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RESEARCH ARTICLE OPEN ACCESS

The Tension Between Open Innovation and Appropriability in Marine Renewable Energy SMEs: Examining the Role of the Chief Executive Officer

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ABSTRACT

Marine renewable energy small and medium-sized enterprises (SMEs) are vital in addressing climate change through radical innovation in a complex, high cost, and high-risk sector. Open innovation (OI) is a strategic approach for SMEs to acquire external knowledge, important for creating their radical devices. However, OI strategies may result in R&D leakage, requiring SMEs to consider the balance between appropriation and OI. Founders/CEOs play a critical role in managing this tension, yet little is known about how they manage the OI–appropriation nexus. This study examines whether appropriability enables or hinders OI and how the founder/CEO's background influences the relationship. Using an explanatory, sequential mixed-methods design, a positive relationship between appropriation and OI is identified. The founders/CEOs' education, passion, and practical experience have a strong influence on OI adoption. This study advances the OI–appropriation literature, shining a light on the neglected but important human-side context of SME innovation management.

1 | Introduction

The European Union has set an ambitious target of climate neutrality by 2050 (European Commission and Directorate-General for Climate Action 2019) and aims to reach a 32% renewable energy target by 2030. In this context, innovative small and medium-sized enterprises (SMEs) specializing in marine renewable energy (MRE) will play a crucial role in enabling this renewable energy transition (Magagna and Uihlein 2015; Vanegas-Cantarero et al. 2022; Falcke et al. 2024). MRE devices are recognized as radical innovations (Bucher and Bryden 2016); however, they are inherently complex, involving advanced technologies, high uncertainty, and demanding significant time and investment, all within a complex and uncertain legal framework (Matos et al. 2022; Vanegas-Cantarero et al. 2022; Barrett et al. 2024). The MRE industry is confronted with significant, sector-specific technological fragmentation and financial challenges (Bucher and Bryden 2016; Lange et al. 2018). A collaborative environment is necessary and is promoted (IEA-OES 2021); however, a lack of trust hinders knowledge dissemination, leading to fewer R&D projects that act as "blocking factors" for MRE firms wishing to advance their technology (Andersson et al. 2017).

Open innovation (OI) (Chesbrough 2003) research recognizes how firms can create and capture value through external knowledge integration and sharing activities (Bogers et al. 2017); however, such OI interactions can be fraught with challenges including appropriation, i.e., how to protect and profit from innovation activities (Colombelli et al. 2020; Veer et al. 2016). Appropriation is a challenge at the heart of knowledge sharing (Bogers et al. 2017; Morales et al. 2024) as firms

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typically want to exert some level of control over the knowledge flows across the boundaries (Zobel and Hagedoorn 2020; Holgersson 2024). This is relevant in the context of SME organizations given their resource constraints and their liability of smallness (Aldrich and Auster 1986; Van de Vrande et al. 2009; Gimenez-Fernandez et al. 2020). MRE SMEs are particularly impeded given the radical nature of their innovative devices, the inevitable high costs and risks coupled with lengthy development timelines, and the market unknowns, i.e., the necessary evolution from niche to mainstream markets (Souder et al. 1998). Thus, a deeper focus on this sector is warranted.

The paper makes several contributions. First, we examine the "human side" of how SME leaders navigate the appropriation challenge and how their background, educational characteristics, and experiences impact OI adoption (Weiss et al. 2022; Bogers et al. 2018; Ahn et al. 2017; Xia et al. 2023; Barrett and Crowley 2025). In this study, the SME founders/CEOs are selected as research participants due to their disproportionate impact on the SMEs strategic vision and performance (Finkelstein and Hambrick 1996; Bai et al. 2020; Lee et al. 2020; Ju et al. 2023). As SME leaders, they are typically the face of the firm and deeply involved in all technical, operational, and strategic issues related to the development, scaling, and validation of the product (Lubatkin et al. 2006). Consequently, the entrepreneurial founder/CEO bears the responsibility of rationalizing and deciding if, when, and how the firm implements its appropriability strategy and OI practices (Barrett et al. 2021). Their previous experience and educational background can directly and indirectly affect firm-level openness (Ahn et al. 2017; Xia et al. 2023) and the firm's appropriability strategy (Holgersson et al. 2018). Thus, the aim of this study is to investigate whether appropriability enables or hinders OI, and we ask the following research question—how does the MRE SME leader's background, educational characteristics, and experiences influence OI adoption and the appropriation conundrum?

Second, this study contributes to the OI literature by examining a niche sector, i.e., MRE, which is dominated by early-stage firms (in terms of scale). While the advantages of firm openness are well documented, the MRE sector offers a unique context, with previous studies finding limited amounts of knowledge sharing and a lack of collaboration within the industry (Bucher and Bryden 2016). This evidence posits a possible tension between OI and appropriability in the MRE industry. The ambiguity surrounding the impact of knowledge protection strategies on OI, particularly in the context of small enterprises (Chen et al. 2022; Gimenez-Fernandez et al. 2023), highlights the necessity for further investigation, echoing calls from Abdelaty and Weiss (2023) for more in-depth research into the role of appropriation strategies. This study addresses this literature gap by using a dedicated survey for testing the relationship between appropriation strategies and innovation collaboration.

Third, this study makes a methodological contribution by using an explanatory, sequential mixed-methods approach (Ivankova et al. 2006; Creswell and Clark 2011; Creswell, 2013) and collects both quantitative and qualitative primary data to answer the research question. The quantitative data were collected through a specially designed survey instrument that was distributed to MRE firms. The quantitative data are complemented by primary qualitative data, which provides nuanced insights into the founder/CEO's backgrounds, educational characteristics, and "human perspective" on the tensions between OI adoption and appropriability. Qualitative data were collected through a series of semi-structured interviews with MRE founders/CEOs explaining the findings from the first study and providing richer and deeper insights heretofore lacking in the quantitative data. This mixed-methods research design provides robust evidence to support the findings (Ivankova et al. 2006). Through the integration of these quantitative and qualitative insights, we derive comprehensive conclusions regarding the dynamic relationship between OI and appropriability, with a specific emphasis on the founder/CEO influence.

Finally, this study contributes to practitioner understandings. Lange and Cummins (2021) identify that decision-makers globally are being challenged to engage in energy transitions to address climate change and develop more sustainable forms of energy supply. MacGillivray et al. (2014) argue that policymakers and investors are willing to provide innovation support for renewable energy where "tangible and credible" results are identified. By identifying how appropriability and the role of the founder/CEO characteristics impacts OI, this paper provides a means for viable strategies and policies to be developed to support OI in this sector (Andries and Faems 2013). This is important as Lange et al. (2018) identify a lack of policy integration as a key barrier for MRE projects.

The paper is structured as follows. Section 2 provides a review of the theory discussing the tensions between OI and appropriability, followed by a review of Upper-Echelons Theory (UET) literature. Data and methods are presented in Section 3. This is followed by both quantitative and qualitative results in Section 4. The final section presents the discussion and concluding comments.

2 | Literature Review

2.1 | Theoretical Framework and Hypothesis Building

2.1.1 | Open Innovation

OI is far from a universal mechanism that can be prescribed in an unspecific manner (Tidd 2014). In fact, many of the limitations and criticisms of OI stem from the seemingly generalized and perhaps "false" dichotomy between open and closed innovation (Trott and Hartmann 2013). It is crucial to conceptualize and measure OI appropriately and that the modes identified are relevant to the context of the study (Carlsson and Corvello 2011; Gianiodis et al. 2010). Much of the literature focuses on OI as a dichotomy of knowledge flow directions, inbound (outside-in) and outbound (inside-out) as well as a "coupled" approach of both knowledge flow directions simultaneously (Chesbrough 2006; Chesbrough and Bogers 2014). However, there have been calls to broaden this understanding

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of knowledge flows, to better account for the nuances of OI, specifically in the context of SMEs (Laursen and Salter 2006; Lazzarotti and Manzini 2009).

Ahn et al. (2015) build on Laursen and Salter's (2006) approach of examining the breadth and intensity of a firm's openness, to include the "dominant changes" necessary for a firm to pursue an OI strategy. This was measured in terms of technology, market, and organizational-oriented changes brought about by OI and added as an important additional factor to the inward and outward nature of the knowledge flow. Lazzarotti and Manzini (2009) suggest modes of OI by crossing two domains—a firm's variety of partners and a firm's "innovation funnel openness," i.e., number of stages of an innovation process opened to external involvement. Although the importance of early OI research goes without question, several authors (e.g., Laursen and Salter 2006; Lazzarotti and Manzini 2009; Ahn et al. 2015) look to expand the previous approaches of measuring through a simplified bidirectional flow of knowledge and to better address the complexities, contexts, and contingencies of OI activities (Tidd 2014). This more precise approach should assist in seizing the research opportunities for OI within SMEs and in new, multifaceted industries (West and Bogers 2017; Lippolis et al. 2023) such as MRE.

2.1.2 | Collaboration and Knowledge Sharing

The resource-based view (RBV) of the firm highlights the importance of internal resources for improving firm performance (Barney 1991). Zack (1999) considers knowledge the most important strategic resource in a firm, as it underpins the ability to acquire, create, and share new insights (Zack 1999; Ferreira et al. 2020). A firm's knowledge management strategy may be developed by the CEO, who often plays a central role in shaping environments that promote innovation (Gutiérrez-Broncano et al. 2024). Strategic decisions concerning knowledge protection and collaboration are often key components of such strategies.

This paper leverages Laursen and Salter's (2006) breadth and intensity approach of openness to conceptualize and measure collaboration. Formal collaboration has been widely acknowledged to positively impact innovation performance throughout a variety of possible collaboration partners (e.g., university, user, supplier, competitor, etc.) and for firms of varying size and industry (Dahlander and Gann 2010; Love et al. 2014; Garcia Martinez et al. 2014; Vahter et al. 2014). Access to a network of direct ties (collaborating partners) as well as indirect ties (partners of collaborating partners) can positively impact firm-level innovation (Ahuja 2000). Furthermore, spanning a rich network of disconnections between a firm's partners, or structural holes (Burt 1992), can impact innovation due to the diverse range of knowledge possessed by the various actors (Ahuja 2000). However, a rich network of structural holes can increase the risk of opportunistic behavior by some actors, potentially undermining innovation output (Ahuja 2000). This risk can be reduced through the adoption of appropriation strategies.

Of course, the benefits of collaboration depend on the organization and individuals within that organization, having the absorptive capacity, or prior related knowledge to acquire, assimilate, and exploit the knowledge that is shared (Cohen and Levinthal 1990; Ebers and Maurer 2014). While a firm's absorptive capacity can be a form of competitive advantage (Zahra and George 2002), knowledge acquisition is a complex process. Zahra and George (2002) contend that while potential absorptive capacity enables firms to acquire and assimilate external knowledge, it does not provide assurance that the knowledge will be exploited. Realized absorptive capacity involves the firms applying their knowledge transformation and exploitation capabilities to utilize the knowledge for competitive advantage purposes (Zahra and George 2002; Williander 2007). The payoff from realized absorptive capacity will be high when the firm adopts a strong appropriability regime that allows them to protect their knowledge (Zahra and George 2002).

Realized absorptive capacity can be facilitated by the CEO's characteristics within the firm. For example, Majhi et al. (2024) find that a synergy of narcissism and humility within a CEO can affect absorptive capacity within a small firm. CEOs with higher levels of humility are associated with the recognition and assimilation of new knowledge, while a narcissistic CEO can facilitate the reconfiguration and application of the knowledge (Majhi et al. 2024). Furthermore, a leadership style that encourages interactions in the workplace and empowers employees can foster firm-level innovation (Gutiérrez-Broncano et al. 2024). Servant CEOs, who aim to develop the potential of their workers, are likely to implement practices that enhance the firm's capability to absorb new knowledge, increasing the potential for innovation (Gutiérrez-Broncano et al. 2024).

One strategy a CEO may adopt is to collaborate with actors who are in close cognitive proximity, as this can enhance mutual understanding and improve the efficiency of knowledge exchange. However, such a strategy can also heighten the risk of unintended knowledge spillovers (Boschma 2005), reinforcing the need for effective appropriation strategies.

Collaboration plays a critical role in enabling the transition to innovation that reduces environmental impact. Such innovation is described in different branches of the literature as either green or environmental innovation; for consistency, we adopt the term green innovation in this study (Bataineh et al. 2024b; De Marchi 2012; Cuerva et al. 2014; Ardito et al. 2019; Melander and Pazirandeh 2019; Cassetta et al. 2023; Oduro et al. 2022). De Marchi (2012) contends that green innovation enables firms to build environmental concerns into their strategies while consolidating their competitive advantage. While one would expect a positive relationship between collaboration and innovation, the empirical findings in the case of green innovations are mixed. For example, in Spanish manufacturing firms, cooperation with external partners is found to be more important for the introduction of green innovation than for non-environmental innovations (De Marchi 2012). Bataineh et al. (2024a) suggest that the combination of external collaboration and increased R&D investment may assist firms in acquiring knowledge and skills, establishing new technologies, and engaging in green patent activities. However, Cuerva et al. (2014) find that collaboration with competitors, suppliers, and customers, and the public sector does not significantly impact green innovation and non-green innovation in Spanish food and beverage firms. In the Italian context, firms who engage in external collaboration

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have a greater probability of increased turnover linked to their engagement in environmental innovation (Cassetta et al. 2023).

2.1.3 | Tension Between OI and Appropriability

A firm's openness to external knowledge acquisition comes with considerable risks and challenges (Gans and Stern 2003; Chesbrough 2006; Luoma et al. 2010). To gain knowledge from outside a firm's boundaries, some degree of the organization's own knowledge will likely be revealed to collaborating external actors, so control of access to knowledge is vital (Zobel and Hagedoorn 2020). While OI brings the benefits of a wider knowledge base, it can also add complexity to how firms appropriate profits from the innovation (Granstrand 1999). This exposure can be defended by both formal (e.g., patents, trademarks, etc.) and informal (e.g., secrecy, lead times, etc.) protection methods (Holgersson et al. 2018).

The tension between OI and appropriability can be significant, yet complex, with many contingent factors or "forces" at play (Laursen and Salter 2014). Two actors rarely partake in OI practices with the intentions of one sole beneficiary. Mutually beneficial relationships based on each other's complementary resources are a much more common and logical OI strategy (Van de Ven 2005). Therefore, each firm's knowledge base prior to OI, the characteristics of this knowledge, and the objectives of the collaborative relationship are central to OI and are influential forces affecting the firm's absorptive capacity and appropriability of the aligned resources (Cohen and Levinthal 1990; Teece 2000). It is unlikely for a firm to know intricate details about an external actor's knowledge and intentions before interacting. Therefore, assessing the degree of asymmetric information is a high priority for SMEs before engaging in any form of collaboration. Trust is a key component in developing an environment where ideas are shared freely for innovation purposes (Dovey 2009) and a lack of trust hinders knowledge dissemination (Andersson et al. 2017). Some uncertainty can be offset by collaborating with agents who are in close social proximity and with whom the organization has a certain level of trust or kinship (Boschma 2005). However, a trust-based relationship does not offer full protection from other actors engaging in opportunistic behavior (Boschma 2005). Many firms see these OI engagements as risky, fearing the possibilities of a knowledge leakage and imitation in the absence of protective mechanisms (Hurmelinna-Laukkanen and Puumalainen 2007; Gimenez-Fernandez et al. 2023; Brunswicker and Chesbrough 2018; Veer et al. 2016). These firms ensure protection mechanisms are in place before engaging with external actors (Alexy et al. 2009); however, the effectiveness of such appropriability mechanisms varies (Veer et al. 2016; Hurmelinna-Laukkanen and Puumalainen 2007)—ultimately depending on actors complying within "the rules of the game" (Orjuela-Ramirez et al. 2024). Despite this, it is reasonable to assume that the relationship between appropriability and OI is strong. However, the direction of this relationship is not as obvious, and the literature often expresses varied and conflicting views (Laursen and Salter 2014; Gimenez-Fernandez et al. 2023).

OI literature has often emphasized the negative effects of a strong appropriability strategy on a firm's openness, encouraging firms to increase their openness to outside actors and to "let go" of a restrictive focus on idea protection (Chesbrough 2003). Moreover, the literature has consistently highlighted the missed opportunities of knowledge absorption and innovation that can occur when firms are excessively guarded about their ideas (Von Hippel 2006; Vanhaverbeke 2017). Brunswicker and Chesbrough's (2018, 44) study calls for firms to formulize OI processes rather than "nurturing an obsession with legal IP control" to tackle the tension between appropriability and OI. However, the OI literature also highlights how appropriability can be an enabler to openness and has outlined many benefits of appropriability strategies for effective OI (West 2006; Alexy et al. 2009) including a firm's increased confidence when engaging with external actors, as the "right" legal appropriability strategy should prevent devious behavior around knowledge theft (Teece 2000; Higgins 2003).

Relevant within the MRE context, is the ability for formal IP to act as a signal of quality of information, which may reduce asymmetric information. By securing patents or other formal protection measures, MRE firms can signal to external parties their possession of high-quality technological knowledge, thereby establishing their credibility for collaboration or outside investment, which is critical as failure to achieve funding is a top ranked risk for MRE firms (Bucher and Bryden 2016). Therefore, we may find that the adoption of strict appropriability strategies in this industry is common, both to signal one's quality of knowledge to ever-important external investors and to prevent leakage of its technical knowledge, although existing investigations into MRE firms have found "limited sharing of knowledge, (and) a lack of collaboration in the industry" (Bucher and Bryden 2016, 188).

Furthermore, the decision to adopt an appropriation strategy is not to be influenced solely by costs and benefits. Recent literature highlights the challenges that firms face in deciding whether to implement such strategies, which include the administrative burden associated with filing for patents and trademarks (Morales et al. 2024), high filing costs associated with patenting (Morales et al. 2022), backlogs and long waiting times for patents to be granted (Barros 2021), and challenges associated with the implementation and enforcement of nondisclosure agreements (NDAs), whereby it can be difficult to determine where the breach occurred (Morales et al. 2024). Furthermore, stakeholders may be unwilling to sign an NDA (Morales et al. 2024), and firms may be unwilling to engage in complex formalized transactions associated with OI (Chen et al. 2024). In the context of green innovation, Orjuela-Ramirez et al. (2024) find that informal appropriation strategies may be more appropriate, as a lower cost option, due to commercial uncertainty. Advanced technology and IP are positively related to green innovation in Spanish firms, with patents being important for increasing green innovation (Bataineh and Sánchez-Sellero 2025). Despite the challenges, Abdelaty and Weiss (2023) argue that IP should be treated as a stimulant to OI rather than a barrier.

Given opposing theories, there is a lack of clarity in the literature as to whether appropriability enables or hinders OI (Chen et al. 2022; Gimenez-Fernandez et al. 2023). We propose that there is a tense balancing point between OI and appropriation, which is in line with the findings of Laursen and Salter (2014),

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who suggest higher levels of appropriability are associated with decreasing openness levels. While appropriability is important for OI, too great an emphasis on appropriability may signal that the firm will be difficult to deal with and conflicts relating to the ownership of knowledge may arise (ibid). Moreover, Love et al. (2014) contend that when firms develop mechanisms for managing relationships with external partners, they learn how to better manage their existing relationships and, over time, can obtain higher returns from a specific breadth of linkages. This combinative strategy between OI and appropriation strategies is more relevant for start-ups during the early years of start-up growth (Gimenez-Fernandez et al. 2023). Furthermore, higher levels of appropriation may send a quality signal to potential external partners and result in increased collaboration (Laursen and Salter 2014; Abdelaty and Weiss 2023). Having considered the opposing viewpoints, we expect that, initially, appropriation will reduce external collaboration breadth in MRE firms, but with stronger appropriability strategies, firms will engage in more collaboration. This leads to Hypothesis 1:

H1. There will be a convex relationship between the strength of a firm's appropriability strategy and external OI breadth.

While appropriability strategies may be important, Zhang et al. (2024) contend that OI also requires firms to have competent leaders who can identify knowledge requirements and who can employ the relevant mechanisms to manage knowledge sharing. Because SMEs tend to have a less complex organizational structure than larger firms (Ahn et al. 2017; Wee and Chua 2013), CEOs have greater freedom in the decision-making process (Ahn et al. 2017) and may have a more direct impact on organizational outcomes than CEOs in larger firms (Bennat and Sternberg 2022). Furthermore, the close connection between the top executive and the business means that SMEs reflect the personality, values, attitudes and education of the top executive to a greater extent than large businesses do (Hammann et al. 2009). This suggests that the personal traits and characteristics of the CEO will likely influence attitudes toward OI and appropriability strategies. Consequently, the next section outlines the relevance of UET in the context of OI and appropriability.

2.2 | UET, OI, and Appropriability

Implementing or avoiding an OI strategy is a significant strategic decision for SMEs and one that might be the difference between the firm sinking and staying afloat (Vanhaverbeke 2017). The RBV of the firm suggests that a firm's ability to implement effective strategies comes from internal human resources (Penrose 1959). In recent years, a greater emphasis has been placed on the importance of leader characteristics for OI adoption (Ahn et al. 2017; da Mota Pedrosa et al. 2013). This has resulted in a surge in the number of studies linking UET to OI (see, for example, Saeed et al. 2024; Xia et al. 2023; Lu et al. 2022; Barrett et al. 2021; Ahn et al. 2017).

The UET aligns with the RBV of the firm by focusing on a micro-level of analysis and the role of the CEO and/or the top management team for competitive advantage (Hambrick 2007). UET is built on the fact that humans are fallible beings with bounded rationality, and so, a CEO can (1) only act on their own interpretation of a strategic decision, and (2) their perception is a function of their individual disposition (e.g., entrepreneurial or risk orientation and competences) and past experiences (Hambrick 2007). In the case of SMEs, the CEO plays a significant role in influencing innovation activities (Bennat and Sternberg 2022; Ahn et al. 2017), and, as such, the personality, values, and competences of the CEO strongly impact innovation (Bennat and Sternberg 2022).

Di Minin et al. (2010) contend that a committed, passionate, and visionary champion is the most important factor in moving from a closed to an OI strategy. Certain personality traits may facilitate engagement within the OI process. For example, egoism propels engagement in discontinuous technologies due to the CEO's self-admiration buoying their belief and risk-seeking behavior (Gerstner et al. 2013), while CEO hubris can be an important driver for introducing green innovation (Arena et al. 2018). Strong CEO leadership, involving new mindsets and strong aspirations, is important in establishing an OI-friendly culture and mitigating against the associated challenges (Ahn et al. 2017).

CEO attributes can be directly tied to the firm's strategic trajectory in risk-taking, proactiveness, and innovation behavior, which are features of entrepreneurial orientation (EO) (Yang et al. 2024). Entrepreneurially orientated managers focus on value creation in the form of new product development (Wang et al. 2020), which may be facilitated by OI. As EO encourages rational but strategic risk taking, entrepreneurial firms that engage in innovation place an emphasis on guarding their knowledge through various appropriation mechanisms (Holgersson 2013). As such, there is a balancing point between the proactive risk-taking nature of the SME (Pérez-Luño et al. 2011; Ahn et al. 2017) and the desire to protect knowledge and inventions (Holgersson 2013).

There is an increasing literature linking green innovation to competitive advantage within the firm (De Marchi 2012; Tu and Wu 2021; Bataineh et al. 2024a; Bataineh et al. 2024b). Green innovation can result in competitive advantage through reduced costs, compliance with regulation, enhanced reputation for the firm, as well as through innovation itself (Bataineh et al. 2024b). Through responsible innovation firms can boost their image and gain an increased market share (Hadj 2020). Green innovation is also positively linked to export performance and internationalization (Chai 2023; Shu et al. 2024; Hemmert et al. 2025). For multinational businesses from emerging countries, green innovation can enhance their legitimacy in host countries through compliance with regulatory and social norms (Shu et al. 2024; Hemmert et al. 2025), which can increase their export performance and facilitate the business in achieving competitive advantage. Increased interest in green innovation has also led to the CEO's environmental disposition being considered in the literature as a crucial factor in shaping strategic choices, particularly in response to environmental issues (González-Benito and González-Benito 2010). For example, environmentally conscious CEOs are attracted into the renewable energy and green sectors, identifying environmental concerns as an opportunity for gaining competitive advantage (Ali et al. 2023). Thus, CEOs with greater environmental awareness tend to adopt practices that reduce the firm's environmental impact and view environmental

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protection as fundamental in developing the firm's competitive strategies (Tang et al. 2024).

CEOs with strong organizational skills may also promote green innovation. Bataineh et al. (2024a) find that components of organizational innovation, which include the management of external relations with partners, improved decision-making, and the introduction of new business practices, promote green innovation in Spanish firms. Tu and Wu (2021) find that green innovation is positively related to competitive advantage in Chinese manufacturing firms, with the process being mediated by organizational learning. They suggest that managers should facilitate internal learning for employees through informal mechanisms, such as meetings to exchange knowledge, as well as formal mechanisms such as seminars. Managers could also engage in information exchange with external organizations to further their learning (Tu and Wu 2021). The willingness of the CEO to make R&D investments is also likely to shape a firm's strategic outcome. In the context of Spanish firms, Sánchez-Sellero and Bataineh (2022) find that internal and external R&D expenditure positively impacts green innovation, while Bataineh et al. (2024b) find that R&D expenditure has a positive moderating effect on the relationship between green innovation and competitive advantage.

2.2.1 | CEO Education and OI

Beyond psychological dispositions, UET highlights the importance of education, career experiences, and functional track, which directly shape strategic decisions (Hambrick and Mason 1984). The imprinting effects of an individual's educational experience affect their future decision-making, and as such, CEOs' decisions are shaped by the values that they internalize during their education process (Bai et al. 2020). Elevated educational attainment leads to faster strategic decision-making (Wally and Baum 1994), rationality (Papadakis and Barwise 2002), and collaboration (Esteve et al. 2013; Ju et al. 2023). Higher levels of education may also improve the top managers' ability to endure ambiguity, absorb new knowledge, and deal with complex situations (Chen et al. 2010). Furthermore, highly educated CEOs demonstrate greater concern for climate change (Amore et al. 2019) and are more likely to pursue innovations with significant societal and sustainable benefits (Zhou et al. 2021). Hambrick and Mason (1984) contend that the amount of formal education undertaken by management is positively associated with innovation. For OI adoption, the willingness of CEOs to take risks is especially important (Najar and Dhaoudai 2020). CEOs with higher levels of education are less risk averse, more open to change (Ting et al. 2015), and thus more open to innovation (Barker and Mueller 2002).

Of course, it is not just the education level achieved that is important; Hitt and Tyler (1991) argue that both the level and type of formal education undertaken affect strategic decision-making. Therefore, the educational discipline of the CEO may also impact MRE innovation. CEOs' willingness to take risks is shaped by their educational backgrounds (Hambrick and Mason 1984; Tyler and Steensma 1998; Barker and Mueller 2002). CEOs with science and engineering backgrounds may be more likely to engage in high levels of R&D expenditure (Barker and Mueller 2002). This is possibly linked to CEOs with a science or engineering education having a better understanding of the technological base of their company (Tyler and Steensma 1998; Barker and Mueller 2002) and a greater commitment to technology development than CEOs with a business education (Tyler and Steensma 1998). Furthermore, CEOs with an educational background in technology may be better equipped to identify the technological needs of a firm and make rapid decisions relating to the same (Ahn et al. 2017).

CEOs with output functional career experience, such as in engineering, marketing, and sales, are likely to favor higher R&D expenditure to support innovation (Gupta et al. 2000). However, CEOs with experience in finance, production, administration, and legal areas will focus on improving firm efficiency (Barker and Mueller 2002). Those CEOs with science/engineering education and backgrounds can better integrate and synthesize new value from external knowledge through a stronger absorptive capacity, higher creative potential for developing novel technologies, and a problem-solving ethos that supports active engagement in the management of OI projects (Barrett et al. 2021). Given that an engineering background positively affects environmental innovation (Arena et al. 2018), it may also be an important determinant of OI adoption in the MRE sector.

In contrast, CEOs with general business or legal backgrounds tend to be more risk averse and may be less inclined to engage in R&D expenditure for innovation (Barker and Mueller 2002). This may be linked to MBA programs focusing more on avoiding big losses rather than developing risk-taking or innovation tendencies (Hambrick and Mason 1984) or developing detailed technological knowledge (Patzelt et al. 2009). While such CEOs may be more risk averse, those with general business or management education still play an important role in determining OI adoption in MRE firms, given OI involves extensive inter-organizational collaboration (Ollila and Yström 2017). Esteve et al. (2013) suggest that those with management education are better able to understand the benefits of collaboration as they are equipped with the necessary knowledge and skills to manage the uncertainties associated with collaboration due to their management education. Those with management education also learn about the legal side of business with an emphasis on the importance of developing and negotiating contracts (Patzelt et al. 2009), which is beneficial for OI.

Of course, education and experience impact not only OI but also appropriation decisions. Amoroso and Link (2021) find that education rather than experience is a key determinant of intellectual property adoption in small, young innovative firms in Europe. Having a highly educated founding team increases the probability of using secrecy or confidentiality agreements (Amoroso and Link 2021). Zhao et al. (2025) contend that top management teams with high educational levels have a greater capacity to manage the trade-offs between R&D and patenting strategies.

Following this discussion, the second set of hypotheses is as follows:

H2a. Founders/CEOs with higher education levels are more likely to adopt OI practices.

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H2b. Founders/CEOs with engineering/STEM educational backgrounds adopt more OI practices.

Figure 1 below provides an overview of the conceptual underpinnings of this study and the predicted hypotheses from H1 through to H2b.

3 | Quantitative Analysis

3.1 | Methodology and Data

To test H1, H2a, and H2b, we first employ a quantitative investigation using firm-level responses from a specially designed survey distributed to firms in the MRE sector. This offers several advantages. First, since MRE enterprises make up a relatively small proportion of national firm populations, secondary data sources would not have enough observations to provide any meaningful analysis. Second, a specially designed survey enables the collection of data around appropriation and collaboration activities that are rarely collected in secondary firm-level datasets. Finally, our survey provides the novelty of questions that focus on the CEO of firms, asking questions about their prior education and disciplinary expertise. Data collection using the Renewable Energy Innovation Survey (REIS) (The research ethics board at University College Cork provided ethical approval for REIS.) was conducted from January 2020 to April 2021. The REIS included questions regarding the company's innovation activities, knowledge sourcing activities, networks, resources, and performance for the years 2017 to 2019. Due to the bias that the COVID-19 pandemic may have caused, firm activity and performance details were not sought for the year 2020.

The MRE supply chain datasets that are publicly accessible online served as the survey's sample frame (see Appendix A1 for more information on the list of databases), which represented 1342 known enterprises at the time of data collection. Given the emerging nature of the offshore renewable energy sector, comprehensive demographic data on firms are unavailable, reflecting the sector's fragmentation and the prevalence of SMEs. A total of 227 replies from the sampling frame were received during data collection, yielding a response rate of 16.4%. This study focuses exclusively on SMEs, with data collected through funding from the SELKIE project (Ireland Wales Programme 2020) to better understand their role within the sector. Initiatives such as SELKIE and the North-West Europe Marine Energy Alliance (Interreg NWE 2020) reflect wider efforts to strengthen SME participation. Broader sectoral reports (ORE Catapult 2023; OWGP 2024; European Commission 2024) confirm that SMEs dominate the offshore renewables supply chain. The marine energy sector includes a broad range of firms, such as technology developers, suppliers, consultants, and asset providers, alongside companies specializing in testing, engineering, maritime operations, and data services, which are represented within our dataset. These firms are predominantly young, micro businesses and are largely involved in the early research and development stages of MRE technologies. While the sample captures many of these key sectoral characteristics, readers should be mindful that some degree of nonresponse bias may exist, and findings are best interpreted as illustrative of broader SME experiences in this emerging sector.

One hunderd forty-six replies from the 227 total responses could be included for the quantitative analysis in this study after checking for errors and omissions. Consideration around the statistical power of the model is important, given the sample size of the dataset. Consequently, the models estimated ensure at least 10 data observations per predictor variable as a pragmatic lower bound for sample size (Harrell 2015).

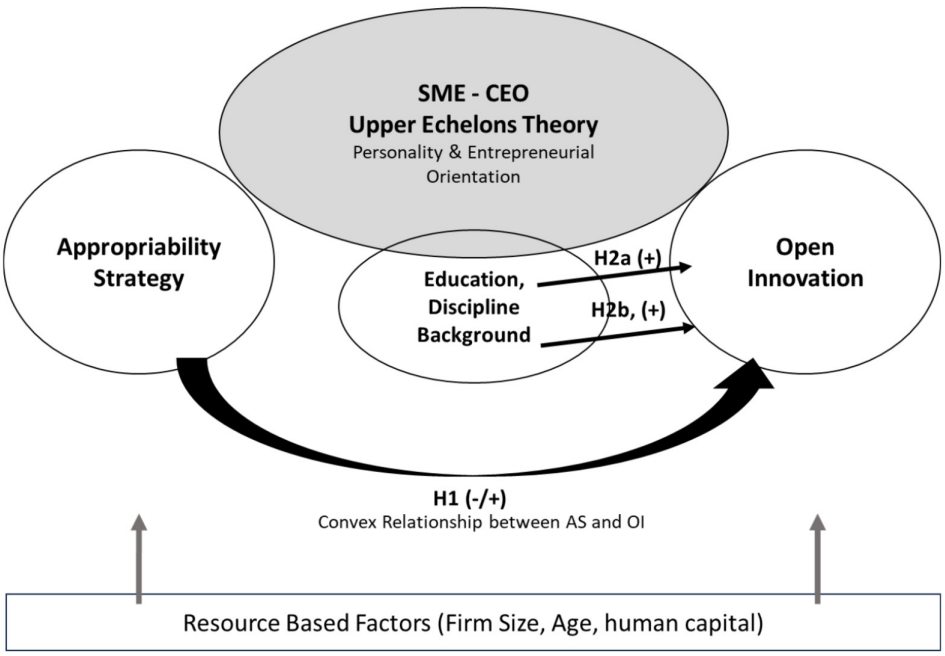

FIGURE 1 | Upper-Echelons Theory, open innovation, and appropriability.

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Our dependent variable is a proportion bounded between 0 and 1, created by dividing an original count variable by its upper bound of 10 (Papke and Wooldridge 1996). Ordinary least squares is unsuitable because it treats proportions as unbounded continuous variables, potentially producing predictions outside the bounded interval. Standard logistic, probit, and ordered models are designed for binary or ordinal outcomes and would either require artificial categorization of the data or incorrectly assume a ranked structure, leading to loss of information and model misspecification. In contrast, fractional response models are specifically designed for proportion data bounded between 0 and 1 (Wooldridge 2002). Similar models have been used in related studies, such as Laursen and Salter (2014), who applied a fractional response model to a comparable dependent variable, ensuring predicted values remain bounded between 0 and 1 through a logistic function. Without requiring rigorous distributional assumptions, fractional logit, which is estimated using quasi-maximum likelihood estimation, models the conditional mean of the proportion dependent on explanatory variables (Wooldridge 2002). Because it allows for interpretable marginal effects within a constrained period, this method is suitable for dependent variables that indicate fractions.

Under H1, a convex relationship is expected between appropriation strategies and collaboration breadth. A comparison between linear and LOWESS (locally weighted scatterplot smoothing) fits can be conducted to assess the relationship between two variables and to determine if a linear model will sufficiently capture the trend in the data (Cleveland 1979; Harrell 2015). Figure 2 suggests that a linear model would be an adequate approximation, as both the linear fit (solid line) and LOWESS fit (dashed line) show a close, steady increasing relationship between Appropriation Strategies and Collaboration Breadth, with minor nonlinear deviations. Additionally, an F test suggests the quadratic term is insignificant. This result suggests a linear model is sufficient and partly provides evidence against H1, which we will return to later in the Results section.

The fractional regression linear model to be estimated in this paper is specified as follows:

$$\begin{aligned} OI_i = {} & \beta_0 + \beta_1 \text{AppropriationStrategy}_i + \beta_2 \text{FirmAge}_i + \beta_3\ \text{MultiPlant}_i \\ & + \beta_4\ \text{UniversityEducation}_i + \text{Subsidy}_i + \beta_6 \text{FirmSize}_i \\ & + \beta_7\ \text{DisciplineCEO}_i + \beta_8\ \text{EducCEOi} + \mu_i \end{aligned}$$

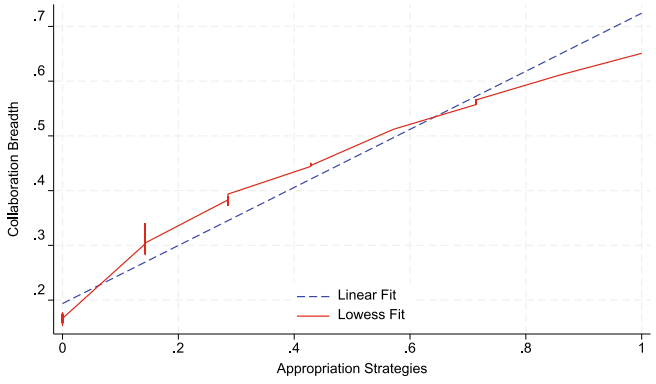

FIGURE 2 | Comparison of linear and LOWESS fits.

3.2 | Measures

OI is the dependent variable incorporating the breadth of collaboration undertaken by firms and is a fractional response variable that takes the fraction of external collaboration partners that the firm engaged with as part of its innovation activity from 2017 to 2019. This includes collaborations with (1) consultants, (2) suppliers, (3) competitors, (4) clients and customers, (5) enterprises within a firm's enterprise group, (6) other enterprises, (7) university, (8) government, (9) public customers, and (10) non-for-profit actors. For example, if a firm engaged with one partner, their observed unit would be 0.10 (1/10). The indicators adopted here for collaborations and OI strategies follow previous research highlighting the advantages of various types of innovation linkages and the complementarities they offer (Laursen and Salter 2006; Love et al. 2014; Garriga et al. 2013).

The independent variable, AppropriationStrategy, important for examining H1, is derived from a survey question about the significance of various protection methods to the firm. The question and approach employed resemble those used in prior research (Jensen and Webster 2009; Laursen and Salter 2014). A fractional response variable of the seven potential appropriation strategies the firm may have employed is created, which includes (1) application for a patent, (2) register an industrial design right, (3) register a trademark, (4) claim copyright, (5) use trade secrets, (6) establish a market lead time, and (7) ensure product complexity (to avoid imitation). The education levels of the CEO denoted EducCEO and the CEOs' background discipline denoted as DisciplineCEO are also used to identify if the CEO's background characteristics have any bearing on the relationship between the firm's appropriation strategy and its collaboration intensity (i.e., OI). These are commonly used measures in the literature examining strategic actions and outcomes of organizations and are essential variables for examining H2a and H2b (Arena et al. 2018; Barker and Mueller 2002; Esteve et al. 2013).

The descriptive statistics and variable definitions are presented in Table 1. The average number of collaborative partners for firms is 4, represented by a 0.40 fractional number. The average number of appropriation strategies is almost 2, represented by a 0.25 fractional number. MRE firms are broadly young, with a small and highly educated workforce and in receipt of a high number of subsidies.

3.3 | Results and Analysis of Quantitative Analysis

Table 2 presents the results of the estimations of Equation (1). First, these results (appropriation), taken together with the earlier LOWESS analysis, reveal a positive linear relationship between appropriation and OI (see Figure 2, where appropriation strategies and OI are positively related). Consequently, we reject H1 and ascertain that potentially firms engage in more OI as they are confident that their knowledge is adequately protected coupled with their collaboration capabilities. Abdelaty and Weiss (2023) suggest that having an appropriation strategy mitigates the risk of knowledge being stolen and encourages more collaboration. Furthermore, higher levels of appropriation may

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TABLE 1 | Variable names, definitions, and summary stats.

Variable name	Definition	Mean	SD
OI	A fractional response variable that takes the fraction of the 10 total potential external collaboration partners that the firm engaged with as part of its innovation activity from 2017 to 2019. (e.g., 1 partner = 1/10 or 0.10 and 5 partners = 5/10 or 0.50)	0.40	0.31
Appropriation strategies	Count variable that takes the value of 0 to 7, depending on the number of appropriation strategies the firm employs	0.25	0.28
Log of firm age	The natural log of subtracting the year the firm was established from the current year	2.58	0.95
Multiplant	A binary variable that takes the value of 1 if the organization has more than one plant	50.68	
% University education	Percentage of the organization's employees who have obtained a third level qualification	70.72	33.24
Subsidy	A binary variable that takes the value of 1 where an organization has received any form of subsidy during the years 2017–2019	54.42	
Firm size	The natural log of the number employees reported in 2019	2.21	1.59
Educational achievement			
CEO education	Binary variable that takes the value of 1 if the CEO has a master's or PhD qualification, 0 otherwise	65.75	
CEO educational discipline			
Mgmt. discipline	Binary variable that takes the value of 1 if "Management" best represents the CEO's (highest ranked officer) educational discipline. (i.e., management, finance, economics, commerce, accounting)	26.02	
Tech_discipline	Binary variable that takes the value of 1 if "Technology based" best represents the CEO's educational discipline. (i.e., engineering or science/STEM)	67.80	
Other discipline	Binary variable that takes the value of 1 if "Other discipline" best represents the CEO's educational discipline. (i.e., arts, design, history, geography, politics)	06.16	

send a quality signal to potential external partners and result in increased collaboration (Laursen and Salter 2014; Abdelaty and Weiss 2023).

The findings relating to UET are mixed. The results suggest that CEO level of education (CEO education) is an important determinant of OI. The variable is positive and significant at the 10% significance level, supporting H2a. Both variables capturing educational discipline (CEO management/business discipline and CEO engineering science/STEM discipline) are, however, statistically insignificant, leading to the rejection of H2b. This contrasts with the body of literature that suggests an engineering background is positively associated with innovation (Barker and Mueller 2002; Arena et al. 2018; Barrett et al. 2021). Our results do, however, strongly resemble those of Esteve et al. (2013), who report that the top manager's level of education has a positive impact on OI, while the field of study does not.

In the context of the MRE sector, it may be the case that the generic skillsets developed through higher levels of education, work experience, and the confidence that those skills deliver are more important in a management context than sector-specific skills (Custódio et al. 2019). For example, Esteve et al. (2013, 943) contend that managers with higher levels of education have acquired better skills and are "less reluctant to confront the managerial complexities that collaborations entail." Furthermore, in industries where technology plays a significant role, technical competences are not sufficient to be competitive, and soft skills are also necessary (Cimatti 2016). Custódio et al. (2019) contend that generalist CEOs (i.e., CEOs with a broad set of knowledge and skills) promote more innovation, encourage firms they lead to pursue risky innovation opportunities, and have skills that can be leveraged externally also through collaboration opportunities, whereas specialist CEOs (i.e., CEOs with relatively narrow but perhaps a deeper skillset) have skills valuable only within their organization (Lu et al. 2025). While it is important that the top manager has the skillset to deal with managerial complexities, they may not need to be educated in a specific discipline, which is relevant to the MRE sector. Such disciplinary knowledge may be acquired through hiring those who possess the discipline-specific education necessary. This could include hiring researchers who can positively impact innovation (Kaiser et al. 2018).

To gain a more lucid insight into the factors shaping OI within the MRE sector and to delve into the influence of CEO entrepreneurial characteristics and orientations, we have bolstered our

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TABLE 2 | Marginal effects of fractional probit regression.

Variables	Collaboration breadth
Appropriation	0.238***
	(0. 089)
Log of firm age	−0.019
	(0.035)
Education (% third level)	0.0003
	(0.0007)
Log of firm size	0.021
	(0.017)
Multiplant firm	0.083*
	(0.049)
Subsidies	0.057
	(0.050)
CEO education	0.090*
	(0.051)
CEO management/business discipline	0.045
	(0.057)
CEO engineering science/STEM discipline	0.051
	(0.129)
Constant	−0.849***
	(0.310)
Observations	146
Pseudo R^2	0.0447
Prob > χ^2	0.001

*Indicates significance at the 90% level.
**Indicates significance at the 95% level.
***Indicates significance at the 99% level.

findings with a qualitative analysis that we discuss in the next section.

4 | Qualitative Analysis

4.1 | Methodology and Data

As outlined, to address our research objective, a quantitative analysis is conducted and complemented with qualitative data collected using semi-structured interviews. Our rationale in selecting this approach is that the quantitative data and analysis provide an understanding in general terms of the research problem; however, the qualitative data and analysis provide an explanation of the statistical results by exploring participants' views in greater depth, providing nuanced insights into the SME founder/CEO's perception of reality and their backgrounds, education, and human perspectives on the tensions between OI adoption and appropriability (Ivankova et al. 2006). The quantitative and qualitative phases were connected in the intermediate stage when the results of the first phase guided the data collection in the second phase.

We conducted and analyzed semi-structured interviews with the founders/CEOs of nine MRE SME firms (see Appendix A2 for interview guide). These interviews allowed us to employ a qualitative, multiple-case study approach, selected due to its ability to offer a more holistic view regarding the importance of the founder/CEO's role in guiding a firm's OI and appropriability strategy (Barrett et al. 2021).

A purposeful criterion sampling strategy was used (Eisenhardt 1989), which included (1) MRE SME firms, (2) founders/CEOs actively involved in running the business, and (3) SMEs actively engaged in radical innovation, developing new-to-market MRE devices. We screened 35 survey respondents from Study 1 who met the sampling criteria. From these 35 SME founders/CEOs, we selected nine cases to ensure a balanced and comparable sample according to three aspects: (1) the radical nature of the innovation, (2) the collaboration activities, and (3) firm size/available resources. Data collection was an iterative process and took place from December 2020 to August 2021. In-depth semi-structured interviews were conducted in each case, which lasted 60 min on average. We purposefully derived the interview questions from the theoretical framework.

Interviews were recorded and transcribed via Microsoft Teams. Interview transcripts were reviewed and analyzed independently by two researchers using a "multi-rater" approach (Larsson 1993). Provisional categories, first- and second-order codes were applied by "lumping" the data followed by "splitting" these data into chunks providing more nuanced analysis (Miles et al. 2014; Saldaña 2013). This analysis was conducted in an iterative "back and forth" fashion from the raw data to each case study narrative (Siggelkow 2007). Figure 3 provides an overview of the data structure elements (Pratt 2009). To ensure methodological rigor, inter-coder reliability was conducted by two researchers coding independently and then using the "percent agreement" method to reach a consensus of 85% (Miles et al. 2014; Larsson 1993; Goffin et al. 2019). This method was used due to the uncomplicated codebook and the researcher's experience (Halpin 2024); throughout this process, issues were discussed and resolved by the two researchers.

4.2 | Results and Analysis of Qualitative Data

4.2.1 | The Appropriation and OI Relationship

From the quantitative study, we reject H1 and demonstrate that, in the case of MRE, there is a positive linear relationship between appropriation and OI. We find that all nine cases (see Table 3 for a description of each case study) are leveraging OI practices with the belief and confidence that their knowledge is protected, with SMEs relying on both formal and informal appropriation methods. As previously outlined, those SMEs adopt an appropriation strategy and leverage deeper and broader OI collaborations. Table 4 provides an outline of the appropriation strategy and methods adopted with each SME relying on both formal and informal appropriation methods. The results indicate that appropriation is expensive but

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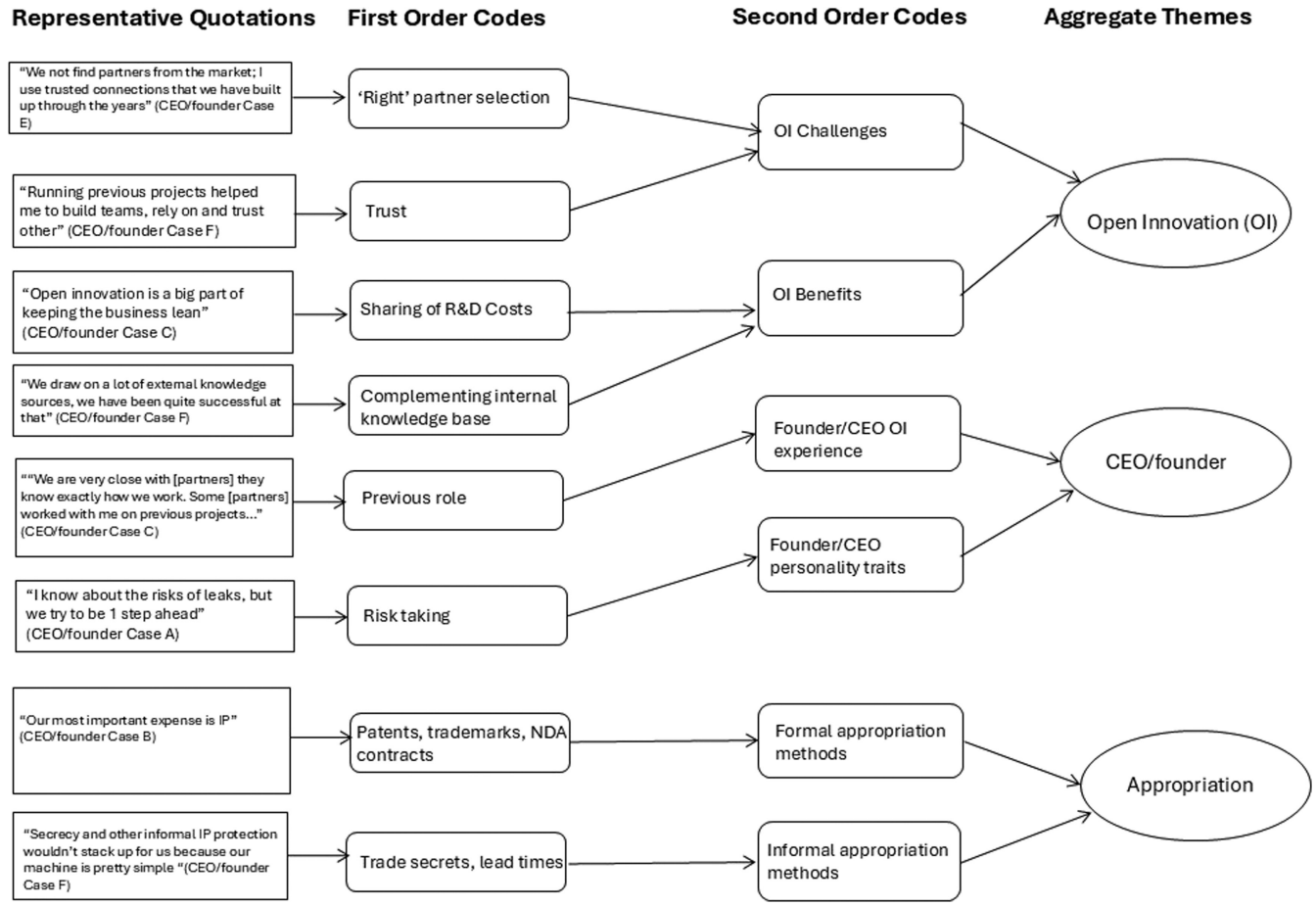

FIGURE 3 | Overview of the data structure elements.

necessary, regarded by CEO—Case G as the "most important expense." Significant advantages are provided by having a strategic appropriation focus, with the obvious benefit of protection against infringement with SMEs—"always try [ing] to be one step ahead" (founder/CEO—Case A). Appropriation also provides the ability to achieve a breadth in collaborations across partner types as "... protection encourages broader OI practices" (cofounder/chairman—Case H). Using appropriation strategies "provides confidence to other stakeholders" (cofounder/CEO—Case I) supporting successful investment and partnerships.

Table 5 provides insights into the OI practices and partners leveraged. The breadth of OI partner was contained to triple helix actors—with a reliance on government institutes for funding, universities and research centers for expert knowledge, and industry partners for complementary knowledge (typically in adjacent fields). We identified a dominance of strategic and purposeful OI with appropriation strategies related to the wide array of MRE sectoral challenges consisting of market and technology unknowns, high level of investment requirements, and the significant time it takes to achieve commercialization. For example, the cofounder/CEO of Case C alludes to these MRE sectoral challenges and their subsequent reliance on OI: "the industry has very niche skills, which means we must work with experts, external companies, and research institutes... And if we are to continue to build its collaboration partners, it is essential to protect our device, failing to do so would impede the company's openness." The founder/CEO of Case D shares the importance of OI as a key strategic pillar of the business to ensure the business remains "lean." A key enabler to achieving this is through building trust and leveraging previous relationships—"we are very close with our current partners; they know exactly how we work. Some have worked with me on previous projects, and we have built up trust." Similarly, founder/CEO of Case E highlights a similar cautiousness in selecting partners with a preference for "... working with trusted connections that [they] have built up through the years." These deep OI collaborations "make many things possible" in the early stages of technological development (founder/CEO—Case G).

4.2.2 | Upper Echelons and the Appropriation—OI Nexus

In this section, we examine, using the nine case studies, how the founder/CEO background influences firm appropriation–OI strategies. The SME leader and their prior entrepreneurial experience and knowledge are the fundamental factor influencing each organization's appropriation strategy adopted. A cautious IP approach is evident across all cases, including the use of multiple forms of appropriation including trade secrets, patents, and trademarks. For example, in Case A, the founder/CEO experienced five high-court appearances due to IP infringements in a previous venture, which provided

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TABLE 3 | Overview of case studies.

Case	Case description	Sector	Location	TRL	Year of foundation	Size
Case A	Case A is a Swedish wave energy company that created a Wave Energy Converter (WEC) device, built upon several patented innovations. The company claims that this device requires fewer parts (cheaper and easier to manufacture and install), is lighter than most devices, yet robust with a longer lifetime, and has "much higher power density than any other known wave energy system" (Case A/CEO and founder).	Wave	Sweden	6–9	2016	6 Employees
Case B	Case B is a Scottish wave energy company that created a WEC device with a dual purpose: (1) generating renewable energy and (2) functioning as an energy storage device (similar to a pumped hydro system), thus offering a dual business stream (renewable energy production and green energy storage).	Wave	Scotland	6–9	2018	4 Employees
Case C	Case C is a French wave energy company with a compact, innovative yet simple patented device that generates energy through an anchoring system. After years of technical studies, feasibility studies, and tank testing, the company has validated the performance of their concept and is now at the "more ambitious development stage," consisting of design manufacturing and sea trials.	Wave	France	3–5	2015	7 Employees
Case D	Case D is a Danish wave energy company that develops compact, easy-to-install, patented and scalable wave power technology devices.	Wave	Denmark	6–9	2010	7 Employees
Case E	Case E is a Scottish wave energy company with an R&D focus aimed at solving the marine wave energy capture and conversion problem. 15 distinct patents have been filed. The innovative device is a "co-location enabler" for wave and wind farms.	Wave	Scotland	3–5	2019	4 Employees
Case F	Case F is an Irish tidal energy device that can create energy from tidal flow acceleration through rivers, oceans or estuaries. Its patented design features acceleration water flow, so the technology is viable at low flow speeds and naturally diverts objects away from the device.	Tidal	Ireland	6–9	2014	4 Employees
Case G	Case G is an Irish university spin-off developing an innovative ocean WEC suitable for energetic deep-water sites and utility-scale arrays. The innovative device is mechanically simple and readily serviced on-site with moving parts securely housed above the waterline.	Wave	Ireland	6–9	2013	1 Employee

(Continues)

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TABLE 3 | (Continued)

Case	Case description	Sector	Location	TRL	Year of foundation	Size
Case H	Case H is an English early-stage tidal energy technology company with innovative technology from a decade of R&D. This patented tidal device uses tidal power to generate electricity and desalinate seawater. Highly focused on commercialization, the company sees remote island communities as being the initial target market. The company is currently self-funded.	Tidal	England	6–9	2019	4 Employees
Case I	Case I is a Dutch solar company that is developing an offshore floating solar system leveraging expertise from land-based solar technologies.	Marine floating solar	Holland	3–5	2018	8 Employees

insights into the risks associated with the creation of disruptive high-tech devices—"you will never know who leaks what" (founder/CEO—Case A). In Case B, the founder/CEO alludes to the importance of choosing the most suitable appropriation form and that it meets the needs of the technology "...not only having a patent but having the right patent" and to working with an experienced patent lawyer "to make it completely secure." Appropriation form selection was further emphasized in Case C as "secrecy and other informal IP protection wouldn't stack up for us because our machine is pretty simple" (founder/CEO—Case F). These insights emphasize the importance of an appropriation strategy for MRE SMEs and how it importantly addresses the technology, the lifecycle of the SME, and the unknowns of the MRE sector.

Turning to the hypotheses, from the quantitative analysis, we found support for H2a: "Founders/CEOs with higher education levels are more likely to adopt OI practices." However, we reject H2b: "Founders/CEOs with engineering/STEM educational backgrounds adopt more OI practices." In Table 6, we provide an overview of the founder of each case, their background, work and sectoral experience, and education. Most SME leaders are educated to master's (Cases A, B, D, and E) or PhD level (Cases C, G, H, and I) including many leaders with MRE sectoral experience (Cases B, C, D, E, and G). For those CEOs without specific MRE sectoral experience, there was evidence to support a deep passion for the sector in the pursuit of "saving the environment with profitable wave power... 60% for the climate, 20% for the journey and 20% for the money" (founder/CEO—Case A).

Given the small scale of each organization, the path taken by the MRE SME was directly influenced by the SME leader. This influence is shaped by the SME leaders' breadth of knowledge and experience gained through education and previous entrepreneurial experiences. Founders/CEOs with general and broader managerial skills from leading entrepreneurial ventures (in Cases B, D, E, F, G, H, I) promote more innovation within their SMEs and externally through OI collaborations as they have developed more human capital through exposure to more diverse knowledge sources. This valuable entrepreneurial experience was alluded to in Case D—"I would not have spotted this technology and appreciated it as the missing link if I had not had all that entrepreneurial background" (founder/CEO—Case D). This entrepreneurial experience shapes how the founder/CEO selects the SMEs partners and manages the subsequent relationships. For example, in Case E, the founder/CEO prioritizes "trusted connections" over "finding partners from the market." Trust also emerges as a central theme in Case C: "We are very close with our current partners; they know exactly how we work. Some have worked with me on previous projects, and we have built up trust" (founder/CEO—Case C).

In Case H, the founder/chairperson emphasized "coordinating, attracting and securing future investment/funding" as well as selecting "quality partners." This entrepreneurial and management background provides guidance on how to engage with partners: "My past business experience and acumen has helped me to develop the ability to deal with partners and negotiate." In Case B, the founder/CEO adopts a cautious approach when working with current and potential partners, practicing selective revealing. This includes refraining from marketing efforts or establishing a web site or social media presence until "it makes sense." He explains, "Why advertise a product when the market hasn't yet developed?" (founder/CEO—Case B). In the past, this founder/CEO expressed concerns about PhD students publishing technical studies of the device, highlighting the vigilance with which he manages external exposure and collaborations. The founders/CEOs in these cases exhibit a passionate, strategic, and experience-driven approach to partnerships and external engagements: "If you compromise on anything in this sector it will take you under" and "patents are a strong example" of this (founder/CEO—Case E).

While their entrepreneurial education and/or disciplinary backgrounds likely informed their entry into this highly niche sector, it is less clear how directly these factors shape their OI strategies, indicating negligible support evidence for H2A and H2B from the qualitative analysis. However, what is evident from the qualitative data is the founder/CEO's entrepreneurial and OI experience coupled with their determination to succeed. The MRE sector is complex, uncertain, and challenging and is still in its infancy

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TABLE 4 | Overview of appropriation strategy by case.

Case	Appropriation strategy	Appropriation methods (formal and informal)
Case A	A strategic approach to appropriation is evident. This is due to the founders/CEOs past entrepreneurial experiences, which included including numerous court cases due to IP infringement—both formal and informal appropriation methods are used, i.e., three patents filed in 20 countries, over 50 NDAs signed with partners (potential partners) plus other informal methods namely lean time and trade secrets.	Formal—patents Informal—secrecy/trade secrets Market lead time Product complexity; NDAs
Case B	The founder/CEO conducts an IP audit early in the SME lifecycle, which confirmed the novelty of the technology. Formal (eight patents) and informal (trades secrets) appropriation methods are evident. A robust patent protection is a key priority for the CEO.	Formal—patents Informal—secrecy/trade secrets
Case C	This SME engages heavily in OI and plans to extend further on these OI practices as the device nears commercialization. A strategic approach to appropriation is evident across formal (patents) and informal (NDAs) methods.	Formal—patents Trademark Informal—NDAs
Case D	This device was invented external to the organization—due to this, a strong appropriation strategy is used—from formal (patents) methods to informal (trade secrets, product complexity) methods.	Formal—patents Informal—secrecy/trade secrets Market lead time Product complexity
Case E	The CEO has a strong technology business background coupled with experience in academia. This experience provided deep insights into the importance of IP protection and influenced the strong appropriation strategy deployed—use of formal methods (patents and trademarks).	Formal—patents Trademark
Case F	Significant time and investment have been spent on IP due to the simplicity of the device design. Huge emphasis on IP necessity within the organization utilizing both formal (patents) and informal methods (lead time).	Formal—patents Informal—market lead time
Case G	The CEO values a strong appropriability strategy, due to previous unsuccessful entrepreneurial experiences. Thus, the organization uses both formal (patents and trademark) and informal (trade secrets) methods.	Formal—patents Trademark Informal—secrecy/trade secrets
Case H	The SME engages heavily in OI but before engaging with partners (and potential partners) a blend of formal (patents) and informal (trade secrets; product complexity) appropriation methods are used.	Formal—patents Informal—secrecy/trade secrets Product complexity
Case I	The CEO values a strong appropriability strategy, due to previous entrepreneurial and R&D experiences. The SME engages heavily in OI and use a blend of formal (patents, trademark) and informal (trade secrets; product complexity) appropriation methods are used.	Formal—patents Trademark Informal—secrecy/trade secrets Market lead time Ensure complexity

(Vanegas-Cantarero et al. 2022); thus, to survive in this demanding context, entrepreneurial and OI experience is necessary, with the founders/CEOs required to leverage their invaluable experience.

5 | Discussion and Conclusion

MRE has the potential to exceed global electricity demand while contributing to decarbonization and energy sustainability (Liguo et al. 2022). Yet, despite its clear environmental benefits, the sector faces challenges in gaining market competitiveness in the global energy market. While innovation research identifies knowledge protection and external collaboration as critical to technological progress (Bogers et al. 2017), their interaction in MRE remains underexplored, particularly in relation to leadership influence. This study responds to recent calls (Abdelaty and Weiss 2023) by offering the first empirical examination of appropriation strategies, OI, and founder/CEO influence in the MRE context, drawing on novel primary survey data and qualitative interviews. Specifically, we investigate whether appropriability enables or constrains OI and further ask how the background, education, and experiences of MRE SME leaders influence OI adoption and the appropriation challenge.

The analysis reveals three key lessons for policymakers and practitioners to consider. First, addressing the primary research objective of whether appropriation enables or constrains OI, the quantitative results reveal a positive relationship between the two, suggesting that MRE firms may rely on protection strategies to support external collaboration. This finding

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TABLE 5 | Overview of OI practices and partners by case.

Case	OI practices	OI partners
Case A	Currently leverages academic and knowledge partnerships, which have enabled the organization to work with 47 master's students and 1 PhD student. The organization is keen to develop future partnerships.	1. Institute of technology (Sweden) 2. Government research institute (Sweden) 3. Government energy agency (Sweden) 4. Public research university (Sweden) 5. Engineering school (other European country)
Case B	OI practices strengthened the early stages of this venture. The founder worked with a leader in engineering simulation and leveraged personal and professional connections to form strategy OI partnerships.	1. Industry (Scotland) 2. Engineering company (other European country) 3. Industry (Scotland) 4. Industry (UK company) 5. Investor
Case C	The organization recognizes that strategic OI partnerships are key to commercialization.	1. Industry (France) 2. European research programs 3. Industry—engineering
Case D	Leveraged OI to bring innovative idea to the firm. Strong network of subcontractors (10+). Close relationship with two universities.	1. Public university (same country) 2. Technical university (same country)
Case E	The company leverages universities as crucial innovation partners; however, the CEO is cautious of external partners after vast experience across ruthless business environments.	1. University (same country) 2. Institute of technology (international)
Case F	The company leverages OI to gain additional expertise across industry and academia.	1. University (same country) 2. Local manufacturing company 3. EU- and national-funded programs
Case G	As a university spin-off, the company leverages a close relationship with the university, while also funding PhDs	1. University (same country) 2. Strong European network with large array of partners—built up from 20 years' experience in wave energy
Case H	The company actively engages in OI and is seeking to expand its team and build up its R&D and commercialization partnerships. A university collaboration has enabled the company to develop a prototype and is now engaging with another university to explore alternative designs, increase research capacity, and act as a quality signal to potential investors, which include the development of a PhD program.	1. Asian university 2. European Marine Energy Centre 3. UK's leading technology innovation/research center 4. EU program
Case I	The company follows a deliberate OI strategy, working within a strong National high-tech entrepreneurial ecosystem, which the CEO leverages to secure the "right" partners in seeking solutions.	1. Multinational chemical manufacturing company (Holland) 2. Independent research organization for applied science (Holland) 3. Technical university (Holland) 4. Marine energy center (Holland)

is complemented by the qualitative interviews revealing that while CEOs acknowledge the importance of OI, they strongly prioritize intellectual property protection in the first instance.

This study provides new insight into the conditions under which appropriation can support, rather than hinder, OI in the MRE sector. While formal protection tools such as patents and NDAs remain important, our qualitative findings suggest that their effectiveness is often reinforced by informal mechanisms, particularly trust. Qualitative insights from founders/CEOs (Cases C, D, and E) show that they navigate the tension between knowledge protection and collaboration by drawing on both informal trust built through long-term relationships and formal tools such as NDAs. This interplay, also noted in related literature (see Huang et al. 2014), takes on particular importance in MRE, where the complexity of technological development requires close and sustained cooperation. In this context, trust operates not only as a social factor but also as a practical foundational condition for openness. This aligns with previous research (Andersson et al. 2017; Wyrwich et al. 2022) while also extending the discussion by identifying trust as a key mechanism linking appropriation to collaboration. To enhance trust for greater sector openness, options for governments include adopting a systems approach, such as sector, regional, and national innovation systems (Chung 2002) or an ecosystem perspective (Radziwon and Bogers 2019). Such system approaches can act as a framework

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TABLE 6 | SME founder/CEO background.

Case	Founder/CEO background	Prior MRE experience	Education
Case A	The founder/CEO worked for over 20 years as an airline pilot while also completing an MBA. Following his airline career, he undertook a career in industry, gaining exposure to various entrepreneurial and IP challenges. Following a successful real estate deal, he invested his time and capital in developing an innovative WEC device.	No	Management (MBA, economics)
Case B	The founder/CEO is an award-winning inventor and entrepreneur. With 20 years' experience as a CEO and COO of several successful entrepreneurial ventures. With an engineering background from the oil/gas and renewables sectors, this has helped create many meaningful connections, to kick-start the company's foundation and radical innovation.	Yes	Engineering (BEng, marine engineering)
Case C	The cofounder has valuable experience working as an R&D manager in the renewables sector. The failure experienced after 12 years of operations influences the organization's current decisions on business models and device strategies, coupled with the PhD and a postgraduate MRE degree.	Yes	Engineering (PhD, fluid mechanics and energetics)
Case D	The founder/CEO is an experienced entrepreneur having started his first company straight from college whereby he experienced the challenges of breaking into an existing market. Subsequently, he spent 7 years with a wave energy company where he experienced further challenges. Learning to focus more on the commercial realities of the sector. This extensive entrepreneurial experience has "been essential" in developing the companies technology and identifying its commercially minded business model.	Yes	Engineering (MSc mechanical engineering)
Case E	The founder started his career in environmental engineering and management consulting in the natural sciences. His entrepreneurial journey began by becoming cofounder/senior VP of strategic development of a national TV station, later becoming CEO of a national enterprise agency. With more than 20 years of international professional experience across a broad spectrum of business fields, he became a senior lecturer in Tech Innovation & Entrepreneurship at an international university and a researcher at a dedicated energy research lab.	Yes	Engineering (MSc electrical and computer engineering with major in energy)
Case F	The CEO/founder has over 30 years' entrepreneurial experience including project management in construction and building services. For many years, he researched a viable tidal energy solution and today works with an extensive and skilled team in building out the device. The CEO currently serves as a board member for a large government research center (marine/renewables) on the Governance and Industry Advisory Board. This strong background has helped attract the right partners, unlock funding, and manage collaboration.	No	Management

(Continues)

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TABLE 6 | (Continued)

Case	Founder/CEO background	Prior MRE experience	Education
Case G	With over 20 years' experience in wave energy, the founder/CEO is a physicist and assistant professor of engineering and possesses a strong business and maritime background. In 1999, he founded one of the first companies to develop a large scale WEC. This experience has helped to recognize some of the company and device failures, which guides this companies' unique business model, strategy, and WEC technology. The company leverages university support, a vast industry network, focuses on device simplicity, scalability and commercial viability, and values secrecy and IP protection.	Yes	Science (physicist)
Case H	The cofounder/chairman has invented a portfolio of technology innovations, is a successful entrepreneur, and is a former director of a public listed company. Thus far, the company has been financed by the founding team.	No	Management PhD economics
Case I	The cofounder/CEO has extensive entrepreneurial experience. After a stint as R&D manager at a multinational conglomerate (4000 researchers), he started an entrepreneurial venture in 2002 and then became cofounder/CEO of another venture in 2007, which specialized in PV installations. Subsequently, he became CTO of a stock-listed company, where he built relationships with the strategic partners.	No	Engineering (PhD engineering and physics)

for fostering trust through cooperation, networking, interorganizational learning, and knowledge transfer (Chung 2002; Radziwon and Bogers 2019; Asheim et al. 2011).

From a practitioner perspective, applying a systems approach takes time and is often dependent on historical regional settings and processes (Bischoff et al. 2023), thus placing it beyond the control of an individual actor or firm. Other options available to policymakers and practitioners to build trust between actors, in conjunction with or without a systems approach, include the employment of innovation intermediaries such as boundary spanners, gatekeepers, and knowledge brokers to support successful partnerships. Such intermediaries can help bridge industry stakeholders, overcome barriers and knowledge bottlenecks, and enhance collaboration and knowledge absorption (Lepore 2023).

Second, in exploring how the background, education, and experiences of MRE SME leaders influence OI and the appropriation challenge, the quantitative analysis highlights the CEO's educational level as a key factor shaping openness. This may be attributed to the increased confidence in confronting the complexities associated with collaboration that is derived from higher education (Esteve et al. 2013). Furthermore, higher levels of education can contribute to the increased absorptive capacity of the SME leader—both in terms of their awareness levels of the latest developments within their own domain and, importantly, within complementary domains (Esteve et al. 2013; Custódio et al. 2019), all of which is highly relevant within the complex MRE context. From the qualitative data gathered, most founders/CEOs have a high level of education, including to PhD level. Although their education and disciplinary backgrounds may have influenced their initial entry into this highly niche sector, the extent to which these factors shape their OI strategies remains unclear. This suggests that these factors provide minimal direct support compared to the predominant influence of their passion and practical entrepreneurial experience due to their generalist skillset and breadth of knowledge developed (Custódio et al. 2019). As mentioned previously, MRE SME leaders with generalist human capital skills promote more innovation and thus influence the firms they lead to pursue risky innovation opportunities (ibid). As policymakers and investors are willing to provide innovation support for renewable energy devices (MacGillivray et al. 2014; Muscio et al. 2023), similar attention toward training programs that prioritize generalist entrepreneurial experience and management skills through targeted higher education and short training courses could significantly enhance OI outcomes.

Third, it is evident from the qualitative data that founders/CEOs recognize the importance of OI, although they are still cautious in their approach and place a strong emphasis on investing in appropriation strategies. This finding has many practical implications for MRE SMEs. For example, SMEs could develop a collaboration culture, i.e., an openness and willingness to collaborate externally and to take risks, and in doing so, create partner selection strategies to ensure SMEs find the "right" partner (Barrett and Tsekouras 2022) while also exploring both formal and informal ties (Zhu et al. 2017). SMEs should also tailor their recruitment and training strategies to emphasize the importance of collaboration and the underlying capabilities required for OI adoption.

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There are future research opportunities to analyze the interplay between UET and the appropriation–OI nexus over a longer time period in the MRE sector, potentially linking the importance of leadership psychology with organizational innovation capacity. Further iterations of this survey would enable such an analysis. Further, these results reflect a specific sectoral and radical technological context, raising the question of whether similar patterns would emerge in other highly uncertain and emergent industries. Future research could explore whether, in such settings, robust appropriation strategies enable rather than constrain openness by giving firms greater confidence to engage externally. It would also be valuable to examine how different appropriation mechanisms (e.g., patents versus secrecy) influence the appropriation–OI relationship in radical innovation contexts.

Finally, this research is not without its limitations. While the sample size is appropriate for the exploratory scope of this study, we acknowledge that a larger dataset could support more advanced modeling, including the use of interaction effects to explore complex relationships in greater depth. Importantly, the qualitative data provided valuable insight into factors that go beyond formal indicators, revealing how entrepreneurial experience, personal values, risk tolerance, and environmental commitment influence strategic decisions. These insights highlight the strength of the mixed-methods approach in capturing the nuanced mechanisms that shape the relationship between appropriation and openness in the MRE sector.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

We confirm that this work is original and has not been published elsewhere, nor is it currently under review for publication elsewhere.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Appendix S1:** Supporting Information.

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