because SMEs will start to reduce risk, increase confidence, and accelerate commercialization. So, when they start having some revenue, that means they are not just reliant on grants and public money anymore, but there are always delays in the market.

Engaging with potential clients and having an audience interested in developing the technology is challenging. It has always been a problem for a smaller technology developer trying to find the customer. For example, the original target market of a mooring technology developer was wave energy; however, due to failures of wave energy technologies in the early 2000s and unsuccessful efforts to build relationships with wave energy companies, they moved into the floating tidal. Therefore, the company realized that they were developing technology for a new market that had not really happened yet, and they had to pivot and change their target markets as they moved along based on the market pull (sectors that are more likely to succeed or are funded). This problem happens in delivering a product to a project, even floating wind, where a firm is involved in a project to deliver a product at a large scale to a deployment which is supposed to happen, e.g., in 2021, but then the project gets pulled by another company in order to lower the risks.

Finding Partners

SMEs mostly rely on a go-to-market partner because they do not have the capability and the resources to manufacture. Sometimes the applications are so specific that you have a partner in developing specific aspects of technology. If they pull out or fold, SMEs might not have Plan B or C because it is so specific. Also, the marine energy developers sometimes do not get funding as they are not progressing fast enough. This challenge is combined with trying to find a strategic partner to help.

- ***External Obstacles***

Covid-19 Delays

Like all other small businesses, the COVID-19 pandemic has represented an unprecedented shock to marine energy sector SMEs.

- ***Sector-specific challenges (Wave)***

Challenges have become more complex for wave energy which lacks credibility. Hence, public sector support is essential as, unlike other technologies, wave energy technologies might need 5 to 20 years to reach commercialization. Also, a severe lack of understanding and awareness at the departmental level of marine energy potentials doubles this challenge. The government should be putting serious money at the national level, but enterprise Ireland does not invest in SMEs that are not start-ups.

They only want to know companies that are less than three years old. So, many micro-SMEs and SMEs do not fit EI’s criteria for funding. Also, enterprise Ireland does not want to consider wave energy as a high potential start-up due to several failures.

Wave energy usually gets grouped with solar, wind and tidal. However, most of the technology development and modelling process for wave technologies is unique compared to more established renewables like solar and wind. For solar and wind, SMEs usually rely on the capacity factor, which means that you have an annual energy production and if you split that across the days of the year, then you have a per day energy production figure. So basically, it is a means of comparing how much energy or power is produced over the year versus how much energy or power is available. So, in a way, it is a measure of efficiency and effectiveness. Wind turbines have a particular rated power, depending on the rated wind speed. When there is no wind, the wind turbine is not moving. As the wind ramps up, you get to a threshold, and the turbine starts to spin. Once it is spinning, it stays at that power level until the wind drops down again significantly enough that the operators decide to switch it off because it is not economical, or the generator cannot handle a lower speed. However, when it is on, it generates a specific power. For a wave energy device, that is not the case; there is no speed, size or period of wave that gives you a specific threshold after or before which you are generating constant power, and they are changing all the time. So, there is no industry-defined method of defining rated power for a wave energy converter.

Approaching the modelling from a blank slate and approaching the technology development process from a blank slate is one of the unique challenges due to the lack of an industry-standard way of modelling the system. This challenge has generally been solved using good open-source tools over the last 5 to 10 years. Therefore, the lack of understanding of how to go about the technology development process for wave energy converters and how to conduct numerical models is a critical challenge. There might be a lot of focus on experimental modelling and proof of concept deployments in the early stages, where there is not a lot of unification in design tools. So, there is a need to build wave tank models and test them without necessarily having a complete understanding of outcomes. Then, doing the same with some proof-of-concept open ocean testing without robust design tools in place to try and understand the system with physical models and prototypes. That is a really challenging way to approach wave energy research and development because the cost and timelines are high. So, it might take a long time to do numerical modelling and build simple and evolving LCOE models. This can lead to informed design choices to optimize the design path based on informed LCOE rather than sort of guessing and checking with physical models. Nowadays, design tools have evolved, and there are tools that are open source and available that can give an understanding of the system. Also, SMEs might have someone on the team, decent at MATLAB and Simulink, which is common.

One of the most challenging things for wave energy convertors is the power take-off system because, unlike wind and tidal, it gets really slow, very high torque, and reversing motion for waves. So, that is really challenging because generators have not really been designed for those conditions. SMEs avoid using gearboxes in the marine environment because that is a significant source of unreliability as it is difficult to access. Sometimes for WECs, SMEs have to bring the machine back to port and detach the PTO. So, technically, that is a big challenge.

The mooring system for WECs is tough because if it is about mooring a boat or offshore platform, it should not move, but if it is about mooring a wave energy converter, it has to be dynamic and move in a particular way to convert the energy. So, there is a bit of a paradox there because the mooring system should keep the station and not drift away, but the motion should not be constrained.

There is a vast market for high-tech marine energy devices but whether wave energy will be able to deliver it commercially is a question mark. The reason is that there is not a great entry point for utility-scale wave energy because of the lack of a market where they need to compete with more mature renewables.

- ***Technology performance***

WEC developers should drive up the technology performance level (TPL) as much as possible before they drive up TRL because if they realize that their performance is suboptimal as they get further up to TRLs, it takes a lot of money to go back and update or change parts of their system. Some companies have been driving up TRL and can make the best performing technology in the world, but if no one knows about it and they do not have any investors, it is never going to get built because it is too low TRL wise; equally, they could have a fantastic business team that can sell even something that is underperforming, but if they can convince the investors, they can get up to really high TRL, but their performance is relatively poor. So, it is a really delicate balance.

4.3.2.2 Theme 2: Capabilities

The second major theme to emerge was technology development capabilities. Based on participants' experiences, the participants advanced three areas of capabilities outlined in Table (4-13). Organizational capabilities were the most prominent, with 23 references among the nine participants.

Table (4-13) Coding related to technology development capabilities

Subtheme		No. of participants	No. of references
2.	Capabilities	**9**	**97**
2.3.	**Internal Capabilities**	**9**	**59**
2.3.2.	**Technological**	**6**	**15**
2.3.2.1.	Concept know-how	**3**	**5**
2.3.2.2.	Design	**1**	**1**
2.3.2.3.	Experimental Modelling-Validation	**4**	**7**
2.3.2.3.1.	Test sites	3	5
2.3.2.3.2.	Modelling	2	2
2.3.2.4.	Scaling	**1**	**1**
2.3.2.5.	Manufacturing, Installation and Operation	**1**	**1**
2.3.3.	**Managerial**	**6**	**21**
2.3.3.1.	Technical skills	**7**	**11**
2.3.3.2.	Team structure	**2**	**8**
2.3.3.3.	Project Management	**1**	**2**
2.3.4.	**Organizational (Commercial)**	**9**	**23**
2.3.4.1.	Access to Finance	**6**	**10**
2.3.4.1.1.	Cashflow	1	2
2.3.4.1.2.	Consultancy	1	1
2.3.4.1.3.	R&D Support	2	2
2.3.4.1.4.	Grants	4	4
2.3.4.2.	Customer Market	**6**	**13**
2.3.4.2.1.	Demand	1	2
2.3.4.2.2.	Engaging with Customers	1	1
2.3.4.2.3.	Intermediate Market	2	5
2.3.4.2.4.	Commercialization	**5**	**6**
2.3.4.2.4.1.	Commercial awareness	2	2
2.3.4.2.4.2.	Scaling	3	4
2.4.	**External Capabilities (Outsourcing)**	**9**	**38**

2.4.2.	Partnership or Collaboration	9	36
2.4.3.	Strong Supply Chain	1	2

Interviews with experts in developing marine energy technologies allowed for more in-depth mapping of SMEs and start-ups' important capabilities. The following sections present resources and capabilities for technology development uncovered from the information provided by the nine interviewees to answer the second question of research:

What technological, organizational/managerial, and commercial level capabilities enable ventures to develop technologies from proof of concept to scalable prototype development within the marine sector?

➢ ***Technological Capabilities***

The most iterated technological challenges are related to concept know-how and experimental modelling.

Concept know-how

Most respondents believe that having a reliable idea and engineering capability is of great importance. SMEs fail quickly, but they need to learn to move on. The ability to learn by doing through the deployment at sea and in the lab because it gives much more credibility.

Experimental Modelling/Validation

Based on the results, having access to test facilities is necessary for modelling and validation steps. Test sites facilitate the testing and development of wave, tidal and offshore wind energy technologies at all TRLs. For example, in Ireland:

- **Lir National Ocean Test Facility** consists of wave tanks and electrical rigs that allow for scaled testing in a controlled environment (TRL1 to 4).

- **Marine and Renewable Energy Test Site - Galway Bay**, collaborating with SEAI, MaREI (UCC) and SmartBay Ireland, developed a national test and demonstration facility in north Galway Bay, near Spiddal (TRL4 to 6).
- **Atlantic Marine Energy Test Site (AMETS)** is developed by the SEAI to facilitate the testing of full-scale WECs in an open ocean environment (TRL7 to 9).

In UK, the **European Marine Energy Centre (EMEC)**[1] in Orkney is the world's largest tidal stream array and the world's most powerful tidal stream turbine.

Besides, university campus companies work with the university, which means they have access to quite a lot of expertise. Also, until TRL7, SMEs usually have expertise in-house in terms of developing something that can be brought from an idea to something that exists. Besides, proximity and access to university facilities, such as wave tanks, make it easier and cheaper for SMEs to access facilities, which are really important to develop the technology.

➢ ***Managerial Capabilities***

The most iterated managerial capabilities are described below.

Technical skills

People are key. In this regard, competent engineers who control any problem, people with the proper knowledge of the industries in terms of the technical side, system side, and marine operation side, and getting all of that knowledge in, especially through mid-TRL development levels, is of great importance because it is a lot cheaper to make

[1] https://www.emec.org.uk/

changes there than later TRL levels. Technical skills in-house in terms of developing something that can be brought from an idea to something that exists (available consultants) diminish the need for multiple partners.

How to obtain funding, manage the cash flow headaches of projects, and manage the unknowns in the projects is highly dependent on the marine energy developers' experience. Having a degree or working in naval architecture, marine engineering, or offshore engineering and having experience in business and issues helps developers know what can and cannot be done in an offshore construction environment, e.g., spreadsheet and hand calculations to show the primary response of the structure.

Team structure

During TRL 1 to 3, SMEs focus on component design, build, and engineering assessments. Maintaining a small company and just bringing expertise as needed prevent SMEs from getting big too quickly and bust. As most marine energy developers rely on public sector research and development grant funding, the contracts are usually on the order of a couple of years. Hence, large batches of hiring for internal resources are difficult because they cannot guarantee that they will be able to employ someone for more than the duration of existing R&D contracts. So, there has been a lot of focus on keeping the team internally small and light and then relying on contractors and consultants for some specialized engineering work and leveraging academia and public sector labs.

SMEs need both business groups for management, commercialization, programmes, and operations and the technology R&D group for engineering, physical modelling, and numerical modelling.

- ***Organizational Capabilities***

Organizational capabilities are the most critical internal capability to deliver a product. The key issues are described below.

Access to Finance

SMEs need to be able to finance the development, even if they have got a brilliant idea. So, it is necessary to have a great grant application (proposal). In this regard, reviewing grant applications and grant agreements can help. Besides the cash flow side of things, getting to the point that somebody is willing to bankroll the project is essential. Hence, cash flow projections and budget management are necessary. Grant funding is never 100% funding, so SMEs need to use cash reserves to help with the cash flow issues

There are various funding opportunities for SMEs and start-ups that can help them get off the ground. Some of them are described below:

- Science Foundation Ireland (SFI) grant: Network with academics can lead to getting research funding like SFI. https://www.sfi.ie/research-news/news/marei-secure-4.4-million-/
- SEAI grants: SEAI supports the sustainable development of Ireland’s ocean energy potential through several activities such as test sites, energy technologies, policy, and funding. https://www.seai.ie/technologies/ocean-energy/

- Wave Energy Scotland (WES): WES is driving the search for innovative solutions to the technical challenges facing the wave energy sector to produce reliable technology that will result in cost-effective wave energy generation. https://www.waveenergyscotland.co.uk/

Some SMEs do consultancy and develop new technologies to get grant money to keep the consultancy running.

Customer Market

There is a market pull and demand for marine renewable energy. It is necessary to speak to all customers and inform them about the impact of technology on their projects. Commercial awareness and the ability to convince a client that the idea is worth investing in are necessary because, ultimately, all engineering is wasted if they cannot do that. So, even if developers get a brilliant idea to develop, keeping a commercial focus is necessary. There is no point in having a bright idea unless you are sure that you will have something that people will buy somewhere down the line. So, SMEs need to have a scalable product in a scalable market and to get the volume to the point that costs are low.

Until TRL 7, SMEs benefit from public grant funding and hide behind the scale of the prototype. The funding is usually for a smaller prototype, but it makes SMEs unique in matching their technology development specification and prototype scale with their budget. So, it is necessary to have a scalable product in a scalable market and get the volume to the point that costs are low. A scalable technology opens up more opportunities by addressing more market needs and accessing more markets in theory.

SMEs can develop and grow the technology through small and intermediary markets until it is mature enough to enter the utility market. If the goal is to do large scale utility projects, but there is no support, firms need to find a way to build and scale up their operations so that they can have some of the access to the learning rates that they could achieve by doing deployments without necessarily doing utility-scale deployments. So, intermediary markets can be anything that takes a firm from point A to point B, gives some support, and powers anything that requires energy at sea, e.g., even straight electricity for niche markets like islands or very remote areas for microgrids where it might be support for higher LCOEs in the short-term because of the lack of availability of other power sources. This is not just an intermediary market because it is a stepping stone to a large utility market.

4.3.2.3 Theme 3: Outsourcing Capabilities

The third major theme to emerge was related to outsourcing capabilities. Marine sector SMEs have been quite effective in advancing knowledge of how to convert the kinetic energy contained in waves and tides into electricity. However, they could do more with greater intercompany collaboration and tailored company development support from the agency with experience and expertise in ocean energy.

The engineering capability of partner companies, engineering consultants, financial consultants, and academics who have theoretical knowledge of the renewable energy sector helps SMEs achieve their goals. So, having strong partners interested in getting grants or research projects or the money that suits SMEs can ease the way. Also, analysing and identifying the steelworks size and stiffening is a very complex computer analysis. Project partners with the staff who can use the software and have the software license can help SMEs at the analysis stages.

On the other hand, the engagement of supply chain stakeholders was evident in UK marine sector SMEs as a source of emerging market trends but also as a channel for market adoption and commercialization. For example, Scotland's energy strategy sets out the Scottish Government's vision for the future energy system in Scotland in which the strategy places a strong emphasis on the energy sector's economic role, benefits, and potential, from established technologies to those that are new or still emerging. Moreover, the Scottish Government is doing more to help realize this potential of strengthening supply chains.

In order to provide an in-depth analysis of this issue, interviewees were asked about the importance of collaboration for technology development and whom they have collaborated with. The response to this question was used to answer the research's third question:

Do SMEs seek external support? How are externally controlled resources and capabilities leveraged by SMEs to support technology development from proof of concept to scalable prototyping within the marine sector?

Case 1's partnership is with engineering firms, consulting firms, and university academic firms. The partnership is usually with academia at the early stage, which provides funding for the initial feasibility study. Also, it works with very strong partners in Spain with about 100 PhD students and Scotland with a big team. Their partners are interested in getting grants or research projects from Europe to get the money that suits the firm.

Case 2 has collaborated with the University of Edinburgh for a long time to develop the power take-off system. Also, a company helped them with the detailed mechanical design of the power take-off system. Besides, they had partners who helped with the mooring design at different stages of technology development. Finally, a company did the actual build, the steelwork, the assembling, etc.

Case 3 has in-house technical skills and does not need multiple partners.

Case 4 collaborates with eight companies that have particular technologies or software licences and that contribute to the overall concept.

Case 5 considered collaboration very important. However, he mentioned that it is sometimes hard to get assistance. Fortunately, UCC has become very much more helpful, but when they started, UCC was very unhelpful. There is an excellent relationship now, and UCC/MaREI do whatever they can do to help. However, before that, it was like an obstacle to push forward the technology as they transformed a difficult process into a very difficult one. Also, Case 5 has tried to collaborate with a number of international companies, but due to covid restrictions, they could not receive much help.

Case 6 considered collaboration laboratories, research institutes, and consortiums an essential capability for technology development. As the wave energy sector is so reliant on public sector research and development grant funding, the contracts are usually on the order of a couple of years, so large batches of hiring for internal resources are difficult because SMEs cannot guarantee that they will be able to employ someone for more than the duration of existing R&D contracts. So, they focus on keeping the team internally small and light and then relying on contractors and consultants for some specialized engineering work and leveraging academia and public sector labs. Also, he considered hiring external consultants helpful where they could get some experience from people who had helped others in this space before.

Case 7 has collaborated with large numbers of companies and organizations. They had a development agreement with a global polymer company that has done a considerable amount of work in their R&D labs supporting their project and the development of their technology. Also, they had to collaborate heavily on the manufacturing side, both in terms of moulding and welding.

Case 8 has done a lot of work in UCC when it was HMRC, and then they worked with MaREI. Also, they have worked with some consultants from MaREI who have theoretical knowledge. Also, they have collaborated with some companies with engineering consultants and financial consultants with knowledge of the renewable energy sector. The interviewee mentioned that collaboration is tricky as they should find another company that will benefit from the work, and there is a need for synergy between the two companies. They have not found the company yet but finding such partners can be kind of a start of the journey through TRLs. Such collaboration might be more than just an intermediate market; and it can be a gigantic market.

The owner/founder of Case 9 is assisting a company in Germany, which will test its prototype in Asia. Also, he consulted with an SME in Dublin (case 2) and several people in the north of Ireland, where there are many capabilities. The marine technology was mainly developed by a large German company, and the interviewee was mainly trying to coordinate the assistance of international companies through contacts in Asia (Japan) to bring together funding and experience.

4.4 Synopsis of Findings

The key findings of this research are outlined in Table (4-14).

Table (4-14) Summary of Key Findings

RQ	Hypothesis	Finding
RQ1	***Hypothesis (1):*** Marine-based SMEs encounter challenges other than technological in developing market-ready offerings	Tools for assessing technology development like TRLs are generated to define the path forward and focus project engineering and R&D tasks on advancing the technologies to increasing maturity levels through modelling, testing, bench-scale demonstrations, pilot-scale demonstrations, and fully integrated prototype demonstrations. This assessment provides insights into the technological challenges that firms in this sector faced.
		While technological issues at lower TRLs slow down the process of technology development, challenges other than technological disruption also occurred. So, the development and demonstration stages take long and require strong background support.
		Across all stages of technology development, SMEs require access to appropriate sources of financing. Firms’ financing needs are high compared to their turnover and assets, and they usually lack assets.

		Moreover, financial institutions have become more risk-averse, and the financing constraints of these firms have become more structurally entrenched.
		Although the ocean energy sector has benefited from EU support to innovate and move forward, there are still barriers to finding markets. Unless technology is proven, it cannot get technology maturity.
		Small businesses and start-ups have a limited credit history and lack the expertise and skills to produce sophisticated financial statements.
		Other challenges are related to human management, accessing managerial training for employees, lack of professional skills, and a shortage of management and other skills needed in the marine energy sector.
		The most immediate challenge is to prove the reliability and power output of wave and tidal technologies.
RQ2	***Hypothesis (2):*** Technological capabilities enable a transition from TRL concept to scaled prototype	Engineers and marine energy developers with new bright ideas use their know-how in offshore and experience to develop new technology. For example, based on in-depth analysis, hand calculations, and scientific research are usually straightforward for entrepreneurs in the marine energy sector. Another crucial technological capability is the experimental modelling and validation of

		technology by testing prototypes at test facilities. Technology developers show the critical functions and main characteristics of their technology in test facilities. Fortunately, due to the collation of marine institutes, SEAI (in Ireland), and universities, test and demonstration facilities have improved and expanded for testing marine energy prototypes and full-scale products.
	Hypothesis (3): Organizational capabilities enable a transition from TRL concept to scaled prototype	In addition to technological capabilities, SMEs need to develop strategies to facilitate the development process. In this regard, developing a solution for financing needs at the early commercial stages enables SMEs to close the 'funding gap' between TRL3 and TRL7. In this regard, the regulatory framework that supports marine energy development is a crucial enabler for developing instruments that can increase the confidence of a broad range of investors in SME markets.
		Extra financial support and an initial market support tariff need to be provided for emerging sectors like wave and tidal energy.
		Continuous support from the government for demonstrating and de-risking the marine energy technologies at test sites facilitates technology

		development as it shows the feasibility of the product.
		The government has an essential role to play in working with the sector and SMEs to remove barriers to technology development and help stimulate the investment needed to cross the valley of death. This is facilitated by continued and increased investment in skills, infrastructure, and associated facilities (such as testing) to build the education and research base; and support the marine sector to build its capacity for research and development.
		Financing R&D activities in the technology business relies on accurate and verifiable projections of the attractive future market for the technology.
		Developed technologies, especially wave and tidal, have applications in the niche and alternative markets around TRL5 and 6 to provide power to offshore operations, islands, and platforms. So, technologies gain proof to be reliable and sustainable and reduce costs and enter other markets.
	Hypothesis (4): Management capabilities enable a transition from TRL	Management or leadership skills are required to build the technology development roadmap, manage complex changes, and ensure that projects are delivered within budget. It is, therefore, important to

	concept to scaled prototype	invest more in training and skills acquisition actions in order to upgrade human capital and provide a better match for marine energy sector requirements.
RQ3	***Hypothesis (5):*** Capability gaps within the venture (internals) are addressed by seeking externally controlled resources.	Partnerships or relationships with a larger company can be the best route to market. Partnerships are usually with engineering firms, consulting firms, and university academic firms. SMEs have intellectual property, and patents, and working with very strong partners interested in getting a grant or a research project from Europe helps them progress.
		Providing support for innovation and innovation grants (research, development, and innovation (RD&I) fund) to SMEs and start-ups encourages firms to plan innovation and work with external knowledge providers with a bonus for collaboration between two companies.
		While collaboration between companies of different sizes helps transfer knowledge and skills, the biggest challenge facing SMEs is how to access additional capital to plan ahead and seize opportunities to grow and diversify. This collaboration between large firms and start-ups as a special kind of open innovation positively affects the performance of both start-ups and established firms.

5 Discussion

The following chapter covers the discussion of the collected results. The initial interviews helped establish the core challenges in this sector. Then, we aimed to achieve a broad understanding of technology development challenges through the quantitative questionnaire. As a result, some issues were raised by the questionnaire that needed further investigation. Semi-structured interviews were designed to collect data on the most significant technological, managerial, and commercial challenges, the most important technological, managerial, and commercial capabilities, and whether these capabilities are acquired from internal resources to externally controlled resources. We conducted several in-depth interviews to ascertain the key challenges, what causes them, and what areas need to be addressed to avoid them. This discussion follows the structure outlined in the findings chapter and marries findings and theory to illuminate the contribution of the research. The discussion focuses on ***how we can better nurture marine-based SMEs in traversing across the valley of death (TRL3-TRL7)***.

5.1 Discussion of findings

This section contains a discussion of the three major themes that emerged during the study. The overarching research question for this study was: ***What capabilities enable technology-based SMEs in the marine sector to support the advancement of their technology from proof of concept to scalable prototype for market adoption?*** Nine subthemes emerged based on the main research question and key ideas from quantitative questionnaires and literature. Based on research questions, the subthemes were grouped into three major themes: (a) challenges, (b) capabilities, and (c) outsourcing capabilities. Both challenges and capabilities were categorized into (a) technological, (b) managerial, and (c) organizational subcategories.

5.1.1 Research Question 1

The first research question explored the challenges that SMEs (start-ups and established) face in developing technologies, from proof of concept to scalable prototype development within the marine sector. The theoretical roots of RQ1 laid on the premise that ***marine-based SMEs face challenges other than technological in developing market-ready offerings (H1),*** which was something not fully understood within the literature of technology-based SMEs in the marine sector.

The study showed that technological challenges related to the **concept development** and **experimental modelling/validation** of technology development were identified as a core challenge for marine-based SMEs. In support of this finding, despite significant investment in test tanks, modelling, and finite element analysis, ***case 1*** found it necessary to go back to re-do the underlying patents of their developing technology as the technological experimentation and highlighted that the developed technological device was not robust enough to 'survive' during deployment offshore and the hard environmental conditions of the wide range of sea states it would face. In fact, ***case 2*** stressed that a better understanding of the baseline requirement necessary for offshore technology performance was a significant challenge in technology development (TRL2 to TRL3). Accordingly, incorporating such critical information into the parameters of the LCOE model for design and test studies would avoid latter phase problems requiring rework and contribute to reducing development time for the technology progressing across TRL 3 and later TRLs.

In addition, **appropriate infrastructure (facilities and site access)** for specific testing of developed prototypes may not be available or have the necessary functionality or capacity. ***Case 1*** endorsed this problem, citing that although Ireland has become good in terms of its test sites (MaREI in Cork, Galway Bay, etc.), wave energy converter prototypes require deep test tanks, which are not widely available. While national investment has occurred in infrastructure in recent years, facilities such as the MaREI centre have only shallow tanks, and this is why ***case 1*** was compelled to test at international sites such as SEM-REV Sea Test Site, Nantes, France. Another technology-enabling issue related to test sites and facilities was permission and licensing issues to test the prototypes in a practical location (***case 3*** and ***case 8***). The slow pace of testing processes is aggravated by the limited availability of testing infrastructure at various scales and expensive environmental monitoring, partly due to expensive and time-consuming permitting processes. These obstacles severely limited technology developers' ability to promptly assess the performance of devices and components, develop innovative technological solutions, and deploy the next generation of technologies to sea and progression across the TRL.

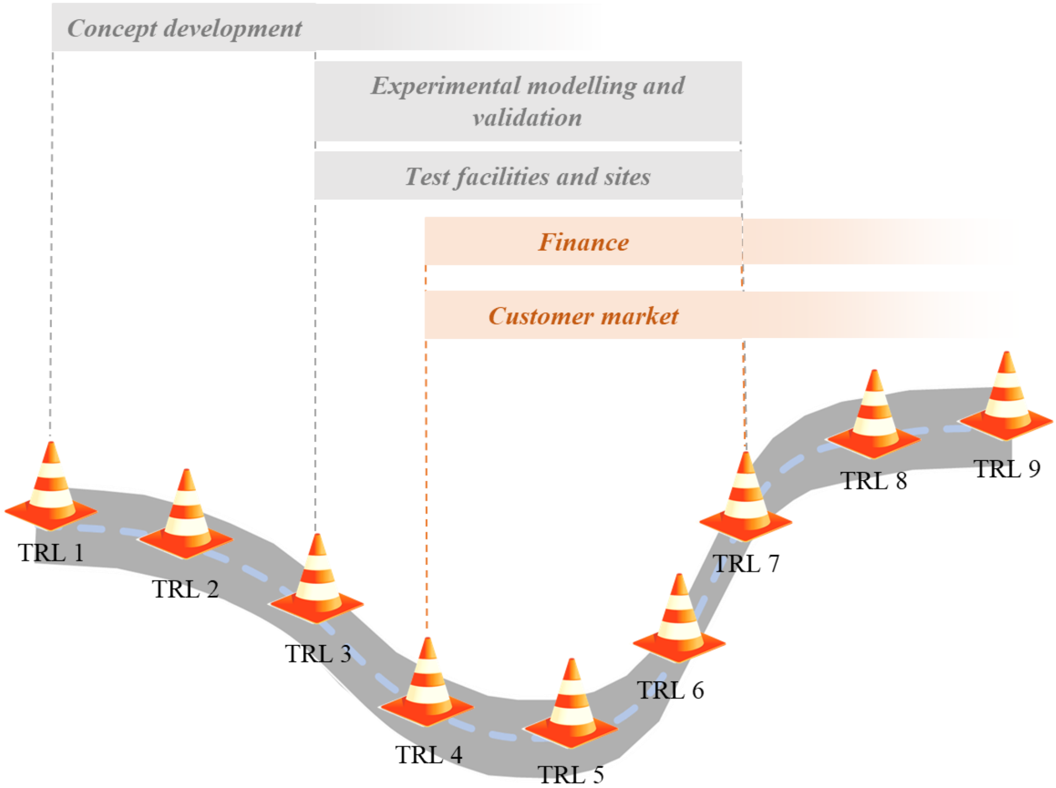
This study also reveals that there are challenges other than direct technological issues impeding marine-based SMEs in developing market-ready offerings. The most significant issue cited by SMEs as impeding their developmental efforts across the '*valley of death*' was a **lack of financial resources**. Developing technology in the marine energy sector requires considerable funding, and micro-SMEs often struggle to access the financial channels to support their ambitions. For instance, ***case 1***, established in 2012 and comprising a small team of entrepreneurs and experts in wave energy, was unable to acquire funding since Enterprise Ireland did not consider them a high potential start-up due to their age. The findings highlight that funding agencies are often unfamiliar with the development adoption cycles of marine-based energy technologies, which means that marine energy technologies depending upon technology in such an emerging sector, might need 5 to 20 years to reach market adaption. However, funding agencies are unrealistic in their commercialisation expectations. Equally, private funding sources (e.g. banks) perceive lending to such micro-SMEs as high risk, given their scarce assets and stage of TRL. Such institutions have a preference for lending to larger-scale entities with collateral and scale to support repayment of the loan. For many SMEs studied, either private funds or public financial backing were their core sources of financial support. However, feedback highlighted that public funding is primarily available only up to TRL 4 and gets more selectively distributed and competitive after this stage. Government funding, given the exponential costs associated with later TRL stages, concentrated available funds towards a selected few cases.

Around TRL 3 and 4, the challenges initially emerge in technological form; however, when SMEs get to TRL 5 and 6, acquiring funding becomes even more complex and creates a critical gap that stalls progress and requires the management team to shift focus from technological development to finding new private investors and clients to support the ventures continuation. In this regard, ***Case 6*** pointed out that although they had interest from some major international companies, they did not progress since the technological offering was too early (too far from large scale commercialisation) for them to invest in. Thus, marine-based SMEs often find themselves ‘stuck’ as initial finances deplete and the higher investment costs of moving between TRL 4 to TRL 6 that will demonstrate and validate the technology for the potential support of international companies becomes a 'glass-ceiling' to progression. At this stage, SMEs need supportive investors to assist what they are doing as a small company and given private investors base their investment decisions on the perceived risk; then there is a need for greater Governmental financial support to assist the SMEs in getting their technology to the level where the larger-scale enterprise will be interested investing.

Also, challenges associated with access to funding are linked to another organizational challenge: finding a **suitable market**. There is market demand for commercially ready products emerging from the marine energy industry, but the market readiness varies significantly depending upon the specific technology. Also, finding a market might seem to press at final TRLs, but there is an indispensable need to consider the importance of commercialization at early TRLs. For example, ***case 1***, developing wave energy technology highlights that its current technological development is questionable in terms of its ability to deliver energy commercially, especially relative to competing technologies such as offshore wind generation. This means that SMEs need to maintain a constant commercial focus, not only on competitors within their technological sector but also in other sectors that can equally address the market requirement of reliable, economical and environmentally benign energy. For SMEs to achieve private investment, they need to be able to demonstrate their competitive advantage relative to market demands, even at low TRLs. Where certain competing technologies advance faster than others, securing financial support and channels for market adoption can become more challenging for the technology at the earlier TRL stage. Thus, in terms of developing technology in competing sectors of wave, wind, solar and tidal technologies, many SMEs cite being squeezed out as both funding and utility companies embrace offshore wind as their preferred option. While this enhances the situation for technology development SMEs in the offshore wind energy sector, others, such as wave energy, are neglected and left in limbo. There is commercial opportunity in all emerging marine-energy technologies, but their unique development should be supported rather than grouped together to realise their full potential. Needless to say, it is really difficult to explain the issue to potential investors of solar, wind, wave, and tidal and again emphasises the role of public funding in supporting the development of these alternative energy technologies, especially since their true commercial potential is not yet been established.

To conclude, the findings highlight that challenges other than those of a technical nature impede SMEs from advancing market-ready offerings across the **valley of death**, and these include financial gaps or a lack of suitable funding sources, testing and validation infrastructural gaps and an unsupportive ecosystem. Therefore, what impedes the technology development by marine-based SMEs is not a single technology-based challenge; nonetheless, the overlap of multiple key challenges shapes the valley of death between TRL 3 and 7 (Figure (5-1)). Although different challenges press at different points, we need to consider all and seek capabilities to traverse them.

Figure (5-1) Key challenges of technology development



These impediments to TRL development align with past studies of Al Natsheh et al. (2021) and An & Zhang (2021).

5.1.2 Research Question 2

The second research question explored the technological, organizational, and managerial level capabilities that enable ventures to develop technologies from proof of concept to scalable prototype development within the marine sector. The theoretical roots of RQ2 lay on the premise that ***(a) Technological capabilities at the organizational level enable a transition from TRL concept to scaled prototype (H2), (b) Organizational capabilities enable a transition from TRL concept to scaled prototype (H3), and (c) Management capabilities enable a transition from TRL concept to scaled prototype (H4),*** which is confirmed across the capabilities literature (not for the marine sector specifically). Mentioned capabilities are addressed in the literature separately and are likely to develop within specific SMEs, dependent upon the contextual challenges that it faces.

Our results cast a new light on the challenges SMEs face in the marine energy sector and the capabilities that enable the technological progression from TRL 3 to TRL 7. Technology development across this Valley of Death is difficult to survive, and despite studies by An and Zhang (2021), Barr *et al.*(2009) and Hartley and Medlock (2017), a consensus on a solution is yet to be reached. Hence, this study strives to contribute by ***better understanding the capabilities facilitating this crossing for marine-based technology SMEs and, subsequently, offer recommendations regarding intervention strategies to better prepare future SMEs in terms of underlying capabilities for enhanced technological and commercial development.***

In terms of technological capabilities, previous research by Lin & Lai (2020) has explored the determinants of improvements to technological capabilities, and Salisu & Abu Bakar (2019) has explored the mediating role of learning capability on the relationship between technological capability, relational capability and SMEs performance, in terms of organizational capabilities. Also, our research focus aligns with previous research by Uhlaner et al. (2013) that identifies drivers of SME sales growth related to knowledge and innovation (e.g. external sourcing and employee involvement) and Klitsie et al. (2019) that explored managerial capabilities advantageous during the design innovation.

A core contribution of this study is that we proposed a conceptual framework of technological, organizational, and managerial capabilities to explore the enablers of technology development when crossing the valley of death in marine sector SMEs and in the findings from research question 2, find support for same.

5.1.2.1 Technological capabilities

It is important to propose a robust, innovative solution at the concept stage because marine energy technologies must survive and remain on-site for the duration of the development in an energetic environment; they must work reliably across a wide range of sea states and possess the scope to become scalable and suitable for utility-scale arrays. However, SMEs' ability to adopt innovation is limited mainly due to the lack of financial capital, human capital, and market knowledge or technical skills. This ties back to technological innovation literature, e.g., Donbesuur et al. (2020), Hervas-oliver et al. (2021), and Indrawati & Suarman (2020).

Traversing TRL3 to 7, the aim is not to fully launch the innovative products but to test ideas within a limited scope to determine whether customers are willing to pay for the product, how much they are willing to pay for it, and how many are likely to buy over what timescale. Hence, having a **robust idea** is of great importance. To shed light on this issue, ***case 1*** mentioned the Wave Energy Converter company that developed a technology that used the motion of ocean surface waves to create electricity, was towed back to land due to the problems encountered during the transition phase. First, there was a technical problem related to buoyancy discovered during testing, and then, due to the financial crisis, partners pulled back from the venture, reducing the financial reserves available to progress the venture. The technology was shelved based on these impediments, and the project's engineering effort and technical developments went unexploited. ***Case 1*** **learn**ed the lesson of this failed project and created a scientific and technological understanding of their concept and the path toward technology readiness. So, the first key capability to avoid falling into the trap of the valley of death is by taking the feedback and experience of prior technology developers and learning from them to develop an adaptable technology. Through successful completion of proof of concept and theoretical modelling, the experimental testing and investigation validate aspects of a technology (Dhanak and Xiros, 2017) to prevent more expensive latter phase problems and increase confidence in the technology.

Moreover, **knowledge transfer** should be embedded among manufacturers, developers, utilities, agencies, regulatory bodies, and government departments to create some general notions for emerging start-ups before they approach the sector. For this purpose, a combination of framed experiences, values, contextual information, and expert insights can provide a framework for assessing and incorporating new experiences and information. For instance, ***case 5*** benefitted from its former history and experience as the founder of the company had a couple of prior companies in the wind energy sector starting from the 1980s, and they guided the company through developing an early-stage renewable technology. So, ***case 5*** was able to cross the valley of death and move forward through the TRL ladder by taking advantage of the knowledge of experts and embarking the technology development based on a robust idea.

Then, technology developers need to test the validity of mathematical models by **experimental analysis** at **test facilities and sites**. In this regard, the scalability of technological components is of great importance for testing in a simulated environment and identifying the barriers to target performance. ***Case 4*** attained feedback resulting in **changes to the technical specifications**, which made the technology more suitable for the test site environment and ultimately assisted their crossing the valley of death. Thus, their ability to apply their technological expertise to resolve these issues from the redesign within these phases resulted in better designed, robust, and scalable for the operational environments. This technology demonstration stage starts from TRL4 and requires ocean test facilities. There might be many test facilities that align with small grants to move into the real demonstration stage, but the permission process might lead to unexpected delays. ***Case 2*** could go through this challenge due to **proximity and access to university facilities** through EngD students. Therefore, besides having a robust technical performance and meeting scaling requirements, a strong understanding of the test labs and facilities helped case 2 to succeed despite its limited resources. Obviously, an overlap of internal and external capabilities is apparent here, as **strong ties with the university** made the testing process easier and cheaper. Anyway, regulators, advisory authorities, and stakeholders should ease the permission process. In this regard, test facility monitoring can aid regulators in defining reasonable regulations and improving the sector's understanding of the technology's environmental impacts. Besides, most test facilities rely on public funding. Early-stage public funding support can help marine energy developers develop this promising sector. Also, private sector collaboration or collaboration through European programmes in demonstrations is beneficial in providing real operational environments for testing, developing, and demonstrating new technologies. This aligns with previous research by Noble et al. (2021), who build on recommendations incorporated into the development of international standards for the marine energy sector.

Therefore, in the early stages of development (TRL 1-3), having a robust concept by grasping the knowledge and experience of expertise and knowledge transfer and learning from others' experiences can prevent several trial and errors and the need for re-design and at the latter stages (TRL4-6), Having a scalable product enables SMEs to demonstrate their technology at different test facilities and opens up more opportunities for SMEs as they can address more market needs. Besides, testing technologies can be eased through access and proximity to university facilities by student replacement. Also, appropriation of test facilities relative to the technologies' requirements might be a worthy point to be considered by governments even though it is a debatable implication whether this expectation from the Irish government is logical or SMEs need to consider all facilities in Europe and worldwide instead of concentrating on few test facilities and sites in Ireland.

5.1.2.2 Organizational capabilities

Based on both results and literature, there should be no surprise that the most prominent solution for bridging the valley of death is to contribute more financial resources to the projects. As mentioned earlier, although having a bright idea is important, being able to **finance** the development is much more crucial. In order to cross this barrier, ***case 4*** pointed out that the key solution to their success in getting funds was by writing a **convincing grant application/proposal** to get funding by reviewing the grant applications or agreements. In some funding supports and programmes, SMEs need to compete for funding with high-tech SMEs from other sectors like pharmaceutical, agriculture, etc. Nevertheless, each sector needs to have **specific funding competitions and rounds**. In this regard, one of the beneficial programs is Wave Energy Scotland (WES) which helped ***case 2***, where the Scottish government specified funding to drive innovation forward in the wave energy sector. In fact, to avoid losing the know-how from commercially unsuccessful projects by two flagship companies (Plemis wave power and Aquamarine), the Scottish government proposed a more structured way of funding with different phases.

Moreover, the **cash flow** side of things is important, too, as grant fundings are never 100%, and sometimes SMEs need to use the cash reserves to help with the cash flow issue. In support of this claim, ***case 9*** developed its technology using the surplus funds from its profits. This can be assumed as an escape way of the financial crisis.

In addition to access to finance, at TRLs 4-6, technology developers should manage competing demands: the need to demonstrate that their technology is reliable to increase investor confidence and the necessity to reduce costs to make their technology commercially viable. In this regard, **customer focus** (**intermediate market**) accelerates the transition from TRL 3 to 7 and to commercialization. Therefore, from TRL4, the company should acquire a customer focus to reduce the market risk of the innovation. This can lead to the validation of the market with the assistance of an active strategic investor where SMEs need a transition between technology push and market pull. This transition is, in essence, the product/market fit. Until that happens, the challenge can be crossed by finding the right way to navigate through the intermediate market. ***Case 2*** and ***5*** could continue to grow and develop the technology through the intermediary market (through microgrids or sort of power in blue economy operations or small-scale remote deployment). Intermediate investors can increase their commercial expertise and utilize customer involvement strategies. This ties back to the literature of key intermediaries (such as government-funded programs, business incubators and technology brokers), which orchestrate two innovation mechanisms: technology-push and market-pull. This is consistent with research by Islam (2017) that developed an integrated technology-push and market-pull framework, a value chain model for crossing the valley of death for emerging technologies. So, using the intermediary market as an alternative way to access finance acknowledges and compliments the proposed ways of crossing the valley of death.

Therefore, Organizational capabilities, namely access to funding and having a commercial awareness and finding intermediary markets enable a transition from TRL concept to a scaled prototype.

5.1.2.3 Managerial Capabilities

In addition to technological and organizational capabilities, developing capabilities in emerging market firms requires **human skills and expertise**. Depending on the capability they would want to acquire, firms could try to attract different service task types. However, a wide variety of partners increases the level of complexity of the partnerships (Bengtsson *et al.*, 2015), which can be challenging for SMEs to manage with limited managerial resources. In this regard, ***case 6*** confirmed that specialized **training in management and business** was helpful for them. In most cases, information gaps make smaller firms less aware of the benefits they would obtain from management training, and few see training as a strategic tool. However, business management training can shed light on some facets of the business, including time and budgetary constraints, market, etc. Therefore, the SME management team will be able to predict the potential risks and mitigate the impact of possible losses. In fact, transition across the TRL 3-7 phases is a learning cycle rather than stage-gate impediments that must be overcome.

Another point that needs to be highlighted here is that managerial capabilities are not limited to TRL3 to 7. The management team should constantly try to create external relations and find partners to fill the internal gaps, keep track of the public and private funding opportunities and develop risk management plans to avoid losses at different TRLs. All this is in line with the previous research of Meyer et al. (2018), who showed the significance of the impact of a shortage of skilled labour, insufficient business training, and the lack of networking opportunities. The implications of these findings point to the importance of the provision and ease of access to quality practical business management training.

In brief conclusion, the concept of technology changes through time and at different TRL phases. SMEs must have a balance of technological, organizational and managerial capabilities to create reiterative learning from 'trial and error' because the concept might need redesign based on environment conditions (technological aspect), the market requirements (organizational aspect), and stakeholders' expectations (managerial aspect). So, by consistent learning, technology developers can become more familiar with the marine energy ecosystem and deliver the market-ready technology to successfully address the market value proposition.

5.1.3 Research Question 3

The third research question explored what externally controlled resources can attain to develop technologies from proof of concept to scalable prototype development within the marine sector. The theoretical roots of RQ3 lay in the premise that ***Capability gaps within the venture (internals) are addressed by seeking externally controlled resources (H5).***

SMEs are significantly resource-constrained in terms of capital, technological knowledge, and human resources, which constantly limits their technology development. They are usually reliant on public sector R&D grants; the contracts are usually on the order of a couple of years. Hence, hiring is difficult as SMEs cannot guarantee the employment of internal skills. In this regard, ***case 5*** had a lot of focus on keeping the team internally small and relying on **contractors and consultants** for some specialized engineering and leveraging academia and public sector labs through the technology development process. So, when SMEs cannot cross the impediments through technology development, outsourcing these capabilities, such as external finance, government readiness, market forces, and using ideas and knowledge from external actors by SMEs, is one way to overcome this problem. Accordingly, it is necessary to examine the role of institutional support through private-government/public partnerships, incubation or through coordination efforts with local government in helping alleviate the Valley of Death.

A debatable point that arises here is that the managerial preference of SMEs at mid-TRLs is to keep the firm small and collaborate with other partners instead. This is due to having limited resources and capabilities and a tendency to learn from their partners to develop new technological, organizational, and managerial capabilities. On the contrary, despite the obvious benefits of collaboration, SMEs might have some concerns about finding appropriate partners, providing finance to pay for some services, time-consuming processes and complicated contracts, and losing their intellectual property through partnership. Also, there might be a geographic or language barrier between SMEs and their desired partners.

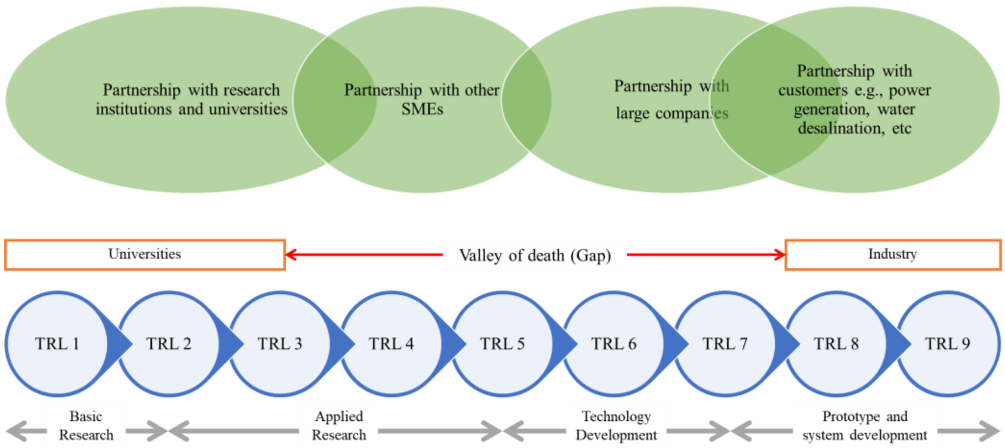
Firms that form **collaborating** agreements establish mechanisms and routines that create a shared context to effectively facilitate knowledge transfer contributing to the firms' success. Also, it helps SMEs avoid duplication and drives innovation more efficiently than working in isolation. This concept is true for collaboration within the sector itself but also for collaboration with other industries, particularly those working offshore. For example, ***case 2*** collaborated with several partners to design the initial power-take-off (PTO) system, mooring design, detailed mechanical design, etc. Similarly, ***case 7*** has collaborated with a large number of companies, such as a polymer company with an R&D lab. Hence, with the right networking skills, they could access resources from the external environment and traverse the valley of death.

The literature addresses this by open innovation through partnership (Tobiassen and Pettersen, 2018) that helps SMEs by engaging a broader set of skills, ideas, resources, and relationships than any organization working alone, where knowledge exchange represents a flow of information that facilitates mutual learning. This research acknowledged the finding by Gui, Wang and Yu (2022), who identifies critical barriers inhibiting knowledge exchange among marine scientists and decisions-maker.

On the other hand, open innovation embraces both innovation through open data and open-source software. Partnership between multinational corporations and SMEs can help facilitate relationships, ensure the successful delivery of technical skills and know-how from the corporation to SMEs, and fill in gaps in execution to help build trust and get the linkage off the ground. The results revealed that entrepreneurs must have utilized external resources to satisfy the absence of their internal resources. Implementing open innovation practices helped them save time and financial resources on marketing and overcome competitors because of their product's unique and improved features, which led to greater customer insight and improved commercialization of new ideas.

Therefore, marine sector SMEs should collaborate with both the public and private sectors to address the internal capability gaps through technology development and harnessing external resources impact the ability of SMEs to cross the valley of death.

Figure (5-2) Partnership through the technology development process



As shown in Figure (5-2), partnerships can start with R&D projects and collaboration with universities (Pereira and Franco, 2022) through resource-sharing and practical solutions to problems and access to complementary resources. In this regard, creating forums where people engaged in offshore renewable energy can meet, discuss, share ideas, and meet future clients can become significant. This collaboration can also facilitate the access of SMEs to university test facilities with lower costs and fewer permission procedures.

Then, it comes to partnership with other SMEs where equal benefits from new technology development, winning a new market, and creating additional income can be seen as essential incentives. For example, wave and offshore floating wind technologies need mooring systems that can be produced by a small company. Also, collaboration can be valuable in helping SMEs to facilitate relationships and ensure the successful delivery of technical skills and know-how from the Corporation to SMEs to traverse the valley of death.

Finally, for most SMEs, success is all about the ability to reach the customers who are aware of or interested in their innovative invention. This is not limited to commercialization at higher TRLs (8 and 9); however, it involves finding an intermediate market at intermediary TRLs where commercial awareness and the ability to convince a client that the idea is worth investing in becomes important, and they can uptake alternative finance and grow. For instance, wave energy technologies can be used to power aquaculture farms to make their business more sustainable. Although it can be a target market for wave energy, this can also be an intermediate market where wave energy prototypes can be used to power some of their equipment and operations.

5.1.4 Summary of Discussion

The primary context of this research was to explore the challenges of developing technologies in the marine energy sector. Then, the ways to cross these challenges were addressed by technological, organizational, and managerial capabilities benefitting from technology developers' perspective. The findings revealed that the key capabilities that SMEs in the marine sector need to be developed along their lifecycle, between TRL3 and 7 (Figure (5-3)). As discussed above, traversing the gap between TRL3 and 7 requires a mixture of capabilities, and the importance of those capabilities varies at different TRLs and sub-sectors. Proposed capabilities help researchers and technology developers to improve the Technology Readiness Levels to manage risk better, communicate development progress and specify deliverables. Therefore, the transition from proof-of-concept to scalable prototyping requires a balance of various capabilities. When SMEs cannot find a solution for the challenges, they look outside for partners to fill those gaps. Partners can open up opportunities that SMEs cannot access alone. At later TRLs, collaboration with large companies can increase the reputation of SMEs and help them pitch and commercialize.

Figure (5-3) Key capabilities for movement from TRL3 to TRL7

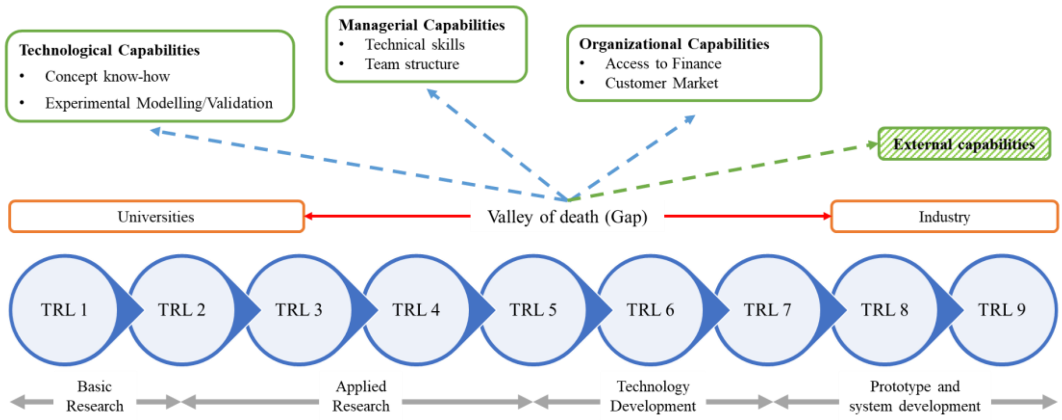


Table (5-1) provides a very brief tabular presentation of the convergence of theoretical findings and results from quantitative and qualitative analyses.

Table (5-1) Comparing the results from theory and empirical research

Key Theme	Theoretical Finding	Research Finding	Our contribution
Challenges (other than technological) of marine-based SMEs in developing market-ready offerings	Markham *et al.* (2010) claim that the **“valley of death”** where public-funded ideas fail to make the transition to private-funded solutions is often the site where many start-up firms or emergent technologies flounder and fail.	All quantitative and qualitative results provided information that SMEs face considerable challenges (other than technological) related to finance, legislations, protecting intellectual property, finding the customer market, etc., through the valley of death to prove their commercial viability. So, the findings confirm that the valley of death has hindered the progress of marine sector SMEs.	Challenges of marine energy sector SMEs were something not fully understood within the literature. However, marine energy is an emerging technology with considerable uncertainty regarding the pace and direction of development. Therefore, this study makes a valuable contribution that addresses the valley of death in the context of marine energy sector SMEs.

Technological, Organizational, and Managerial Capabilities that enable a transition from TRL concept to scaled prototype	The **resource-based view** (Barney, 1991) is the leading theory underpinning this research, which is widely confirmed across the capability literature. In particular, findings are consistent with the literature on **technological** (Lin and Lai, 2020), **organizational** (Klitsie, Price and De Lille, 2019) and **managerial** capabilities (An and Zhang, 2021) contributing to crossing the valley of death.	All quantitative and qualitative results provided information that SMEs in the marine energy sector should propose an innovative solution at the concept stage which ties back to technological innovation literature (Donbesuur *et al.*, 2020) (technological capability). Also, regulators, advisory authorities, and stakeholders should ease the permission process of test facilities for testing, developing, and demonstrating new technologies. In order to increase investor confidence and reduce costs, customer focus (intermediate market) accelerates the transition between technology push and market pull (Marin *et al.*, 2017) (organizational capability).	Mentioned capabilities (our framework) are addressed in the literature separately. Therefore, one contribution of this study was proposing a framework of technological, organizational, and managerial capabilities to explore the enablers of technology development, and no single factor enables crossing the valley of death.

		Moreover, the results revealed that managerial capabilities facilitate deployment and alignment of organizational capabilities toward a transition from TRL 3 to 7. So, the findings confirm that internal capabilities help SMEs traverse the valley of death.	
Seeking externally controlled resources to fill the capability gaps within the venture (internals)	The literature addresses the concept of seeking external capabilities by extending the **RBV theory** (Wernerfelt, 1984; Barney, Wright and Ketchen, 2001; Barney and Arikan, 2006) and confirming the **innovative partnership** (Su, Tsang and Peng, 2009), **open innovation**	All cases provided information revealing the firm's ability to integrate and build the internal and external capabilities to traverse the valley of death. Marine sector SMEs can benefit from networks in the form of collaboration, with universities and research institutes seem where	The positive influence of partnership on nurturing SMEs in traversing across the valley of death (TRL3-TRL7) was widely evident. The present study provides substantial evidence that, like SMEs in other sectors, marine-based SMEs should leverage partnerships to raise the

	(Su, Tsang and Peng, 2009; Rocha, Mamédio and Quandt, 2019; Sabando-Vera *et al.*, 2022), and **technology transfer** (Cedano and Hernández-Granados, 2021) literature.	they can get off the ground and acquire credibility, with other SMEs where they can complement each other's capabilities and thus co-create and deliver new value propositions, with large companies where they can acquire external knowledge resources and stake their reputation and future on the large partner's integrity and willingness to find win-win solutions, and finally with customers where SMEs can receive market-related resources as knowledge of customer needs,	needed resources and successfully navigate all the pitfalls of the valley of death.

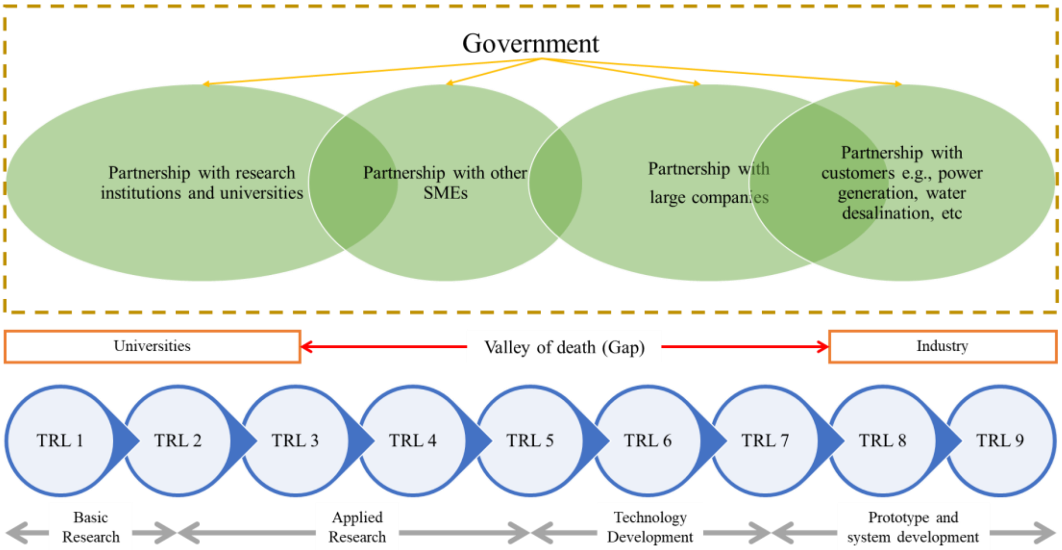
		preferences, purchasing procedures, distribution and sales access to customers, customer goodwill.	

5.2 Policy measures

Direct public policy measures facilitate SMEs' innovation and growth by providing direct incentives for R&D, such as R&D subsidies, government tax credits and loans and encouraging them to collaborate with external institutions across industries. These SME-focused programs include state funding for R&D projects, dedicated innovation managers and facilitating networking between business and science to reduce costs and risks. However, the transfer and flow of information between firms or between firms and public research organizations rather than the actual production of R&D might make technology development difficult. In this regard, indirect policy measures that focus on network-facilitating activities such as financing test facilities, incubation centres, business network initiatives and technology intermediaries are crucial to identify and refine promising policy means for SMEs.

Also, as shown in Figure (5-4), the gap between public institutions like universities and industry and the fragmented function of public and private sectors leads to the failure of technology development. In order to avoid this problem, the government should develop an integrated marine sustainable development plan, focusing on all aspects of marine energy technology development from the early stages of R&D until full-scale commercialization. Government support must go beyond financial support for research and development or technological demonstration projects in the marine energy sector, such as a "technology roadmap" program for technology improvements.

Figure (5-4) Government role in partnership creation through the technology development process



5.2.1 Action points

In sum, we can better nurture marine-based SMEs in traversing across the valley of death (TRL3-TRL7) through providing the below supports:

- Providing innovative infrastructures and test facilities that are capable of enduring the severe marine environmental stresses and guaranteeing their constant operability
- Providing financial support for (innovative) SMEs and start-ups to different levels of technology development for the transition of laboratory prototypes to commercialized products
- Complementing financial support and improving stakeholder engagement in regulatory development of the marine energy sector by a comprehensive bundle of policy measures to address other challenges, such as a high regulatory burden, weak managerial skills, access to skilled labour, innovation, and internationalisation.

- Targeted education programmes to help entrepreneurs develop a long-term strategic approach to business financing, enhance understanding of the economic and financial landscape of relevance to their business, identify and approach providers of finance and investors, understand and manage financial risk for different instruments.
    - Stimulate apprenticeships or mentorships for entrepreneurs
    - Develop plans for financial and managerial education for small business owners and managers
    - Recruitment of new researchers from different disciplines for multi-disciplinary research to address complex development issues
- Partnerships for risk-sharing by both public and private sectors by providing research and development funding
- Developing new business models might be needed to address the technology, risk, and financial challenges
- Facilitating knowledge and scientific information transfer and exportation of best practices through joint-effort of academic and industry groups, as well as government and other institutional stakeholders involved in the policy development around marine renewable energy
- Facilitating knowledge transfer from other booming sectors like pharmaceutical in Ireland to get their experience and proven approaches for technology development
- Creating a public source of knowledge and experiences sharing to keep and transfer the individuals' or private sector's experience (Developers were usually individuals or private sector. So, the acquired knowledge and experience are based on their costs, and they are unwilling to share that. Even the business prospects and

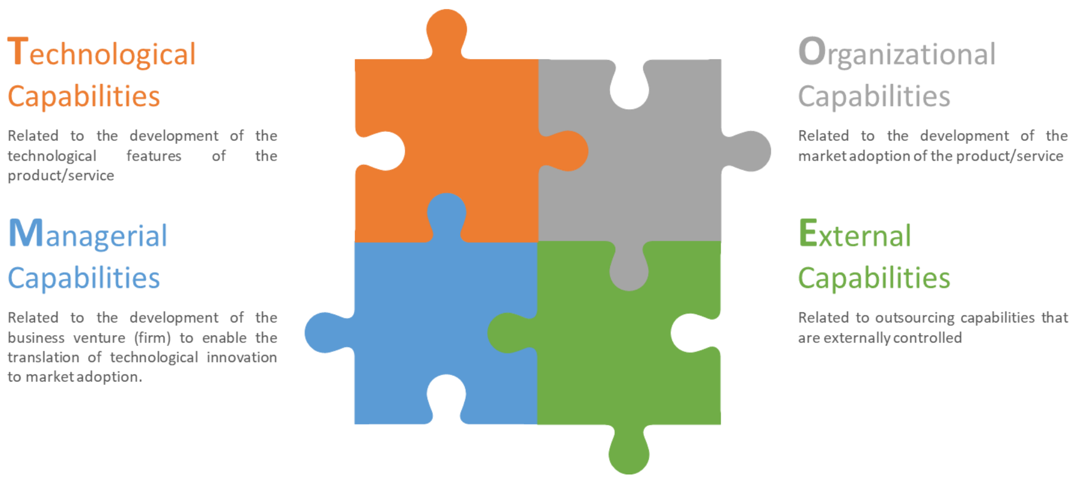
financial failures are not usually shared, preventing the newcomers' failure through technology development.)

- Considering a longer life cycle than two or three years for emerging marine technologies since developing SME momentum with a lot of experience in the industry takes a long time

6 Conclusion

This research has a more general approach to exploring the impediments of technology development by marine energy SMEs and the factors helping them cross the valley of death. It leads to a broader scope on both the factors stated in the literature and new factors identified within this research. The broader scope of these factors in terms of having a framework of technological, organizational, and managerial capabilities had been a gap in the literature. Figure (6-1) shows the novel TOME[1] framework proposed to explore the ways of traversing the valley of death.

Figure (6-1) TOME framework



This research used a mixed-method combined with the thematic analysis to identify and categorize these factors to make a narrower valley of death. Surprisingly, the technology push and market pull forces play an essential role in many factors. There is a clear difference between technology-driven and market pull-driven companies to cross the valley of death. For instance, currently, there is a huge demand for offshore floating wind technologies, which paves the way for such companies. In contrast, there is no reliance on wave technologies, aggravating the situation. For such companies, the active involvement of the strategic investor can empower commercialization,

[1] Technological, organizational, managerial, and External

increasing the commercial expertise in the high-tech company and enabling customer involvement.

6.1 Implications for Theory

This study contributes to a clear identification of the key barriers to crossing the valley of death and the capabilities to traverse it. One significant result suggests that marine energy sector SMEs like other sectors face challenges other than technological through their technology development. While prior research has not considered marine sector SMEs' main challenges, we emphasised the most significant challenges that entrepreneurs and owners/managers of marine sector SMEs encounter.

These findings provided helpful guidelines on "what capabilities are required to cross the valley of death" and "how to facilitate this transition effectively". Many SMEs in the marine energy sector struggle with a wide range of challenges (not just technological). The section concludes with a series of reflective remarks on the issues that qualify the results of a research study as a theoretical contribution.

The first contribution of this research was to explore the challenges of SMEs through their advancement from proof-of-concept to prototyping. While a significant part of the literature gap (e.g., Murphy and Edwards (2003), Barron and Amorós (2020)) contend that there is a gap between TRL3 and 7 and suggest ways to bridge this, very few studies (Weller *et al.*, 2014) have actually investigated the challenges of high-tech SMEs in the marine energy sector to traverse the valley of death in TRL ladder. Therefore, in this research, the extant literature on marine-based SMEs' challenges from TRL 3 to 7 has been extended by creating a broad understanding of challenges through questionnaires and a detailed analysis of challenges through semi-structured interviews. Hence, our theoretical implications come from our data analysis and show that other than technological barriers, internal skill gap, a lack of finance, and a lack of customer market are the major barriers in the lives of small businesses in the marine sector. Nevertheless, SMEs often lack partnership and networking capabilities.

The second contribution of this research was to the advancement of capability-based research in a marine energy SME context. This study brings a new insight into the capability literature of marine-sector SMEs in relation to the resource-based view. This contribution is important as there is very little research on the emergence of capabilities in marine-based SMEs. Moreover, the proposed framework to explore the key capabilities to move toward the technology development process is totally novel. In doing so, we have identified and planned to focus on the capabilities of SMEs through three lenses: **t**echnological (Salisu and Abu Bakar, 2019), **m**anagerial (Sebhatu, 2021), and **o**rganizational (Lau, Man and Chow, 2004). In addition to this, SMEs look for **e**xternal capabilities to fill the gaps in their internal resources. Therefore, from the theoretical point of view, our most outstanding contribution to the field is by applying a new framework (TOME) in the context of marine sector SMEs, whereas before, it had not been considered. Thus, the study extends the existing knowledge by positing that technological, organizational and managerial, and external capabilities enable a transition from TRL3 to 7. Through its findings, the study contributes to the literature on the resource-based view and capability literature with a new insight into how technology developers in the marine energy sector can develop capabilities to cross the valley of death.

The study also aligns with the previous research of Tobiassen and Pettersen (2018), focusing on open innovation and innovative partnership by adding new insights into how smaller firms attract and build trusting relationships with larger customers highlighting customers' contribution to SMEs' innovation process. This study also complements and extends the open innovation theory. In this regard, we argued that it is valuable to collaborate with research institutions – regardless of whether these institutions are customers – because they are involved in fundamental research and can be vital for innovations. Also, open innovation is suggested by both industry and customers by building trust through various mechanisms such as knowledge and technology transfer. SMEs' survival and integration depend on the deployment of their knowledge environments/bases, the acquisition and creation of new knowledge, learning abilities, and the efficient use of new technologies to manage internal and external knowledge flows. This aligns with the study of Hamburg and Marin (2010), supporting knowledge sharing, creation and transfer of individual and organisational knowledge

All this requires a concentrated collaboration between researchers, technology developers and experts from different policy fields and disciplines, as discussed in the following section.

6.2 Implications for Practice

In summary, the key implications are:

6.2.1 For technology developers

In addition to theoretical contributions, the results can help potential entrepreneurs and technology developers who are thinking to develop marine energy technology. With the assistance of the suggested internal and external capabilities, technology developers, whether in an established SME or start-up, can utilize this information to face the challenges of the valley of death with more confidence.

This research proposes three areas of focus for technology developers to support the technology development process by marine sector SMEs. Firstly, technology developers in the marine energy sector should give more attention to organizational and managerial capability development besides their technological capabilities. Thus, the first implication of present research for technology developers is that owners, managers, and CEOs of SMEs in the marine energy sector should consider the **balance** between TOME capabilities.

Second, given that capability development begins through learning, technology development in such an emerging industry requires a constant **learning** process in different areas such as scaling, operations and maintenance for ocean energy from other industries – drinks, aerospace and oil and gas and developed sub-sectors – offshore floating wind. Based on results and discussion, it can be formulated that increasing the opportunities for learning from others through workshops and seminars enables wider and deeper engagement with and between SMEs and other innovation actors. Thus, such experiences enable SMEs to fast-track the life cycle of young innovative companies, compressing years' worth of learning-by-doing into just a few months.

All this requires managers to be able to communicate and build trusting relations. This leads to the third implication, the broader **collaboration and partnership**, as a necessary factor for their survival through the valley of death. Technology developers should be proactive, consciously seeking out appropriate collaboration partners and not leaving the initiative to customers or other actors. This can be facilitated by open innovation and knowledge exchange.

6.2.2 For governments and policymakers

Although Ireland has aimed to achieve a transition to a low-carbon, climate-resilient and environmentally sustainable economy by 2030, targeting up to 80% renewable electricity, 30% reduction in CO_2 emissions, and 32.5% improvement in energy efficiency[1], it does not have a robust energy strategy for consideration of new opportunities for the development of an innovative and competitive supply chain of marine technologies, especially offshore wind in Irish waters. Marine energy has a lot of potentials, but it needs to be more economical. Larger demonstration projects should be supported to keep its growth from basic to applied research and commercial deployment. To achieve scale and scope, public and private investments should be coordinated. As a result, a detailed policy framework is required to support investment-led growth in the region while balancing the demand for attractive risk-return rates with affordable and sustainable energy production.

Also, as mentioned earlier, no programs support a range of projects focused on the key systems and sub-systems of Wave Energy Converters or tidal technologies, which

[1] https://www.gov.ie/en/policy/9cd812-energy/

compels many technical challenges to the wave and tidal energy sector. Technologies for harnessing wave are still in the developing stage as big companies did invest in offshore wave energy technology, and the result in terms of investment was not so good but reflecting back 30 years, it is the same scenario faced by wind and solar when they were early technologies. Wave energy is unique as it is the most concentrated form of renewable energy on earth, with a much higher power density than wind and solar energy.

Therefore, there is a very strong case for wave energy in the future, and the government is responsible for building trust. It is unrealistic to think that new wave or tidal energy technologies could be brought to maturity quickly without the expertise and knowledge gained through sharing best practices and consultation with other industrial sectors or industries. The transfer of knowledge (Hamdoun, Chiappetta Jabbour and Ben Othman, 2018) (such as failure data, foundation designs, or mooring designs) provides a significant opportunity for improvement within the ocean energy sector. Therefore, governments should support sharing information across developers internationally and ensuring that this information is provided by all technology developers and parties involved. Also, just similar to other renewables, financing support for wave energy converters should be with some incentives like feed-in tariff subsidies or renewable energy certificates or carbon credits. Policymakers should be responsible for this by creating supporting mechanisms for a long period that would add certainty to the wave energy developers and give some relief to the investors.

6.3 Limitations and Recommendations

All interviewees have been aware of the concept of the valley of death, and many have also experienced this challenge. For further research, these barriers could be included as a theoretical framework and act as a foundation to determine how these barriers are highly important in technology development by SMEs. Also, it is essential to note that the present evidence relies on factors mentioned by various companies in different marine energy development sectors. While all companies are active in the marine sector, the companies differ in size and subindustry (wave, tidal, offshore floating wind, offshore floating solar, other). For example, offshore wind technology companies could utilize specific strategies to cross the valley of death, whereas wave orientated companies could not. The current sample size is too small to judge the results based on the firms' subindustry. Therefore, further research could define their sample by investigating high-tech companies of similar size in the same subindustry. For this research, it has been a challenge to execute this approach. The amount of time and the limited network would not have led to a sufficient sample.

This study is solely focused on a small sample of targeted high-tech SMEs in the marine energy sector in the Irish and UK context and aims to show a broader perspective, which allows the easier generalization of the results. Thus, future research of broader samples may highlight more significant differences. A cross-cases with a rich mix of data from different countries that are more successful in the marine industry can lead to new results.

Respondents were CEOs and managing directors, who overall are the most knowledgeable people to answer questions with truthful information. Future studies should consider having multiple respondents from marine energy sector SMEs to enhance the reliability of the findings. It could be expanded to enhance the research findings by adding suppliers, end-users, and policymakers.

Those readers/researchers interested in this topic can read this research to enhance their understanding of the valley of death through technology development and ways of crossing it. Also, at present, there is very limited literature available on the capabilities of marine sector SMEs. The researcher should concentrate more on the subject itself since this field is somewhat new. Hence, it was difficult to find comparable information that could be used for this study. New researchers can fill this gap.

Also, there is a problem with applying capabilities theory in an emerging industry. The present study identified capabilities of critical importance in developing new technologies; however, it is critical to see how SMEs develop dynamic capabilities in emerging markets to integrate, learn and reconfigure internal and external resources and competencies in response to changing environments.

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Appendix 1: Descriptions about TRL

The TRL as adapted to European industry is described as below:

TRL1 – Basic principles observed

In TRL 1, initial scientific research begins, and the principles and phenomena of new technology within the marine sector are identified to satisfy the demand for that technology. Required funding for this level can range from very low to very, very high from one research discipline to another. Finding a customer segment, understanding the customers' pain points, and explaining how they will benefit from the new technology under development are included in the physical experiments of this stage. Then, peer-reviewed publications can be used for the validation of basic science. With this fundamental qualitative understanding, the technology may be ready to transition to applied research in TRL2.

TRL2 – Technology concept formulated

TRL2 activities confirm the technical and business potential of the technology to satisfy the need identified in TRL 1. For this purpose, the experimental plans' organization should be planned with an eye toward the final practical application(s) to reduce scientific risk to a level where external investors can be approached. The costs of TRL2 are typically low, and its activities may be undertaken by almost any kind of organization but would most often arise among universities, small businesses, individual entrepreneurs, etc. This level requires a sound business plan with a well-defined value proposition. So, technology developers become able to assess commercial opportunities using market studies for the expected market size and competitive landscape.

TRL3 – Experimental proof of concept

In TRL3, applied research continues, and active research and early-stage process development begin, encompassing both analytical studies to put the technology into the proper context and laboratory-based studies to physically validate the analytical predictions. The costs to achieve TRL3 are typically low to moderate and tend to connect with technology. That is why techno-economic analysis (TEA) initiates around TRL3. Like TRL2, such activities might be undertaken by almost any organization, but they might involve some formal sponsorship through government or industry investments.

TRL4 – Technology validated in lab

TRL4 is the first step where the conceptual process design determines whether a technology can be integrated within a system. In the lab, process components are validated through experiments to see whether the whole idea supports the formulated concepts and is consistent with the requirements of potential system applications. Hence, exiting TRL4 requires a significant funding commitment to support additional technical labour and capital equipment, and a compelling story is necessary to convince investors. Fortunately, the decreasing risk funding at TRL4 or greater could come from most types of venture funding sources.

TRL5 – Technology validation in relevant environment (industrially relevant environment in the case of key enabling technologies)

TRL5 marks the end of bench-scale work and the final reduction of scientific risk. With the integration of basic technological elements and reasonably realistic supporting features. The applications can be tested in a simulated or somewhat realistic environment. At this level, R&D costs might typically be expected to be still moderate to high and would tend to be largely technology-specific. Generally, there is no sharp transition between TRL5 and TRL6, and technology development may still occur in a laboratory. However, experiments are carried out at an engineering scale rather than a bench scale. So, firms should seek to grow their engineering departments by hiring full-time process engineers and/or expanding relationships with engineering and consulting firms.

TRL6 – Technology demonstration in a relevant environment (industrially relevant environment in the case of key enabling technologies)

As stated above, the transition from TRL5 to 6 is somewhat blurry, and firms may find themselves in TRL6 during their technology development activities. For TRL6, R&D costs might typically be expected to be high and would most likely be similar to but less than investment(s) to reach TRL7.

TRL4 to TRL6 bridge from development to demonstration and the reduction of engineering risk, and to the extent that a valley of death for firms exists, it is almost certainly TRL5/6.

TRL7 – System prototype demonstration in an operational environment

TRL7 is a significant step beyond TRL 6, requiring an actual system prototype demonstration in the expected operational environment. The prototype should be of the same scale as or larger than the planned operational system, and the demonstration should occur in the real expected operational environment. For TRL7, R&D costs would typically be very high. Between TRL7 and TRL8, the project takes tens of months and tens of millions of dollars.

TRL8 – System complete and qualified

TRL8, in almost all cases, is the end of R&D in almost all cases. In TRL8, the demonstration is constructed, troubleshot, and operated continuously. By analysing demonstration operability, actual manufacturing costs will be determined, and the process simulation is finalized and scaled up to a commercial scale.

TRL9 – Actual system proven in an operational environment (competitive manufacturing in the case of key enabling technologies; or space)

Technologies in TRL9 are in their ultimate form and proven throughout the full range of operating conditions. R&D and demonstration resources can be directed to other commercialization targets. Costs of this level depend on the mission and would be typically high but usually less than the cost of TRL8 (full-scale system development).

Appendix 2: Target population

- ***Ireland***

In 2018, Ireland's ocean economy had a turnover of €6.2 billion. Gross Value Added (GVA) measured the direct economic contribution of €2.2 billion or 1.1% of GDP. Ireland's ocean economy provided employment for 34,132 FTEs. Compared to 2016, 2018 saw a 13% increase in turnover, an 11% increase in GVA and a 13% increase in employment. The indirect GVA generated from ocean-related activity in Ireland in 2018 amounts to €1.96 billion, with a total GVA (direct and indirect) of €4.19 billion, representing 2% of GDP (Tsakiridis *et al.*, 2019).

Ireland's marine renewable energy sector includes offshore wind energy generation and technology and energy development from wave and tidal resources. Currently, wave energy technologies and investments are mainly in the planning and R&D stages. On the other hand, significant technological innovations and investment in offshore wind farm projects have occurred at a European and global level due to increased financial support for wind energy and operational experiences gained from offshore oil and gas platforms. The turnover generated by the marine renewable energy sector was €59 million in 2016, which was a 119% increase in 2014. In 2014, the total GVA generated was €15 million. In 2016, GVA increased by 147% compared to 2014, reaching €38 million. From 2014 to 2016, employment in the sector also increased by 13%, with 454 FTEs in 2016. The higher growth rates of turnover compared to employment indicates an increase in productivity over this period (Tsakiridis *et al.*, 2019).

- ***United Kingdom***

United Kingdom is home to the world's first tidal stream arrays and has deployed more wave and tidal energy technologies than the rest of the world. The European Marine Energy Centre (EMEC) was recognized as the world's first ocean energy Renewable Energy Testing Laboratory (RETL) in 2020, highlighting another milestone for the UK ocean energy sector. In 2020, the wave energy industry will continue to invest in innovative R&D to push the industry toward design convergence and commercialization (Kim Nielsen *et al.*, 2021).

- ***France***

France has about 11 M km² of Exclusive Economic Zone (EEZ) with favourable conditions for Marine Renewable Energy (MRE) wind, tide, current and overseas territories, and thermal gradient. A network of test sites to test wave, floating offshore wind, tidal, hybrid and subsystems for MRE technologies are being developed and operated. Actions are closely integrated with R&D capabilities and programs (Sweeney, 2015).

- ***Netherlands***

Dutch expertise plays a crucial role in a variety of challenging maritime engineering projects all around the world. As a result, it is no wonder that the Netherlands has adopted the concept of floating solar farms. Floating solar farms with high yields have already been developed in several sites, including sand extraction lakes, water treatment plants, and reservoirs. Dutch companies, research institutes, and water authorities have formed a national consortium with the vision of attaining 2,000 hectares of floating solar farms by 2023. Dutch firms are concentrating their technological innovations on the quality and reliability of the technology, which is becoming increasingly important as the scale of floating solar farms increases worldwide. Furthermore, Netherlands is a pioneer in investigating the environmental effects of floating solar farms, such as water quality and biodiversity. Such understanding makes it easier to identify areas where solar energy can be harvested for years without causing any harm to the environment (Werther *et al.*, 2020).

- ***Denmark***

Denmark has long ranked in the top ten of global maritime nations. With cutting-edge innovation and an excellent regulatory framework, it offers favourable conditions for marine companies worldwide.

The Danish Wave Power Roadmap and the Strategy for Wave Power have guided wave energy activities in Denmark for over a decade. The Danish Partnership for Wave Energy began defining a new plan for developing wave power in Denmark in 2020. Denmark confirmed plans to construct two “energy islands” populated by wind turbines that would add 4GW to the country’s renewable energy capacity by 2030 (Kim Nielsen *et al.*, 2021).

- ***Norway and Sweden***

Sweden and Norway are collaborating with Ocean Harvesting Technologies through an R&D study on how installation of wave energy converters could provide stable and cost-effective electricity to an offshore oil and gas platform. The joint project will run until February 2022 and provide data and information on electrifying major offshore operations with wave power. Despite being highly efficient and low carbon, the challenges to the wider sector in decarbonizing production can be significant, especially offshore. So, working with Ocean Harvesting Technologies to identify new ways of powering offshore activities with their innovative wave energy converter (WEC) solution can be helpful (Offshore, 2021).

Appendix 3: Online Survey

Introduction

As part of the Marine Energy Alliance (MEA) project, conducted by the MaREI Centre, UCC, this research seeks to explore the process and capabilities that enable marine technology SMEs to advance their technology from proof of concept to scalable prototyping and beyond. This data will help me complete my master (by research) in management and marketing. By exploring the technical and commercial challenges of technology-based SMEs in the marine energy sector, this research will provide insights into how firms may leverage technological, organisational, and managerial capabilities to cross the "valley of death" through the advancement of technology. You have been selected as a key informant in this study. It takes about 10 minutes to complete the questionnaire. Note that there is no correct or wrong answer. However, you are required to provide accurate responses in order to enable us to generate valid findings for the study. Responses provided will be used solely for research purposes.

*Participation in this study is completely voluntary. There is no obligation to participate, and should you choose to do so, you can decide to withdraw your consent at any time in the subsequent two weeks.

*All the information you provide will be kept confidential and anonymous and will be available only to Negar Sadeghi Gargari (Researcher), Prof. Edward Shinnick (Supervisor), Dr. Lawrence Dooley (Supervisor), and Ms. Fiona Flemming (Project Manager).

*If you have any queries about this research, you can contact my supervisors or me at:

Me (Negar Sadeghi Gargari) 120222859@umail.ucc.ie +353 (0)89 271 6583

Prof. Edward Shinnick e.shinnick@ucc.ie +353 (0)21 490 2052

Dr. Lawrence Dooley L.Dooley@ucc.ie

1. General background information

1.1. Contact Name

1.2. Company Name

1.3. Marine Energy Concept

1. Wave
2. Tidal
3. Offshore Floating Wind
4. Offshore Floating Solar
5. Other

2. Movement across the TRL spectrum

2.1. What is your current TRL?

1. TRL 3
2. TRL 4
3. TRL 5
4. TRL 6
5. TRL 7
6. TRL 8

2.2. Has the technology readiness level (TRL) of your marine energy technology changed since the initial benchmark survey (since 2018/2019)? If yes, then please indicate the movement across the TRL spectrum. [example: TRL 3 to TRL 5 or TRL 2 to TRL 3, etc.]

3. Technical and Commercial Challenges

Description

Technical: related to the development of the technological features of the product/service

Commercial: related to the development of the market adoption of the product/service

Managerial: related to the development of the business venture (firm) to enable the translation of technological innovation to market adoption.

3.1. Technical Challenges

Technical: related to the development of the technological features of the product/service

3.1 Please indicate the degree of technical challenges experienced at different stages of development of your marine technology.

0 = Not Yet at This Stage 1 = Not challenging 2 = Somewhat Challenging

3 = Neutral 4 = Significantly Challenging 5 = Highly Challenging

3.1.1 Concept

	0	1	2	3	4	5	
Not challenging	○	○	○	○	○	○	Highly Challenging

Main Reason Why?

3.1.2 Design

	0	1	2	3	4	5	
Not challenging	○	○	○	○	○	○	Highly Challenging

Main Reason Why?

3.1.3 System integration

	0	1	2	3	4	5	
Not challenging	○	○	○	○	○	○	Highly Challenging

Main Reason Why?

3.1.4 Deployment

	0	1	2	3	4	5	
Not challenging	○	○	○	○	○	○	Highly Challenging

Main Reason Why?

3.1.5 Manufacturing, Installation & Operation

	0	1	2	3	4	5	
Not challenging	○	○	○	○	○	○	Highly Challenging

Main Reason Why?

3.1.6 Scaling

	0	1	2	3	4	5	
Not challenging	○	○	○	○	○	○	Highly Challenging

Main Reason Why?

3.1.7 Other

	0	1	2	3	4	5	
Not challenging	◯	◯	◯	◯	◯	◯	Highly Challenging

What is this? Main Reason Why?

3.2. Up to this point in time, what were the TOP THREE technical challenges that impacted/delayed technological development?

- ☐ Concept
- ☐ Design
- ☐ System integration
- ☐ Deployment
- ☐ Manufacturing, Installation & Operation
- ☐ Scaling
- ☐ Other

3.3. Currently, please indicate the TOP THREE technical challenges impacting/delaying technology development.

- ☐ Concept
- ☐ Design
- ☐ System integration
- ☐ Deployment
- ☐ Manufacturing, Installation & Operation
- ☐ Scaling
- ☐ Other

3.4. Commercial Challenges

Commercial: related to the development of the market adoption of the product/service

Please identify the degree of commercial challenges experienced up to this point in time.

0 = Not Yet at This Stage   1 = Not challenging   2 = Somewhat Challenging

3 = Neutral   4 = Significantly Challenging   5 = Highly Challenging

3.4.1 Cost Modelling

	0	1	2	3	4	5	
Not challenging							Highly Challenging

Main Reason Why?

3.4.2 Access to Finance

	0	1	2	3	4	5	
Not challenging							Highly Challenging

Main Reason Why?

3.4.3 R&D Costs

0 1 2 3 4 5

Not challenging	◯	◯	◯	◯	◯	◯	Highly Challenging

Main Reason Why?

3.4.4 Supply Chain

	0	1	2	3	4	5	
Not challenging	◯	◯	◯	◯	◯	◯	Highly Challenging

Main Reason Why?

3.4.5 Customer Market

	0	1	2	3	4	5	
Not challenging	◯	◯	◯	◯	◯	◯	Highly Challenging

Main Reason Why?

3.4.6 Business Model

	0	1	2	3	4	5	
Not challenging	◯	◯	◯	◯	◯	◯	Highly Challenging

Main Reason Why?

3.4.7 Technical (Technology Development) Skill Gap

	0	1	2	3	4	5	
Not challenging	○	○	○	○	○	○	Highly Challenging

Main Reason Why?

3.4.8 Managerial (building the venture) Skill Gap

	0	1	2	3	4	5	
Not challenging	○	○	○	○	○	○	Highly Challenging

Main Reason Why?

3.4.9 Commercial (market adoption) Skill Gap

	0	1	2	3	4	5	
Not challenging	○	○	○	○	○	○	Highly Challenging

Main Reason Why?

3.4.10 Government Regulations and Awareness

0 1 2 3 4 5

Not challenging	○	○	○	○	○	○	Highly Challenging

Main Reason Why?

3.4.11 Other

	0	1	2	3	4	5	
Not challenging	○	○	○	○	○	○	Highly Challenging

What is this? Main Reason Why?

3.5. Currently, please indicate the TOP THREE commercial challenges impacting/delaying technological adoption by the market?

- ☐ Cost Modelling
- ☐ Access to Finance
- ☐ R&D Costs
- ☐ Supply Chain
- ☐ Customer Market
- ☐ Business Model
- ☐ Technical (Technology Development) Skill Gap
- ☐ Managerial (building the venture) Skill Gap
- ☐ Commercial (market adoption) Skill Gap
- ☐ Government Regulations and Awareness
- ☐ Other

3.6. Ranking of Challenges

3.6 Rank these three challenges (1=greatest, 3=least) in terms of their greatest impediment to the firm development.

	1	2	3
Technical Challenges	○	○	○
Commercial Challenges	○	○	○
Managerial Challenges	○	○	○

3.7. Looking to the Future

3.7 Looking to the next 18 months, what do you perceive to be the key challenges of concern, either technical, commercial and\or managerial challenges?

3.7.1. Technical Challenges (1 to 3 challenges)

3.7.2. Commercial Challenges (1 to 3 challenges)

3.7.3. Managerial Challenges (1 to 3 challenges)

4. Capabilities and Enablers

4.1. Please identify your key capabilities\enablers under each of the below headings that have facilitated your marine technology development?

4.1.1 Technological Capabilities (1 to 3 capabilities)

4.1.2 Organizational Capabilities (1 to 3 capabilities)

4.1.3 Managerial Capabilities (1 to 3 capabilities)

Thank you for taking the time to complete this survey.

Negar Sadeghi Gargari 120222859@umail.ucc.ie +353 (0)89 271 6583

Appendix 4: Introductory E-mail

Subject: [MEA] Marine Energy Insight

Dear X,

My name is Negar Sadeghi Gargari, a master's (by Research) student in Management and Marketing at University College Cork (UCC). I am contacting you as part of the Marine Energy Alliance (MEA) project, conducted by the MaREI Centre, UCC. This research is under the supervision of Prof. Edward Shinnick, Dr. Lawrence Dooley, and Ms. Fiona Fleming and is exploring the process and capabilities that enable marine technology SMEs to advance their technology from proof of concept to scalable prototyping and beyond.

As part of this research, we have developed a short questionnaire (max. 10-minutes) to be completed by relevant SMEs. We would be grateful if you would support the research of the Marine Energy Alliance (MEA) project by completing the attached survey instrument. The findings of this research will only be reported in their aggregate form, so please be assured that confidentiality is assured. The research findings will enhance policy and intermediary supports to nurture the development of this critical sector.

Follow the link to the survey please:

https://forms.gle/rNUABxhjc9aYhMMb6

Again, thank you for your time, and we hope you can give us the benefit of your experience by completing the questionnaire and returning it to us by the **10th of October 2021**.

If you require any further information, feel free to contact me.

Best Regards,

Negar Sadeghi Gargari

Appendix 5: Follow Up E-Mail (+1 week later)

Subject: [MEA] Marine Energy Insight – Reminder

Dear X,

I hope that this email finds you well. I am contacting you with this gentle reminder to request that you complete our short survey as part of the Marine Energy Alliance (MEA) project, which forms the basis of my MSc research. This research is under the supervision of Prof. Edward Shinnick, Dr. Lawrence Dooley, and Ms. Fiona Fleming, exploring the process and capabilities that enable marine technology SMEs to advance their technology from proof of concept to scalable prototyping and beyond. The questionnaire should take **no longer than 10 minutes** and is accessible through the below link. The deadline for completing the survey will be Monday **10th October 2021**.

Link: **https://forms.gle/DvfYDdHDD4hFwgXs9**

If you have any questions regarding the survey, please do not hesitate to contact me (please see contact details below), and I will be glad to answer any queries.

Thank you for your time.

Best Regards,

Negar Sadeghi Gargari

Appendix 6: Follow-Up E-Mail (12 days later)

Subject: [MEA] Marine Energy Insight – Closing Soon

Dear X,

I recently contacted you to seek your participation in my MSc research regarding exploring the process and capabilities that enable marine technology SMEs to advance their technology from proof of concept to scalable prototyping and beyond. I would be grateful if you could take the opportunity to complete the short survey (link below) to help other SMEs like yourself deal with future challenges. The closing date is Sunday 10th October. If you have already completed the survey, I would like to take this opportunity to thank you. A brief online questionnaire has been created, and I would be grateful if you could take some time to complete it. I have included a link below that will take you to the questionnaire. The questionnaire should take no longer than 10 minutes. The deadline for completing the survey will be Sunday, 10th October 2021.

Link: **https://forms.gle/DvfYDdHDD4hFwgXs9**

If you have any questions regarding the survey, please do not hesitate to contact me (please see contact details below), and I will be glad to answer any queries.

Thank you for your time.

Sincerely,

Negar Sadeghi Gargari

Appendix 7: Ethics Approval Form

UCC University College Cork, Ireland Coláiste na hOllscoile Corcaigh | Social Research Ethics Committee (SREC)

SREC ETHICS APPROVAL FORM

Introduction

UCC academic staff and postgraduate research students who are seeking ethical approval should complete this approval form. Ethical review by the Social Research Ethics Committee (SREC)[1] is required where the methodology is not clinical or therapeutic in nature and proposes to involve:

- direct interaction with human participants for the purpose of data collection using research methods such as questionnaires, interviews, observations, focus groups etc.;
- indirect observation with human participants for example using observation, web surveys etc.;
- access to, or utilisation of, anonymised datasets;
- access to, or utilisation of, data or case files/records concerning identifiable individuals;
- conducting Internet Research or research online.

SREC considers itself an enabling committee, promoting strong research ethics amongst UCC's community of staff and student researchers. We are open to all types of research in the social research domain. If your research approach does not readily fit into this form, do not be

[1] SREC is a committee of the University Ethics Committee. If you are unsure which University ethics committee you should apply to, please consult this resource. Acknowledgement: An early version of this form was adapted from pp. 13-14 of the Guidelines for Minimum Standards of Ethical Approval in Psychological Research (British Psychological Society, 2004).

discouraged: please add additional relevant notes to convey what you think is pertinent about the ethical aspects of your study.

Contact us: srec@ucc.ie

Click here for further information about research ethics at UCC.

Click here for further information on SREC, training videos, and

sample informed consent / information sheet / assent forms.

APPLICATION CHECKLIST

This checklist includes all of the items that are required for an application to be deemed complete. In the event that any of these are not present, the application will be returned to the applicant ***without*** having been sent for review. Please ensure that your application includes all of these items prior to submission. Thank you and best of luck with your research!

Please complete prior to submission	***Delete as applicable***
All relevant files are combined into **one PDF** file (SREC application form, consent/assent forms, information sheets, data collection instruments, permission letters, etc.)	**Yes**
Completed SREC Application Form	**Yes**
Information Sheet(s) / Information Statement (i.e. at the beginning of an electronic survey) included	**Yes**
Consent / Assent Form(s) / Consent Statement (i.e. at the beginning of an electronic survey) included	**Yes**
Data Collection Instrument: Psychometric Instruments / Interview Guide / Focus Group Schedule / Survey Questionnaire / etc. included	**Yes**
Copy of permission letters to undertake research from relevant agencies/services included (if available)	**NA**

Have you applied for ethical approval for this project from another UCC ethics committee?	**No**
If you are under academic supervision, your supervisor(s) have approved the wording of and co-signed this application prior to submission	**Yes**
If this is a resubmission, all the revised and new text is highlighted in yellow	**NA**

NOTES

1. Your SREC application form should be concise: please do not copy and paste a research proposal. Applications typically range between 10-20 pages (including appendices) with some longer applications at 25-30 pages. Overly long applications will be returned without a review.
2. Your SREC application form should be written so that researchers outside of your discipline can understand how you plan to undertake your study.
3. If your study requires a Data Protection Impact Assessment (DPIA), you **do not** need to include a copy of the DPIA with your SREC application form.

Resources and services:

UCC Code of Research Conduct	**EU Commission, Responsible Research and Innovation RRI Tools Website**
UCC Child Safeguarding Statement	**Irish Qualitative Data Archive (IQDA)**
Guidance Document for Conducting Internet Research	**Irish Social Science Data Archive (quantitative datasets)**
Garda Vetting of UCC Staff	**Health Service Executive National Consent Policy**
UCC Student Garda Vetting Policy	**IT Service Catalogue**
UCC Data Protection Policy and Procedures	**UCC GDPR website**
UCC Library Research Data Service	**UCC Guidance for Researchers Conducting Research with Vulnerable People**
UCC Supplied Survey Platforms	**SREC FAQs and Amendment Process**
UCC Device Encryption Service	

APPLICANT(S) DETAILS

Name of UCC applicant(s)	Negar Sadeghi Gargari	**Date**	12/09/2021

<table>
<tr><td>Name of Department / School / Research Institute / Centre / Unit / College</td><td colspan="2">Department of Management and Marketing & Department of Economics/ Cork University Business School</td><td>Contact No.</td><td>089 2716583</td></tr>
<tr><td>Correspondence Address</td><td colspan="2">Apartment 104, The quadrants, Ballincollig, Cork, Ireland</td><td>Email Address</td><td>120222859@umail.ucc.ie</td></tr>
<tr><td>Course Code/Name and year of course (students only)</td><td colspan="2">MSc by Research in Management and Marketing</td><td>Name of supervisor(s) (students only)</td><td>Prof. Edward Shinnick
Dr. Lawrence Dooley</td></tr>
<tr><td>Is this a resubmission?</td><td colspan="2">No</td><td colspan="2">SREC Log No. (if a resubmission):</td></tr>
<tr><td>Is this research funded?</td><td>Yes</td><td>If Yes please provide name/s of Funding Agencies</td><td colspan="2">MaREI Centre / UCC/EU InterReq Marine Energy Alliance project</td></tr>
<tr><td colspan="5">Obtaining ethical approval from SREC does not free you from securing permissions and approvals from other institutional decision-makers and agency ethical review bodies. These bodies may accept the SREC approval, but researchers are responsible for ensuring they are compliant in advance of collecting data.</td></tr>
</table>

Project working title	Exploring Capabilities Driving SME Development of Technological Readiness Within the Marine Sector

If this is a collaborative project / community-based participatory research project / *joint* application with another agency, please complete this additional section:

Names of research partners / civil society organisations	NA

collaborating on this project (this section must be completed for participatory / community-based participatory research studies)	
Agency contact person and position	
Agency address	
Details of the partnership (Please identify clearly the roles and responsibilities held by each party in the partnership in relation to the different aspects of the research).	

ETHICAL APPROVAL SELF-EVALUATION

If your answer falls into any of the shaded boxes below, please address each point later in the application form		**YES**	**NO**
		Use X or NA	
1	Do you consider that this project has significant ethical implications?		X
2	Will you describe the main research procedures to participants in advance, so that they are informed about what to expect?	X	
3	Will participation in this project be voluntary?	X	
4	Will you obtain informed consent in writing from participants?	X	

5	Will you tell participants that they may withdraw from the research at any time and for any reason, and (where relevant) omit questionnaire items / questions to which they do not wish to respond?	X	
6a	Will data be treated with full confidentiality / anonymity (as appropriate)?	X	
6b	Does your project require you to carry out a Data Protection Impact Assessment (DPIA) in compliance with UCC Data Protection Policy?		X
7	Will data be securely held for a minimum period of ten years after the completion of a research project, in line with the University's *Code of Research Conduct* (2016)?	X	
8	If results are published, will anonymity be maintained and participants not identified? (see Q. 30 below regarding open data considerations, if relevant)	X	
9	Will you debrief participants at the end of their participation (i.e. give them a brief explanation of the study)?	X	
10	Will your project involve deliberately misleading participants in any way?		X
11	Will your participants include children / young persons (under 18 years of age)?		X
12	If yes to question 11, is your research in compliance with the UCC *Child Safeguarding Statement* which sets out the legal requirements under the Children First Act 2015?		X
13	Will your project require you to carry out "relevant work"[1] as defined in the National Vetting Bureau (Children and Vulnerable Persons) Acts 2012 to 2016?		X
14	Do you require official Garda Vetting through UCC before collecting data from children or vulnerable adults? (Please note that having a Garda Vetting through another body is not sufficient; a separate UCC Garda Vetting is always required for UCC researcvhers)		X
15	Will project participants include people with learning or communication difficulties?		X
16	Will project participants include patients / service users / clients? A service user or client is a person who is served by or uses the services under consideration as part of this research.		X
17	Will project participants include people in custody?		X
18	Will project participants include people engaged in illegal activities (e.g. drug taking, illegal Internet behaviour, crime, etc.)?		X
19a	Is there a realistic risk of participants experiencing either physical or psychological distress?		X

[1] Relevant work constitutes any work or activity which is carried out by a person, a necessary and regular part of which consists mainly of the person having access to, or contact with, children or vulnerable adults.

19b	Is there a realistic risk of the researcher experiencing either physical or psychological distress?		X
20	If yes to question 19a, has a proposed procedure for linking the participants to an appropriate support, including the name of a contact person, been given? (see Q. 33)	NA	
21	If yes to question 19b, has a proposed procedure/support structure been identified?	NA	
22	Are the research participants students with whom you have some current/previous connection (module coordinator, research supervisor, professional tutor, etc.)?		X
23	Will the research participants receive payment / gifts / voucher / or other incentives for participating in this study?		X
24	If your research is conducted on the internet, does it involve human participants? (e.g. through web surveys, social media, accessing or utilising data (information) generated by or about the participant/s; or involve observing human participants in their online interactions/behaviour). If yes, please review and utilise the UCC policy for conducting Internet Research.		X

DESCRIPTION OF THE PROJECT

*Ethical review requires that you **reflect** and seek to **anticipate** ethical issues that may arise,*

rather than reproduce copious text from existing research proposals into these boxes.

*Entries should be **concise** and relevant to the point / question.*

25. Very brief description of your study (15-25 words max.) [e.g. This is a qualitative study of primary school teachers' attitudes towards religious teaching using focus groups to collect original data]
This is a qualitative study exploring the capabilities of technology-based SMEs in the marine sector, necessary for the transition from proof-of-concept to scalable prototyping (and beyond)

26. What is your study about? (100-200 words max.)
An exploratory study focused on how technology-based SMEs can develop technological, organisational, and managerial capabilities through their technology development to move from proof-of-concept to scalable prototyping through the technology readiness spectrum. Case studies are chosen to study technology SMEs in the marine energy sector, given the strategic importance of the sector and the emergence of a cluster of such firms along the south-west Irish coast. Understanding the chronological evolution path of multiple marine technology companies, together with the managerial response to critical incident challenges experienced, will contribute to both the strategy and innovation literature by deepening the understanding of technological, organisational, and managerial capabilities that SMEs develop for a transition from proof of concept to scalable prototype development and beyond (TRL 3-7). Research findings will contribute to improving the ability of SME marine renewable energy firms to develop their technology and bring it to the market for societal benefit.

27. What are your research questions?[1] **(**The research questions are the overall aim(s)/objective(s) of your study)
What capabilities enable technology-based SMEs in the marine sector to support the advancement of their technology from proof of concept to scalable prototype for market adoption? 1. What challenges do SMEs (start-ups and established) face in advancing technologies from proof of concept to scalable prototype development within the marine sector context? 2. What technological, organisational, and managerial level capabilities enable ventures to develop technologies from proof of concept to scalable prototype development within the marine sector? 3. Do SMEs seek external support? How are externally controlled resources and capabilities leveraged by SMEs to support technology development from proof of concept to scalable prototyping within the marine sector?

28. Who are the participants in your study? (recruitment methods including details of how you will engage with participants, number, age, gender, exclusion/inclusion criteria, detail permissions to be sought / secured already, and how will you recruit participants?)
The potential interview participants for this study will be drawn from marine-sector energy SMEs. SMEs are selected from an existing database of MaREI centre from the Marine Energy Alliance (MEA) project (a 4-year European Territorial Cooperation project running from May 2018 to May 2022). The aim of MEA was to progress the technical and commercial maturity level of early-stage (TRL 3 – 4) marine energy technology companies with the overall goal of reducing the risk of device failure in subsequent demonstration phases. As a studentship partly funded by MEA, my project has full permission to use this data source and all aggregated data from it. In addition, Ms. Fiona Fleming, as the project manager, is regularly contacted on the progress of my research and data access issues to gain ger consent. Although targeted SMEs have agreed to collaborate with research for the MEA project, all

[1] If your study approach does not normally require that research questions are set in advance, please provide a rationale in Q. 27. **Do not** include your interview/survey questions in Q27.

interviewees will initially be contacted once again by Ms. Fiona Fleming to ensure they want to participate in further stages.

Our study is a complementary study of the existing MEA project in which we aim to perform a deep-dive analysis on some technology-based SMEs in the marine sector. For this purpose, the selection criteria include participants who represent firms that:

1) are SMEs (employ between 2 – 250 staff members, have a maximum annual turnover of €50 million, and have a maximum annual balance sheet total of €43 million)
2) are active in the marine energy sector (e.g., wave, tidal, offshore floating wind, offshore floating solar, etc.)
3) are one of the 42 companies that are selected by the MEA project
4) are exemplar cases at TRL3-4 who have transited to higher TRLs (5-7)

The research will focus on technology SMEs in the marine energy sector, given the strategic importance of the sector and the emergence of a cluster of such firms along the south-west Irish coast. Within these ventures, the target interviewees are senior management team members (e.g., founder or co-founder, CEO, project manager, or director) with a holistic view of the progress. Selection of this cohort of individuals is necessary since such individuals possess a holistic perspective of how capabilities are leveraged through technology development to cross the challenges and barriers. These upper-level managers are "considered influential, prominent, and/or well informed in an organisation or community; they are selected for interviews based on their experience in areas relevant to the research" (Marshall and Rossman, 2016).

Undertaking multiple individual interviews within each case allows the triangulation of the information received to ensure the reliability of the research and to counteract personal bias. Subject to ethical approval, the intention is to secure 6-8 companies from the potential interview list. A list of SMEs in the marine energy sector will be identified to engage in the discussion. A single-country study has been chosen due to the access and communication feasibility and consistent economic context in terms of policies and legislation. As the research progresses by interviewing a senior management team member, the list will be added through snowball sampling, as leads identified in interviews are followed upon. Respondents will be contacted via an invite email (see Appendix 8), informing them of the research objectives (project information sheet (see Appendix 9)), assuring them of anonymity and confirmed that they could withdraw from the process at any point in the process without prejudice. Receipt of a confirmatory email response from interested respondents will result in scheduling a suitable interview time and a follow-on email containing the agreed consent form (see Appendix 10) and interview protocol guide (see Appendix 11). Given the nature of the selection criteria, all respondents will be adults, familiar with research approaches and the rules of practice that govern this pillar of our research. Respondents will complete the Agreed Consent form prior to the interview taking place and will again be informed that their right to anonymity will be protected, and they are free to withdraw from the research process and have their relevant data deleted from the project up to the point where they provide feedback on the analysis of the findings of the interview.

29. Concise statement of *anticipated* ethical issues raised by your project. How do you intend to deal with them? Please address *all* items where your answers fell into a shaded box in the self-evaluation above. (350 words max.)

The anticipated ethical issues raised by this project are outlined as follows:

In general:

- Companies that nominate to participate in the research will have their identity protected to ensure sensitive data does not make it into the public domain and damage their competitive position.
- While preference is for this research to be undertaken face-to-face, given the current Covid restrictions within UCC (https://www.ucc.ie/en/research/support/researchbusinesscontinuitysupports/) then the fallback position (until things return to normality) will be to use either MS Teams or traditional telephone as an alternative platform to undertake the interviews. If the call

becomes interrupted, we will hang up and re-establish a direct connection. If such a change (physical to virtual) is required to facilitate the undertaking of the research, it will not require any other alteration in the process of data gathering (interview protocol is unchanged etc.).

- Anonymised transcripts will be reviewed by the research supervisors and emailed to the respective interview participants for feedback using password-protected files to ensure security.
- These digital transcripts will be stored securely on a OneDrive file (1) in a secure location on UCC premises.
- All data gathered from the semi-structured interviews will be recorded on an audio recording device. These recordings will be downloaded onto a secure, separate OneDrive file (2) and will then be deleted from the recording device. This NAS file (2) will ensure the recordings remain confidential.

In terms of Recruitment:

- The target sample is identified based on their individual experience and role in the firm, and recruitment of interview respondents is purely voluntary, something explicitly reinforced in the Agreed Consent form and Project Information Sheet (embedded in the invite emails).
- To ensure that respondents are fully briefed ahead of the interview, each receives an advanced copy of the interview protocol guide and an offer of a telephone conversation, should they wish clarification on any issue.
- Participants will be able to withdraw any or all information they deem necessary up to two weeks after the interview process. After their approval, all data will be anonymised and stored in UCC staff one-drive in an aggregate form.

* The project information sheet informs participants of their right to withdraw from the research at any stage in the process, and this is reinforced prior to the interview start, together with a cross-check that the agreed consent form has been completed.

- As an interview quality check, respondents are sent a case synopsis of the main points of the interview for verification and agreement before including their anonymised data into the ongoing research. This allows for clarification\fact checking BUT also provides the participant with an additional opportunity in the process to raise any concerns of the study, should they wish to.

In terms of ethics related to data:

- All material is 'anonymised' of identifying content (name, company, contact details, etc.) prior to being made explicit in electronic document and data files (word and excel), which are encrypted with passwords and stored on the secure UCC staff One drive.

* Anonymity does not just mean changing the participants' names but means that all identifying information in the data will be anonymised and de-identified (e.g., place names, employing organisations, specific job title if only one person does that role and so on).

- If a respondent raises issues of the case, efforts are made to amend the same, and in a severe scenario, all data concerning the same is deleted from the project. Where research data (amalgamated data only) will be presented/published, it will be primarily in aggregate form, and if 'power quote' is used, the respondent will have prior sight ahead of submission/presentation for approval.

What apps and platforms can I use to collect, securely store, transcribe, and share research data? Please read before completing Q. 30

As researchers, it is imperative that we can assure participants in our study that their data will be collected, transported, stored and archived securely; this is particularly important where sensitive personal details are involved. Exact details are required as to the use (and location) of locked cabinets, management of audio files, encryption of laptops, electronic data collection / storage / sharing, and so on. We have prepared this 1-page summary guidance to support you in articulating your plan; however, in the case of conflicting advice, official UCC policies will take precedence over this guidance.

I / we would like to undertake online survey / interviews / focus groups

All data, both anonymised and non-anonymised, including sensitive personal data, can be collected and stored on the following cloud platforms; Microsoft Products (OneDrive, Teams, SharePoint, Microsoft Forms, etc.) and Google Workspace Products (formerly Google G-Suite; Google Forms, Meet, Sheets, Drive etc.) ***subject to logging in to these services with your UCC credentials***. The only other app approved for survey data collection is Qualtrics (UCC does not have a site licence for Qualtrics; some Colleges and units may have a licence). ***Personal versions*** of Microsoft and Google Workspace apps **should not** be used to collect and/or store research data.

Only apps / platforms that have been approved through the central UCC procurement system (Agresso) should be used for data collection, data sharing and data storage. If you would like to use an app / platform that is not covered here please seek approval *prior* to applying to SREC. The first step to getting an app approved for use in research is to complete the "IT System Request Form". Please note that SREC has **no role** in approving apps / platforms for collecting, storing, transcribing or sharing research data.

I / we have audio to be transcribed by a person / software

If transcription is being outsourced, the transcription service used needs to be trustworthy, reliable, and confidential. It is essential that data transferred outside of UCC is done securely (see HEAnet FileSender). Please note that the only software and cloud-based transcription services approved by UCC for use in research for transcribing audio data are the tools embedded in Microsoft's products: use the dictate tool in newer versions of Microsoft Word, and the dictate and transcribe audio file upload tool through the online Office 365 Microsoft Word when using your UCC credentials, and Microsoft Stream/Microsoft Teams when using your UCC credentials.

We are a team and would like to collaborate online (UCC colleagues only and/or UCC and external team members)

UCC-supplied collaboration and storage services like Microsoft Teams and the equivalent Google Workspace apps, can facilitate you to safely collaborate and communicate on research studies with UCC staff and students, and to collaborate with partners outside of the university. Data saved in Microsoft Teams / Google Workspace apps when you login with your

UCC credentials are stored on the UCC's tenancies on Microsoft and Google's servers. Data is encrypted in transit and at rest. Features such as version control, external sharing and audit logging are available. Microsoft Teams sites can also be archived after the research is completed. If you have questions about these services, please contact the UCC IT Helpdesk. For collaborative projects, research data should only be stored on approved storage and collaboration services (Microsoft Teams and Google Workspace apps using your UCC credentials). If applying for ethical approval through SREC for collaborative, multi-agency projects and the data will not be stored in UCC / EU, please include comprehensive details on how these external services meet the relevant standards.

Although UCC students currently have access to institutional cloud storage, access to Microsoft Office 365 does not extend beyond their period of being a UCC student. Relying on one person's access to online data storage is not best practice. To ensure that the minimum data storage period of 10 years is adhered to, data should be stored in a shared Google Drive or Microsoft SharePoint site using your UCC credentials (UCC email address & password) to login.

Anything else I need to know?

1. Further details on IT Services Storage Options: click here. Information on data storage and backup during research click here.
2. If data does not need to be identifiable, it should be converted to anonymous form as soon as is possible.
3. Microsoft Azure Information Protection - AIP - enables you to protect documents on your computer before sharing them, and also enables you to protect emails in Outlook before sending them (PCs only). Click here for the Azure how to guide. Click here to download the software.
4. Applicants must consider how to maintain safe storage of their data beyond the life of their laptop/pc to meet the 10-year requirement in the UCC Code of Research Conduct.
5. Do not use free versions of services of services and platforms for data collection, sharing data, and/or data storage.
6. All laptops and PCs used to access data must be encrypted and password protected. Applicants should never store research data on a USB and only use an encrypted portable hard drive for short-term storage until data has been anonymised.
7. In the exceptional case where there is a requirement for on premise storage (e.g. a requirement of a data-sharing agreement with a third party), Research Data Store can be accessed by researchers for storing research data. UCC Network File Store (NAS) can be used for secure storage if the researcher has access to it (UCC staff).
8. The HEAnet's FileSender is a way to share large files with strong encryption to any email address in a safe manner, which is useful for sending audio files to a transcriber or between team members outside of UCC if not using Microsoft Teams / Google Workspace using your UCC credentials.
9. Where possible, **physical data** such as survey and consent forms etc. should be converted to electronic format as soon as possible and the originals shredded; however, if you need to retain physical data then it should be safely stored on premises at UCC in a locked cabinet/office.

30. Data. (Please provide your answers to these questions in the white area below; see advice on data collection and data storage on the previous page)

(a) How will you collect your data? Provide a brief description and justification of methods and data collection measures to be used.

i. If conducting an online survey/questionnaire, what survey platform do you plan to use?

ii. If you plan to use a virtual meeting platform such as MS Teams or Google Meet (using your UCC credentials to login), please outline the steps you will take in the event of a security breach or an interruption during a virtual call.

(b) If you are creating audio/video recordings, who will perform the transcription? (If transcription is being outsourced the transcription service needs to be trustworthy, reliable, and confidential. Ensure that data transfer is done securely. Recorded data must be deleted from a mobile recording device. When will the data recordings be deleted from the recording device and who will be assigned responsibility for this?)

(c) What type of data will you be storing? (Briefly describe the type of data you plan to collect).

(d) How and where will you store your data?[1] (Provide details about both physical ***and*** electronic documents).

(e) For how long will you store the data? (A minimum storage period of 10 years is required)

(f) Who will you share the data with? (*Sample* prompts: If you plan to make your raw research dataset available publicly as part of the open data movement, or if you are required to do so as part of funding/journal requirements, please address your protocol here (make explicit links to Q. 32 below and show that you have addressed this in your consent form and information sheet). For collaborative/community-based participatory research, please address issues such as shared ownership of data, will data be transferred (how?), publication of findings, etc. If your funder contractually requires you to give them access to the 'raw' dataset, examine relevant implications, including appropriate anonymisation, protocols for secure access to the dataset, etc.).

[1] Data management should follow the FAIR guiding principles (Findability, Accessibility, Interoperability & Reusability). See, for example, Wilkinson, M. D. et al. (2016) The FAIR Guiding Principles for Scientific Data Management and Stewardship. It is required that all staff and student researchers store those data which are required to replicate research findings, and the information required to enable re-use of data. Details of the UCC policy on research data storage can be found in section 8 of the UCC Code of Research Conduct. SREC advises against storing research data on non UCC approved cloud-based storage services. Physical data must be stored in a locked cabinet and you must specify who has permission to access this data.

(g) If you are planning to analyse an existing dataset, please outline how the original consent process allows for your data analysis. **(h) If you are planning to request access to health/case files/personal records that were not created for research purposes, please address Data Protection considerations, provide a strong rationale and comprehensively address associated ethical issues.** **(i) If you ticked yes to Q.6b in the SREC Checklist (above), have you submitted your DPIA?**
(a) Data will be collected through semi-structured interviews (see Appendix 11). No confidential information is being sought from respondents about developing their technology, etc. Instead, we aim to offer the benefit of their experience through facing challenges of the technology development phase and their internal and external capabilities to cross this valley of death. Preference is for a face-to-face chat as swift trust can be established easier, and conversations are fruitful and "more giving". However, if Covid restrictions are still in place when conducting interviews, using MS Teams using institutional ID or traditional telephone is the natural default (depending upon respondents' preference and ensuring compliance with UCC Covid guidelines). If the MS Teams platform is used as an interaction platform, it will be a one-to-one call the Teams platform will be used as a comms channel only, and recordings via Dictaphone will be simply audio files and saved with word docs, txt, etc. on the server and deleted from Dictaphone once transferred. If the telephone platform is used as an interaction platform, it will be a one-to-one call. And where recordings of the interview are made (personal preference is for interview notes taken during and post-interview), an independent Dictaphone device (offline) is used to make the recording. This ensures only a single offline copy of the recording exists, and once interview notes have been appropriated from the same, it is deleted from Dictaphone. Based on collective interview notes, a password protected anonymous case is developed in a word document and stored on UCC's staff one-drive. This is returned to the respondent, and once approved, it is transferred to the approved case folder (under a new password) and integrated into the ongoing thematic analysis of the password-protected Excel sheet.

The identification key of the individual cases is only maintained in hard copy and stored in a locked filing cabinet.

(b) Based on the research approach, the use of third-party transcription services is not required because detailed interview notes and maybe recording is preferred. After reviewing and analysing the recording personally, data has been appropriated; then, it is deleted from the Dictaphone.

(c) Hand-written interview notes and supplemental notes from any “necessary” interviewee recordings will be maintained in hard copy in a locked filing cabinet in a locked office until the synopsis case document is approved. Following this, hard copy documents will be shredded and destroyed as “confidential waste”.

Audio recordings (where used) will be maintained on a single Dictaphone in the office and, once reviewed and information appropriated, it will then be deleted from the independent device. This process occurs completely offline, and the Dictaphone is stored in a locked drawer of the office. When the Dictaphone leaves the office to undertake in-person interviews, it is blank, so only the single recording is stored on the device at any one time. If MS Teams is used as an interview platform, it will not be recorded in any medium other than this independent Dictaphone.

Synopsis case (anonymous) created in word document and password protected by alpha-numeric code for security and stored on UCC staff OneDrive. When the case is returned to the interviewee for review and validation via email, it is password protected (separate codes for the draft and approved cases), and the relevant password is communicated via telephone. Passworded excel file is used as a mega-matrix to allow in-case and cross-case analysis of the data stored on UCC staff OneDrive.

(d) The audio files and digital interview transcripts, and electronic consent forms will be held securely and separately on three OneDrive files, which will be stored on a secure server on University College Cork premises. A OneDrive file is a dedicated and secured centralised server storage device that will be accessible by the research team only. The members of this team are outlined above. OneDrive File (1) contains the digital transcripts of the interviews, while OneDrive file (2) contains the audio recordings from the interviews, and OneDrive File (3) contains the electronic consent forms. The interview recordings can be deleted once it has been transcribed.

(e) All word and excel document files will be securely held for a minimum of ten years after completing the research project. Following this period, the data will be destroyed, paper documents will be shredded, and computer files and other digital material will be permanently deleted. Any audio recordings and hard copy notes are destroyed as soon as relevant data has been appropriated into the electronic case document.

(f) Project manager of Marine Energy Alliance and MaREI Centre, Investigator, supervisors as outlined above and examiners of the research output.

(g) Not Relevant

(h) Not Relevant

(i) Not Relevant

31. Arrangements for informing participants about the nature of the study (e.g. information sheets, letters of invitation, social media information, participant recruitment, focus group welcome/schedule, withdrawal, etc.)
Participants will be informed of the nature of the study in the following ways: - The interviewees receive an invite email (see Appendix 8) with embedded project information that outlines the nature of the research. - After receiving a positive response, respondents receive a follow-up email with the agreed consent form (see Appendix 10) and interview protocol (see Appendix 11)

and an invite (see Appendix 8) for a preliminary telephone call should they have any questions or queries.

- After confirmation of suitable interview time by the interviewee and the Consent form completed (either returned physically or emailed electronically), the interview takes place.
- Respondents will be reassured that they can withdraw from the research
- The voluntary participation in the interview will be made clear to each participant.
- Respondents will be reassured of the confidentiality of all data and all information specific to any organisation.

32. How you will ensure that participants provide informed consent? (cf. Question 4 - attach relevant form(s); address special considerations in terms of children / young people / vulnerable persons / adults who have difficulty in making decisions unaided)
Once respondents have agreed to participate in the study via return email, they are sent the Agreed Consent form to complete (see Appendix 10). This form can be returned electronically via email, returned by post or face-to-face meeting, and can be handed over personally before the commencement of the scheduled interview. Importantly, no interviews will take place without this Agreed Consent form being completed. For the purpose of testing the validity through the convergence of information from different sources, consent forms have been drafted (Appendix 10). This consent form requests consent for their participation in the research study. Therefore, after sending an invitation email (see Appendix 8) and receiving a positive response, we will send the consent form (see Appendix 10) and interview protocol (see Appendix 11) with a scheduled time for an interview. The interview will take place ONLY once the consent forms are signed. Thus, the consent is granted by each company protects the owner/manager, their company, and their employees. Once the interview is complete, candidates are afforded an additional opportunity to ask questions regarding the study and its trajectory. Also, a copy of the interview transcript will be sent to the interview participant to make any amendments or confirm their satisfaction with the accuracy of the

interview transcript. Respondents receive the draft synopsis case for review, feedback, and validity check.

33. Outline of debriefing process at the end of the data collection process (cf. Question 9)**. If you answered Yes to Questions 19a or 19b, give details here. State what you will advise participants to do if they should experience problems (e.g. who to contact for help – provide name and contact details where required.)**
NA

34. Estimated start date and duration of project (by months)
The research began in 01/January/2021. Up to this point, the research has been desk-based. A review of the literature has been conducted. Subject to ethical approval, the research fieldwork will begin 1st of November 2021 or when UCC Ethical approval is received. The intention is to complete the interviews by the end of November to allow adequate time for data analysis critique, and write up. MSc by research 2-months duration in total.

35. Additional information of relevance to your application
See Appendix for support forms (Project Information Sheet, Agreed Consent form, Invite email and Interview protocol)

36. Declarations (clickable links to policies and codes quoted here are on the next page)	Delete as applicable

I/we agree that should there be unexpected ethical issues arising during the course of this study, that I/we will utilise my/our professional/disciplinary code of ethics, and/or notify UCC SREC, where appropriate.	Yes
I/we have consulted the UCC *Code of Research Conduct* and believe my/our proposal is in line with its requirements.	Yes
I/we have consulted the UCC *Child Protection Policy* and believe my/our proposal is in line with its requirements.	NA
I/we have consulted the UCC GDPR guidelines and declare that our project is GDPR compliant. Where required under the UCC GDPR Guidelines, I have submitted a DPIA to the UCC Information Compliance Department	Yes NA
I/we have consulted the UCC Garda Vetting Guidelines, and where appropriate, researchers on this project have valid Garda vetting through UCC (having a valid Garda Vetting through another body is insufficient).	NA

37. Signatures	
UCC Applicant(s)	**Academic Supervisor / Principal Investigator / Tutor** All academic supervisors (where applicable) must approve the contents of this application
N. Sadeghi Negar Sadeghi Gargari	Edward Shinnick Dr. Lawrence Dooley Prof. Edward Shinnick
Date: 12/09/2021	Date: 12/09/2021

1. Please submit a *signed* copy of this form and all relevant attachments **as one PDF file** to srec@ucc.ie.
   A picture of signatures pasted into section 37 is acceptable once the application is emailed to srec@ucc.ie from a UCC email address. No hard copies of this application are required.
2. SREC is not primarily concerned with methodological issues, but we may comment on such issues in so far as they have ethical implications.

Appendix 8: Invite Email

Dear X,

I hope you find this email well. Thank you again for taking the time out of your busy schedule and filling in the questionnaire I sent you. Your participation is much appreciated. As a follow up to the second stage of my research, I am contacting you to see if you would agree to a short follow-up interview (**max 30 minutes**) to find out more about the challenges facing firms in this industry and how policymakers can better provide support.

The approach adopted by this research is that of ‘expert’ interviews carried out with members of management teams of SMEs, and I would be greatly appreciative if you consider giving me 30 minutes of your time to support my research with the benefit of your experiences.

All interview data is anonymised, and analysis is based on aggregate as opposed to respondent-specific data. In addition, all participants have the right to withdraw from the research at any point in the process and have their data be deleted from the analysis (should this be required).

I hope you will consider this request by **signing the consent form and emailing it back to me within one week, with a day and time that suits you best for this interview**. I do appreciate your help.

FYI: An information sheet is attached to this email. If you require any further information, feel free to contact me.

Appendix 9: Participants Information Sheet

Thank you for considering participating in this research project. This document aims to explain to you what the work is about and what your participation would involve enabling you to make an informed choice.

The purpose of this study is to explore how technological, organisational, and managerial capabilities enable your company through the advancement of your technology, from proof of concept to scalable prototyping. I am interested in understanding what has both helped and hindered you in your attempts to develop your technology. This research would involve me talking to a member of the management team and another relevant staff member. Should you choose to participate, you will be asked to participate in a one-to-one interview with a research team member. This interview will be audio/video recorded and is expected to take 30 minutes to complete.

Participation in this study is completely voluntary. There is no obligation to participate, and should you choose to do so, you can refuse to answer specific questions or decide to withdraw from the interview. Once the interview has been concluded, you can choose to withdraw at any time in the subsequent two weeks.

All the information you provide will be kept confidential and anonymous and will be available only to Negar Sadeghi Gargari (Researcher), Prof. Edward Shinnick, and Dr. Lawrence Dooley (Supervisors). Once the interview is completed, the recording will immediately be transferred to a safe UCC data storage platform and wiped from the recording device. The interview will then be transcribed by the researcher, and all identifying information will be removed. Once this is done, the recording will also be deleted, and only the anonymised transcript will remain. This will be stored on a University College Cork supported cloud storage platform, namely UCC staff One Drive. The data will be stored for a minimum of ten years.

The information you provide may contribute to a thesis and research publications, and/or conference presentations.

We do not anticipate any negative outcomes from participating in this study as questions are not of a sensitive and personal nature. At the end of the interview, I will discuss with you how you found the experience and how you are feeling. Should you experience distress arising from the interview, the contact details for support services provided below may be of assistance.

Prof. Edward Shinnick	e.shinnick@ucc.ie	+353 (0)21 490 2052
Dr. Lawrence Dooley	L.Dooley@ucc.ie	
Ms. Fiona Flemming	fiona.fleming@ucc.ie	+353 (0)86 060 1941

This study has obtained ethical approval from the UCC Social Research Ethics Committee.

If you have any queries about this research, you can contact me or my supervisors at:

Name	Email	Phone Number
Me (Negar Sadeghi Gargari)	120222859@umail.ucc.ie	+353 (0)89 271 6583
Prof. Edward Shinnick	e.shinnick@ucc.ie	+353 (0)21 490 2052
Dr. Lawrence Dooley	L.Dooley@ucc.ie	

If you agree to take part in this study, please sign the consent form overleaf.

Appendix 10: Research Consent Form

I …………………………………… agree to participate in **Negar Sadeghi Gargari**'s research study.

The purpose and nature of the study have been explained to me in writing.

I am participating voluntarily.

I give permission for my interview with **Negar Sadeghi Gargari** to be audio/video recorded.

I understand that I can withdraw from the study, without repercussions, at any time, whether before it starts or while I am participating.

I understand that I will have the opportunity to review and make any amendments I deem fit after the interview transcript has been written up.

I understand that I can withdraw permission to use the interview data any time up to the approval of the case, in which case the material will be deleted.

I understand that anonymity will be ensured in the write-up by disguising my identity.

I understand that disguised extracts from my interview may be quoted in presentations and subsequent publications, but if this is the case, then I will receive a 'draft' for review and approval before submission/delivery.

It is based on the above that I give permission below (please tick one box):

I agree to participate in this study ☐

I do not agree to participate in this study ☐

Signed: …………………. Date: ……………….

PRINT NAME: ………………….

Appendix 11: Interview Protocol

1. Introductions of participants

1.1. Could you tell me a first more about your background and your current role in the company?

1.2. What motivated you and your company to participate in the existing marine energy alliance project (MEA)?

2. Company Background

2.1. When was the company founded?

2.2. How many employees?

2.3. Could you also tell me a bit more about the company and its products and services?

2.4. When did your company start to develop technologies in the marine energy sector? When did you start [specific] technology?

3. Movement Across TRL3

3.1. Based on nine levels of TRL, what do you feel is the most challenging phase of TRL to date TO TRAVERSE and why?

3.2. Did you face specific constraints in your technology development? What constraints? Why?

3.3. How important is collaboration for your technology development? Who have you collaborated with?

4. Challenges

4.1. What were the main challenges that impacted your technology development when you first started?

4.2. Nowadays, what are the main challenges impacting your technology development?

5. Capabilities

5.1. When you first started, what capabilities and resources helped your technology development?

5.2. Nowadays, what capabilities and resources are helping your technology development?

5.3. Which capabilities do you think are most important? Why?

5.4. What do you see as the uniqueness of your company? Innovations in technology development

Appendix 12: Thematic Analysis Steps

Braun and Clarke (2006) outlined six steps for thematic analysis:

a) Familiarizing with the data or immersion in the data

This step involved listening to the audio recordings and "repeated reading" of the transcripts, and reading the data in an active way. To accomplish this, the entire collection of transcripts was read once without taking notes. After that, the researcher began taking notes on the side of the transcripts and underlining keywords or phrases to find meanings and patterns. Each interview was analysed individually first, proceeded by a cross-interview analysis (Braun and Clarke, 2006).

b) Generating initial codes

Coding, an essential element of qualitative data analysis, organizes data into meaningful groups to reduce the amount of data into more manageable slices of data and understand the meaning of the data (Miles and Huberman, 1994). Coding involves labelling each data unit within a data item with a code that symbolizes or summarizes that extract's meaning (Saunders and Lewis, 2018). Like the first step, each interview was coded and analysed individually, followed by a search for cross-case patterns. At this stage, the researcher aimed to code for as many potential themes/patterns as possible to capture as many of the significant remarks and observations of the respondents.

c) Searching for themes

"A theme captures something important about the data in relation to the research question and represents some level of patterned response or meaning within the data set", and "researcher judgement is necessary to determine what a theme is" (Braun and Clarke, 2006). In this step, data extracts were sorted in constant comparison to identify commonalities and differences (Miles and Huberman, 1994). The final purpose of this step was to identify similar and related codes that could be aggregated to form a main idea or a more significant overarching theme (Braun and Clarke, 2006; Saunders and Lewis, 2018).

Through an interpretative analysis, the data was scrutinized in relation to the phenomenon being examined, and the research objectives and the long list of codes developed in stage two were collated and categorized into possible themes and sub-themes, refocusing the analysis on a broader level (Braun and Clarke, 2006).

d) Reviewing and refining the themes

In order to check the themes' fit with the coded extracts and with the entire data set, convergence or recurring regularities in the data were identified (Braun and Clarke, 2006). Hence, this process is based on moving back and forth between data and the classification system to verify the accuracy of the categories (Patton, 2014). In an attempt to identify and analyse the relationship between codes, themes, and different levels of themes, the newly developed candidate themes were analysed, and the concepts were grouped together. This process ensures the consistency of the data set (Miles and Huberman, 1994). During this phase, the entire data set was re-read once more to determine whether the themes "work" in relation to the data set and are thus valid. Consequently, it was essential to identify any additional data within themes missed in earlier coding stages (Braun and Clarke, 2006).

e) An on-going analysis

This step was to refine the specifics of each theme and the overall story the analysis tells. Through the process of “defining and refining” to identify the “essence” of what each theme is about, as well as the themes overall, the final stories around each of the themes and their relationships were illustrated (Braun and Clarke, 2006).

f) Telling the complicated story of data

This step should be done in a way that convinces the reader of the merit and validity of the analysis (Braun and Clarke, 2006). At this phase, the analytic storyline has to go beyond data description, make an argument for the research question, and confront the analysis with the existing formalized body of knowledge (Miles and Huberman, 1994; Braun and Clarke, 2006).

Appendix 13: Case Studies' background

Case 1: This Irish micro-SME was founded in 2012. Due to previous failures, employment and cash burn were kept to the absolute minimum whilst pre-revenue. Trinity College Dublin (TCD) offered "campus company" status, making the situation easier and leading to an excellent symbiotic relationship with the School of Engineering. During the time, full-time staff varied between 2 and 6. Then, the Ocean Energy Prototype Development fund by the Sustainable Energy Authority of Ireland (SEAI) was closed in January 2019 when they were starting to gear up for sea ¼-scale trials. Hence, full-time staff was necessarily reduced to 2 and then 1 to let individuals go, e.g., to complete PhDs or good secure jobs. A new business model was adopted to out-source the non-core R&D to suitable engineering consultancy partners and jointly seek Irish or European public sector funding. This is made a vastly more practical option by splitting the work between Ireland, Scotland, and Spain. The approach has been to develop a Wave Energy Converter (WEC) that is as seaworthy and as mechanically simple as possible, with onboard intelligence and an ability to operate effectively and autonomously in a changeable wave climate. They have done around over 600 tank tests in Ireland, France (ECN and OCEANIDE) and Spain (IH Cantabria), empirically validated numerical programs and simulations, including boundary element methods, linear simulations, and a CFD "virtual tank" validation by tests at the ECN and OCEANIDE facilities, and developed a detailed economic model, using offshore costs and the evidence of performance from validated tests. However, they realized that the economics were not really looking as good as possible, and there were still technology problems. They wanted to develop a device that could be deployed safely offshore and reliable, so they moved back from TRL 4 to TRL 3 to achieve an LCOE of less than €100/MWh.

Case 2: This UK-based micro-SME was founded in 2015 by two co-founders. The employees include 13 full-time employees, 2 EngD students, and a couple of advisors, and it is growing fast. The company has two main groups: the business group and the technology R&D group. Tech R&D includes three teams of engineering, physical modelling, and numerical modelling. The business part is split between management, commercial, programmes, and operations teams. The firm is a wave energy developer with a core business in designing, building, and selling wave energy converters. There are about three active products, all variations of this core technology on different scales, and TRLs starting from 2015. Also, there is an optimisation process (a numerical tool) developed in-house to quickly iterate based on a set of requirements for what the product needs to do, for example, the size or the amount of power and numerically generate new geometries and assess their fitness for a particular goal.

Case3: This UK based micro-SME was founded in 2010. They basically just provided contract engineering services to established offshore oil and gas construction companies as a senior project engineer on a rolling basis. The company director worked as a construction planning and execution engineer and offshore field engineer on several offshore pipeline construction projects. He started hand calculations and developed the Drop Keel concept, a semi-sub/spar composite foundation structure for a 10MW wind turbine in 2018. Then, in 2019, the company collaborated with ORE Catapult (OREC), Atkins Engineering (AE), and the University of Strathclyde (UoS) on an Innovate UK funded research project to investigate the potential of the original Drop Keel concept. So, they started a set of laboratory tests in 2019 and did similar in 2020. So, they have done lab tests every year from 2019 to 2021.

Case4: This Irish micro-SME was founded in 2018, started with consultancy and provides a wide range of technical services across Product Development, Project Delivery and Engineering Advisory. Three directors of the firm are experienced in delivering complex and high-value projects in the offshore industry. Having international experience across the marine and offshore energy industries, focusing on floating offshore wind, they started developing a floating offshore wind mooring component in early 2020. The Load Reduction Device (LRD), a novel sub-component of the mooring system for a Floating Offshore Wind (FOW) platform, reduces the mooring load acting on the system by approximately 50%, resulting in similar CAPEX, OPEX and LCOE reductions. It is fully scalable and tenable to deliver the mooring systems' specific requirements and is manufactured using basic low-cost materials - steel and concrete - which have a demonstrated track record in the marine environment. They provided technical skills in-house and used UCC test sites for numerical analysis, tank testing, and validation.

Case 5: This UK-based micro-SME was founded in 2008. The parent company was founded in 1998, with development occurring both on tidal turbines and wave energy converters. The sister company started with tidal technology in 2002, and then it started wave energy research and development in 2008 at the parent company. The firm does not have any direct employees as employees are hired through the parent company. In 2013, at-sea proof of concept trials was conducted with a multi-point absorber WEC. These trails allowed the team to gain a first-hand physical understanding of the challenges inherent to the envisioned system and understand the concept practically. The starting point for deeper technical work was an advanced control system not constrained by any presupposition of power take-off capabilities. This controller resulted in modelled electrical production several times larger than a simplistic control. By applying numerous hypothetical power take-off constraints (e.g., maximum force, velocity, etc.) and collecting performance data, the team was able to reach an idealized power take-off system requirements document. The resulting system requirements set the foundation for developing power take-off, a direct drive linear generator that has been fully designed and is currently being fabricated for laboratory testing in 2019.

Case 6: This Irish micro-SME was founded in 2008. They started developing Wave driven ocean going Tug in 2018. Their technology looks like a ladder in the water. It uses the properties of the waves moving, orbital motion and gets forces moving in both directions. Prototype testing in the Lir Deep Ocean Basin in 2019 followed a detailed test plan to investigate the Tug performance and achieved the following objectives: Verified Proof of Concept, Verified Tug stability & survivability, Measured Tug Towing Force and Speed, and Validated concept for irregular waves.

Case 7: This Irish micro-SME was founded in 2005 and evolved over the years. They originate a consultancy company helping commercialized technologies coming out of the university, basically reviewing technologies, talking to companies in the industry to determine what they solve and the opportunity to bring them forward by doing any additional or validation work for those companies. Then, they started to develop polymer spring sort of technology with the ability to build flexibility into structures using high load handling plastics or polymer plastics about a decade ago. The fundamental core technology is the polymer pieces, and now they are entirely focused on the polymer spring sort of technology and have more than one application for it. The core application manages load to mooring systems and an extra application that uses it as a punk system to generate power.

Case 8: This Irish micro-SME was founded in 2006. The initial company was set up as a research and development company, primarily and solely to investigate the tidal technology and see whether there was any viability to the product or the device. The founder of the company was always attracted by renewable energy and came up with the idea of a crossflow, closed-loop hydro-kinetic energy extraction device that uses a system of "flyers" with symmetrical foils and a tail control system to drive chains connected to a generator in 2001. However, he landed upon the most current configuration, around 2004, which means that the technology had slight modifications, but the concept was the same. In this regard, HMRC was contracted to conduct physical test campaigns in 2004. Later, in 2013, Black & Veatch (BV) ran independent techno-economic reviews of the device as the experimentation progressed. Ten physical test programmes have been completed following the TRL pathway, bringing the device to TRL4.

Case 9: This Irish micro-SME was founded in 2010. The company has only one employee as a director, who is a director of an international company. The founder of the firm had kind of an alternative view and provided insightful recommendations regarding policy issues in Ireland. Working with a foreign company with a floating platform for the offshore wind in the context of an Irish offshore floating wind platform has helped this firm bring its technology to TRL8.

Appendix 14: A sample of a Transcript

Interviewer:

21:27: Based on nine levels of technology readiness, what was the most challenging phase of TRL to date?

Interviewee:

21:44: Yeah, good question again. So obviously, you have, broadly speaking, you have growing costs as you move up the TRL scale. So, depending on the status of your company, you might find that at some point, you have a massive influx of funds. And so, it's actually easier to move up in later TRL, as opposed to at the beginning. But in general, I would say that the [redacted], between four and six, is difficult because you still don't have a product, really. But you do need quite a bit of funds to get a product from a model that you've tested in a lab to a big prototype that you're testing in the sea. And you might not have been able yet to, you know, convince a big investor to say:

"Yes, I believe in your validated technology in the lab; I'm going to invest.".

Essentially, we are talking about millions to build a large-scale version and put it in the open ocean. So that is a tough one. You can do it with grants, but often, it is not enough.

And actually, what [redacted] did. So [redacted] aims to have technology between, you know, around TRL six to seven, by the end of stage three, so those are not loans. That is just if you are successful, and you win that competitive bid, and you have access to the money that you need to get up to; obviously, there is a fixed budget, so you know. But that is really nice because, at that stage, we did not have anyone that was ready to commit a couple of million pounds to build a big prototype machine. So, [redacted] gave us a lifeline in that sense and really helped us bridge that.

So, to answer the question, to get there, we had to do well in stage one, which was lower TRLs. And stage two, that was, you know, three, three to four, etc. So quite hard to say. I think even when you are at TRL six to seven, then that is when unless you become a huge company that can actually manufacture also a prototype, which is unlikely for an SME. That is really when you need to start attracting big investors and also clients that want to buy your wave energy converter. I mean, we have not got further up than seven, so I cannot really comment on seven to nine from experience. But, another thing to kind of think about is, so one side of it is the readiness. So how qualified or emotionally ready is your technology and the other is, and what is the performance of the technology.

There are some interesting papers by a guy called Jochem Weber, who coined the technology performance level, so TPLs. And the theory says that you want to drive up your TPL as much as possible before you drive up TRL. Because as you get further up to TRLs, if you realize that your performance is suboptimal, it takes a lot of money to go back; it becomes sometimes impossible because your investors will not allow you to do that to go back to lower TRLs and update or change parts of your system, of your work.

So, some companies have been, kind of really, really driving up TRL, and you can kind of think of it as you know, your business branch and your technology R&D branch, you know, you can make the best performing WEC in the world. But if no one knows about it, if you do not have any investors, it does not matter. It is never going to get built because it is too low TRL wise; equally, you could have an amazing business team that can sell, you know, a shoe that they have fished out of the ocean; if they can convince the investors, you can get up to really high TRL. But actually, your performance is relatively poor. So, it is a really delicate balance.

The failure that I was talking about before in 2013 of [redacted] was a big, big contributor to that, because at that point, actually, wave energy was trending, there was enthusiasm around it, and then, but the industry itself was relatively immature. So, if you could say, you know, inevitably there were setbacks. And I guess maybe it was a bit of a shortcut way of getting to, you know, massive, massive machines. And if anything goes wrong there, that is a lot of money, and you really risk folding and having to start again, which is kind of what happened. But thankfully, through [redacted], and I am sure through other programs, it seems like slowly but surely kind of getting some experience and some learning and some confidence back in the sector.

Interviewer:

29:37: And did you face any specific constraints in your technology development?

Interviewee:

30:01: Yep. So, I guess technology-wise, one of the most challenging things is the power take-off system. Because unlike for wind, and also tidal to a degree where you have got turbines that spin in one direction, depending on the way they are set up, let us say for the wind to simplify the case, you are the generator in your wind turbine spinning in one direction. And there is also a rated speed at which you would switch; you would decide to start generating power. And so, the conditions within which you are generating are massively challenging. But you could argue they are a little bit more simplified than for wave, because for wave, you got really slow, very high torque, but also reversing motion, at least in our device, and many other devices as well. And so that is really challenging because so far, generators have not really been designed for those conditions. Also, you really want to try and avoid using gearboxes because that is a big source of unreliability. And that is really key if you are putting something in the sea that is more difficult to access than potentially, if, even a wind turbine that is offshore. Yeah, I mean, a wind turbine that is offshore is still very hard to access themselves, to be honest. But at least in our devices floating, someone would need to climb into the device to do that, or you would have to bring it back to port or detach the PTO and bring it back to port. So, technically, that is a big challenge, and big steps forward have been made.

The development of the PTO is actually something that we have worked with partners on. So that is one of the things that have been outsourced to a degree. Equally, the mooring is tough because, again, if you are mooring a boat, you are mooring it because you do not want it to move. If you are mooring an offshore platform, you are mooring it because you do not want it to move. If you are mooring a wave energy converter that has to be dynamic in order to convert the energy, then you do want it to move in a particular way. So, you have got a bit of a paradox there because you want it to keep the station and not drift away, but you do not want to constrain its motion. And so, the mooring systems tend to be more dynamic, to be more compliant, and it is a tricky, tricky thing to solve. So, again, motion does not have any internal mooring expertise.

That has been largely outsourced, as well as the offshore operations, we do have a team of two helping to maintain the device and kind of overseeing the operations, but we do not have any mooring experts who can design the mooring and the operation. So that is something we are looking to film. It is expensive to outsource things. So as now we are growing, we are really keen to try and fill those gaps.

And the other constraints. Well, I guess an obvious one was COVID delays during the build of [redacted], but managers did a good job there.