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Exploring Effective Supply Chain Readiness and Resilience Within the Marine Renewable Energy Sector: A Future Reality Tree Approach

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Abstract

Marine renewable energy technologies (MRE-T), which capture energy from oceans and seas, represent a pivotal area for sustainable energy development. These technologies, including wave energy converters, tidal energy systems, ocean thermal energy conversion, and salinity gradient power, offer the potential to diversify energy sources, reduce reliance on fossil fuels, and mitigate climate change impacts. Despite its vast potential, marine renewable energy currently constitutes only a small fraction of global electricity generation, highlighting the challenges and complexities associated with its development and deployment. This paper builds on original research undertaken in 2019 by the authors exploring the barriers for companies attempting to enter the Marine Renewable Energy-Supply Chain (MRE-SC). The aim of this paper is to adopt the Theory of Constraints (ToC) approach to develop a Future Reality Tree (FRT) which creates a roadmap to enable companies to successfully enter the MRE-SC. This will enable academics and practitioners to visualize the cause-and-effect relationships around market entry into MRE-SCs for companies, whilst outlining the future goals, and the pathways to achieving the desired results within a holistic system. Therefore, the FRT provides a bridge between current and future visions and provides a valuable strategic perspective on the way companies can transition into the MRE-SC, thereby enabling a future state to be described, guiding the identification of changes that are required to establish an effective change management approach.

Keywords: theory of constraints; supply chain resilience; future reality tree; systems thinking

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1. Introduction

Marine renewable energy technologies, which capture energy from oceans and seas, represent a pivotal area for sustainable energy development [1]. These technologies, including wave energy converters, tidal energy systems, ocean thermal energy conversion, and salinity gradient power, offer the potential to diversify energy sources, reduce reliance on fossil fuels, and mitigate climate change impacts [2]. Despite its vast potential, marine renewable energy currently constitutes only a small fraction of global electricity generation, highlighting the challenges and complexities associated with its development and deployment [3]. The expansion of marine renewable energy necessitates a robust and competitive supply chain, capable of delivering innovative, reliable, and cost-effective components and systems. However, manufacturers face numerous barriers that hinder their entry into this emerging market, including technological uncertainties, high capital costs, regulatory complexities, and a lack of established standards [4]. Overcoming these barriers requires strategic interventions and enablers to foster innovation, reduce risks, and create a supportive ecosystem for manufacturers. The transition to renewable energy is a major priority, driven by environmental concerns that threaten various aspects of human life [2].

The steep rise in fossil fuel prices and stringent emission norms implemented by governments has forced marine industries to search for efficient power conversion methods [5]. Adopting green technologies is now critical to protecting oceans for future generations [6]. Marine Renewable Energy (MRE) technologies represent a promising frontier in the global transition to sustainable energy systems. These technologies harness the vast energy potential of oceans and seas, offering clean, predictable, and locally available power.

Over the years, a number of MRE technologies have been developed. Their basic purpose is to convert tidal and oceanic energy into electricity. For instance, tidal energy utilizes the kinetic and potential energy of tidal currents and tidal range, whilst wave energy captures energy from surface waves. It is tidal stream energy that is currently the most technologically mature and predictable [7]. For instance, it is projected that up to 10 GW of ocean energy capacity will be installed by 2030, highlighting the role of MRE in expanding energy access. Therefore, tidal energy systems will be the focus of this study [8].

With the focus on how MRE technologies contribute to the wider scope of environmental sustainability, it is helpful to frame the contributions in terms of how the technologies meet the UN's Sustainable Development Goals SDGs. For instance, MREs provide an obvious connection to SDG 7 (affordable clean energy) in providing clean and renewable electricity, especially to remote coastal areas and island communities, through offering predictable energy generation, particularly from tidal sources, which complement the intermittent sources of energy production such as solar and wind. MREs in this area also support energy diversification and grid stability.

MRE supports climate action (SDG 13) through reducing greenhouse gas emissions through fossil fuel displacement and enhancing climate resilience. It contributes to nationally determined contributions (NDCs) under the Paris Agreement and supports the decarbonization of the power sector [9]. Also, MRE can impact marine ecosystems (SDG 14); it also promotes sustainable ocean use through careful planning and environmental monitoring. Research emphasizes the importance of marine spatial planning and ecosystem-based management to ensure sustainable deployment [9,10].

A comprehensive review of ocean energy technologies conducted by [10] emphasizes their strategic role in niche markets and integration with other renewables. Ref. [11] highlights offshore renewables' role in powering the blue economy and their potential for job creation and sustainable development. Ref. [12] explores innovation in MRE, focusing on cost reduction, environmental assessments, and policy frameworks. Ref. [9] discusses how ocean energy supports multiple SDGs, including energy security and ecosystem protection. The UN Ocean Capacity Report [11] underscores the importance of international cooperation and scientific research in aligning MRE with SDG 14. In summary, MRE technologies are well-aligned with the UN Sustainable Development Goals, particularly SDGs 7, 13, and 14. While challenges remain in terms of cost, scalability, and environmental governance, MRE holds significant promise for a sustainable and resilient energy future. Continued investment in research, policy support, and international collaboration will be essential to fully realize this potential. As such, this paper addresses the following research questions:

RQ1. *"What are the Desirable Effects (DEs) required to orientate manufacturing companies towards working within the MRE SC?"*

RQ2. *"In what form should these DEs be structured to provide maximum impact in companies?"*

This paper explores the key issues facing manufacturers seeking to enter the MRE-SC by employing the Theory of Constraints Future Reality Tree to construct a desirable future state. The Future Reality Tree is a powerful tool within the Theory of Constraints framework, used to identify and address the core problems that prevent an organization from achieving its goals. This analytical approach allows us to systematically identify the root causes of the challenges faced by manufacturers and develop targeted strategies to overcome these obstacles and provide a roadmap to enable companies to enter the MRE-SC.

2. Literature Review

2.1. Literature Review Design

A systematic literature review approach was adopted with the aim of exploring and identifying the key issues specifically pertaining to tidal MRE technologies and their respective supply chain development practices. More importantly, the focus was on identifying the issues surrounding the barriers and enablers for the entry of companies into the MRE-SC, as well as the contribution of MRE to the sustainability and circular economy agenda. The databases utilized were Scopus, MDPI, and Emerald Insight.

A set of carefully selected keywords and Boolean operators was employed to capture relevant literature. The main search terms included "Marine Renewable Energy", "Marine Renewable Energy Supply Chains", "Tidal Energy Supply Chains", "Theory of Constraints and MRE", and "MRE and sustainability". Boolean operators (AND, OR) were applied to combine concepts, ensuring that retrieved articles addressed both managerial and environmental perspectives. To maintain quality and relevance, inclusion and exclusion criteria were applied. Eligible studies were limited to peer-reviewed journal articles published between 2005 and 2025, written in English, and directly focused on the integration of MRE technologies and MRE supply chains. Conference abstracts, book chapters, and editorials were excluded.

The screening process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach. The initial search identified 2675 records across the three databases (MDPI, Scopus, and Emerald). After removing duplicates, 2370 unique articles remained. Title and abstract screening excluded 1239 records for lack of direct relevance. Full-text screening of the remaining 1039 articles resulted in the further removal of studies with limited methodological rigor or insufficient focus, leaving a final set of 92 articles for in-depth review and citation. The final pool of 92 peer-reviewed papers forms the basis of this synthesis. These studies provide a comprehensive and balanced representation of global MRE-SC practices, the barriers and enablers of MRE-SCs, and managerial approaches for aligning MRE systems with sustainability objectives. Also, the connections between the MRE companies, their supply chain configurations, and the SDGs and other sustainability goals were of particular interest and were included in this study. Finally, articles applying ToC in non-manufacturing environments were reviewed. A total of 102 papers were identified from within the 2675 unique articles initially identified. However, following screening, only five of these papers offered potential contributions to the literature analysis, with only one publication showing the direct application of ToC to map renewable energy supply chains.

2.2. A Review of the MRE Literature

Several barriers impede the entry of manufacturers into the marine renewable energy supply chain, including the substantial upfront capital investments required for research and development, prototyping, and manufacturing infrastructure [13]. Regulatory uncertainty and the absence of standardized permitting processes also pose significant challenges, creating delays and increasing project costs. Moreover, the lack of established performance standards and certification schemes can hinder market access and investor confidence [14]. The dominance of established "legacy sectors" that resist disruptive innovation further exacerbates these challenges, as these sectors often benefit from existing infrastructure, subsidies, and political influence that favor traditional energy technologies [15]. To overcome barriers and adapt to changing environmental conditions, companies operating in the distributed energy market need to develop innovative business model solutions [16]. Overcoming these barriers requires coordinated efforts from governments, industry stakeholders, and research institutions to de-risk investments, streamline regulatory processes, and promote technological advancements [13,17]. Addressing financial and technical obstacles, creating supportive policies, and building public awareness are essential for the widespread adoption of renewable energy sources [18]. The deployment of renewable energy is crucial not only to meet energy demands but also to address concerns about climate change, but existing barriers in this sector prevent the development and penetration of renewable energy globally [19].

Underdeveloped physical infrastructure and logistical challenges, coupled with inadequate government support, create additional impediments for manufacturers seeking to establish and scale their operations [20]. The absence of robust transmission and distribution of energy systems, which can accommodate the variable profile of renewable energy resources, impacts overall system security [21]. The industry's nascent stage results in a shortage of skilled labor, hindering the development and adoption of renewable energy technologies also significantly affects a company's ability to enter the MRE-SC with confidence and capability. Private sector entities are hesitant to invest because of inaccurate risk assessments [22].

Furthermore, significant barriers impede manufacturers' entry into the MRE-SC. One of the most prominent hurdles is the high capital costs associated with the research and deployment of marine energy technologies. The initial investment for developing and testing prototypes, establishing manufacturing facilities, and deploying commercial-scale projects can be substantial, creating a significant financial barrier for many companies. The nascent nature of the marine renewable energy sector also contributes to technological uncertainties and risks. Many technologies are still in the early stages of development, with limited real-world operational data and performance validation [23], although more rapid advancements in technologies are now starting to occur as infrastructure developments increase and the technologies are implemented [24]. However, despite advancements, it still makes it difficult for manufacturers to assess the long-term viability and profitability of investing in these technologies. Regulatory and permitting processes also pose significant challenges. Obtaining the necessary permits and approvals for marine energy projects can be a lengthy, complex, and costly process, involving multiple regulatory agencies and stakeholders [25]. The absence of standardized regulations and streamlined permitting procedures further exacerbates these difficulties, creating uncertainty and delays for manufacturers. Access to specialized infrastructure and skilled workforce is another critical barrier [13], and since both infrastructure and training take significant time to develop and implement, these two issues are priority issues for companies if they are to operate effectively in an MRE-SC.

The pressure for successful supply chain development, management, and sustained capacity growth is growing as the proposed targets for marine projects draw closer [26]. The sector report highlights the need to focus on "collaboration on supply chain development" to ensure there is sufficient capacity, especially at the manufacturer level, to 'anchor' the sector development opportunities in Wales [27]. Furthermore, the work undertaken by [13] also identified similar issues for MRE-SCs. Therefore, understanding how the future reality state of the sectors' holistic supply chain needs to look is key to enabling a resilient strategy for both capacity growth in the short term and effective long-term performance maximization. The strategic aim of a stronger renewable base for energy production is evident in the UK government's manifesto, and Wales is well disposed to develop a range of energy sources, with marine resources playing an important role. This research is therefore focused on exploring what the future state should look like, and the resulting actions needed to ensure that the MRE sector takes the necessary actions to realize the opportunity available.

From a manufacturer's perspective, several enablers can facilitate the entry of manufacturers into the MRE-SCs, including technology transfer and knowledge sharing initiatives that promote collaboration between research institutions, established companies, and new entrants. These initiatives can accelerate the development and commercialization of innovative technologies, reduce duplication of effort, and foster a culture of continuous improvement. Furthermore, workforce development programs can equip individuals with the skills and expertise needed to design, manufacture, install, and maintain marine renewable energy systems. Supportive government policies, including feed-in tariffs, tax incentives, and renewable energy mandates, can create a stable and predictable market environment, incentivizing investments in marine renewable energy technologies [18]. These measures include political commitment through renewable energy targets and renewable promotion measures, including support mechanisms such as feed-in tariffs, renewable energy certificates, renewable portfolio standards, and net metering [26]. The implementation of clear and streamlined regulatory frameworks reduces administrative burdens and project development timelines, while the establishment of performance standards and certification schemes enhances investor confidence and facilitates market access. These programs can address the skills gap in the sector and ensure that manufacturers have access to a skilled workforce [27].

Facilitating collaborations between research institutions, industry players, and government agencies fosters innovation and knowledge sharing, accelerating the development and commercialization of marine renewable energy technologies. In addition, targeted financial support, such as grants, loans, and venture capital, addresses the funding gap faced by manufacturers, particularly small and medium-sized enterprises. Developing demonstration projects and test facilities provides opportunities for manufacturers to validate their technologies in real-world conditions, reducing technological risks and building investor confidence. Investing in workforce development programs ensures the availability of skilled personnel to support the growth of the marine renewable energy sector. Public awareness campaigns can also play a key role in increasing public acceptance of marine renewable energy technologies and fostering a supportive social environment [18]. Addressing risk mitigation and energy storage through government policy helps encourage further investment and development in the renewable energy sector [28].

The Theory of Constraints (ToC) was developed by Eliyahu M. Goldratt [29,30] offers a systematic approach to identifying and addressing the most critical constraints that limit an organization's or system's performance. The Theory of Constraints posits that every system has at least one constraint that limits its performance. By identifying and addressing these constraints, organizations can achieve significant improvements in throughput, profitability, and overall efficiency. The Theory of Constraints provides a structured methodology for identifying and eliminating constraints that impede the achievement of a desired future state [31–35].

The Future Reality Tree is a key tool within the Theory of Constraints framework, used to visualize and validate the positive effects of proposed solutions to overcome identified constraints. The ToC process starts with the organization first identifying the typical problems and issues that affect business performance. These are termed as undesirable effects (UDEs). Following the identification of the initial set of UDEs, a Current Reality Tree (CRT) can then be constructed. The tree uses the UDEs and develops a structure that connects the UDEs to provide a picture of how they link together to clarify the overall problem or limitation that the company has. During the CRT construction, further UDEs may appear as the cause-and-effect logic is applied. Once all the UDEs have been captured and connected to create a coherent system of cause-and-effect, the UDEs are then analyzed and a series of desirable effects (DEs) is then identified. The creation of the DEs comes from a teamwork approach using experts to propose potential solutions to converting the UDEs into DEs. The DEs are the effects that, when connected, will result in improved performance and the elimination of the UDEs. To create a clear future vision for our system through linking DEs to a solution-based strategy, a Future Reality Tree (FRT) can then be constructed.

The FRT diagram begins with DEs and 'injections'. The injections are the proposed solutions and logically connect to the DEs. Using Figure 1 as an example, the DEs are shown at the top of the FRT diagram in shaded and bold type. In this case, the DE is shown as "*Renewable Energy technologies are Implemented On-Time and in-full*". These DEs are identified as being the ideal state and the effects most likely to unlock the potential, and to create the opportunities for companies to enter the MRE SC. These DEs are then joined by enabling activities (injections), defined by the rectangular boxes towards the bottom of the diagram. In this case, the injections are as follows:

I1: Suitable technology is identified by the company to align with the REI.

I2: Suitable technology matches the company's capabilities and needs.

I3: The company thoroughly identifies all constraints and sets objectives to utilize technology to its full potential.

I4: Technology performance is measured and action is taken to ensure correct alignment with the MRE SC objectives

Alongside the injection activities, connector activities (shown in the rounded-edge rectangular boxes) help connect the injections together and provide a pathway to meeting the DE requirements. This, in turn, helps create the cause-and-effect relationships that lead to desirable outcomes. This systematic approach, coupled with the previous work undertaken on CRT development of MRE supply chains, provides a foundational basis for the design and application of the FRT. Furthermore, ToC/CRT/FRT has traditionally been used by managers and engineers to solve 'manufacturing' related issues. Therefore, the authors see the opportunity to apply ToC in a new environment and application, that of MRE-SCs, where the evaluation of the methodology as to its applicability to effectively assist in developing a roadmap and trajectory for companies to enter the MRE-SC will be made at the end of this paper.

The structure of an FRT diagram is similar to the CRT diagram, but focuses on actions and interventions that need to be 'injected' into the current reality to resolve the core drivers of the current system that cause the UDEs. Thus, the FRT diagram's starting point is proposing the relevant injection and then builds up via cause-and-effect logic towards a set of desirable effects (DEs) to move towards the required future state [36,37]. This offers a cause-and-effect framework based on the logical visualization of the proposed future state and its benefits. Importantly, the focus is on the system as a whole and the way barriers and obstacles to desired outcomes can be understood and minimized, if not entirely removed.

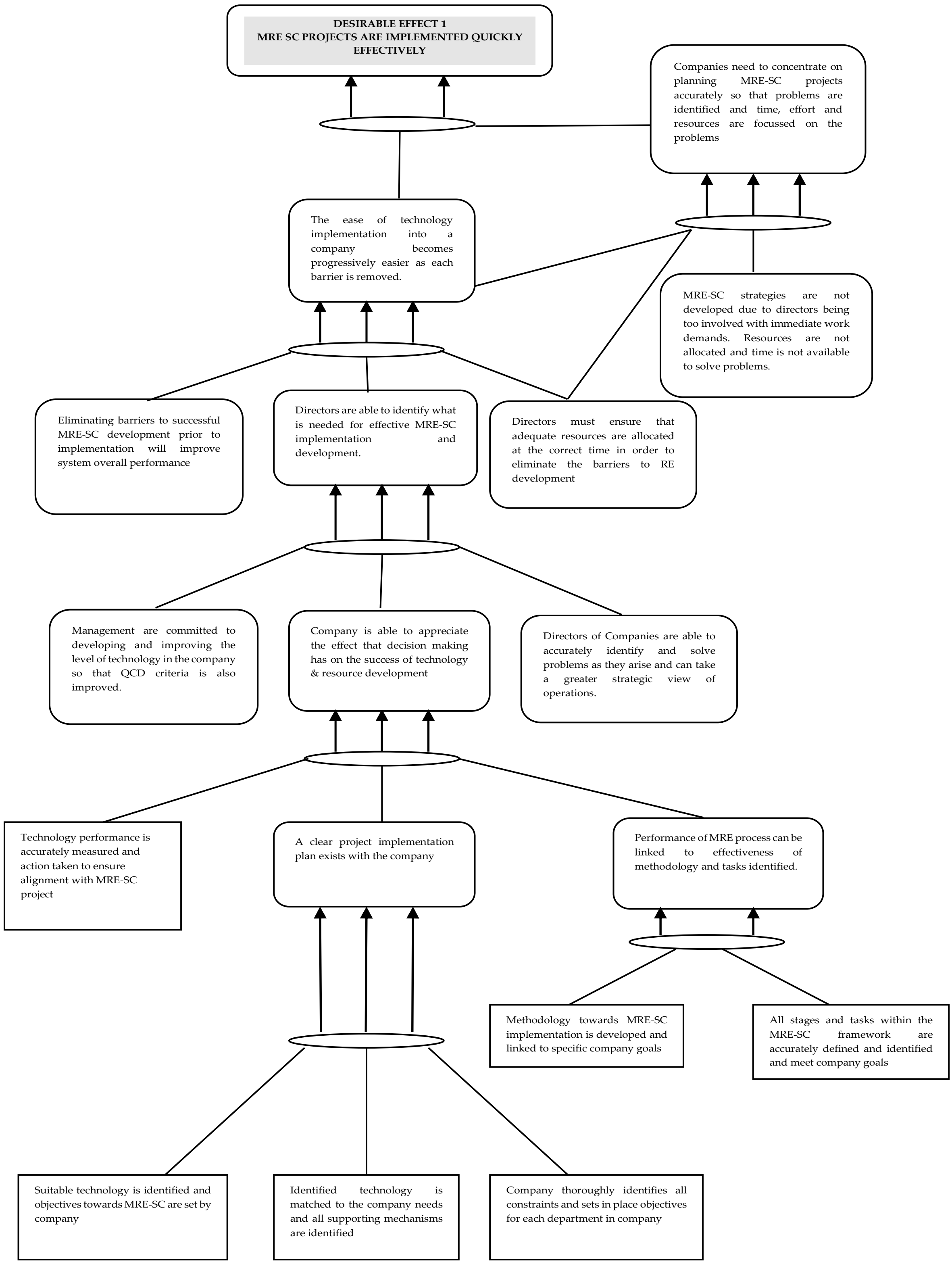

Figure 1. Future Reality Tree for MRE SC projects and project management.

To facilitate the entry of manufacturers into the MRE-SC, a Future Reality Tree can be constructed to visualize the desired future state and the interventions necessary to achieve it. The initial input into the process (called an injection in ToC terms) focuses on implementing a set of strategic enablers that address the key constraints facing manufacturers. To explain the DE/injection connection further, and in the context of MRE-SCs, one of the primary injections suggested is the establishment of a government-backed incentive program that provides financial support for research and development, manufacturing infrastructure, and early-stage deployment of marine renewable energy technologies. This incentive program reduces the financial burden on manufacturers, encouraging them to invest in the sector and accelerate innovation. Further injection may be the creation of a streamlined regulatory framework that simplifies the permitting process and reduces administrative burdens for marine renewable energy projects. Injections are shown by the rectangular boxes on the diagrams shown later. This approach ensures that every improvement effort is focused on maximizing the overall performance of the system; by incorporating sustainability principles into supply chain management, companies can reduce their environmental impact and improve their long-term resilience [38–40]. Another injection is the development of collaborative research and development initiatives that bring together industry, academia, and government to accelerate technological advancements and knowledge sharing [41]. It is first necessary to map across the UDEs and to identify the desirable effects (DEs) that can be used in the FRT. Figures 1–5 show the UDE/DE mapping so that a desired state is created through the FRT. These are shown as the terminal nodes.

The successful application of ToC in the marine renewable energy sector requires careful consideration of various factors, including the specific context, stakeholders involved, and the dynamic nature of the industry. Stakeholder engagement is crucial for gathering diverse perspectives, building consensus, and ensuring that the proposed solutions are aligned with the needs and priorities of all parties involved. This approach facilitates the socialization of participant thinking and the construction of collective futures [31]. By constructing a Future Reality Tree, stakeholders can gain a deeper understanding of the benefits and potential risks associated with different interventions, enabling them to make more informed decisions and strategic investments. Continuous monitoring and evaluation are essential for tracking progress, identifying emerging constraints, and adapting strategies as needed [32].

Further work on the CRT development directly relating to this paper is shown in the author's previous work [13]. This work on the CRT, shown in [13], was previously published by the authors and acts as the initial study for this paper. The CRT establishes foundations for the development of the future state study shown in this paper and forms part of the overall ToC approach. This paper takes on the current reality tree development and creates a future reality tree that aims to provide a roadmap for companies to start to move into the MRE supply chain sector.

The Theory of Constraints approach is designed to create meaningful system improvement, focusing on "What to change", "What to change to", and then "How to cause the change" [34]. The preceding research undertaken by the authors [13] was focused on the first stage, exploring "What to change". Through the development of the CRT diagram produced previously by the authors [13], the current research identified six undesirable effects (UDEs), shown in Table 1. The UDEs establish the key areas that need to be focused on for the improvement of the MRE supply chain if the capacity growth to support strategic aims is to be realized. The research undertaken in this paper focuses on the next stage, "What to change to", and therefore explores and identifies the required actions and strategic interventions (injections) required to move companies closer to working within the MRE supply chain. Enabling the system to effectively convert the UDEs to DEs (desired effects) through the implementation of the injections [35] within the processes and flows within the supply chain moves companies closer to the identified strategic aims.

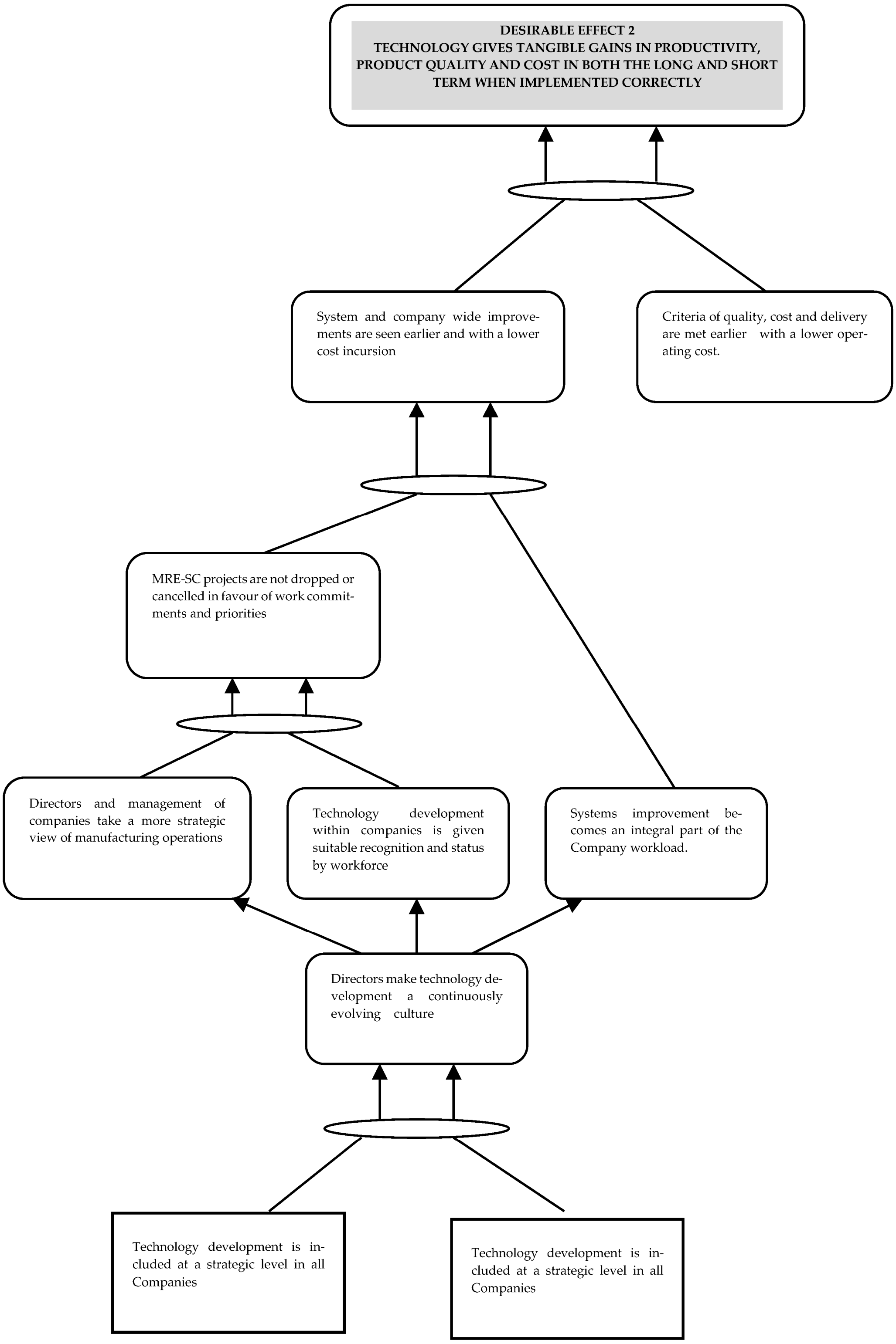

Figure 2. Future Reality Tree for MRE technology implementation.

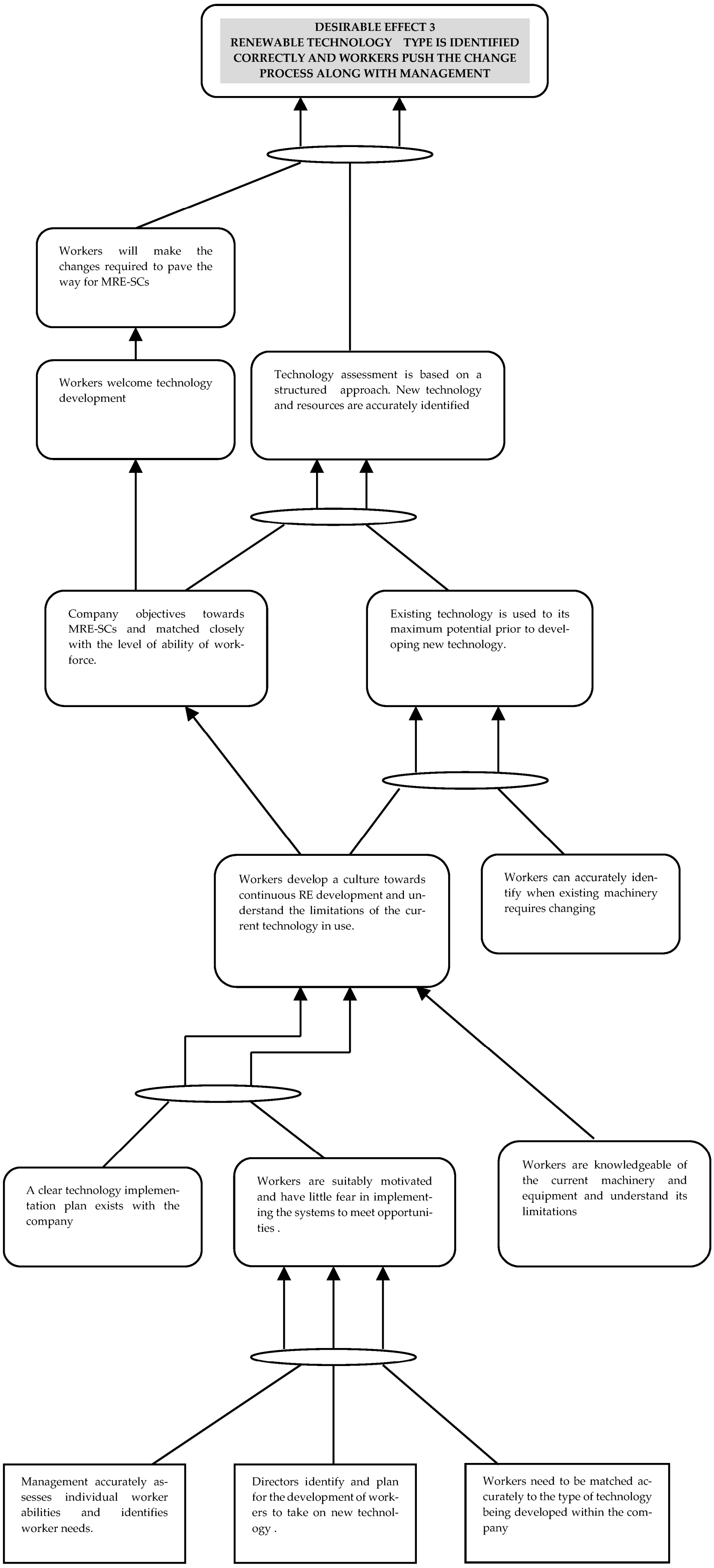

Figure 3. Future Reality Tree technology and workforce alignment.

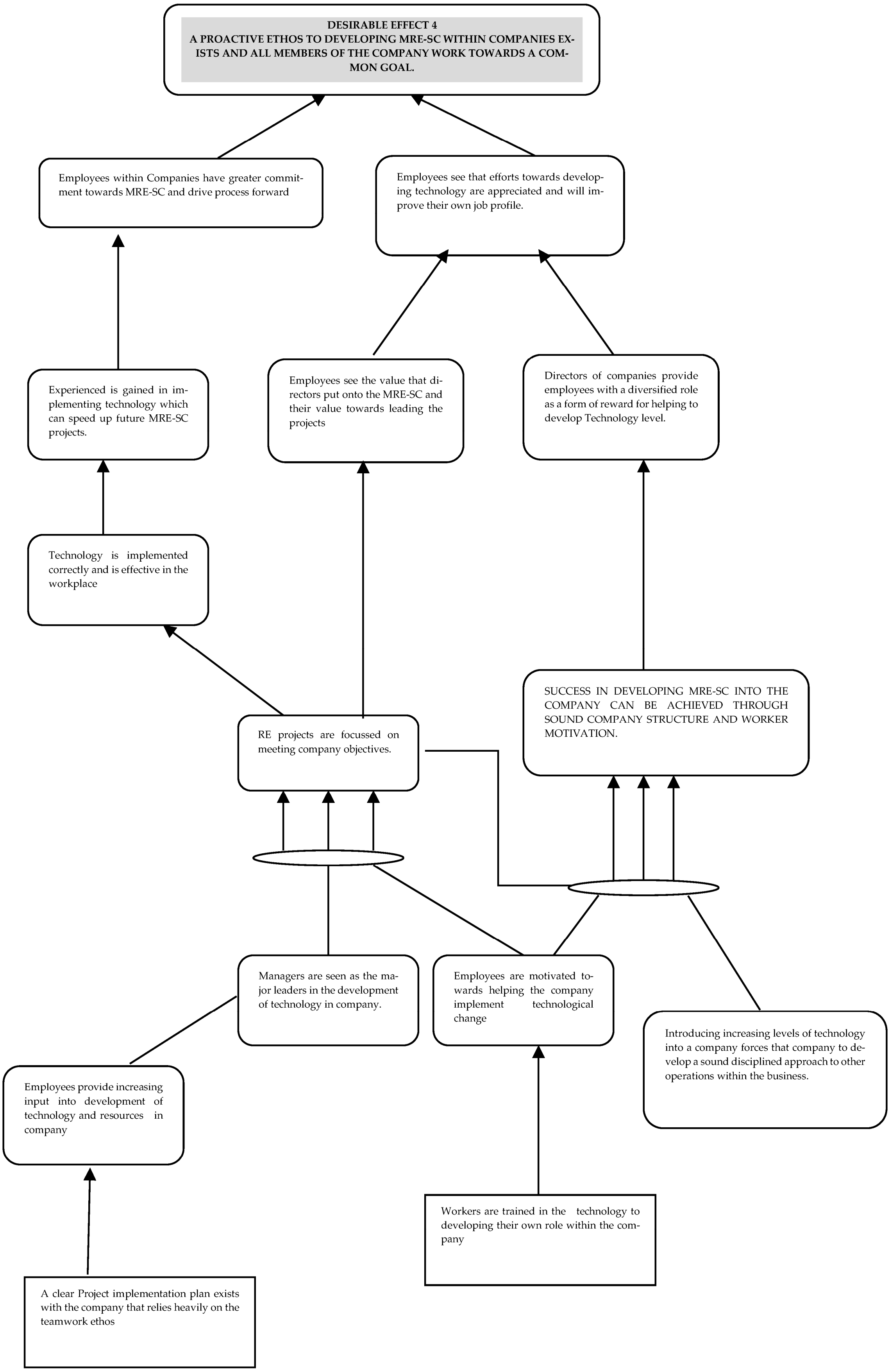

Figure 4. Future Reality Tree for worker development and motivation.

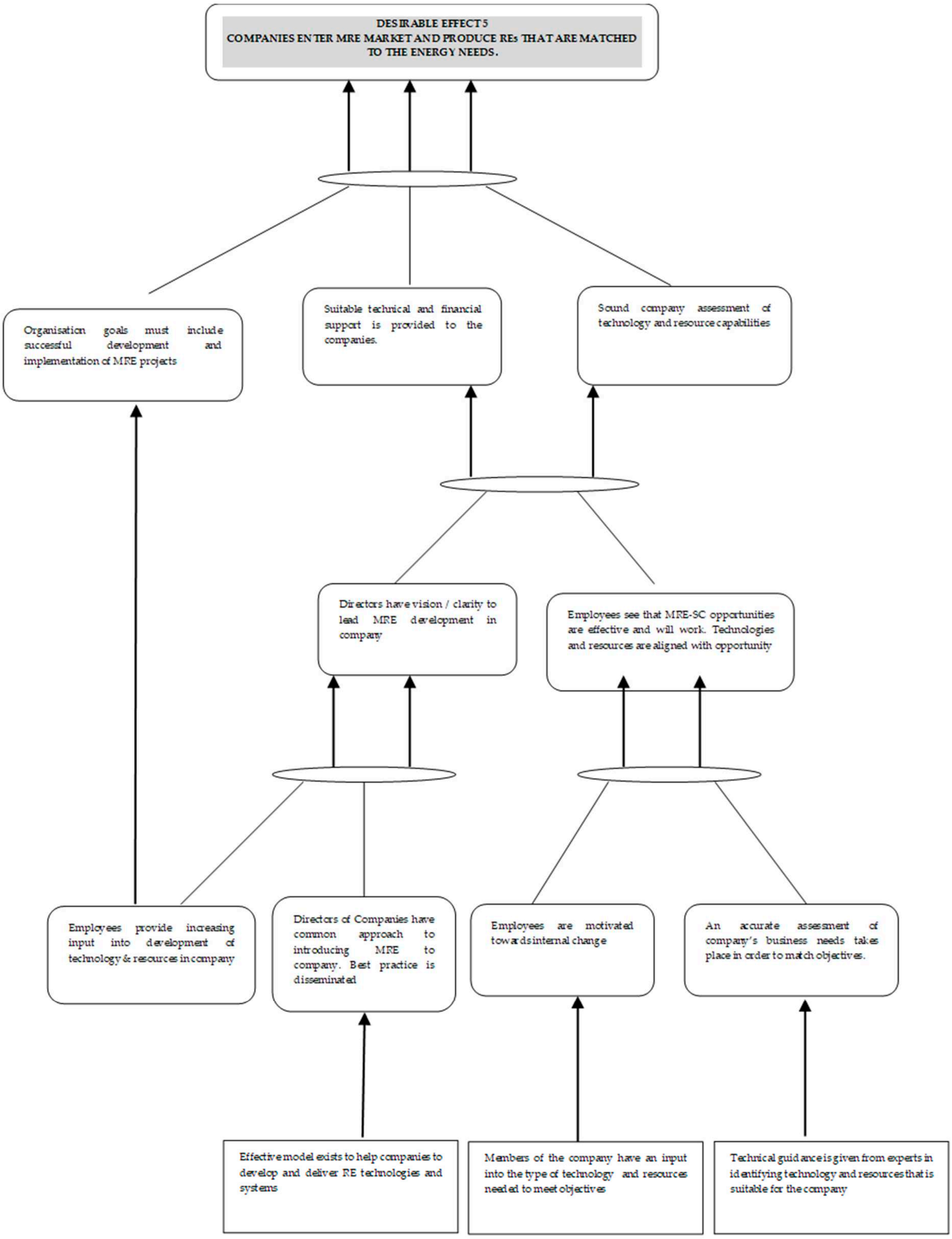

Figure 5. Future Reality Tree for technology/MRE alignment.

Table 1. UDEs within the Welsh MRE holistic supply chain (Mason-Jones et al., 2019) [13].

Thematic Areas	Key UDEs Identified
Supply Chain Readiness	1. Companies need a clear strategic direction to identify specific technologies to develop 2. Companies do not have the resources to support new technologies.
Policy and Investment	3. Investment in renewable technologies is currently focused on service/maintenance, and high-value manufacturing opportunities are being lost. 4. A clear strategic development program and regulatory framework are needed from the Welsh government to align companies and lead the way. 5. Welsh supply chain companies' readiness to respond is poor. Need to focus on the development of the technology's readiness level.
Skills	6. Company readiness levels are limited and not fit for current demands

3. Research Methodology and Conceptual Research Framework

This study adopts a design-oriented systems research approach that combines (i) a systematic literature review (SLR) to synthesize evidence on barriers and enablers for manufacturer entry to marine renewable energy supply chains (MRE-SCs) with (ii) the ToC thinking processes, specifically the transition from a previously established Current Reality Tree (CRT) to a Future Reality Tree (FRT). The SLR establishes the empirical and conceptual problem space, the CRT provides a structured causal diagnosis, and the FRT operationalizes 'what to change to' by specifying injections and the logical chain to desirable effects (DEs) relevant to MRE-SC readiness and resilience.

The unit of analysis is the manufacturer's pathway into tidal MRE supply chains, with attention paid to supply chain readiness, policy and investment conditions, and skills. The geographical lens is Wales (UK), where sectoral targets and regional cluster development foreground manufacturer capability, port and test infrastructure, and regulatory alignment. The technological lens prioritizes tidal stream—highlighted as the most technologically mature and predictable class in MRE—while recognizing interactions with broader marine technologies. The methodology employed follows the general theoretical model developed by Goldratt [30].

As stated previously, database- and timespan-related searches were conducted in Scopus, MDPI, and Emerald Insight for peer-reviewed journal articles published 2005–2025 in English. Search strategy: Boolean strings combined technology, supply chain, and managerial constructs. Eligibility criteria: Inclusion of peer-reviewed journal articles directly concerning MRE technologies and/or MRE-SC development; exclusion of conference abstracts, book chapters, and editorials. Screening protocol: PRISMA-style procedure followed. Initial retrieval produced 2675 records, duplicate removal yielded 2370 unique studies, title/abstract screening excluded 1239, and the full-text screening of 1039 papers yielded a final corpus of 92 for in-depth analysis. Data extraction and synthesis: Findings were thematically coded to align with supply chain readiness, policy and investment, and skills.

3.1. Design of the ToC Methodology

Constraint identification and Current Reality Tree development were conducted previously and are shown in the work of [13]. This phase consolidated the CRT developed in the authors' prior study, which employed large-scale survey work to elicit sector constraints and structure them as UDEs within the Welsh MRE holistic supply chain. Six key UDE themes were identified, spanning supply chain readiness, resource constraints, policy/investment misalignment, skewed investment emphasis, insufficient TRL progression, and skills gaps.

Following the CRT stage, the main UDEs are identified with the need to now translate the UDEs into desirable effects (DEs). UDEs from the CRT were systematically inverted into DEs that express the targeted future-state performance of the MRE-SC. The research team applied ToC cause–effect sufficiency logic and explicit assumption tracking to ensure each DE directly addressed one or more of the UDEs and aggregated into a feasible, system-level end state.

With the DEs in place, the team was then able to construct the Future Reality Tree (FRT). Defining injections: Feasible interventions were enumerated, including government-backed incentive programs, streamlined regulatory frameworks, collaborative R&D facilities, targeted workforce development, and supply chain collaboration platforms. Causal chaining and logic testing: Injections were connected via cause–effect links to intermediate conditions and DEs using ToC logical rigor, including clarity and existence tests, sufficiency tests, and Negative Branch Reservation. Representation conventions: The rectangles depict injections, rounded rectangles depict actions, ellipses denote AND gates, and UPPER-CASE boxes denote terminal DEs.

The construction of the FRT is then verified and triangulated through robustness checks. Internal logical verification was conducted through iterative audits. Proposed injections and intermediate conditions were cross-checked against the SLR and CRT phases. Face validity was ensured via prior sector engagement. All search strings, screening decisions, and inclusion rationales were maintained in a structured log, enabling replication of the SLR. The figures provide formalized FRT artifacts for reuse or extension.

The development of the primary research work consisted of three main phases. The primary research phase of the study was conducted between December 2024 and was completed in November 2025. It is the data obtained from the primary data study that enables the FRT to provide more detailed and contextualized information, new insights, and further specialized knowledge that an FRT constructed purely on secondary data could not provide. The primary research phase is and was as follows:

Phase 1—Construct Elicitation and Validation. Secondary literature analysis is augmented by focus-group discussions with a cross-section of stakeholders (Welsh Government, renewable-technology companies, sector bodies) and semi-structured interviews with firms active in renewables and industry bodies. These activities surface and refine a preliminary inventory of risks and barriers.

Phase 2—Large-Scale Survey. An online questionnaire (see Appendix A) was distributed to 500+ organizations, yielding 297 completed responses from firms across manufacturing, technology development, consultancy, engineering, installation, support, and composites. Respondents are segmented by engagement with renewables: 28% fully engaged (n = 83), 46% partially engaged (n = 136), and 26% not engaged (n = 78).

Phase 3—ToC/CRT Modeling and Validation. Survey outputs and qualitative insights are synthesized by an expert group (academics, CEOs, government innovation/support, sector skills councils) to derive three key constraints and six UDEs, which are structured into a CRT and then face-validated in an industry meeting [13].

This staged approach aligns with ToC's diagnostic emphasis ("what to change") and systems-thinking logic, using empirical prevalence and stakeholder judgment to prioritize systemic bottlenecks [13]. Participants included policy actors, renewables OEMs/technology companies, and industry bodies; interviews focused on firms already active in the sector and representative organizations. Although roles are described, exact counts, sampling criteria, and duration/setting are not reported, limiting transparency about breadth and saturation [33]. The survey achieved n = 297 usable responses across diverse subsectors. The engagement segmentation is a methodological strength because it includes both incumbents and prospective entrants (26% not engaged), which is crucial for studying entry barriers rather than only incumbent frictions. However, the recruitment frame and channels are not fully specified, so response bias and frame coverage cannot be assessed. Two expert groups were set up, comprising academics, CEOs, government innovation/support agencies, and sector skills councils. Each group contained eight participants and the duration of the expert group meetings lasted three hours each on average. Because this panel adjudicates the mapping from survey items to constraints and UDEs, more documentation of panel composition and procedures would strengthen reliability [35].

3.2. Primary Data Analysis

The results of the interviews further refined a priori inventory of risks and barriers derived from the literature. This inventory is operationalized in the survey to quantify prevalence/importance. The study reports percentage endorsements for each item—for example, "lack of policy and financial investment" (92%), "lack of sector knowledge" (86%), "readiness to respond" (72%), "planning issues" (54%)—providing empirical salience that guides prioritization (Table 1).

From descriptive statistics to ToC Entities (Phase 3), the survey results were synthesized with qualitative evidence provided from the focus group studies and the interview activities. The interviews and focus group discussions were held with a cross-section of the surveyed participants. A total of 33 respondents took part in the interviews (12 × industry participants, 10 × academic, and 11 × government). Interviews were held individually and took approximately one hour each to complete. Three focus group discussions took place with six participants involved in each focus group discussion. These focus groups lasted three hours on average. The candidates were selected to ensure that 2 × industrialists, 2 × government representatives, and 2 × academic representatives were in each group (n = 18). The participants for the focus groups and the interviews were not the same, thus ensuring a wider number of participants from the initial survey respondents were included in the triangulation phase of the work

The combined result of the survey plus focus group analysis identified three constraints: (i) poor supply chain readiness, (ii) lack of suitable policy and investment, and (iii) lack of sector knowledge. These are linked to six UDEs and are shown in the Results section. The CRT's cause–effect chains also incorporate additional survey-elicited conditions such as low conversion from planned to actual projects, "one-off" project perceptions, and planning/appeals bureaucracy. The analysis is descriptive (item prevalence), combined with structured causal modeling (CRT). The paper does not report inferential tests (e.g., group comparisons across engagement segments) or psychometric validation of the survey instrument. CRT logic rests on expert consensus and face validity rather than statistical causal estimation. This is acceptable for diagnostic system mapping, but it constrains claims about relative effect magnitudes or generalizable group differences [13].

The strengths of this multi-modal research approach include triangulation and sequencing. Multi-modal evidence (focus group studies, interviews, survey) reduces single-method bias and embeds stakeholder relevance before ToC modeling [13]. Inclusion of Non-Engaged Firms: The 26% "not engaged" segment captures authentic entry frictions, not only incumbent constraints, improving the ecological validity of the findings for policy and market-entry strategy. Breadth of Survey Coverage: With n = 297 across multiple supply chain roles, the dataset provides a broad perspective on perceived risks and barriers. Structured Synthesis into a CRT: The ToC framework enables a transparent causal narrative linking high-salience risks to systemic constraints/UDEs and facilitates stakeholder dialog around leverage points, with informed consent being obtained and IRB not being applicable given the nature of the data.

In summary, a coherent mixed-methods design is developed that leverages stakeholder input and descriptive survey evidence to construct a sector-level CRT. The primary data analysis is fit for diagnostic system mapping and stakeholder dialog, especially given the inclusion of non-engaged firms. To strengthen the evidentiary base for policy and managerial interventions, future work should add transparent qualitative reporting, inferential statistics for segment contrasts, and structured consensus procedures, while documenting ToC logic tests used in the chain-of-reasoning. The study progresses from evidence synthesis to causal diagnosis and solution design, culminating in a validated FRT that offers a practical roadmap for manufacturer entry into MRE-SCs.

4. Results

The results of the Future Reality Tree analysis highlight the potential benefits of implementing the proposed enablers, including increased investment in marine renewable energy, accelerated technology development, the application of appropriate technology implementation and adoption leading to reduced costs, and job creation. These outcomes contribute to the growth and competitiveness of the marine renewable energy sector, while also promoting sustainable development and environmental stewardship. The development of the key stages of the FRT and the construction of the tree is shown in the next few pages. Table 1 shows the UDEs, which were obtained from the previous study undertaken by the authors and shown in [13]. These UDEs are the cornerstone of the development of the FRT.

Figures 1–5 show the construction of the individual trees, with Figure 6 showing the overall combined tree with its interconnections between the individual trees.

The FRT reads as follows. Reading from the bottom up (although constructed from the top down), the rectangular blocks represent the injections; these are the inputs that, when acted upon, will help change the undesirable state to the desirable state. The curved-cornered rectangles show the actions created from the injections. An injection creates one or several actions and interactions. In some cases, the actions converge into ellipses, where the actions combine to create an AND gate with the interaction between creating a new action. Finally, the boxes with capitalized lettering show the desirable effects as terminal nodes or outputs from the interactions along the tree. In this case, Figure 6 shows the interconnectivity of the actions and outputs.

In building the FRT, the following steps are undertaken:

- Start with the desirable effects above as the terminal nodes;
- Work backward to identify the necessary conditions or injections that would cause these effects;
- Use cause–effect logic to connect injections to intermediate outcomes and ultimately to the Des;
- Ensure logical consistency and test for negative branches or unintended consequences.

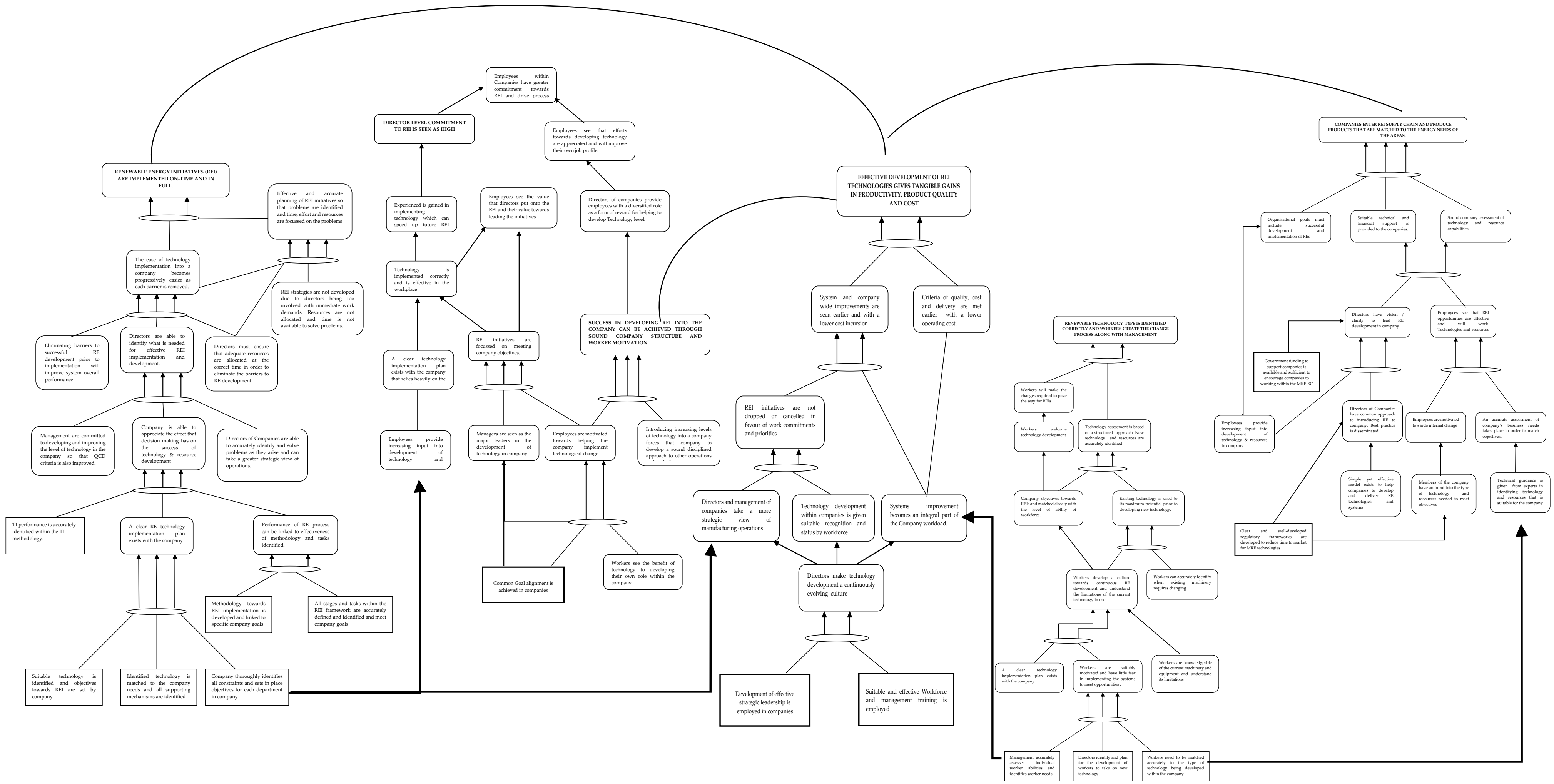

Figure 6. Future Reality Tree: "How REI can be implemented successfully into Companies". Combined tree.

5. Discussion

The discussion revolves around the strategic enablers and interventions required to foster a thriving marine renewable energy supply chain. By addressing the constraints identified through the Current Reality Tree and implementing the enablers outlined in the Future Reality Tree, stakeholders can create a favorable environment for manufacturers to enter the market and contribute to the growth of the marine renewable energy sector.

In addition to the above efforts, it is crucial to create dedicated research and development funding for marine renewable energy, thereby helping manufacturers develop better technologies. The six UDEs identified via the Welsh MRE sector analysis, shown in Table 1, using the CRT constructed previously offer the starting point from which to focus the discussions with the stakeholder group to identify the strategic injections to construct the FRT. Therefore, utilizing the Theory of Constraints logic Thinking Process captures and explores the opinions and perceptions of those currently engaging in the MRE sector supply chain. However, as with the initial study, it is important to include the perceptions of those organizations that, while currently not engaging in the sector supply chain, may provide future needed capacity. This focus is key due to the continued capacity growth challenges and indicated urgent need for supply chain collaboration and development indicated by the MEW State of the Sector report [36]. The attractiveness of the sector and the perceived barriers to entry are significant challenges to be remedied for desired growth to be realized. The approach being adopted within the proposed research is the utilization of the TOC, particularly the development of an FRT for the MRE supply chain in Wales, as a problem understanding, learning, and diagnostic technique, and not as a problem-solving technique, which much literature tends to focus on. This aligns with calls for more works from the literature providing data regarding the utilization of TOC techniques within a supply chain setting with a focus on continuous improvement [42,43] and strategic systems development and richer stakeholder dialog. This approach addresses a gap in the existing literature and aligns with calls for more data-driven applications of TOC in supply chain contexts.

Overcoming barriers in the marine renewable energy sector necessitates the mitigation of environmental effects and a transition toward sustainable practices [44,45]. The construction of a holistic supply chain knowledge-based FRT, highlighting the identified strategic injections, will offer a starting point for meaningful discussions regarding the development of a resilient MRE supply chain within the Welsh context.

The decarbonization of energy systems is accelerating the demand for marine-based renewables. As governments and industry actors invest in MRE technologies, the associated supply chains must evolve to meet new technical requirements, policy frameworks, and sustainability standards. The main issues are (1) the mechanisms through which MRE systems stimulate supply chain development, (2) the strategic interventions that enable regional actors to participate in MRE-SCs, and (3) the application of Future Reality Trees to map pathways and overcome constraints.

In addressing the issue of Marine Renewable Energy Systems as Supply Chain Catalysts, MRE systems require specialized components—floating platforms, mooring systems, corrosion-resistant materials, and subsea infrastructure. This drives demand for localized manufacturing in coastal regions with engineering capabilities and port infrastructure upgrades to support fabrication, assembly, and deployment. This necessitates new supply chain configurations, creating opportunities for SMEs and regional clusters. As a result, the sector needs Innovation Ecosystems and Cross-Sector Synergies, where MRE strategies often include innovation accelerators that support startups and SMEs with IP development, investor readiness, and market access. Cross-sector innovation, such as applying aerospace technologies to turbine inspection or robotics to subsea maintenance. These ecosystems foster adaptive supply chains capable of responding to evolving technical demands. Furthermore, government interventions play a pivotal role in shaping MRE-SC dynamics; Contracts for Difference (CfD), with ringfenced support (e.g., GBP 30 M for tidal stream), create market certainty; supply chain plans and clean industries bonuses incentivize domestic sourcing and job creation; and strategic alignment with policy instruments enhances competitiveness and investment readiness. Furthermore, countries with mature MRE sectors can export high-value components (e.g., turbines, control systems), as well as technical expertise in installation, maintenance, and grid integration. The UK, for instance, supplies over 80% of the domestic content in tidal stream projects and is well-positioned to lead globally. Likewise, modular designs are essential for ease of maintenance and upgrade. Recyclable composites and end-of-life strategies for blades and platforms should also be investigated. New niches in decommissioning, remanufacturing, and materials recovery all contribute to the circular supply chain, enhancing sustainability and resilience.

Future Reality Tree: A Strategic Roadmap for MRE-SC Entry

The Future Reality Tree, derived from the Theory of Constraints, is a visual tool that maps the pathway from current limitations to desired outcomes. It identifies the necessary conditions for achieving strategic goals, obstacles, and root causes that hinder progress, as well as the interventions that resolve constraints and enable transformation. Furthermore, Future Reality Tree mapping supports companies by clarifying strategic leverage points (e.g., certification, partnerships, infrastructure); aligning technical, economic, and policy factors to reveal systemic interdependencies; enabling scenario planning across multiple entry pathways (e.g., manufacturing, services, R&D); and facilitating learning and collaboration among engineers, strategists, and policymakers.

The FRT is also effective in identifying the key barriers to supply chain company entry into the MRE market. This includes the lack of certification pathways, no direct OEM relationships, limited production capacity, fragmented regional coordination, and unclear CfD eligibility timelines. Likewise, interventions to enable supply chain development include engaging with Tier 1 and OEMs as a catapult for tech validation and collaboration with the Welsh government on infrastructure investment. This FRT serves as a living roadmap, guiding SMEs through capability building, risk mitigation, and strategic alignment.

6. Conclusions and Recommendations

In conclusion, facilitating the entry of manufacturers into the marine renewable energy supply chain requires a multifaceted approach that addresses both the barriers and enablers in the sector. By implementing the strategies discussed in this paper, stakeholders can create a more favorable environment for manufacturers to invest in marine renewable energy and contribute to the development of a sustainable energy future.

This paper posed two key RQs. Research question number one: "What are the Desirable Effects (DEs) required to orient manufacturing companies towards working within the MRE SC?". This is addressed through the identification of the DEs. The DEs are created through a team-working approach and are identified by considering the UDEs created within the CRT process and then working out suitable solutions from these UDEs. The DEs are shown at the top of each FRT diagram in shaded and bold type. These DEs are identified as being the effects most likely to unlock the potential and to create opportunities for companies to enter the MRE SC. These DEs are then joined by enabling features (injections) in the rectangular boxes, along with the connector activities in the rounded-edge boxes that help connect the injections to provide a suitable pathway to meeting the DE requirements.

RQ2: "In what form should these DEs be structured to provide maximum impact on companies?". The structure of aligning the DEs together is created by the FRT. As stated, the injections and connecting activities are structured in a way that enables the DEs to be achieved. Figure 6 shows, schematically, the overall connectivity of the individual trees.

By investing in sustainability initiatives and advocating for policy changes, companies can play a pivotal role in shaping a more sustainable future for the maritime industry and beyond. A comprehensive approach to sustainability requires collaboration, innovation, and a commitment to continuous improvement. Furthermore, this work has explored the strategic enablers necessary to foster a resilient and competitive marine renewable energy supply chain (MRE-SC), with a particular focus on the Welsh context. Using the Theory of Constraints (TOC) and the Future Reality Tree (FRT) as a problem-understanding framework, the analysis has identified key leverage points for sectoral transformation. Furthermore, it has proven effective in mapping causal relationships between existing constraints and desired outcomes, offering a structured roadmap for stakeholders seeking to enter or expand within the MRE-SC. It provides a systems-level learning tool that supports strategic planning, stakeholder engagement, and continuous improvement.

6.1. Key Conclusions Drawn from the Analysis

Strategic enablers that drive sectoral growth via the implementation of targeted enablers—such as increased investment and dedicated R&D funding—can accelerate technology development, reduce costs, and stimulate job creation. These outcomes contribute directly to the competitiveness and sustainability of the marine renewable energy sector. Likewise, greater supply chain collaboration, as shown in the MEW State of the Sector report (2024) [36], highlights the urgent need for capacity expansion and enhanced collaboration across the Welsh MRE-SC. Engaging both current and potential future participants is vital to ensure inclusive development and long-term resilience.

6.2. Further Policy and Research Implications

The findings underscore the importance of policy support, certification mechanisms, and funding structures that de-risk market entry and incentivize innovation. Using the ToC methodology as a method to provide a structured understanding of the issues can inform regional industrial strategies and guide the development of a robust, future-ready MRE-SC in Wales. In summary, the construction and application of the Future Reality Tree offer a valuable foundation for strategic decision-making, stakeholder engagement, and systems-level learning. By addressing identified constraints and implementing targeted enablers, stakeholders can contribute meaningfully to the growth, sustainability, and global relevance of the marine renewable energy sector.

6.3. Recommendations

Marine Renewable Energy systems are not only environmental imperatives but also industrial catalysts. Their deployment demands new supply chain configurations, innovation ecosystems, and policy alignment. The Future Reality Tree provides a structured, collaborative tool for companies to navigate this complexity and enter the MRE-SC strategically. This paper makes the following recommendations: (1) regional governments should invest in certification pathways, port infrastructure, and innovation clusters; (2) SMEs should leverage accelerators and strategic partnerships to build capabilities; (3) industry coalitions should adopt FRTs to foster shared learning and roadmap development.

6.4. Implications for Future Research Design

In order to strengthen future research evidence and analysis in this area, the following suggestions are made.

Using the extensive survey data feedback, the next phase of work will be to introduce segment-level inferential tests that would enable comparison of barrier endorsement across fully engaged, partially engaged, and non-engaged firms; the modeling of predictors of entry intention with logistic regression is considered. Furthermore, the Delphi or Nominal Group Technique can be employed to identify explicit consensus thresholds and iterations to mitigate group dynamics.

Further work will include documenting ToC logic tests to make explicit the application of entity clarity, necessity/sufficiency, and negative branch reservation checks during CRT construction to strengthen internal logic validity, as well as longitudinal validation. Through re-contacting a subset of survey respondents to examine whether constraints/UDEs predict subsequent entry or non-entry, external validity can be enhanced.

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Appendix A. Comprehensive Semi-Structured Interview Questionnaire

Purpose: To gather opinions from industry, academia, and government on the development of marine renewable energy (MRE) technologies and supporting supply chains.

Instructions: This questionnaire is semi-structured. Begin with general questions, then proceed to stakeholder-specific sections (Industry, Academia, Government).

Appendix A.1. General Questions

- What is your current role and organization?
- Which sector do you represent? (Industry/Academia/Government)
- How long have you been involved in marine energy or related fields?
- How would you describe the current status of marine renewable energy technologies in your region or globally?
- What do you see as the main drivers for development in this sector?
- What are the biggest technical or non-technical challenges currently facing marine renewable energy?
- How mature do you think the supply chain for marine renewable energy is today?
- Which components or services in the supply chain are most critical for scaling up marine energy technologies?
- Are there any gaps or bottlenecks in the supply chain that need urgent attention?
- How do you see the role of collaboration between industry, academia, and government in advancing marine renewable energy?

- What policies or incentives do you think are most effective for supporting technology development and supply chain growth?
- Are there examples of successful partnerships or initiatives you can share?
- What is your vision for marine renewable energy in the next 10–15 years?
- Which emerging technologies or innovations excite you most in this space?
- What skills or workforce capabilities will be essential for future supply chain development?

Appendix A.2. Industry-Specific Questions

- Do you currently work in the marine renewable energy (MRE) sector? (Yes/No)
- If yes: Approximately what percentage of your organization's work is related to MRE? (0–10%, 11–25%, 26–50%, 51–75%, 76–100%)
- What are the main products, services, or capabilities your organization provides to the MRE sector?

Appendix A.3. Academia-Specific Questions

- What is your primary area of research related to marine renewable energy (MRE)?
- How long has your institution been involved in MRE research or related fields?
- What percentage of your research portfolio currently focuses on MRE? (0–10%, 11–25%, 26–50%, 51–75%, 76–100%)
- Which MRE technologies (e.g., tidal, wave, floating offshore wind) are you most actively researching?
- What do you see as the most promising innovations or breakthroughs in MRE over the next decade?
- Are there any critical technical challenges your research aims to address?
- How effective do you think current collaboration between academia, industry, and government is in advancing MRE technologies?
- What barriers exist to transferring research outcomes into commercial applications?
- Are there examples of successful knowledge transfer or joint projects you can share?
- How adequate is current funding for MRE research in your region?
- What types of funding mechanisms or policy support would most benefit academic research in this field?
- Do you see gaps in government policy that hinder academic contributions to MRE development?
- What skills or expertise do you believe future graduates need to support MRE technology and supply chain growth?
- How is your institution preparing students for careers in the marine energy sector?
- What role do you envision academia playing in shaping the future of MRE technologies and supply chains?
- Are there emerging interdisciplinary areas (e.g., AI, materials science, robotics) that you think will significantly impact MRE research?

Appendix A.4. Government-Specific Questions

- What is your role in shaping or implementing policies related to marine renewable energy (MRE)?
- How would you assess the current regulatory environment for MRE development in your region?
- Are there specific regulations or permitting processes that you believe hinder or accelerate MRE deployment?
- What are the government's main priorities for marine renewable energy over the next 5–10 years?
- How does MRE fit into broader energy transition and decarbonization strategies?

- Are there national or regional targets for MRE capacity or technology development?
- What types of financial support or incentives does the government currently provide for MRE technologies and supply chain development?
- Do you see gaps in funding or investment that need to be addressed?
- How does the government plan to attract private investment into the MRE sector?
- How does the government facilitate collaboration between industry, academia, and other stakeholders?
- Are there existing programs or initiatives that have successfully supported MRE development?
- What mechanisms could improve stakeholder engagement and accelerate technology adoption?
- How important is local content or domestic supply chain development in government policy for MRE?
- What steps are being taken to build workforce skills and capabilities for the marine energy sector?
- Are there plans to support training or education programs aligned with MRE growth?
- What role do you see government playing in ensuring the long-term sustainability and competitiveness of MRE technologies?
- Are there emerging policy areas (e.g., environmental standards, digitalization, resilience) that will impact MRE development?
- How does the government plan to balance environmental protection with accelerated deployment of marine energy projects?

References

1. Cabrerizo-Morales, M.Á.; Molina, R.; Rojas, L.P. Small-Scale Study of Mooring Line Tension Thresholds Based on Impulsive Load Analysis during Big Floating Structure Operation and Commissioning. *Water* **2021**, *13*, 1056. [CrossRef]
2. Jelti, F.; Allouhi, A.; Büker, M.S.; Saadani, R.; Jamil, A. Renewable Power Generation: A Supply Chain Perspective. *Sustainability* **2021**, *13*, 1271. [CrossRef]
3. Westwood, A. Ocean power. *Refocus* **2004**, *5*, 50. [CrossRef]
4. Apolonia, M.; Fofack-Garcia, R.; Noble, D.R.; Hodges, J.; da Fonseca, F.X.C. Legal and Political Barriers and Enablers to the Deployment of Marine Renewable Energy. *Energies* **2021**, *14*, 4896. [CrossRef]
5. Seabased. Ocean Energy's Role in Realizing the UN's Sustainable Development Goals. 2020. Available online: https://seabased.com/news-insights/ocean-energy-unsdgs (accessed on 14 November 2025).
6. Wu, J.J.; Vijayamohan, V.; Field, R.W. On the potential of ocean energy technologies to contribute to future sustainability. *Discov. Sustain.* **2025**, *6*, 741. [CrossRef]
7. UN. *International Renewable Energy Agency (IRENA) Input to 2022 Report of the Secretary General on Oceans and the Law of Sea*; United Nations: Aby Dhabi, United Arab Emirates, 2022.
8. Tang, E.; Gao, J.; Huang, W.; Qian, Y. Marine renewable energy: Progress, challenges, and pathways to scalable sustainability. *Energy* **2025**, *335*, 138083. [CrossRef]
9. Kihlström, V.; Elbe, J. Constructing Markets for Solar Energy—A Review of Literature about Market Barriers and Government Responses. *Sustainability* **2021**, *13*, 3273. [CrossRef]
10. Baziar, A.; Parsa, N. Legal Challenges in Renewable Energy Development: A Comparative Study of China and Selected Countries. *arXiv* **2024**, arXiv:2412.10203. [CrossRef]
11. Weiss, C.; Bonvillian, W.B. Legacy sectors: Barriers to global innovation in agriculture and energy. *Technol. Anal. Strateg. Manag.* **2013**, *25*, 1189. [CrossRef]
12. Horváth, D.; Szabó, R.Z. Evolution of photovoltaic business models: Overcoming the main barriers of distributed energy deployment. *Renew. Sustain. Energy Rev.* **2018**, *90*, 623. [CrossRef]
13. Mason-Jones, R.; Davies, P.G.; Thomas, A. Applying the Theory of Constraints to Explore the UK Renewable-Energy Supply Chain. *Sustainability* **2022**, *14*, 13307. [CrossRef]
14. Onuh, P.; Ejiga, J.O.; Abah, E.; Onuh, J.O.; Idogho, C.; Omale, J. Challenges and Opportunities in Nigeria's Renewable Energy Policy and Legislation. *World J. Adv. Res. Rev.* **2024**, *23*, 2354. [CrossRef]
15. Seetharaman Moorthy, K.; Patwa, N.; Saravanan; Gupta, Y.P. Breaking barriers in deployment of renewable energy. *Heliyon* **2019**, *5*, e01166. [CrossRef] [PubMed]
16. Gabriel, C.-A. What is challenging renewable energy entrepreneurs in developing countries? *Renew. Sustain. Energy Rev.* **2016**, *64*, 362. [CrossRef]

17. Relva, S.G.; Silva, V.O.; da Gimenes, A.L.V.; Udaeta, M.E.M.; Ashworth, P.; Peyerl, D. Enhancing developing countries' transition to a low-carbon electricity sector. *Energy* **2020**, *220*, 119659. [CrossRef]
18. Hutchinson, N.; Dennis, M.; Grann, E.D.; Clevenger, T.; Manion, M.; Bøggild, J.; Layke, J. Unlocking a Renewable Energy Future. 2021. Available online: https://www.wri.org/research/unlocking-renewable-energy-future (accessed on 21 November 2025).
19. Braun, A.; Kleine-Möllhoff, P.; Reichenberger, V.; Seiter, S. Case Study Analysing Potentials to Improve Material Efficiency in Manufacturing Supply Chains, Considering Circular Economy Aspects. *Sustainability* **2018**, *10*, 880. [CrossRef]
20. Cui, Y.; Zhao, H. Marine renewable energy project: The environmental implication and sustainable technology. *Ocean Coast. Manag.* **2024**, *232*, 106415. [CrossRef]
21. Asante, D.; He, Z.; Adjei, N.O.; Asante, B. Exploring the barriers to renewable energy adoption utilising MULTIMOORA- EDAS method. *Energy Policy* **2020**, *142*, 111479. [CrossRef]
22. Painuly, J.P.; Wohlgemuth, N. Renewable energy technologies: Barriers and policy implications. In *Renewable-Energy-Driven Future*; Academic Press: Cambridge, MA, USA, 2021; pp. 539–562. [CrossRef]
23. Fernández-Miguel, A.; Riccardi, M.P.; Veglio, V.; Muiña, F.E.G.; del Hoyo, A.P.F.; Settembre-Blundo, D. Disruption in Resource-Intensive Supply Chains: Reshoring and Nearshoring as Strategies to Enable Them to Become More Resilient and Sustainable. *Sustainability* **2022**, *14*, 10909. [CrossRef]
24. Ottinger, R.L.; Bowie, J. Innovative Financing for Renewable Energy. *Pace Environ. Law Rev.* **2015**, *32*, 701. [CrossRef]
25. Xu, X.; Chen, X.; Xu, Y.; Wang, T.; Zhang, Y. Improving the Innovative Performance of Renewable Energy Enterprises in China: Effects of Subsidy Policy and Intellectual Property Legislation. *Sustainability* **2022**, *14*, 8169. [CrossRef]
26. Márton, M.; Paulová, I. Applying the Theory of Constraints in the Course of Process Improvement. *Res. Pap. Fac. Mater. Sci. Technol. Slovak Univ. Technol.* **2010**, *18*, 71–76. [CrossRef]
27. Goodier, C.I.; Austin, S.A.; Soetanto, R.; Dainty, A. Causal mapping and scenario building with multiple organisations. *Futures* **2009**, *42*, 219. [CrossRef]
28. Shim, H.; Kim, T.; Choi, G. Technology Roadmap for Eco-Friendly Building Materials Industry. *Energies* **2019**, *12*, 804. [CrossRef]
29. Goldratt, E.M. Theory of Constraints. 1990. Available online: https://www.academia.edu/7095271/Theory_of_Constraints_Eliyahu_M_Goldratt (accessed on 21 November 2025).
30. Goldratt, E.M. *Theory of Constraints: What Is This Thing Called and How Should It Be Implemented*; North River Press: Great Barrington, MA, USA, 1990.
31. Scoggin, J.M.; Segelhorst, R.J.; Reid, R.A. Applying the TOC thinking process in manufacturing: A case study. *Int. J. Prod. Res.* **2003**, *41*, 767–797. [CrossRef]
32. Rahadi, K.B.; Setyanto, A.; Rohmansyah, D. Application of Theory of Constraints (TOC) in Power Generation to Increase Overhaul Maintenance Performance and to Strengthen Overhaul Management Process. In *IOP Conference Series: Materials Science and Engineering, the 6th International Conference on Industrial, Mechanical, Electrical and Chemical Engineering—ICIMECE 2020, 20th October 2020*; IOP: Solo, Indonesia, 2021; Volume 1096, p. 12130.
33. Shoemaker, T.E.; Reid, R.A. Using the Theory of Constraints to focus organizational improvement efforts: Part 2-Determining and implementing the solution. *Am. Water Work. Assoc. J.* **2006**, *98*, 83–96. [CrossRef]
34. Dettmer, H.W. *The Logical Thinking Process. A Systems Approach to Complex Problem Solving*; American Society for Quality Press: Milwaukee, WI, USA, 2007.
35. Ikeziri, L.M.; Souza, F.B.; de Gupta, M.C.; de Camargo Fiorini, P. Theory of constraints: Review and bibliometric analysis. *Int. J. Prod. Res.* **2018**, *57*, 5068–5102. [CrossRef]
36. MEW. State of the Sector Report. 2024. Available online: https://www.marineenergywales.co.uk/ (accessed on 21 November 2025).
37. Gupta, A.K.; Bhardwaj, A.; Kanda, A. Fundamental Concepts of Theory of Constraints: An Emerging Philosophy. *World Acad. Sci. Eng. Technol.* **2010**, *46*, 686–692. [CrossRef]
38. Modi, K.; Lowalekar, H.; Bhatta, N. Revolutionizing supply chain management the theory of constraints way: A case study. *Int. J. Prod. Res.* **2018**, *57*, 3335. [CrossRef]
39. Jaegler, A.; Burlat, P. What is the impact of sustainable development on the re-localisation of manufacturing enterprises? *Prod. Plan. Control* **2013**, *25*, 902. [CrossRef]
40. Banerjee, D.; Lowalekar, H. Communicating for change: A systems thinking approach. *J. Organ. Change Manag.* **2021**, *34*, 101. [CrossRef]
41. Banerjee, A.; KMukhopadhyay, K. A contemporary TOC innovative thinking process in the backdrop of leagile supply chain. *J. Enterp. Inf. Manag.* **2016**, *29*, 400–443. [CrossRef]
42. IRENA. *Offshore Renewables: Powering the Blue Economy*; International Renewable Energy Agency: Abu Dhabi, United Arab Emirates, 2020.
43. Rahim, Z.A.; Bakar, N.A. Technology Development and Assessment to Market Using TRIZ. *Int. J. Bus. Anal.* **2016**, *3*, 83. [CrossRef]

44. Rometius, S.; Wei, X. Blue Horizons for Resilient Islands: Legal–Technological Synergies Advancing SDG 7 and 13 Through the UNCLOS–Paris Agreement Integration in SIDS' Energy Transitions. *Sustainability* **2025**, *17*, 6011. [CrossRef]
45. Hung, Y.-H.; Yang, F.-C. Toward Integrated Marine Renewables: Prioritizing Taiwan's Offshore Wind Projects for Wave Energy Compatibility Through a Cross-Efficiency Data Envelopment Analysis Approach. *Sustainability* **2025**, *17*, 2151. [CrossRef]