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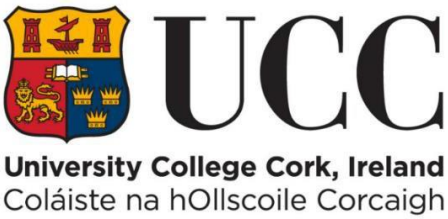

Interactive Linkages, Non-Interactive Linkages, and Innovative Activity in the Offshore Renewable Energy Sector

Thesis presented by

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Abstract

This research utilises novel firm-level data from a purpose-built survey to examine the relationship between interactive and non-interactive linkages and innovative activity. This thesis provides the rationale for the research, noting it's contributions to the existing literature. The unique dataset used for this research and the quantitative methods employed are then discussed. This thesis then provides the full MSc research paper. This research suggests that more interactive linkages are positively related to more innovative activity, albeit this relationship is subject to diminishing returns. In contrast, a significant relationship is absent for increased levels of non-interactive linkages and innovative activity. This study then disaggregates both firm-level innovation and external linkages which provides novel insights into the relationship between these variables. This research finds that collaborating with suppliers, consultants, and accessing scientific journals are conducive for R&D activity and process innovation. Collaborating with customers is associated with the decision to introduce new products and processes. The disaggregation of the external linkages and firm-level innovation allows for the development of managerial and policy implications. This thesis concludes with a further discussion around the key findings and policy implications.

Table of Contents

Abstract **2**
1. Introduction **4**
1.1 Rationale for the research 4
1.2 Contributions to the literature 6
2. Data and Method **7**
2.1 The Renewable Energy Innovation Survey (REIS) 7
2.2 Empirical Method 9
3. MSc Research Paper **10**
3.1 Introduction 12
3.2 Literature Review 16
3.3 Data 23
3.4 Methodology 32
3.5 Results 34
3.6 Conclusion 43
3.7 References 47
4. Discussion **66**
4.1 Discussion of the hypothesis 66
4.2 Other general findings of the research 68
5. Conclusion **69**
5.1 Contribution of the paper 69
5.2 Implications 70
5.3 Limitations and avenues for future research 71
6. Appendix **73**
7. References (excluding the MSc research paper) **152**

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

1. Introduction

1.1 Rationale for the research

The sustainable development of offshore renewable energy (ORE) technologies is central in the European Commission's (2020; 2011) energy policy. The European Wind Energy Association (2011) estimates that 14% of Europe's electricity demand would be supplied by offshore wind energy technologies by 2050. By 2030, the European Commission (2014) estimates that ocean energy can contribute to over €5.8bn in Gross Value Added. In meeting the EU's development targets, the sustainable development of ORE technologies can reduce carbon emissions, increase energy security, contribute to policy objectives, and provide affordable energy to consumers (Roesch *et al.*, 2020). In order to meet the almost carbon-free EU energy targets, innovation in the ORE sector plays a key role in the development and deployment of large-scale ORE technologies to meet the 2050 targets (Jacobsson and Karltorp, 2013).

EU-based companies are global leaders in developing ORE technologies, as the European Commission (2020) reports that 44% of patents in wave energy, and 66% of patents in tidal energy are held by EU-based companies. The future potential of the ORE sector has attracted large power companies and investment (Jay and Jeffrey, 2010). The UK and Ireland have a favourable climate and location for the development of ORE technologies, and financial instruments such as feed in tariffs make the UK and Ireland attractive locations for investment (Leete, Xu and Wheeler, 2013; Bürer and Wüstenhagen, 2009). The UK and Ireland are noted to have a wide range of renewable resources, related skills, research institutes and a high level of policy commitment which supports new technologies (Leete, Xu and Wheeler, 2013). It's important to note that while Ireland is a member of the EU, the UK are not. In 2016, the UK government accepted the mandate of the Brexit referendum and have since withdrawn from the EU (Glencross, 2021; Thissen *et al.*, 2020).

The sea area around the island of Ireland is 900,000 square kilometres which is ten times the landmass of Ireland (SEAI, 2010). For the afore mentioned reason, Ireland has notable wave energy resource due to its favourable climate and position at the Atlantic edge of the EU, which is suitable for the development of a range of ORE technologies (Rourke, Boyle, and Reynolds, 2009). Carbon Trust (2011) estimates that the global wave and tidal energy market could be worth in excess of €535 billion by 2050.

Wales are working hard (over £123 million spent on the development of ORE technologies to date) to establish an early mover advantage and position themselves at the forefront of an export market which is estimated to be valued at £76 billion by the year 2050 (MEW, 2020). The unstandardized nature of products, the number of recent policy initiatives and revisions to existing policy initiatives show high levels of learning, experimentation, investment, and product innovation in the ORE sector (Jeffrey, Jay and Winskel, 2013; Richter, 2013).

The consensus in the literature is that open innovation and external interaction are key drivers of innovation (Chesbrough, 2017; 2006; 2003; Laursen and Salter, 2006). External interaction has been shown to play an important role in firms' decision to innovate (Xie *et al.*, 2020; Rodriguez, Doloreux and Shearmur, 2017; Doran, Jordan and O'Leary, 2012) and scholars have shown that firms are becoming more open to external interaction and collaborations with actors outside their organisation for innovations (Flor, Cooper and Oltra, 2018; Laursen and Salter, 2014; Dahlander and Gann, 2010). Searching for commercially exploitable knowledge and technologies from outside the organisation increases creative thinking and stimulates knowledge recombination for innovative activity (Bogers *et al.*, 2017; Leiponen, 2012).

Open innovation and external interaction avoids the cognitive "lock-in" of the sector (Topper and Ingram, 2011; Baumol, 2002). Avoiding cognitive lock-in is of utmost importance for the

ORE sector as ORE innovation involves several interdependencies across a highly complex and diversified knowledge domain (Medina-Lopez *et al.*, 2021; Garrone, Piscitello and Wang, 2014). External knowledge searching and cross-border cooperation is at the forefront of EU ORE sustainable development policies (EuropeanCommission, 2014).

The thesis proceeds to examine the relationship between interactive and non-interactive linkages and innovative activity. The novelty of this study and the contributions of the research to the existing literature are discussed in the immediate paragraph. In section 2, this thesis will discuss the unique purpose-built survey used and the empirical methods employed. The full MSc research paper is then presented in section 3. Section 4 provides a further discussion around the key findings of the MSc research paper. This thesis concludes with a discussion around the policy implications of the results.

1.2 Contributions to the literature

This paper is concerned with five different types of innovative activity (internal R&D, external R&D, new-to-market innovation, new-to-firm innovation, and process innovation). Existing literature often tests the effects of external linkages on innovation performance as a whole, and often fails to distinguish between product and process innovation (Ebersberger *et al.*, 2012; Duarte and Sarkar, 2011; Kutvonen, 2011; Lichtenthaler, 2009). Focusing on five different types of innovative activity rather than the aggregate innovation performance allows for more granular results regarding the effects of specific linkages on a specific innovation activity.

Previous studies have found more external linkages lead to more innovation activities (Criscuolo *et al.*, 2018; Xia and Roper, 2016; Leiponen and Helfat, 2010; Jordan and O'leary, 2008), however, there is a dearth of empirical evidence for the ORE sector. This paper tests whether more interactive and non-interactive linkages lead to more innovation activity and provides empirical evidence of these relationships for the ORE sector. A number of studies have shown

that external knowledge linkages have been subject to diminishing returns to innovative activity (Radicic, 2020; Lacerda and van den Bergh, 2020; Cruz-González *et al.*, 2015; Ferreras-Méndez *et al.*, 2015). This paper contributes to the literature by testing whether interactive and non-interactive linkages are non-linearly related to innovative activity for the ORE sector. While previous studies such as Roper *et al.* (2017) have examined the relationship between interactive and non-interactive knowledge search strategies and innovative activities, this is the first study that has examined this relationship for the ORE sector, which also represents a sector at the very early stages of the product life cycle.

This paper further contributes to the literature by disaggregating the interactive linkages and non-interactive linkages to individual level indicators. The inclusion of each individual level interactive linkage (with customers, suppliers, competitors, and knowledge institutions) and non-interactive linkage (conferences, scientific journals, industry associations, other data sources) answers the call of previous scholars (Ardito and Petruzzelli, 2017), who suggest more work should be undertaken in examining the significance of each individual search channel in stimulating innovation activity. Disaggregating interactive and non-interactive linkages to individual level indicators allows us to examine the extent to which a firm's innovation activity is facilitated or hindered by the inclusion of each individual interactive or non-interactive linkage in their knowledge acquisition strategy.

2. Data and Method

2.1 The Renewable Energy Innovation Survey (REIS)

The Renewable Energy Innovation Survey (REIS) is a unique business, enterprise, and environmental survey which is similar in form and in content to the Community Innovation Survey (CIS) or World Bank Enterprise Surveys. The REIS was purpose-built for this research and was available to complete online via Google Forms (https://uccireland-

my.sharepoint.com/:b:/g/personal/117425654_umail_ucc_ie/EQcpECzlgihJqsG002ItuCIBu65u1E2l6ARIdQyCYh2-Ow?e=7B50mP, alternatively please see page 85 of this document).

Publicly available sources were employed to obtain information about the companies which were included in the sampling frame. In total, the sample frame consisted of 1,342 firms who were operating in the ORE sector or its potential supply chain. The REIS was conducted in early 2021 and specifically targeted EU and UK based firms who were operating in the ORE sector or its potential supply chain. Please consult Table A9 in the appendix for a list of the data sources used to compile the sampling frame.

The purpose of the questionnaire was to acquire a better understanding of the innovation activities, knowledge sourcing activities, resources, networks, and performance of firms operating in the ORE sector and its potential supply chain for a three-year period from 2017 to 2019. Data for 2020 activities was not collected due to any potential bias which may arise due to the ongoing global pandemic. The REIS included industry specific questions which were not included in the CIS or World Bank Enterprise Survey which made the data obtained from the REIS truly unique. Organisations were asked their relation to the ORE sector, the type of ORE sector they are involved in (offshore wind, wave energy, solar energy, tidal energy etc.), how long they have been operating in the ORE sector, in addition to qualitative questions which asked for the organisations opinion on the future of the sector and the capabilities needed to operate in the ORE sector. The inclusion of industry specific questions provided the research team with a great level of detail and a novel insight to the ORE sector.

The rationale for using the purpose-built survey for the research was due to the small sample size and misrepresentation of the ORE sector in the more well-known innovation questionnaires (e.g., World Bank Business Enterprise Survey, CIS, IIP, UKIS). Using Ireland as an example, the CIS is a representative sample of roughly 4,600 firms. However, the reality is that the ORE sector

makes up a very small component (due to its size) of this sample for researchers to obtain reliable and representative business and policy advice on the economic activities of these firms.

The specific ORE sample and specific ORE questions included in the REIS provided the research team with a more accurate and representative insight into the innovation activities and knowledge search strategies of those involved in the ORE sector and its supply chain. The findings from the purpose-built survey provides a unique insight into the innovative activities and networking capabilities of the ORE sector, which can more accurately inform policy while identifying future directions to advance ORE capacity. The REIS had obtained ethical approval from the UCC Social Research Ethics Committee prior to contacting any organisation in the sample frame.

2.2 Empirical Method

An innovation production function is used in the research paper and shows the probability of the firm engaging in innovation activity and is regressed against a number of explanatory variables. The innovation production function is commonly used in the literature (Audretsch and Belitski, 2020; Crowley, 2017). To test for possible quadratic effect (i.e., diminishing returns) the squared terms of interactive and non-interactive linkages are included as is consistent in the literature (Love, Roper and Vahter, 2014; Radicic, 2020).

The unique data which was obtained from the REIS was transferred from Google Forms to Microsoft Excel which was then transferred to the Stata statistical analysis computer package. The data was then transformed, and variables were created using Stata. The creation of the variables from the raw data allows for the hypotheses of the research paper to be tested. The hypotheses were estimated using a series of regression models. A more detailed discussion of the models is on Section 3.4 of this thesis.

3. MSc Research Paper

The full MSc Research Paper which I completed during the years 2020 to 2021 commences on the next page. This paper was sent to the Technovation research journal for review. I also had the opportunity to present my work at various stages of the research during the academic year. I had presented my work to members of the Selkie board (funders of this research, please see page 73 of this thesis for more information) at different stages of the research journey. I had presented my work to students, academics, and members of the Spatial and Regional Economics Research Centre (SRERC) in UCC. I received great feedback every time I presented my work, which ultimately improved the content of the final paper.

3. Interactive Linkages, Non-Interactive Linkages, and Innovative Activity in the Offshore Renewable Energy Sector

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Abstract: Previous firm level studies have provided evidence of a positive relationship between external knowledge linkages (interactive and non-interactive) and innovative activity. However, empirical evidence for the offshore renewable energy sector remains scarce. Using novel firm level data from a purpose-built survey, this paper examines the effect external linkages has on innovative activity. We find that more interactive linkages are positively related to more innovative activity. However, this relationship is subject to diminishing returns. In contrast, a significant relationship is absent for increased levels of non-interactive linkages and innovative activity. When the type of linkages is disaggregated to individual indicators, collaborating with suppliers, consultants, and accessing scientific journals are conducive for R&D activity and process innovation. Collaborating with customers is associated with the decision to introduce new products and processes. This paper suggests policymakers support backward linkages to suppliers and consultants by providing tax incentives for external R&D collaborations.

3.1 Introduction

The sustainable development of offshore renewable energy (ORE hereafter) technologies is at the forefront of the European Commission's energy policy (2020; 2014). In order to meet the ambitious 2050 EU energy targets, innovation in the ORE sector plays a key role in the development and deployment of large-scale ORE technologies which reduce carbon emissions, increase energy security, contribute to policy objectives, and provide affordable energy to consumers (Jacobsson and Karltorp, 2013). In recent years, the potential of the ORE sector has attracted large power companies and investment in the ORE sector has significantly increased (Roesch *et al.,* 2020; Jay and Jeffrey, 2010). The unstandardised nature of products, the number of recent policy initiatives and revisions to existing policy initiatives show high levels of learning, experimentation, investment, and product innovation in the ORE sector (Jeffrey, Jay and Winskel, 2013; Richter, 2013).

There has been a burgeoning theoretical and empirical focus on the innovative activities of firms in the economic and management literature since the pioneering work of Schumpeter (1934; 1942). The general consensus in the literature is that innovation is regarded as one of the key drivers for firm success (Jiménez-Jiménez and Sanz-Valle, 2011; Bell, 2005), survival (Crowley and McCann, 2018; Nickell, 1996; Porter, 1990) and competitiveness in a market economy (Aghion *et al.,* 2005). Innovation is key to the health of economies in which firms operate; indeed, Kline and Rosenberg (1986) assert that it is *"absolutely central to economic growth"* (Kline and Rosenberg, 1986, p. 279).

Firms' innovation strategies often involve searching for commercially exploitable technologies or knowledge from outside their organisation (Laursen and Salter, 2014; Dahlander and Gann, 2010; Nelson and Winter, 1982). More recently, scholars have placed increasing importance on open innovation strategies, emphasising how knowledge, resources, and individuals flow in and out of firms (Chesbrough, Heaton and Mei, 2021; Enkel, Bogers and Chesbrough, 2020;

Bogers *et al.*, 2019; 2017). External collaboration has been shown to contribute to R&D performance (Asakawa, Nakamura and Sawada, 2010) and plays a key role in the introduction of new and improved products (Köhler, Sofka and Grimpe, 2012) and processes (Inauen and Schenker-Wicki, 2011). Open innovation is of particular importance for the sustainable development of the ORE sector as ORE innovation involves several interdependencies across a highly complex and diversified knowledge domain (Medina-Lopez *et al.*, 2021).

Sources of external collaboration can be described as interactive linkages or non-interactive linkages (Zahran *et al.*, 2020; Roper and Love, 2018; Hewitt-Dundas and Roper, 2011). Interactive linkages (or *exploratory* relationships) occur when firms strategically build relationships and work with other external actors to jointly develop knowledge (Borgatti and Halgin, 2011). In alignment with the categorisation of pivotal external knowledge linkages provided by Wang *et al.* (2020) and Ganotakis and Love (2012), this paper recognises forward linkages to include customers, backward linkages to suppliers and consultants, horizontal linkages to competitors, and public linkages to research institutes as interactive linkages.

Non-interactive linkages (or *exploitative* relationships) occur when there is the absence of reciprocal knowledge transfer between parties (Glückler, 2013). In alignment with the classification of non-interactive firm linkages provided by Roper *et al.* (2017), attendance at conferences, trade fairs, or exhibitions, reading scientific journals, trade, or technical publications, involvement with industry or trade associations, and any other data source are collectively known as non-interactive linkages.

An extensive external knowledge search strategy increases creative thinking and stimulates knowledge recombination (Leiponen, 2012), which facilitates innovative activity (Laursen and Salter, 2006). Prior research has suggested that the ability of firms to effectively exploit external knowledge is determined by the heterogeneity of the firms' knowledge base and the skill set of

the workforce (Van der Vegt and Janssen, 2003). This means that searching for effective interactive and non-interactive linkages depends on the capabilities of the individual organisation (Lacerda and van den Bergh, 2020).

Though more external linkages leads to more innovative activity (Roper, Love and Bonner, 2017; Leiponen and Helfat, 2010), previous literature suggests the benefits of interactive and non-interactive linkages are not directly proportional to the number of linkages the firm engages with (Ghisetti, Marzucchi and Montresor, 2015; Laursen and Salter, 2006). A curvilinear relationship between external linkages (interactive or non-interactive) and innovative activity has been found in the literature (Radicic, 2020; Cruz-González *et al.*, 2015). Benefitting from external knowledge sources is difficult for firms and can be impacted by factors such as the R&D intensity of the firm, the cognitive limitations of management, and the capabilities of the firm to assimilate and exploit external knowledge i.e., its absorptive capacity (Lööf and Johansson, 2014; Makri, Hitt and Lane, 2010; Cohen and Levinthal, 1990).

Previous studies have shown that renewable energy technologies at least, partly emerge from ORE firms being more open to external knowledge sources (Popp, 2017). Innovations in the ORE sector typically involve a combination of diversified and complex knowledge (Garrone, Piscitello and Wang, 2014). Wieczorek *et al.* (2013) discuss the benefits of collaboration in the ORE sector, noting how the success of innovations in the offshore wind industry is heavily dependent on the interconnectedness of the actors in the industry. Topper and Ingram (2011) call for organisations to be more open and highlight the risk of "in-house development" for wave energy organisations, in which unsuitable technologies are being applied to problems regardless of their appropriateness to the problem.

Existing literature which examines external linkages and innovation activities looks at the innovation performance of the firm in general, often not distinguishing between product and

process innovation (Kobarg, Stumpf-Wollersheim and Welpe, 2019; Duarte and Sarkar, 2011; Kutvonen, 2011; Lichtenthaler, 2009). Scholars such as Terjesen and Patel (2017, p. 1422) note that *"there is limited understanding of how firms devise knowledge search strategies to develop process innovation".* This paper contributes to the innovation and management literature by examining the effects of external linkages for five different types of innovative activity (i.e., internal R&D, external R&D, new-to-market innovation, new-to-firm innovation, process innovation).

This paper contributes to the literature by testing for the presence of a curvilinear relationship between external linkages and innovative activity in the ORE sector and aims to provide further clarity on whether the inverted U-shape relationship previously identified in the literature (Ferreras-Méndez *et al.*, 2015; Leiponen, 2012; Garriga, Von Krogh and Spaeth, 2013) is also situated in the ORE sector. While previous studies such as Roper *et al.* (2017) have examined the relationship between interactive and non-interactive knowledge search strategies and innovative activities, this is the first study that has examined this relationship for the ORE sector.

This paper further contributes to the literature by disaggregating interactive and non-interactive linkages to individual indicators and examines the extent to which a firm's innovation activity is facilitated or hindered by the inclusion of each individual interactive or non-interactive linkage in their knowledge acquisition strategy. Studies such as Laursen and Salter (2014), Love *et al.* (2014), and Garriga *et al.* (2013) examine the effects of external search breadth as a whole rather than the effects each individual type of linkage has on innovative activity. The inclusion of each individual level interactive linkage (forward, backward, horizontal, public) and non-interactive linkage (conferences, scientific journals, industry associations, other data sources) answers the call of Ardito and Petruzzelli (2017) who suggest more work should be undertaken in examining the "*relative significance of each search channel"* in stimulating innovation (Ardito and Petruzzelli, 2017, p. 270).

Drawing on previous open innovation literature and contributions, this paper develops hypotheses and tests them based on original data gathered through a purpose-built survey. The unique survey was targeted specifically at EU and UK firms operating in the ORE sector and its supply chain and provides novel insights into the innovative activities and networking capabilities of the ORE sector, which can more accurately inform policy while identifying future directions to advance ORE capacity. A series of regression models are used to estimate the relationship between external linkages and innovative activity.

This paper proceeds with reviewing previous literature regarding interactive linkages, non-interactive linkages, and innovative activity. Section 3.2 also develops the hypotheses which will be tested. Section 3.3 discusses the novel data set used, while section 3.4 looks at the empirical methods employed. Section 3.5 considers the key empirical results. The paper concludes with a discussion around the findings of the estimations.

3.2 Literature Review

3.2.1 External linkages and innovative activity

Firms employ interactive knowledge acquisition strategies to source external knowledge from outside the firm to improve their competitive advantage (Chesbrough, 2017; Ferreras-Méndez *et al.*, 2015; Leiponen and Helfat, 2010; Dosi, 1988) and to uncover *new* knowledge, technologies, and opportunities (Xia and Roper, 2016; March, 1991). They are deliberate and purposive connections with the intent to develop collaborations that provide a platform that generates radical new-to-the-world commercial knowledge (Roper *et al.*, 2016). Interactive linkages are characterised by the strategic intent of both parties, the reciprocal knowledge transfer among parties, and the interactive learning of all involved (Glückler, 2013).

In contrast, non-interactive knowledge search strategies are employed by firms who wish to exploit *existing* knowledge, technologies, and opportunities (He and Wong, 2004; Zerjav, Edkins and Davies, 2018). Non-interactive linkages or exploitative relationships are the deliberate

acquisition of knowledge without the direct participation of the other party (Roper, Love and Bonner, 2017). Non-interactive learning occurs when there is the absence of reciprocal knowledge transfer between parties where organisations exploit knowledge previously implemented by others (Glückler, 2013). While interactive linkages may generate radical innovations (Mention, 2011; Nieto and Santamaría, 2007), firms who engage in non- interactive linkages as part of their knowledge acquisition strategy may forego first mover advantages (Roper and Love, 2018).

Firms sourcing interactive linkages (i.e., consultants, suppliers, customers, competitors, and universities) require considerable time and effort to build meaningful working relationships and understanding (Criscuolo *et al.*, 2018). Absorptive capacity, as defined by Cohen and Levinthal (1990) is viewed as the firm's ability to assimilate, absorb, and exploit external knowledge, which influences the innovation performance of the firm (Radicic *et al.*, 2019; Arranz and de Arroyabe, 2008). Conversely, non-interactive linkages or exploitative relationships are often more cost effective and feasible knowledge sourcing alternatives to interactive linkages or exploratory relationships (Ordanini, Rubera and DeFillippi, 2008; Yang and Hyland, 2006). Firms interested in non-interactive linkages benefit by letting other firms absorb the uncertainty and costs of exploring and experimenting with novel knowledge and technologies first (Lavie, Stettner and Tushman, 2010). Previous studies suggest this type of exploitative learning strategy can result in sustainable competitive advantage, an increased internal knowledge base, and improved innovative performances for firms that undertake such second mover actions (Ali, 2021; Onufrey and Bergek, 2020; Lee and Tang, 2018; Doha *et al.*, 2018).

Previous literature suggests the more interactive or non-interactive linkages the firm has, the more likely they are to receive useful knowledge for the introduction of innovations (Ritala *et al.*, 2015; Love, Roper and Vahter, 2014; Leiponen and Helfat, 2010; Jordan and O'leary, 2008). Searching for external linkages directly affects the firm's knowledge base and indirectly increases

the likelihood of complementarities from internal and external knowledge combinations producing successful innovations (Garriga, Von Krogh and Spaeth, 2013; Wu, Lin and Chen, 2013; Voudouris *et al.*, 2012; Cassiman and Veugelers, 2006). Access to interactive and non-interactive linkages allow firms to avoid cognitive myopia, particularly in contexts where incentives for learning new technologies and competencies are lower (Levinthal and March, 1993). Having more external linkages also reduces the potential for cognitive lock-in, ensuring firms are more open to technologies from outside their region which, in turn, increases their ability to keep up with the market (Boschma, 2005).

Considering the above arguments, the following hypotheses are proposed:

Hypothesis 1a: Interactive linkages have a positive relationship with innovative activity.

Hypothesis 1b: Non-Interactive linkages have a positive relationship with innovative activity.

3.2.2 Diminishing returns to innovative activity from external linkages

Even though more interactive and non-interactive linkages increase the probability of acquiring useful external knowledge for innovations (Baldwin and Clark, 2006), the step changes between more interactions and innovation is unlikely to be smooth nor linear (Love, Roper and Vahter, 2014). Leiponen and Helfat (2010) note the uncertain nature of the innovation process, meaning the anticipated returns from innovation are unpredictable and variable. Laursen (2012) argues how firms often do not have the ability to recognise and identify the most relevant knowledge sources, and as a result face a risk of over-searching (Koput, 1997; Laursen and Salter, 2006). Firms benefit from interactive and non-interactive search strategies up to the point in where their absorptive capacity is exhausted (Chen, Chen and Vanhaverbeke, 2011). Absorptive capacity plays a key role in the effectiveness of firms' external knowledge acquisition strategy (Ferreras-Méndez, Fernandez-Mesa and Alegre, 2016; Zahra and George, 2002; Nelson and Winter, 1982).

Firms may reach a point where their absorptive capacity is exhausted and the marginal benefits of innovative activities diminish as the number of interactive or non-interactive connections increase (Duysters and Lokshin, 2011; Prahalad and Bettis, 1986).

Consequently, the number of external knowledge linkages and the innovation performance of the firm have been argued to follow an inverted U-shaped (Marullo *et al.*, 2021; Garriga, Von Krogh and Spaeth, 2013; Leiponen and Helfat, 2010). This inverted U-shaped relationship has been previously referred to as the *"paradox of openness"* (Triguero and Fernández, 2018, p. 636). As management have limited cognitive capacity (Simon, 2013), firms reach a point where additional external linkages hinders the returns to their innovation performance, which contributes to the inverted U-shape found in the literature (Radicic, 2020; Cruz-González *et al.*, 2015; Ghisetti, Marzucchi and Montresor, 2015; Laursen and Salter, 2006).

Another cause of diminishing returns from external linkages refers to the attention allocation problem (Ocasio, 1997). Firms may have difficulty exploring new knowledge once they exceed the number of external linkages that they can effectively dedicate time and resources to (Radicic, 2020; Ferreras-Méndez *et al.*, 2015). Ardito and Petruzzelli (2017) give an alternative cause of diminishing returns from linkages, noting how firms may not be able to fully exploit an innovative idea as it simply came at the wrong time. The more linkages a firm has the higher the probability of new ideas emerging at the wrong time and when other R&D investments have already commenced. Koput (1997) describes how the variety of external knowledge sources and perspectives make it difficult for firms to be able to select the right time to exploit innovative ideas. Roper *et al.* (2017) found decreasing returns occur at a lower turning point for non-interactive linkages compared to the number of interactive linkages employed in the firm's knowledge search strategy.

Following this review of the literature, the following hypotheses are outlined:

Hypothesis 2a: Interactive linkages have a positive relationship with innovative activity, but at a diminishing rate.

Hypothesis 2b: Non-Interactive linkages have a positive relationship with innovative activity, but at a diminishing rate.

3.2.3 Individual level linkages and innovation activities

Each of the separate interactive search channels allows the innovating firm to access diverse knowledge from various actors, and allows the firm to tap into relevant markets, knowledge and technologies which contributes differently to the firms' differing types of innovative activity (Ardito *et al.*, 2020; Leiponen, 2005). The types of knowledge needed from any given interactive linkage depends on the type of innovation activity and the development stage of the innovation (Flor, Cooper and Oltra, 2018; Arvanitis *et al.*, 2015; Cassiman and Veugelers, 2006). He and Wong (2012) suggest firms should engage in interactive linkages based on the potential for complementary effects and the learning potential from the relationship.

Forward linkages to customers have been shown to be positively related to product innovation, with customers being an important source of information for the commercialisation of new products (Rodriguez, Doloreux and Shearmur, 2017; Su *et al.*, 2013; Arranz and de Arroyabe, 2008). Lead (or potential) customers have been shown to provide critical knowledge regarding product innovations, therefore reducing the risk associated with the introduction of a new product to the market (Chen, Chen and Vanhaverbeke, 2011; Tödtling, Lehner and Kaufmann, 2009; Su, Chen and Sha, 2007). Previous scholars suggest lead customers are crucial in the development of novel or complex new products due to the reduced likelihood of poor product design in the early stages of development (Grimpe and Kaiser, 2010; Brockhoff, 2003).

Backward linkages to suppliers or consultants have been previously shown to be conducive to process innovation, due to the increased focus on cost reduction (Roper, Du and Love, 2008; Horn, 2005). Engaging with suppliers and consultants provide access to external knowledge which complements the R&D performance of the firm (Mishra, Chandrasekaran and MacCormack, 2015; Cassiman and Veugelers, 2006). Horizontal linkages to competitors are important for firms as collaborating with competitors provides access to similar resources (which reduces costs) and complementary technical knowledge (Radicic *et al.*, 2019; Tsai, Su and Chen, 2011). More recent studies have noted the importance of backward linkages and horizontal linkages for innovative activity in the form of process innovation and firm competitiveness (Li, Gagliardi and Miles, 2019; Grandinetti, 2018).

Public linkages to universities and research institutes have been previously shown to improve firm-level absorptive capacity, which is positively related to R&D activity (Fabrizio, 2006; Cockburn and Henderson, 1998). Boehm and Hogan (2013) reports that more public linkages to research institutes by firms are associated with more exploitation of published scientific research, which complements the firm's internal knowledge base for innovations (Belderbos, Carree and Lokshin, 2004; Caloghirou, Kastelli and Tsakanikas, 2004). Radicic (2020) found that the development of process innovations at firm level benefits the most from a wider variety of interactive linkages, such as collaborations with suppliers and research institutes. This is argued to be of particular importance for the ORE sector as ORE innovation is complex and is reliant on a broad range of knowledge sources (Garrone, Piscitello and Wang, 2014). Collaboration with public research institutes provides access to complementary knowledge which enhances the R&D performance of the firm (Asakawa, Nakamura and Sawada, 2010; Murovec and Prodan, 2009).

Exploitative learning in the form of non-interactive linkages have been shown to be positively related with product innovation, due to the reduced cost of sourcing knowledge that already exists

in the market, which enhances the absorptive capacity of the firm (Enkel *et al.*, 2017; Wang and Hsu, 2014; Andriopoulos and Lewis, 2009; Katila and Ahuja, 2002). As the exploration for new knowledge and experimental learning is key for new-to-market innovations (Bolton, 1993; March, 1991), the exploitation of existing knowledge through the interaction with and observation of competitors at conferences is conducive for new-to-firm innovation (Bathelt and Schuldt, 2008; Maskell, Bathelt and Malmberg, 2006). For a sample of SME's in Birmingham (United Kingdom), Jones and Craven (2001) found non-interactive linkages such as attending trade fairs and reading scientific journals contributed to the innovative activity of the firms, in the form of R&D and the introduction of new products.

Roper *et al.* (2014) found non-interactive linkages such as scientific journals and industry associations are more common in incremental innovations and process innovations, as the knowledge exploited from these kinds of sources already exists in the market (Katila and Ahuja, 2002). For a sample of firms operating in the energy sector, Popp (2016) found scientific journals to be positively related to undertaking R&D. Industry associations and trade fairs have been shown in the literature to be conducive for innovative activity in the form of product and process innovation (Maskell, 2014; Lyytinen, 2001).

This leads us to the third and final set of hypotheses:

Hypothesis 3a: Forward interactions (customers) will be positively related to product innovations

Hypothesis 3b: Backward linkages (suppliers) and horizontal interactions (competitors) will be positively related to R&D and process innovations

Hypothesis 3c: Public linkages (universities and research institutes) will be positively related to R&D activities.

Hypothesis 3d: Conference, trade fairs, or exhibitions attendance will be positively related to product and process innovations.

Hypothesis 3e: Accessing scientific journals will be positively related to R&D activities and to product innovations.

Hypothesis 3f: Industry association involvement will be positively related to product and process innovations.

3.3 Data

A purpose-built survey was employed to collect the data used in this paper. The Renewable Energy Innovation Survey (REIS hereafter) is a business enterprise, innovation, and environmental survey which is similar in form and content to the Community Innovation Survey (CIS) or World Bank enterprise surveys and was specifically targeted at EU and UK firms operating in the ORE sector and its potential supply chain. Collection of data on ORE firms and its supply chain provides a unique insight into the innovative activities and networking capabilities of the ORE sector, which can more accurately inform policy while identifying future directions to advance ORE capacity.

The REIS[1] was conducted in early 2021 and required information on the firm's innovation activities, knowledge sourcing activities, networks, resources, and performance for the years 2017 to 2019. Performance data for 2020 was not collected due to bias that may occur as a result of the COVID-19 pandemic. Publicly available online ORE supply chain databases were used to compile the sampling frame. In total, 1,342 firms were in the sampling frame. These firms were contacted by email with follow up calls which elicited 186 responses, leading to a response rate of 14%. While 14% response rate may initially seem low, it is an acceptable response rate in the literature. Previous innovation studies have been published with response rates as low as 10%

[1] The REIS obtained ethical approval from the University College Cork Social Research Ethics Committee. Ethics approval number: "Log 2020-171".

and 9% (Goktan and Miles, 2011; Djellal and Gallouj, 2001).

Survey data in the form of secondary sources such as the Community Innovation Survey (CIS), and the World Bank Enterprise surveys are commonly used to analyse firm innovation performance (O'Connor, Doran, and McCarthy, 2020; Crowley and Jordan, 2017). In an Irish context, the CIS is a representative sample of approximately 4,500 firms (CSO, 2021). The ORE sector makes up a very small component (due to its size) of the CIS sample, and consequently relying on the CIS sample could lead to the misrepresentation of the economic activities of ORE firms.

Table 1. Breakdown of respondents by type of firm

Type of Firm	Percentage of Respondents
Academic/Research Performing Institute	8%
Consultancy/Engineering Company	29%
Marine Operations	11%
ORE Technology/Developer	39%
Other	13%

In terms of the REIS, 33% of respondents are located in the Republic of Ireland, 47% of respondents are located in the UK, while the remaining 20% of respondents are based in the EU. The European category consists of respondents from 9 EU based countries. These countries are France, Denmark, Sweden, the Netherlands, Belgium, Norway, Spain, Italy, and Luxembourg.[2]

Table 1 above, displays the breakdown of respondents by the type of firm.[3] 39% of respondents in our sample are ORE technology developers, 8% are academic or research performing institutes, 29% are consultancy or engineering companies, 11% are involved in maritime

[2] Please consult Table A1 in the appendix for a breakdown of respondents by country of main establishment.
[3] The type of firm categories were determined by members of the research team from the information of each company provided in the sampling frame.

operations, and 13% are categorised as other firms. Firms such as business support organisations, training or skills providers and firms who offer legal services to the ORE sector are among the types of firms included in the "Other" category. Though ORE Technology/Developer firms have the resources to design and develop ORE technologies, some do not have the capacity to install the device. This is the key distinction between ORE Technology/Developer and Consultancy/Engineering. Subsea engineering companies have the capacity to install ORE technologies.

Table 2: Variable Definition Table

Variable Name	Definition
In-house R&D	A binary variable which takes the value of one where a firm has invested in internal R&D during the years 2017-2019, 0 otherwise.
External R&D	A binary variable which takes the value of one where a firm has invested in external R&D during the years 2017-2019, 0 otherwise.
New-to-Market Innovation	A binary variable which takes the value of one if the organisation has introduced a new or significantly improved product innovation (goods or services) to the market before their competitors (it may have already been available in other markets) during the years 2017-2019, 0 otherwise.
New-to-Firm Innovation	A binary variable which takes the value of one if the organisation has introduced a new or significantly improved product innovation (goods or services) that was only new to the enterprise during the years 2017-2019, 0 otherwise.
Process Innovation	A binary variable which takes the value of one where the firm implemented new or significantly improved methods for producing goods or providing services, logistics, delivery, or distribution methods, methods for information processing or communication, methods for accounting or other administrative operations during the years 2017-2019, 0 otherwise.
Interactive Linkages	Count variable which takes a value of 0-10 depending on the number of co-operation partners the organisation had as part of its innovation activity from 2017-2019. Partners could include consultants, suppliers, enterprises that are competitors, enterprises within the firms' enterprise group, other enterprises, Universities or Higher Education Institutions (HEI's), public research institutes, customers from the public sector, customers from the private sector and, non-profit organisations.
Non-Interactive Linkages	Count variable which takes the value of 0 to 4 depending on the number of non-interactive linkages the organisation has interacted with as part of its innovation activity. Non-interactive linkages could include conferences, scientific journals, industry associations, other data sources.
Forward Linkages	A binary variable which takes the value of one where respondents had indicated they interacted with customers from the public sector or customers from the private sector, 0 otherwise.
Backward Linkages	A binary variable which takes the value of one where respondents had indicated they interacted with suppliers or consultants, 0 otherwise.
Horizontal Linkages	A binary variable which takes the value of one where respondents had indicated they interacted with competitors, or enterprises in the organisation's own enterprise group, or other enterprises, 0 otherwise.
Public Linkages	A binary variable which takes the value of one where respondents had indicated they interacted with research institutes or non-profit organisations, 0 otherwise.
Conferences	A binary variable which takes the value of one where respondents indicated their attendance at conferences, or trade fairs, or exhibitions, 0 otherwise.
Scientific Journals	A binary variable which takes the value of one where respondents had consulted scientific journals, or trade/technical publications, 0 otherwise.
Industry Associations	A binary variable which takes the value of one where respondents are involved in professional associations or industry associations, 0 otherwise.
Other Data Sources	A binary variable which takes the value of one where other any other data source not previously mentioned are considered for the enterprise's innovation, 0 otherwise.
Employment (log)	The natural log of the number employees reported in 2019.
Firm Age	Continuous variable which is calculated by subtracting the year the firm was established from the current year (2021).
% University Education	The percentage of the organisation's employees who have obtained a third level qualification (i.e., University, College, HEI).
Multi Plant	A binary variable which takes the value of one if the organisation has more than one plant, 0 otherwise.
Received Subsidy	A binary variable which takes the value of one where an organisation has received public financial support for acquiring knowledge or innovation activities from one of or a combination of local government, regional government, national government, European level government during the years 2017-2019, 0 otherwise.

Table 2 provides definitions for each of the variables used in our empirical models. This paper employs five different types of innovation activity: internal R&D; external R&D; new-to-market innovation; new-to-firm innovation; and process innovation. The definitions for internal R&D, external R&D, new-to-market, new-to-firm, and process innovation are in line with the definitions provided by the Oslo Manual (Eurostat, 2018). Table 3 provides a list of descriptive statistics for respondents in the sample including the different types of innovation activity.

65% of respondents (Table 3) report that they had in-house R&D expenditure during the reference period 2017 to 2019. Almost half of respondents have invested in external R&D activities during the three-year period. The percentage of our sample who engaged in R&D is relatively high to the findings of previous studies (Roper, Du and Love, 2008; Doran and O'leary, 2011; Berchicci, 2013), though scholars such as Tang (2006) and Mancusi and Vezzulli (2010) have reported more than half of their respective samples have engaged in R&D activities. In-house R&D and external R&D are positively and relatively strongly correlated with a correlation coefficient of 0.47.[4] Focusing on the different types of innovation, 49% of respondents have introduced a new-to-market innovation, 40% of respondents have introduced a new-to-firm innovation, while 54% of respondents introduced a new or significantly improved process to their business operations during the years 2017 to 2019.

Having more of the ORE sample introducing new-to-market compared to new-to-firm innovation is likely to be representative of new ORE industries. ORE innovation is characterised by a combination of diverse knowledge bases, the early stage in the product life cycle and high levels of learning and experimentation (Løvdal and Aspelund, 2011; Weinzettel *et al.*, 2009; Garrone, Piscitello and Wang, 2014). Previous organisational economics studies suggest firms enjoy greater opportunities to innovate in emerging sectors than in maturing contexts (Lo *et al.*, 2020; Klepper, 1996). Trippl *et al.* (2018) found that industries with diverse knowledge structures

[4] Please consult the correlation matrices (Table A2 and Table A3) in the appendix for more information on the relationship between each individual variable.

are more likely to access external knowledge from outside the organisations region compared to industries embedded in cognitive specialisation (Boschma, 2005). Table 3 suggests the ORE sector is more innovative relative to other sectors due to the larger proportion of respondents indicating they have introduced new products or processes compared to previous findings (Radicic, 2020; Doran *et al.*, 2020; O'Connor, Doran and McCarthy, 2020; Un, Cuervo-Cazurra and Asakawa, 2010).

Table 3. Summary Statistics

Variable	**Mean**	**Std Dev**
In-house R&D	0.649	0.479
External R&D	0.487	0.501
New-to-Market Innovations	0.494	0.502
New-to-Firm Innovations	0.403	0.492
Process Innovation	0.539	0.500
Interactive Linkages	3.455	3.380
Non-Interactive Linkages	1.513	1.300
Forward Linkages	0.448	0.499
Backward Linkages	0.545	0.500
Horizontal Linkages	0.448	0.499
Public Linkages	0.383	0.488
Conferences	0.513	0.501
Scientific Journals	0.435	0.497
Industry Associations	0.526	0.501
Other Data Sources	0.039	0.194
Employment (log)	2.260	1.694
Firm Age	25.020	33.130
% University Education	0.730	0.344
Multi Plant	0.487	0.501
Received Subsidy	0.234	0.425
Observations	154	154

The REIS asked respondents to indicate the number of innovation co-operation partners they were working with. The survey gave respondents a choice of ten innovation partner types. These innovation co-operation partners consisted of consultants, suppliers, enterprises that are considered competitors, other enterprises, enterprises within the firms' enterprise group, Universities, or higher education institutes (HEIs), Government or public research institutes, clients and customers from the public sector, clients and customers from the private sector and non-profit organisations.

Following the seminal contribution of Laursen and Salter (2006), the measurement of interactive linkages is the sum of the number of innovation co-operation partners the firm had, a measure consistently used in the literature (Ko, O'Neill and Xie, 2021; Lacerda and van den Bergh, 2020; Cainelli, De Marchi and Grandinetti, 2020; Ferreras-Méndez *et al.*, 2015; Wu, 2014; Garriga, Von Krogh and Spaeth, 2013). A firm with no innovation co-operation receives an interactive linkage value of 0, while a firm that had interacted with all innovation partners is assigned a value of 10. As illustrated in Table 3, firms on average had 3 innovation co-operation partners.

Non-interactive linkages were measured in a similar way to the approach of Roper *et al.* (2017) and Hewitt-Dundas and Roper (2011). Respondents were asked to indicate which non-interactive data sources were considered for their innovations. Respondents were given four options: conferences and trade fairs; scientific journals or trade publications; professional and industry associations; and other data sources. Firms are assigned a value of 0 where they had no non-interactive linkages and firms are assigned a value of 4 where they had considered each non-interactive data source for their innovations. On average, firms had consulted 2 non-interactive data sources for their innovations (Table 3 above).

Turning our attention to the individual level interactive linkages, Table 3 shows that 55% of respondents engaged in backward linkages with suppliers and consultants, 49% of respondents engaged in forward linkages with customers, 49% of respondents engaged in horizontal linkages with competitors, and 38% of respondents engaged in public linkages with research centres or universities. Table 3 suggests the ORE sector is more open to external collaboration as the number of respondents who engaged in external interactive linkages is higher than those found in the literature (Roper, Du and Love, 2008; Lee *et al.*, 2010; Tsai, 2009).

Looking at the individual level non-interactive linkages, 51% of respondent's innovation strategy included conference attendance and participation, 44% of respondents had consulted scientific journals, 53% of respondents had consulted industry associations, and 4% of respondents had consulted other data sources during the reference period. The proportion of our sample engaging in non-interactive linkages such as conference attendance and participation and consulting scientific journals is consistent with previous findings in the literature (Marullo *et al.*, 2021; Lee *et al.*, 2010).

Previous studies indicate the importance of firm size in influencing firm openness (Grillitsch, Martin and Srholec, 2017; Drechsler and Natter, 2012). Firm age is important as older firms have more potential to accumulate knowledge from previous innovations and due to organisational learning (Levitt and March, 1988; Pellegrino and Piva, 2020). The percentage of the workforce who have a third level qualification gives an indication of the labour quality of the firm which influences the heterogeneity of innovative activities of the different firms (Freel, 2005). Organisations operating in multiple plants gives an indication of the firms' resources and internal knowledge base (Jensen, 2004). Government support in the form of subsidies has been previously shown to encourage firm interaction and networking capabilities (Kang and Park, 2012).

3.4 Methodology

This paper focuses on the link between innovation inputs and innovative activity and employs an innovation production function which is a common empirical strategy in the innovation literature (Audretsch and Belitski, 2020; Crowley, 2017; Lööf, Mairesse and Mohnen, 2017; Doran, Jordan and O'Leary, 2012; Hall, Lotti and Mairesse, 2009). The innovation production function used in this paper shows the probability of the firm engaging in innovation activity and is regressed against a number of explanatory variables. Eq. (1) below is estimated using five distinct probit models, each examining a different type of innovative activity (Doran and O'leary, 2011).

$$IA_{ih} = \beta_0 + \beta_1 Inter_{ih} + \beta_2 NonInt_{ih} + \beta_3 InterSq_{ih} + \beta_4 NonIntSq_{ih} + \beta_3 Z_{ih} + \varepsilon_i \qquad (1)$$

IA_{ih} refers to the innovation activities for firm i and h is the type of innovation activity (i.e., the dependent variables in the probit models). As indicated earlier, this paper examines five types of innovation activity: in-house R&D, external R&D, new-to-firm innovation, new-to- market innovation, and process innovation.[5] If the $\beta's$ included in the model are positive, this would suggest a positive relationship between the dependent and explanatory variables. If the $\beta's$ included in the model are negative, this would suggest a negative relationship between the dependent and the independent variables.

[5] Internal R&D and External R&D are included as separate dependent variables in this paper as it is concerned in the literature that innovation inputs like R&D and innovation outputs like product and process innovations are largely endogenous (Grossman and Helpman, 1994).

The data used in this paper is cross-sectional in nature meaning the lagged effects of R&D spend cannot be examined. Table A4 and Table A5 in the appendix are multivariate probit models which examine if the error terms are related. The multivariate probit models are significant and robust suggesting the error terms are related and unobserved characteristics are driving both innovation inputs and outputs. Due to these empirical considerations, this paper concentrates on overall innovative activity.

β_0 is the constant or intercept term. $Inter_i$ refers to the number of interactive linkages for firm i. $NonInt_i$ refers to the number of non-interactive linkages for firm i. This paper expects both $\beta_1 Inter_{ih}$ and $\beta_2 NonInt_{ih}$ to be positive, as more external linkages are more likely to yield useful external knowledge for innovative activity, which leads to economies of scope and can reduce cognitive lock-in (Garriga, Von Krogh and Spaeth, 2013; Chiang and Hung, 2010; Boschma, 2005).

$InterSq_i$ and $NonIntSq_i$ are the squared terms of interactive and non-interactive linkages, respectively. These are included to test for possible quadratic effects (Love, Roper and Vahter, 2014; Radicic, 2020). In line with previous studies who have tested the returns of innovation activity from external linkages (Lacerda and van den Bergh, 2020; Ardito and Petruzzelli, 2017; Cruz-González *et al.*, 2015; Chen, Chen and Vanhaverbeke, 2011), this paper expects both $\beta_3 InterSq_{ih}$ and $\beta_4 NonIntSq_{ih}$ to be negative. Negative $InterSq_i$ and $NonIntSq_i$ coefficients would suggest diminishing returns to innovative activity from interactive and non- interactive linkages (Roper, Love and Bonner, 2017). Z_i refers to several firm specific control variables which include firm size, firm age, recipient of subsidies, and operating multiple plants.

$$IA_{ih} = \beta_0 + \beta_1 Forward_{ih} + \beta_2 Backward_{ih} + \beta_3 Horizontal_{ih} + \beta_4 Public_{ih} + \beta_5 Conferences_{ih} + \beta_6 ScientificJounrnals_{ih} + \beta_7 IndustryAssociations_{ih} + \beta_8 OtherDataSources_{ih} + \beta_9 Z_{ih} + \varepsilon_i \quad (2)$$

Eq. (2) includes the disaggregated individual level interactive and non-interactive linkages and is estimated using five distinct probit models[6], with each probit model examining a different type of innovative activity (Roper, Du and Love, 2008).

[6] The country of main establishment variable and type of firm variable were omitted from the final regressions due to degrees of freedom concerns. However, the results remain robust with the inclusion of these variables with Table A6 and Table A7 in the appendix displaying the results of the specifications.

$\beta_1 Forward\ are$ forward linkages to customers, $\beta_2 Backward$ are backward linkages to suppliers or consultants, $\beta_3 Horizontal$ are horizontal linkages to competitors and $\beta_4 Public$ are public linkages to universities, or research institutes.

$\beta_1 Forward, \beta_2 Backward, \beta_3 Horizontal\ and\ \beta_4 Public$ are the individual level interactive linkages. This paper expects forward linkages to customers to be positively related to product innovation, backward linkages, and horizontal linkages to be positively related to process innovation and R&D, and public linkages to be positively related to R&D performance.

Regarding the individual level non-interactive linkages, this paper expects $\beta_5 Conferences_{ih}$ and $\beta_7 IndustryAssociations_{ih}$ to be positively related to both product and process innovation, and $\beta_6 ScientificJounrnals_{ih}$ to be positively related to R&D activity and product innovation.

3.5 Results

The probit estimation models used to test Eq. (1) report marginal effects and each model is statistically significant. Table 4 displays the results from Eq. (1) for each of the five innovation activities. Interactive linkages were found to have a significant positive relationship with each innovation activity except for new-to-firm innovation. This finding is consistent with the results of previous studies which indicate the positive effects of interactive linkages on firm level innovation outcomes (Chesbrough, Heaton and Mei, 2021; Berchicci, 2013; Leiponen and Helfat, 2010). Hypothesis 1a is therefore supported. Non-interactive linkages appear to have a negligible effect on each type of innovative activity as non-interactive linkages are not statistically significant. Hypothesis 1b is therefore rejected.

Although interactive linkages positively affect innovation activity, the negative coefficient of the squared interactive linkage term suggests the relationship is subject to diminishing returns (Cruz-González *et al.*, 2015; Ghisetti, Marzucchi and Montresor, 2015). Diminishing returns from interactive linkages were found for internal R&D, external R&D, and process innovation.

This finding supports the presence of a curvilinear relationship that has been previously found in the literature (Lacerda and van den Bergh, 2020; Love, Roper and Vahter, 2014). Therefore, this result offers support for Hypothesis 2a. This indicates that once the cognitive capacity of management is reached (Radicic, 2020; Simon, 2013), it is more difficult for management to dedicate time and effort to external linkages, which hinders their returns to innovative activity (Ferreras-Méndez, Fernandez-Mesa and Alegre, 2016; Ferreras-Méndez *et al.*, 2015; Ocasio, 1997).

Fig. 1 displays the returns to innovative activity from interactive linkages. It is worth noting that despite the relationship being subject to diminishing returns, it is not an inverted U-shape as other studies have found (Lacerda and van den Bergh, 2020; Roper, Love and Bonner, 2017; Garriga, Von Krogh and Spaeth, 2013). In other words, there is no "tipping point" (Laursen and Salter, 2006, p. 142) where more interactive linkages lead to less innovative activity.[7] We do not find any significant evidence that there is a curvilinear relationship between non- interactive linkages and innovation activities.[8] This finding contradicts the inverted U-shape found by previous studies (Radicic, 2020; Cruz-González *et al.*, 2015). Hypothesis 2b is rejected.

[7] The "Inno_Activity" variable is the fraction of innovation activity variable and was constructed by adding the sum of each binary dependent variable and then dividing by the number of dependent variable (i.e., dividing by five to make a fraction). Table A8 in the appendix displays the fractional probit regression.
[8] Please find Fig. A1 in the appendix which displays the margins plot for non-interactive linkages.

Table 4. Output from Eq. (1) reporting marginal effects

VARIABLES	(1) In-house R&D	(2) External R&D	(3) New-to-Market	(4) New-to-Firm	(5) Process Innovation
Interactive Linkages	0.220***	0.186***	0.113**	0.0594	0.222***
	(0.0429)	(0.0467)	(0.0443)	(0.0444)	(0.0493)
Non-Interactive Linkages	-0.0237	-0.106	-0.204	-0.134	0.149
	(0.128)	(0.147)	(0.131)	(0.121)	(0.143)
Interactive Linkages Squared	-0.0208***	-0.0149***	-0.00703	-3.75e-05	-0.0171***
	(0.00446)	(0.00490)	(0.00451)	(0.00466)	(0.00502)
Non-Interactive Linkages Squared	0.0190	0.0688	0.0620	0.0537	-0.0464
	(0.0401)	(0.0472)	(0.0417)	(0.0385)	(0.0471)
Employees (log)	0.0724**	0.0532	0.0619**	0.0503*	0.0732**
	(0.0292)	(0.0325)	(0.0299)	(0.0303)	(0.0343)
Firm Age	-0.00477*	-0.00270	-0.00342	-0.00363*	-0.00113
	(0.00254)	(0.00249)	(0.00217)	(0.00199)	(0.00136)
% University Education	0.0984	0.113	-0.00953	-0.147	0.206
	(0.125)	(0.140)	(0.134)	(0.130)	(0.144)
Multi Plant	0.101	0.0701	0.115	-0.0162	-0.0778
	(0.0861)	(0.0960)	(0.0886)	(0.0905)	(0.0972)
Received Subsidy	0.0809	-0.0700	0.00309	-0.0277	0.176*
	(0.0983)	(0.115)	(0.105)	(0.101)	(0.0959)
Observations	154	154	154	154	154
Wald Chi-square (prob)	54.74	54.08	30.98	32.66	44.52
	(0.0000)	(0.0000)	(0.0000)	(0.0002)	(0.0000)
Pseudo R2	0.2931	0.2735	0.1732	0.1782	0.2561

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Fig. 1

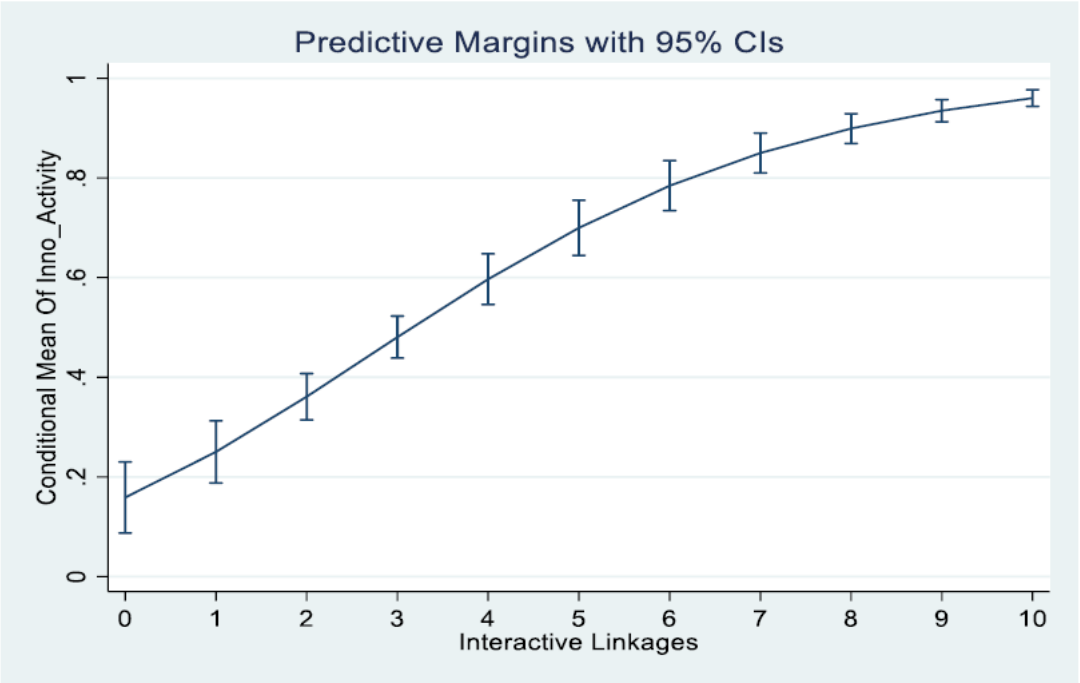

Fig. 1 Margins plot displaying the returns to innovative activity from interactive linkages.

Table 5 indicates the results from Eq. (2) and again each probit model is statistically significant. Firm size, firm age, percentage of the workforce with a third level qualification, the multi plant dummy variable and the subsidy dummy variable were included as control variables.

Starting with the interactive linkages, Table 5 indicates that forward linkages to customers are positively and significantly related to new-to-market, new-to-firm, and process innovations providing support for hypothesis 3a. In the theoretical discussion, it was not expected that interaction with customers would be important for process innovations. This level of significance may signal the importance of learning about all types of innovations in the early stages of sector development and between all actors. For example, although ORE technology/developer firms have the resources to design and develop ORE technologies, many do not have the capacity to install their devices offshore and they will require support from other companies (engineering/consultancy firms). In turn, it is likely that consultants and engineers will heavily rely on ORE technology/developers for process innovation development. Similarly, business support organisations, training or skills providers feeding into this sector will constantly need to upgrade process innovations by learning from their customers as the skill needs of the sector evolves.

Backward linkages to suppliers and consultants are positively related to in-house R&D, external R&D, and process innovation. This finding supports previous studies where a complementary relationship between in-house knowledge generation and external knowledge sourcing was found (Hung and Chou, 2013; Cassiman and Veugelers, 2006; 2002). Absorptive capacity (Cohen and Levinthal, 1990) as proxied by the percentage of the workforce with a third level qualification is likely to play a key role here, as previous scholars have suggested the greater internal capabilities of the firm, the greater the effect external knowledge sourcing has on innovative activity (Denicolai, Ramirez and Tidd, 2014; Vanhaverbeke, 2012; Laursen and Salter, 2006).

However, this study finds negligible effects of horizontal linkages to competitors and innovative activity. This is a surprising finding as horizontal linkages allow firms to learn from their competitors which has been shown to facilitate product and technological development (Gnyawali and Park, 2011). Cooperation between competitors has been shown to increase the likelihood of product innovation through competition (Crowley and Jordan, 2017; Teece, 1992).

We do not find a significant relationship between public linkages to universities, research organisations and innovative activities. This is a surprising result due to the unstandardised nature of products in the ORE sector and the early stages of the product life cycle (Løvdal and Aspelund, 2011; Weinzettel *et al.*, 2009; Baumol, 2002). Cohen and Klepper (1996) describe how in the early stage of the product life cycle few actors have sufficient knowledge underlying the emerging innovations. As Laursen and Salter (2006) suggest, in the early stage of the product life cycle, innovative firms need to draw on the knowledge of *"lead users, component suppliers, or universities"* (Laursen and Salter, 2006, p. 146). Due to the aforementioned reasons, this paper rejects Hypothesis 3c.

Turning to the individual level non-interactive linkages, we find a negative relationship between conferences and new-to-firm innovation (hypothesis 3d). This result contradicts the findings of previous scholars, who find firms who attend and participate in professional conferences are more likely to surpass their current level of innovative activities (Tether and Tajar, 2008; Maskell, Bathelt and Malmberg, 2006), while studies such as Bathelt and Schuldt (2008) emphasise the importance of conference attendance and participation for new-to-firm innovation. Moon *et al.* (2019) provide a potential reason for the negative association between conferences and new-to-firm innovation, noting how the magnitude of importance for conferences diminishes as the firm's absorptive capacity increases. New to firm innovations are generally incremental and less radical than new to market innovations, hence they require less scientific knowledge which are more likely to motivate conference and trade fair attendance. Consequently, the negative relationship identified here may be a function of the

particular type of innovation objective (Tödtling, Lehner and Kaufmann, 2009).

Scientific journals have a positive and significant relationship with internal R&D, external R&D, and process innovation providing support for hypothesis 3e. Analytical (scientific) knowledge may be required to solve fundamental problems in the product or production process particularly prevalent in the research and development phase (Davids and Frenken, 2018). This further relates to the complementary relationship often found between a firms' internal knowledge generation and external knowledge sourcing (Roper *et al.*, 2014; Vanhaverbeke, 2012; Jones and Craven, 2001). In line with previous findings (Maskell, 2014; Lyytinen, 2001), a positive relationship has been found between industry associations and new-to-firm innovations, but a negative relationship between industry associations and R&D (hypothesis 3f). This is not all that surprising as membership of industry associations may be more pertinent for the commercialisation stage of the innovation process again signalling the type of interaction may be strongly related to the type of innovation objective. Other non-interactive data sources have a negligible effect on all types of innovative activity with the exception of process innovation. Our results suggest other non-interactive data sources are negatively related to process innovation. Roper *et al.* (2016) does not find strong evidence of a positive relationship between other non-interactive data sources in the form of manuals and process innovation. As ORE innovation is known to be complex and requires a diverse range of knowledge (Garrone, Piscitello and Wang, 2014; Nemet, 2012), these results emphasise the importance of ORE firms being open to external knowledge sources (Chesbrough, 2017; 2006; 2003) and their ability to assimilate and exploit the appropriate external knowledge sources (Zahra and George, 2002; Cohen and Levinthal, 1990).

Turning to the control variables (Table 4), the coefficients for the natural log of employees are positive which suggests a positive relationship between employment and undertaking in-house R&D, introducing new-to-market innovations, introducing new-to-firm innovations and process innovations. Regarding firm size, the results from Table 4 are consistent with the literature in terms of R&D investment and size (Acs and Audretsch, 1988; Dosi, 1988). This result offers support for studies who have found the potential for economies of scale (Shefer

and Frenkel, 2005) to exist in relation to firm size and R&D.

Firm age is negatively associated with the decision to engage in internal R&D and the introduction of new-to-firm innovations. Previous studies have found more mature firms find it more difficult to capitalise on innovations to improve firm performance (Leyva-de la Hiz and Bolívar-Ramos, 2021). This paper echoes the points of Barron *et al.* (1994) and suggests some ORE firms may experience the effects of inertia and struggle to keep up with relatively young ORE firms. Finally, firms who have received any form of subsidy are more likely to engage in process innovation compared to firms who have not received any form of subsidy. This finding is consistent with the results of previous studies (Griliches, 1995).

Table 5. Output from Eq. (2) reporting marginal effects

VARIABLES	(1) In-house R&D	(2) External R&D	(3) New-to-Market	(4) New-to-Firm	(5) Process Innovation
Forward Linkages	-0.0966	-0.126	0.261**	0.338***	0.338***
	(0.116)	(0.146)	(0.116)	(0.104)	(0.112)
Backward Linkages	0.490***	0.452***	0.0714	-0.0887	0.305**
	(0.124)	(0.112)	(0.128)	(0.130)	(0.122)
Horizontal Linkages	-0.0728	0.0300	0.197	0.176	0.0123
	(0.122)	(0.144)	(0.126)	(0.121)	(0.125)
Public Linkages	-0.0914	0.0528	-0.0697	-0.00565	-0.105
	(0.120)	(0.136)	(0.133)	(0.119)	(0.132)
Conferences	-0.0199	0.0639	-0.140	-0.265**	0.0280
	(0.111)	(0.142)	(0.134)	(0.134)	(0.136)
Scientific Journals	0.381***	0.291**	-0.00143	0.187	0.306**
	(0.0852)	(0.123)	(0.135)	(0.131)	(0.122)
Industry Associations	-0.188*	0.00169	0.115	0.217**	-0.146
	(0.111)	(0.133)	(0.120)	(0.104)	(0.123)
Other Data Sources	-0.0149	0.227	0.145	-0.0187	-0.580***
	(0.227)	(0.202)	(0.237)	(0.213)	(0.0569)
Observations	154	154	154	154	154
Wald Chi-square (prob)	48.50	57.42	35.85	32.96	52.08
	(0.0000)	(0.0000)	(0.0006)	(0.0017)	(0.0000)
Pseudo R2	0.3413	0.2985	0.1914	0.2112	0.3356

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

3.6 Conclusion

Firms are increasingly relying on external knowledge linkages for their innovative activities, and openness to external knowledge sources is regarded as a key driver of innovation. (Ferreras-Méndez, Fernandez-Mesa and Alegre, 2016; Cruz-González *et al.*, 2015; Laursen and Salter, 2006; Chesbrough, 2017). In order to gain further insight into the role of external knowledge linkages and innovative activity, this paper examines the relationship between interactive linkages, non-interactive linkages and five types of innovation activity for a sample of EU and UK firms operating in the ORE sector and its supply chain, using data from a unique purpose-built survey. Often studies do not distinguish between product and process innovation (Ebersberger *et al.*, 2012; Kutvonen, 2011), however, examining five different types of innovative activities provides more detailed results regarding the effects interactive and non-interactive linkages have on each type of innovation activity.

This paper contributes to the open innovation literature (Chesbrough, 2017; 2006; 2003) by distinguishing between two types of external knowledge linkages, interactive linkages (exploratory) and non-interactive linkages (exploitative) and examining the effects of each search strategy for innovative activity in the under-researched ORE sector. This paper argues that firms who are more open to interactive linkages and non-interactive linkages are more innovative than firms who are less open to external linkages. Although interactive linkages were found to be positively associated with innovative activity in the form of internal R&D, external R&D, new-to-market, and process innovation, this paper finds interactive linkages to be subject to diminishing returns. This paper finds a tipping point after five interactive linkages, in which over-searching hinders innovative activity. Conversely, there is an absence of a significant relationship for non-interactive linkages and all types of innovative activity.

In addition to examining interactive and non-interactive linkages as a whole, this paper answers the call of previous literature (Ardito and Petruzzelli, 2017) and disaggregates each type of

linkage to individual indicators to examine the relative significance of each type of linkage for innovative activity. Customers are identified to be more important in the production and commercialisation innovation outcome stages for firms, whilst interactions with suppliers and sourcing analytical knowledge (from scientific journals) is more important in the basic technology research, feasibility, development, and process stages. Critically, the results indicate that different types of innovation are related to different, but specific combinations of knowledge linkages.

Our findings have implications for management practices. Our results find diminishing returns to innovative activity, as the number of interactive linkages increase. Due to the cognitive limitations of management, some innovative ideas may not be fully exploited (Radicic *et al.*, 2019). From our findings this paper recommends organisations who are focused on product innovation to interact with customers. Organisations who are prioritising R&D activity should interact with suppliers and consultants, while organisations focused on introducing new processes should interact with customers, suppliers, and consultants.

In using these findings organisations can prioritise and identify the most efficient interactive linkages relative to their innovation objective, thus avoiding absorptive capacity exhaustion (Cohen and Levinthal, 1990). Of course, this is a difficult task which requires an understanding of the market (Lacerda and van den Bergh, 2020). Due to the afore mentioned reason, Cruz-González *et al.* (2015) warns how scholars must be more cautious when interpreting the results of external knowledge searching.

Our findings indicate the importance for policymakers to recognise the importance of interactive linkages, with customers, suppliers, and consultants for development of product and process innovation. To enhance product and process innovation in the ORE sector, this paper sees the benefit in policy which promotes and builds collaborations or interactive partnerships among ORE firms. These types of relationship create a wider benefit which extend past participating

firms through stimulating knowledge creation and diffusion (Roper, Love and Bonner, 2017). Interactive relationships can be enabled by providing a legal and regulatory framework which supports external collaboration across ORE firms by lowering the cost of external collaboration and the development of the relevant infrastructure. Our results show backward linkages to suppliers and consultants is positively related to ORE firms' R&D activity. This paper suggests policymakers support backwards linkages by providing tax incentives for ORE R&D collaboration, which improves the experience, skills, knowledge, and competence between parties.

A cross-sectional survey was employed in this paper, meaning results show the directional evidence of a relationship, but fails to provide conclusions on the causal direction between variables. Consequently, a longitudinal study has the opportunity for more complex causal analysis. A second limitation was the response rate of the REIS. While the REIS had many benefits due to its novelty and its construction specifically for this research, the response rate was initially lower than anticipated due to business upheaval in the economy from COVID-19. Natural disasters inevitably bring crises to firms and finding alternative suppliers and external partners is more difficult (Wang *et al.*, 2020; Benson and Clay, 2004). A study concentrating on the exogenous effect the COVID-19 pandemic had on the ORE firm's knowledge sourcing activities would be a fruitful avenue for research.

Due to the sample size, this paper examined the ORE sector as a whole rather than examining the ORE sector by ORE technology sources. Future research could work to increase the sample size in order to identify the differences in knowledge sourcing strategies of firms involved in different ORE sources (i.e., offshore wind versus tidal). This would provide rich results in how different knowledge search strategies could be more or less important to different innovative activities in different ORE sources. In doing so, policy could be more accurately informed for different sources of ORE.

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4. Discussion

4.1 Discussion of the Hypotheses

The empirical results from the study indicate that interactive linkages are positively related to internal R&D, external R&D, new-to-market innovation, and process innovation. This finding offers support to Hypothesis 1a. This may not come as a surprise as previous studies provide evidence that the more external linkages the firm has the more likely they are to receive useful knowledge for innovations (Ritala *et al.*, 2015; Leiponen and Helfat, 2010; Jordan and O'leary, 2008). Having more interactive linkages increases the likelihood of complementarities from internal and external knowledge combinations to innovate (Voudouris *et al.*, 2012; Cassiman and Veugelers, 2006). Hypothesis 1b is rejected due to the absence of a significant relationship.

The squared Interactive Linkage term suggests diminishing returns to R&D activity and process innovation. This finding offers support to hypothesis 2a. Previous scholars attribute this non-linear relationship between knowledge inputs and innovation activity to the cognitive limitations of management (Lacerda and van den Bergh, 2020; Ardito and Petruzzelli, 2017; Roper *et al.*, 2014). Hypothesis 2b is rejected due to the absence of a significant relationship.

This study then disaggregates interactive and non-interactive linkages to individual level indicators and examines the relative significance of each type of linkage for each innovation activity. This study found customers to be more important in the production and commercialisation of products and processes, while interactions with suppliers are more important for R&D activities, therefore offering support for hypothesis 3a. It has been previously shown that customers have access to critical knowledge regarding product innovations, therefore reducing the risks associated with new product development (Rodriguez, Doloreux and Shearmur, 2017; Chen, Chen and Vanhaverbeke, 2011).

Backward linkages to suppliers and consultants are positively associated with innovative activity in the form of R&D and process innovation, offering support to the complementary relationship between in-house knowledge generation and external knowledge sourcing (Hung and Chou, 2013). Interacting with suppliers and consultants has been previously shown to reduce the costs associated with process innovations (Roper, Du and Love, 2008). However, this study finds negligible effects of horizontal linkages to competitors. This is a surprising finding as horizontal linkages provide the innovating firm with access to similar resources and complementary knowledge (Radicic *et al.*, 2019). This finding shows the importance of learning about all types of innovations in the early stages of the development of the ORE sector and between all actors operating in the sector.

This paper rejects hypothesis 3c due to the absence of a significant relationship between public linkages to universities and research institutes and innovative activity in the form of R&D. Previous literature suggests that innovating firms operating in the early stages of the product life cycle need to draw on the knowledge of universities as few actors have sufficient knowledge regarding innovations in the early stages of the product life cycle (Løvdal and Aspelund, 2011; Laursen and Salter, 2006; Cohen and Klepper, 1996).

A negative relationship is identified between conferences and new-to-firm innovation, therefore hypothesis 3d can be rejected. Previous literature suggests the reduction in cost due to the exploitation of existing knowledge by the attendance at conferences is positively related to new-to-firm innovation (Bathelt and Schuldt, 2008; Maskell, Bathelt and Malmberg, 2006). New-to-firm innovations are generally incremental and less radical than new to market innovations; hence they require less scientific knowledge which are more likely to motivate conference and trade fair attendance.

Results indicate that firms who access scientific journals as part of their knowledge search strategies are positively related to R&D activity, offering further clarity to previous literature from the energy sector (Popp, 2016). Hypothesis 3e is therefore supported. Absorptive capacity (Cohen and Levinthal, 1990) plays a key role here as firms with higher levels of absorptive capacity are better suited to absorb the analytical knowledge from scientific journals which is used to solve the fundamental production problems that are prevalent in the R&D phase (Davids and Frenken, 2018; Roper *et al.*, 2014).

Industry associations are positively associated with product innovation in the form of new-to-firm innovations but are negatively associated with R&D activity (hypothesis 3f). The negative relationship between industry associations and R&D may be due to the stage of the innovation process the innovating firm is at. Industry association memberships may be more relevant to firms in the commercialisation stage of the innovation process.

4.2 Other general findings of the research

The results from our empirical analysis indicated that firm size is positively related to in-house R&D, new-to-market innovation, new-to-firm innovation, and process innovation. Larger firms have a higher probability of engaging in R&D due to their human resources, market power, and appropriation capabilities (Baumann and Kritikos, 2016; Sasidharan and Kathuria, 2011; Shefer and Frenkel, 2005). Firm age is negatively related to in-house R&D and new-to-firm innovations. The age of the firm influences their resources, experience, reputation, and market share (D'Amato and Falivena, 2020). Previous literature suggests more mature firms may experience the effects of inertia thus finding it more difficult to capitalise on innovations to keep with up changing market environment (Leyva-de la Hiz and Bolívar-Ramos, 2021; Barron, West and Hannan, 1994). Firms who have received financial support in the form of subsidies are positively associated with the introduction of new and improved processes, as is consistent in the literature (Howell, 2017).

5. Conclusion

5.1 The paper's contribution

This paper examines the effect external linkages has on five different types of innovative activity (i.e., internal R&D, external R&D, new-to-market innovation, new-to-firm innovation, and process innovation). Many studies fail to distinguish between product and process innovation when looking at the effects of external linkages on innovation activity (Kobarg, Stumpf-Wollersheim and Welpe, 2019; Duarte and Sarkar, 2011). Terjesen and Patel (2017, p. 1422) assert that *"there is limited understanding of how firms devise knowledge search strategies to develop process innovation".*

This paper tests whether more external linkages lead to more innovative activity, and tests for the presences of a curvilinear relationship between external linkages and innovative activity. This study aims to provide further support on whether external linkages are subject to diminishing returns for a sample of firms in the ORE sector (Radicic, 2020; Ferreras-Méndez *et al.*, 2015; Laursen and Salter, 2006). While previous studies have tested for the presence of an inverted U-shaped relationship between external linkages and innovation activity (Triguero and Fernández, 2018; Roper, Love and Bonner, 2017), this is the first study which examines this relationship for the ORE sector.

This paper then disaggregates the interactive and non-interactive linkages to individual level indicators, which answers the call of Ardito and Petruzzelli (2017) who call for more work be undertaken in examining the significance of each search channel in fostering innovative activity.

The data set used in this study is another contribution of this research. As the REIS was constructed specifically for this research, the data obtained from the survey is truly unique. The REIS overcomes problems such as the misrepresentation of ORE activities, as the REIS was purpose-built and was specifically targeted at the ORE sector and supply chain.

The addition of industry-specific questions and quantitative questions provided opportunities for ORE firms to give their thoughts and opinions on the barriers and opportunities for the sector, which provided a rich level of detail about the potential of the sector. The data received from the

REIS is truly unique as no other studies has access to it, which provides a novel insight into the networking capabilities and innovative activities of the actors involved in the ORE sector.

5.2 Implications

Our results indicate diminishing returns to innovative activity from interactive linkages. In the case of the ORE sector, after five interactive linkages are employed the marginal benefits from an additional interactive linkage decrease. A significant relationship was absent for non-interactive linkages. As a result, management should identify the most efficient interactive linkages relative to their innovation objective, thus avoiding absorptive capacity exhaustion (Cohen and Levinthal, 1990). Management should try to further improve the organisations absorptive capacity to better absorb and exploit knowledge from external linkages. Training could be provided to improve the internal knowledge base for innovation activity (Cainelli, De Marchi and Grandinetti, 2015). External linkages are more valuable to organisations with higher levels of absorptive capacity (Flor, Cooper and Oltra, 2018).

Regarding the individual level interactive indicators, collaborating with customers, suppliers, and consultants is important for development of product and process innovations. Interacting with suppliers and consultants is conducive for R&D activity. This paper suggests policymakers support backward linkages to suppliers and consultants by providing tax incentives for R&D collaboration among ORE parties, which improves the knowledge, skills, and experience among the ORE parties involved. Regarding the individual level non-interactive indicators, accessing scientific journals and being a member in industry associations is positively related to R&D activity and the development of new and improved products and processes. The results highlight that ORE organisations should consider ensuring resources are available that enable staff to access scientific journals, industry associations, and attend conferences. At the same time, providing adequate resources for such activities may be difficult for businesses and consequently there may be a role for policy to ensure grants and targeted supports can be obtained for marine energy businesses to participate in such activities.

Our results indicate Government subsidies are positively related to process innovations. Policy makers should attempt to develop suitable ORE innovation policies to incentivise ORE firms to engage in innovative activity. Contracts for Difference are arguably the main policy mechanism in the UK which incentivises the investment in low-carbon technologies (Welisch and Poudineh, 2019). The fixed price over (typically) a 15-year period guarantees developers a minimum "strike price" for the electricity they sell, which maintains confidence in the industry and reduces uncertainty. These mechanisms allow for both the increased offshore energy output and the reduction in cost through learning-by-doing (Jamasb and Sen, 2022). Management of ORE firms should become more familiar with the current requirements to obtain subsidies in the ORE sector in order to obtain more external resources and support for future ORE innovations. Our findings indicate the importance of the interaction with customers, suppliers, and consultants for the development of new and improved products and processes. By developing the relevant infrastructure and lowering the cost of external collaboration interactive relationships can be promoted.

5.3 Limitations and Avenues for Future Research

This paper uses data obtained from a purpose-built cross-sectional survey. Cross-sectional surveys are commonly employed in the innovation literature (Radicic, 2020; Doran and O'leary, 2011; Laursen and Salter, 2006) but are not without limitations. Firstly, the coefficients are viewed as indicators of directionality of the relationship but fails to provide absolute proof on the causal direction between the variables. A longitudinal study has more opportunity for more complex analysis and can establish causal effects. This would allow for the examination of the firm's long term innovative activities.

The response rate of the REIS was initially lower than anticipated due to business upheaval in the economy from COVID-19. The COVID-19 pandemic has changed the way organisations interact with other organisations, and finding external partners is now more difficult (Wang *et al.*, 2020). A fruitful avenue for research would be to examine the effect the COVID-19 pandemic had on ORE firm's knowledge sourcing activities and innovation activities.

The data obtained from the REIS provided information on the knowledge sourcing capabilities, networking capabilities and innovation activities for a sample of ORE firms. Due to the sample size, this paper examined the ORE sector as a whole as opposed to focusing on the effects of different linkages in different ORE technology fields. Future research could work to improve the sample size to examine the role of different external linkages on the innovation activities of firm's involved in different ORE technology sources (i.e., offshore wind versus tidal). The results from the study would show the different effects external linkages has on innovative activity in two different ORE technology fields (i.e., offshore wind energy innovation versus tidal energy innovation). By comparing two different ORE technologies, the results could assess whether certain external linkages are contingent on the ORE technology field. In doing so, different knowledge search strategies could be more or less important to different innovative activities in different ORE technology fields. Policy could be more accurately advised with ORE technology-specific policies to stimulate innovation in the technology field.

6. Appendix

6.1 Funding of the research

This research has received funding from The Selkie Project, which is focused on the development of a streamlined commercialisation pathway for the ORE industry. This research is part of the wider Selkie network and has received funding from the European Union's European Regional Development Fund through the Ireland Wales Cooperation Programme (The Selkie Project, for more details see here: https://www.selkie-project.eu/).

6.2 Individual contributions to the research

In addition to completing the MSc Research Paper, I was involved in numerous tasks for the duration of the research. At the beginning of my research, I successfully completed the online Epigeum course in Research Integrity. I was involved in the survey design, pilot survey, and final question construction of the REIS. I had numerous meetings (online via Microsoft Teams) with my supervisors and a post-doctoral researcher, where we discussed the template for the questionnaire and the aims of the questionnaire. I shared my thoughts on the questionnaire, providing feedback and suggestions to certain questions or parts of the survey. I also added specific questions to the REIS which allowed me to test my hypotheses for my research paper when we had acquired sufficient data.

I compiled the sample frame for this research on Microsoft Excel. I scoured the web for publicly available ORE supply chain databases to include in the sample frame. Domestic and international ORE supply chain databases were used. Relevant companies were included in the Excel sheet, and I would make note of the firm's primary business classification (ORE technology developer, consulting, engineering, research, marine operations, etc.), the company name, the county/city of operations, the country of operations, the email address of the firm, and the phone number of the firm. In total, there were 1,342 firms included in the sample frame.

I then separated the firms in the sampling frame by country. Firms located in the Republic of Ireland accounted for 16% of the sample frame (212 firms), Welsh firms accounted for 31% of

the sample (419 firms), the rest of the UK (England, Scotland, & Northern Ireland) accounted for 31% of the sample (419 firms), and European firms accounted for 22% of the sample (292 firms). In total, there was 16 different European countries included in the sampling frame.

Once the questionnaire was finalised, 50 companies from the sample received the questionnaire for a pilot study. I contacted those included in the pilot study via telephone and email, to try and increase the response rate. Once the pilot test was completed the data collection began. The collection of data was broken into four stages. Stage 1 consisted of firms in the Republic of Ireland, Stage 2 were Welsh firms, Stage 3 were firms located in the UK (excluding Wales) and Stage 4 consisted of the European firms.

To improve the response rate, I made follow-up phone calls with the recipients of the survey. I called the firms in the sample who had received the questionnaire to assist the firm into responding. I introduced myself and the purpose of the study and asked if the relevant individual had firstly, received the survey and secondly, had the chance to look at the questionnaire. Often the questionnaire ended up in spam folders, so I enquired about, and received the email address of a specific individual (usually the CEO or managing director) and sent the questionnaire to them personally. As people were out of the office due to COVID-19 restrictions I organised calls at specific times and on specific days to speak to the relevant members of management about the questionnaire. I was available by phone, email, and Microsoft Teams to answer any questions about the questionnaire any respondents had.

Once sufficient data had been collected, I was involved in the construction of a report for the funders of the research. The report gave information and statistics about the sample, how the sample frame was constructed and how the data was collected. My role was to provide an insight into the four stages of the data collection, noting any issues or problems we encountered at each stage. Remote working and the language barriers were common reasons why the survey was not completed. We had also received some rich qualitative data in the form of emails from respondents and I was tasked with summarising the qualitative responses we received during

the data collection phase.

I had the opportunity to present my work to the funders of my research, academics, and other research students on numerous occasions during the past twelve months. I presented my progress to representatives from the Selkie Project in December 2020 and July 2021. I also had the opportunity to present my work to members of the Spatial and Regional Economics Research Centre (SRERC) in UCC, in which I received great suggestions which ultimately improved the content of the principal paper.

The data obtained from the REIS was transferred from Google Forms to Microsoft Excel and then to Stata. I created and transformed variables using Stata and estimated my hypothesis using a series of probit models on the Stata statistical analysis computer package. All thoughts and ideas from previous authors have been cited appropriately using the Endnote Online "Cite Them Right- Harvard" style. During my research I successfully completed three postgraduate modules in UCC. I successfully completed PG6016 "An Introduction to Research Integrity, Ethics and Open Science", PG7045 "Advanced Econometrics using Stata", and BU7006 "Quantitative Research Methods".

6.3 Supplemental Documentation

Table A1. Breakdown of respondents by country

Country of Main Establishment	Percentage of Respondents
Republic of Ireland	33%
United Kingdom	47%
Europe	20%

The United Kingdom consists of England (18%), Wales (18%) and Scotland/Northern Ireland (11%). The European category consists of respondents from 9 EU based countries such as France, Denmark, Sweden, the Netherlands, Belgium, Norway, Spain, Italy, and Luxembourg.

Table A2. Matrix of correlations Eq. (1)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(1) In-house R&D	1.000													
(2) External R&D	0.471	1.000												
(3) New-to-Market	0.453	0.363	1.000											
(4) New-to-Firm	0.270	0.233	0.355	1.000										
(5) Process Innovation	0.467	0.354	0.340	0.255	1.000									
(6) Interactive Linkages	0.333	0.428	0.372	0.424	0.438	1.000								
(7) Non-Interactive Linkages	0.186	0.346	0.100	0.186	0.195	0.311	1.000							
(8) Interactive Linkages Squared	0.201	0.329	0.305	0.397	0.336	0.955	0.283	1.000						
(9) Non-Interactive Linkages Squared	0.195	0.372	0.140	0.220	0.191	0.340	0.964	0.311	1.000					
(10) Employment (log)	0.141	0.134	0.177	0.157	0.173	0.096	0.063	0.082	0.100	1.000				
(11) Firm Age	-0.240	-0.152	-0.130	-0.103	-0.125	-0.125	-0.091	-0.064	-0.079	0.306	1.000			
(12) % University Education	0.140	0.160	0.049	-0.017	0.136	0.105	0.270	0.090	0.267	-0.175	-0.246	1.000		
(13) Multi Plant	0.253	0.220	0.234	0.101	0.145	0.219	0.106	0.153	0.113	0.180	-0.114	0.167	1.000	
(14) Received Subsidy	0.084	-0.016	0.007	-0.015	0.142	0.062	0.066	0.062	0.041	-0.052	-0.023	0.069	0.014	1.000

Table A3. Matrix of correlations Eq. (2)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
(1) In-house R&D	1.000																	
(2) External R&D	0.471	1.000																
(3) New-to-Market	0.453	0.363	1.000															
(4) New-to-Firm	0.270	0.233	0.355	1.000														
(5) Process Innovation	0.467	0.354	0.340	0.255	1.000													
(6) Forward Linkages	0.252	0.298	0.390	0.405	0.440	1.000												
(7) Backward Linkages	0.477	0.498	0.327	0.271	0.464	0.639	1.000											
(8) Horizontal Linkages	0.279	0.350	0.364	0.379	0.362	0.606	0.586	1.000										
(9) Public Linkages	0.271	0.355	0.264	0.279	0.300	0.579	0.612	0.633	1.000									
(10) Conferences	0.128	0.274	0.026	0.058	0.167	0.120	0.128	0.199	0.180	1.000								
(11) Scientific Journals	0.315	0.403	0.103	0.214	0.312	0.237	0.301	0.342	0.305	0.645	1.000							
(12) Industry Associations	0.038	0.196	0.105	0.196	0.087	0.123	0.047	0.175	0.160	0.610	0.518	1.000						
(13) Other Data Sources	0.007	0.072	0.070	0.040	-0.150	0.089	0.049	0.089	0.117	-0.005	0.026	0.057	1.000					
(14) Employment (log)	0.141	0.134	0.177	0.157	0.173	0.104	0.084	0.170	0.008	0.017	0.015	0.072	0.156	1.000				
(15) Firm Age	-0.240	-0.152	-0.130	-0.103	-0.125	-0.102	-0.152	-0.101	-0.117	-0.143	-0.113	-0.068	0.220	0.306	1.000			
(16) % University Education	0.140	0.160	0.049	-0.017	0.136	0.139	0.108	0.002	0.058	0.262	0.216	0.195	0.076	-0.175	-0.246	1.000		
(17) Multi Plant	0.253	0.220	0.234	0.101	0.145	0.141	0.211	0.141	0.194	0.066	0.036	0.144	0.072	0.180	-0.114	0.167	1.000	
(18) Received Subsidy	0.084	-0.016	0.007	-0.015	0.142	0.027	-0.020	0.058	0.070	0.016	0.041	0.094	0.047	-0.052	-0.023	0.069	0.014	1.000

Table A4. Multivariate Probit Output from Eq. (1)

Variables	(1) In-house R&D	(2) External R&D	(3) New-to-Market	(4) New-to-Firm	(5) Process Innovation
Interactive Linkages	0.597***	0.444***	0.263**	0.162	0.552***
	(0.122)	(0.119)	(0.116)	(0.120)	(0.126)
Non-Interactive Linkages	-0.139	-0.247	-0.489	-0.290	0.385
	(0.338)	(0.367)	(0.319)	(0.319)	(0.354)
Interactive Linkages Squared	-0.0559***	-0.0350***	-0.0154	-0.000658	-0.0425***
	(0.0124)	(0.0122)	(0.0116)	(0.0124)	(0.0129)
Non-Interactive Linkages Squared	0.0738	0.168	0.149	0.123	-0.111
	(0.104)	(0.118)	(0.101)	(0.100)	(0.116)
Employment (log)	0.195**	0.137	0.155**	0.125	0.184**
	(0.0816)	(0.0839)	(0.0772)	(0.0769)	(0.0827)
Firm Age	-0.0144**	-0.00739	-0.00906	-0.00862*	-0.00307
	(0.00714)	(0.00650)	(0.00574)	(0.00459)	(0.00333)
% University Education	0.229	0.216	-0.0891	-0.437	0.433
	(0.342)	(0.350)	(0.350)	(0.344)	(0.376)
Multi Plant	0.235	0.211	0.290	-0.0391	-0.182
	(0.245)	(0.241)	(0.227)	(0.243)	(0.245)
Received Subsidy	0.169	-0.133	0.0557	-0.0297	0.483**
	(0.281)	(0.279)	(0.250)	(0.267)	(0.245)
Constant	-0.774**	-1.434***	-0.665*	-0.621*	-1.673***
	(0.372)	(0.444)	(0.387)	(0.359)	(0.419)
Observations	154	154	154	154	154
Wald Chi-square (prob)	210.92				
	(0.0000)				
Log pseudolikelihood	-381.29556				

Robust
standard errors
in parentheses
*** p<0.01, **
p<0.05, *
p<0.1

Table A5. Multivariate Probit Output from Eq. (2)

Variables	(1) In-house R&D	(2) External R&D	(3) New-to-Market	(4) New-to-Firm	(5) Process Innovation
Forward Linkages	-0.145	-0.254	0.644**	0.881***	0.861***
	(0.301)	(0.356)	(0.304)	(0.302)	(0.311)
Backward Linkages	1.360***	1.132***	0.173	-0.248	0.777**
	(0.402)	(0.329)	(0.319)	(0.340)	(0.337)
Horizontal Linkages	-0.152	0.110	0.494	0.536*	0.0562
	(0.323)	(0.342)	(0.312)	(0.309)	(0.312)
Public Linkages	-0.311	0.102	-0.210	-0.0469	-0.265
	(0.333)	(0.332)	(0.340)	(0.313)	(0.336)
Conferences	-0.314	0.0725	-0.410	-0.687*	-0.000587
	(0.325)	(0.324)	(0.320)	(0.365)	(0.339)
Scientific Journals	1.066***	0.741**	0.0600	0.472	0.806**
	(0.320)	(0.298)	(0.328)	(0.342)	(0.338)
Industry Associations	-0.219	0.118	0.353	0.624**	-0.232
	(0.316)	(0.311)	(0.292)	(0.287)	(0.299)
Other Data Sources	0.183	0.567	0.192	-0.0931	-2.534***
	(0.715)	(0.631)	(0.608)	(0.566)	(0.857)
Constant	-0.752**	-1.574***	-0.713**	-0.737**	-1.644***
	(0.372)	(0.432)	(0.352)	(0.352)	(0.411)
Observations	154	154	154	154	154
Wald Chi-square (prob)	326.38				
	(0.0000)				
Log pseudolikelihood	-358.88687				

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note: Though not included in Table A5, the natural log of employees, firm age, the percentage of staff with a third level qualification, multi plant organisations and organisations who received a subsidy are included in the estimation.

Table A6. Output from Eq. (1) reporting marginal effects controlling for Country and Type of Firm

VARIABLES	(1) In-house R&D	(2) External R&D	(3) New-to-Market	(4) New-to-Firm	(5) Process Innovation
Interactive Linkages	0.212***	0.132***	0.0885*	0.0513	0.223***
	(0.0447)	(0.0424)	(0.0483)	(0.0467)	(0.0502)
Non-Interactive Linkages	-0.135	-0.106	-0.289**	-0.0744	0.179
	(0.138)	(0.122)	(0.131)	(0.132)	(0.144)
Interactive Linkages Squared	-0.0206***	-0.0104**	-0.00486	0.000848	-0.0168***
	(0.00479)	(0.00439)	(0.00490)	(0.00482)	(0.00509)
Non-Interactive Linkages Squared	0.0564	0.0600	0.0919**	0.0383	-0.0570
	(0.0438)	(0.0387)	(0.0408)	(0.0413)	(0.0475)
Ireland	-0.314**	0.0440	-0.307**	0.176	0.128
	(0.142)	(0.122)	(0.121)	(0.138)	(0.124)
UK	-0.149	0.00809	0.0441	0.255**	0.130
	(0.136)	(0.110)	(0.132)	(0.122)	(0.131)
Academic or Research Institute	0.316***	0.900***	0.166	0.131	-0.0480
	(0.0847)	(0.0272)	(0.241)	(0.258)	(0.239)
Consultancy or Engineering	0.370***	0.995***	-0.0327	0.279	0.114
	(0.118)	(0.00311)	(0.190)	(0.185)	(0.198)
ORE Technology Developer	0.520***	1.000***	0.0210	0.201	0.131
	(0.119)	(0.000370)	(0.185)	(0.182)	(0.199)
Other Firm Type	0.303***	0.933***	0.0632	0.290	-0.131
	(0.0953)	(0.0217)	(0.208)	(0.207)	(0.218)
Observations	154	154	154	154	154

Note: Table A6 and Table A7 also control for the natural log of employees, firm age, the percentage of staff with a third level qualification, multi plant organisations and organisations who received a subsidy. The Europe and Marine operations dummy variables are the reference categories.

Table A7. Output from Eq. (2) reporting marginal effects controlling for Country and Type of Firm

VARIABLES	(1) In-house R&D	(2) External R&D	(3) New-to-Market	(4) New-to-Firm	(5) Process Innovation
Forward Linkages	-0.0292	-0.0759	0.323***	0.286***	0.334***
	(0.138)	(0.119)	(0.111)	(0.110)	(0.115)
Backward Linkages	0.493***	0.386***	0.0124	-0.0618	0.321**
	(0.129)	(0.101)	(0.129)	(0.131)	(0.136)
Horizontal Linkages	-0.108	0.00708	0.194	0.171	0.00966
	(0.130)	(0.115)	(0.133)	(0.120)	(0.129)
Public Linkages	-0.193	-0.000819	-0.123	0.0102	-0.0873
	(0.133)	(0.108)	(0.140)	(0.125)	(0.138)
Conferences	-0.0244	0.0637	-0.157	-0.233*	0.0152
	(0.119)	(0.122)	(0.134)	(0.135)	(0.135)
Scientific Journals	0.425***	0.232**	0.00591	0.152	0.260**
	(0.0920)	(0.116)	(0.137)	(0.138)	(0.128)
Industry Associations	-0.210*	-0.0110	0.121	0.241**	-0.106
	(0.123)	(0.114)	(0.131)	(0.104)	(0.125)
Other Data Sources	0.00555	0.151	0.313	0.00116	-0.578***
	(0.233)	(0.245)	(0.205)	(0.204)	(0.0545)
Ireland	-0.221	0.169	-0.299**	0.150	0.115
	(0.156)	(0.130)	(0.132)	(0.133)	(0.133)
UK	-0.00419	0.128	0.0339	0.207*	0.0622
	(0.145)	(0.116)	(0.138)	(0.124)	(0.149)
Academic or Research Institute	0.322***	0.891***	0.259	0.183	-0.0322
	(0.0777)	(0.0297)	(0.214)	(0.266)	(0.253)
Consultancy or Engineering	0.305**	0.993***	-0.0165	0.285	0.0911
	(0.155)	(0.00466)	(0.196)	(0.189)	(0.217)
ORE Technology Developer	0.512***	0.999***	0.0866	0.231	0.142
	(0.139)	(0.000632)	(0.187)	(0.183)	(0.212)
Other Firm Type	0.322***	0.925***	0.0705	0.265	-0.0475
	(0.0891)	(0.0241)	(0.222)	(0.223)	(0.243)

Table A8. Fractional Probit regression using explanatory variables from Eq. (1) with robust standard errors

Variables	Fraction of Innovation Activity
Interactive Linkages	0.379***
	(0.0708)
Non-Interactive Linkages	-0.141
	(0.185)
Interactive Linkages Squared	-0.0279***
	(0.00664)
Non-Interactive Linkages Squared	0.0692
	(0.0597)
Employment (log)	0.144***
	(0.0482)
Firm Age	-0.00733**
	(0.00293)
% University Education	0.108
	(0.186)
Multi Plant	0.0891
	(0.133)
Received Subsidy	0.0725
	(0.139)
Constant	-0.978***
	(0.217)
Observations	154

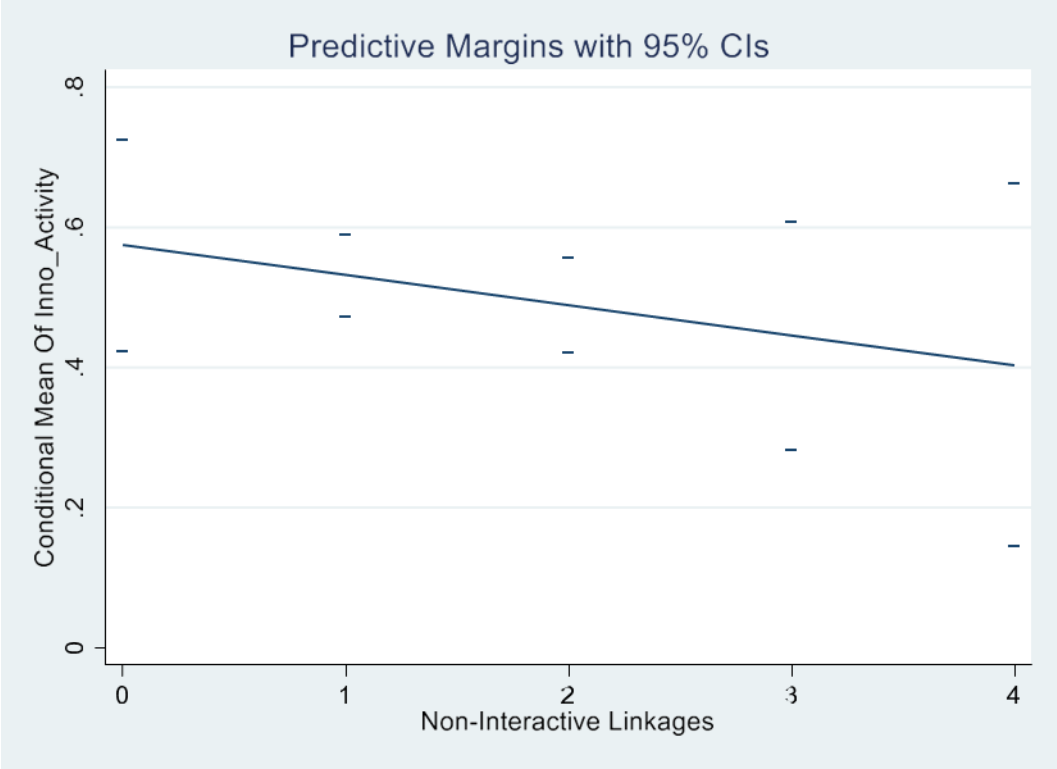
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note: The fraction of innovation variable was constructed by adding the sum of each binary dependent variable and then dividing by the number of dependent variables (i.e., dividing by five to make a fraction).

Table A9. Data Sources used to compile to Sampling Frame

Publicly Available Data Sources used for the Sampling Frame
1. https://www.oceanenergyireland.com/SupplyChain/Database.html
2. https://www.mescg.co.uk/
3. https://www.nweurope.eu/projects/project-search/opin-ocean-power-innovation-network/#tab-7
4. http://www.emec.org.uk/marine-energy/wave-developers/
5. https://www.offshore-energy.biz/companies/?fwp_market_checkboxes=green-marine%2Cmarine-energy%2Cfloating-solar-energy%2Cocean-thermal-energy%2Ctidal-energy%2Cwave-energy%2Csubsea
6. https://www.marineenergywales.co.uk/membership/members-directory/
7. https://www.geoscience.ie/member-companies/
8. http://www.british-hydro.org/bha-directory/
9. https://www.brydencentre.com/partners
10. https://www.uhi.ac.uk/en/contact-us/
11. https://www.ukdirectory.co.uk/manufacturing-and-industry/engineering/marine-engineering-companies/
12. https://www.oceanologyinternational.com/exhibitor-directory/#
13. PRIMRE/Databases/Technology Database | Open Energy Information (openei.org)
14. OEE: the largest global network of ocean energy professionals - Ocean Energy Europe (oceanenergy-europe.eu)
15. Members' Directory | Regen

Fig A1. The returns to innovative activity from non-interactive linkages.



This marginal plot shows the confidence intervals overlap each other, which suggests no significant difference in innovative activity as the number of non-interactive linkages increase. For the afore mentioned reason, this paper rejects Hypothesis 2b.

Innovation and Sustainability Survey

This study is focused on the innovation activity of firms in the offshore renewable energy sector and the potential supply chain for the sector.

This form should take approximately 30 minutes to complete.

ucc

Coláiste na hOllscoile Corcaigh, Éire
University College Cork, Ireland

1. Number Allocated? (Please note: This is the number assigned to the firm in the original email)

_____

2. Do we have permission to follow up about this survey with you?

Mark only one oval.

- ◯ Yes
- ◯ No

Skip to question 3

Information Sheet: Innovation and Sustainability in the Offshore Renewable Energy Sector

Information Sheet

Innovation and Sustainability in the Renewable Energy Sector

Thank you for considering participating in this research project. The purpose here is to explain to you what the work is about and what your participation would involve to enable you to make an informed choice.

The objective of this study is to obtain a better understanding of the innovation activities, knowledge sourcing activities, networks, resources, and performance of firms within the offshore renewable energy sector and its potential supply chain. Should you choose to participate, you will be asked to complete a questionnaire, which will include items on innovation activities, knowledge sourcing activities, networks, resources, policy mix, and performance.

The information you provide may contribute to several academic contributions: research dissertations, industry and policy reports, conference presentations, and peer-reviewed paper publications.

This research is part of the wider Selkie project and has received funding from the European Union's European Regional Development Fund through the Ireland Wales Cooperation Programme (the Selkie project for more details see here:

https://www.selkie-project.eu/).

Participation in this study is completely voluntary. There is no obligation to participate, and should you choose to do so you can refuse to answer specific questions or decide to withdraw from the study. All information you provide will be confidential and your anonymity will be protected throughout the study. IP addresses will not be collected at any point. Data collection will be completed electronically using Google Forms.

You maintain the right to withdraw from the study at any stage up to the point of data submission. At this point, your data will be collated with that of other participants and can no longer be retracted.

The anonymous data will be stored on the University College Cork OneDrive system and subsequently on the UCC server. The data will be stored for a minimum of ten years. The full dataset (i.e. non-anonymized) will only be made available to members of the research team Dr. Frank Crowley, Professor Justin Doran, Dr. Aon Waqas, and Dr. Gordon Dalton and Masters by Research Students working on this project. In addition, access to the anonymous form of the data may be provided to other Ph.D., research assistants or Masters by Research students who may use the data to produce papers and reports. A limited and anonymized dataset (that EXCLUDES potentially identifiable information and commercially sensitive information) may be released publicly in 2022. We do not anticipate any negative outcomes from participating in this study and we do not intend to cause any distress to participants. However, you can choose not to answer questions, or to withdraw from the survey. Should you experience distress arising from participating in the research please contact the research team.

These contact details are provided below.

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

If you have any queries about this research, you can contact me at

aon.waqas@ucc.ie or other team members at frank.crowley@ucc.ie

Justin.doran@ucc.ie

3. Consent Form: Do you consent to participate in this study?

Mark only one oval.

- ◯ Yes *Skip to question 4*
- ◯ No

This project has received funding from the European Union's European Regional Development Fund through the Ireland Wales Cooperation programme

Skip to question 4

Section 1

General information about the enterprise

4. In what country is your main establishment based?

Mark only one oval.

- United Kingdom
- Ireland
- Afghanistan
- Albania
- Algeria
- American Samoa
- Andorra
- Angola
- Anguilla
- Antigua & Barbuda
- Argentina
- Armenia
- Aruba
- Australia
- Austria
- Azerbaijan
- Bahamas, The
- Bahrain
- Bangladesh
- Barbados
- Belarus
- Belgium
- Belize
- Benin
- Bermuda
- Bhutan
- Bolivia
- Bosnia & Herzegovina
- Botswana
- Brazil
- British Virgin Is.
- Brunei

- [ ] Bulgaria
- [ ] Burkina Faso
- [ ] Burma
- [ ] Burundi
- [ ] Cambodia
- [ ] Cameroon
- [ ] Canada
- [ ] Cape Verde
- [ ] Cayman Islands
- [ ] Central African Rep.
- [ ] Chad
- [ ] Chile
- [ ] China
- [ ] Colombia
- [ ] Comoros
- [ ] Congo, Dem. Rep.
- [ ] Congo, Repub. of the
- [ ] Cook Islands
- [ ] Costa Rica
- [ ] Cote d'Ivoire
- [ ] Croatia
- [ ] Cuba
- [ ] Cyprus
- [ ] Czech Republic
- [ ] Denmark
- [ ] Djibouti
- [ ] Dominica
- [ ] Dominican Republic
- [ ] East Timor
- [ ] Ecuador
- [ ] Egypt
- [ ] El Salvador
- [ ] Equatorial Guinea
- [ ] Eritrea
- [ ] Estonia

- [ ] Ethiopia
- [ ] Faroe Islands
- [ ] Fiji
- [ ] Finland
- [ ] France
- [ ] French Guiana
- [ ] French Polynesia
- [ ] Gabon
- [ ] Gambia, The
- [ ] Gaza Strip
- [ ] Georgia
- [ ] Germany
- [ ] Ghana
- [ ] Gibraltar
- [ ] Greece
- [ ] Greenland
- [ ] Grenada
- [ ] Guadeloupe
- [ ] Guam
- [ ] Guatemala
- [ ] Guernsey
- [ ] Guinea
- [ ] Guinea-Bissau
- [ ] Guyana
- [ ] Haiti
- [ ] Honduras
- [ ] Hong Kong
- [ ] Hungary
- [ ] Iceland
- [ ] India
- [ ] Indonesia
- [ ] Iran
- [ ] Iraq
- [ ] Isle of Man
- [ ] Israel

- [ ] Italy
- [ ] Jamaica
- [ ] Japan
- [ ] Jersey
- [ ] Jordan
- [ ] Kazakhstan
- [ ] Kenya
- [ ] Kiribati
- [ ] Korea, North
- [ ] Korea, South
- [ ] Kuwait
- [ ] Kyrgyzstan
- [ ] Laos
- [ ] Latvia
- [ ] Lebanon
- [ ] Lesotho
- [ ] Liberia
- [ ] Libya
- [ ] Liechtenstein
- [ ] Lithuania
- [ ] Luxembourg
- [ ] Macau
- [ ] Macedonia
- [ ] Madagascar
- [ ] Malawi
- [ ] Malaysia
- [ ] Maldives
- [ ] Mali
- [ ] Malta
- [ ] Marshall Islands
- [ ] Martinique
- [ ] Mauritania
- [ ] Mauritius
- [ ] Mayotte
- [ ] Mexico

- [ ] Micronesia, Fed. St.
- [ ] Moldova
- [ ] Monaco
- [ ] Mongolia
- [ ] Montserrat
- [ ] Morocco
- [ ] Mozambique
- [ ] Namibia
- [ ] Nauru
- [ ] Nepal
- [ ] Netherlands
- [ ] Netherlands Antilles
- [ ] New Caledonia
- [ ] New Zealand
- [ ] Nicaragua
- [ ] Niger
- [ ] Nigeria
- [ ] N. Mariana Islands
- [ ] Norway
- [ ] Oman
- [ ] Pakistan
- [ ] Palau
- [ ] Panama
- [ ] Papua New Guinea
- [ ] Paraguay
- [ ] Peru
- [ ] Philippines
- [ ] Poland
- [ ] Portugal
- [ ] Puerto Rico
- [ ] Qatar
- [ ] Reunion
- [ ] Romania
- [ ] Russia
- [ ] Rwanda

- [ ] Saint Helena
- [ ] Saint Kitts & Nevis
- [ ] Saint Lucia
- [ ] St Pierre & Miquelon
- [ ] Saint Vincent and the Grenadines
- [ ] Samoa
- [ ] San Marino
- [ ] Sao Tome & Principe
- [ ] Saudi Arabia
- [ ] Senegal
- [ ] Serbia
- [ ] Seychelles
- [ ] Sierra Leone
- [ ] Singapore
- [ ] Slovakia
- [ ] Slovenia
- [ ] Solomon Islands
- [ ] Somalia
- [ ] South Africa
- [ ] Spain
- [ ] Sri Lanka
- [ ] Sudan
- [ ] Suriname
- [ ] Swaziland
- [ ] Sweden
- [ ] Switzerland
- [ ] Syria
- [ ] Taiwan
- [ ] Tajikistan
- [ ] Tanzania
- [ ] Thailand
- [ ] Togo
- [ ] Tonga
- [ ] Trinidad & Tobago
- [ ] Tunisia

- Turkey
- Turkmenistan
- Turks & Caicos Is
- Tuvalu
- Uganda
- Ukraine
- United Arab Emirates
- United States
- Uruguay
- Uzbekistan
- Vanuatu
- Venezuela
- Vietnam
- Virgin Islands
- Wallis and Futuna
- West Bank
- Western Sahara
- Yemen
- Zambia
- Zimbabwe

5. In what county is your main establishment based?

_____

6. 1.1 Do you operate in more than one country?

Mark only one oval.

- Yes *Skip to question 7*
- No *Skip to question 10*

7. 1.1a In what country is your second largest establishment based?

Mark only one oval.

- United Kingdom
- Ireland
- Afghanistan
- Albania
- Algeria
- American Samoa
- Andorra
- Angola
- Anguilla
- Antigua & Barbuda
- Argentina
- Armenia
- Aruba
- Australia
- Austria
- Azerbaijan
- Bahamas, The
- Bahrain
- Bangladesh
- Barbados
- Belarus
- Belgium
- Belize
- Benin
- Bermuda
- Bhutan
- Bolivia
- Bosnia & Herzegovina
- Botswana
- Brazil
- British Virgin Is.
- Brunei

- [ ] Bulgaria
- [ ] Burkina Faso
- [ ] Burma
- [ ] Burundi
- [ ] Cambodia
- [ ] Cameroon
- [ ] Canada
- [ ] Cape Verde
- [ ] Cayman Islands
- [ ] Central African Rep.
- [ ] Chad
- [ ] Chile
- [ ] China
- [ ] Colombia
- [ ] Comoros
- [ ] Congo, Dem. Rep.
- [ ] Congo, Repub. of the
- [ ] Cook Islands
- [ ] Costa Rica
- [ ] Cote d'Ivoire
- [ ] Croatia
- [ ] Cuba
- [ ] Cyprus
- [ ] Czech Republic
- [ ] Denmark
- [ ] Djibouti
- [ ] Dominica
- [ ] Dominican Republic
- [ ] East Timor
- [ ] Ecuador
- [ ] Egypt
- [ ] El Salvador
- [ ] Equatorial Guinea
- [ ] Eritrea
- [ ] Estonia

- [ ] Ethiopia
- [ ] Faroe Islands
- [ ] Fiji
- [ ] Finland
- [ ] France
- [ ] French Guiana
- [ ] French Polynesia
- [ ] Gabon
- [ ] Gambia, The
- [ ] Gaza Strip
- [ ] Georgia
- [ ] Germany
- [ ] Ghana
- [ ] Gibraltar
- [ ] Greece
- [ ] Greenland
- [ ] Grenada
- [ ] Guadeloupe
- [ ] Guam
- [ ] Guatemala
- [ ] Guernsey
- [ ] Guinea
- [ ] Guinea-Bissau
- [ ] Guyana
- [ ] Haiti
- [ ] Honduras
- [ ] Hong Kong
- [ ] Hungary
- [ ] Iceland
- [ ] India
- [ ] Indonesia
- [ ] Iran
- [ ] Iraq
- [ ] Isle of Man
- [ ] Israel

- [ ] Italy
- [ ] Jamaica
- [ ] Japan
- [ ] Jersey
- [ ] Jordan
- [ ] Kazakhstan
- [ ] Kenya
- [ ] Kiribati
- [ ] Korea, North
- [ ] Korea, South
- [ ] Kuwait
- [ ] Kyrgyzstan
- [ ] Laos
- [ ] Latvia
- [ ] Lebanon
- [ ] Lesotho
- [ ] Liberia
- [ ] Libya
- [ ] Liechtenstein
- [ ] Lithuania
- [ ] Luxembourg
- [ ] Macau
- [ ] Macedonia
- [ ] Madagascar
- [ ] Malawi
- [ ] Malaysia
- [ ] Maldives
- [ ] Mali
- [ ] Malta
- [ ] Marshall Islands
- [ ] Martinique
- [ ] Mauritania
- [ ] Mauritius
- [ ] Mayotte
- [ ] Mexico

- [ ] Micronesia, Fed. St.
- [ ] Moldova
- [ ] Monaco
- [ ] Mongolia
- [ ] Montserrat
- [ ] Morocco
- [ ] Mozambique
- [ ] Namibia
- [ ] Nauru
- [ ] Nepal
- [ ] Netherlands
- [ ] Netherlands Antilles
- [ ] New Caledonia
- [ ] New Zealand
- [ ] Nicaragua
- [ ] Niger
- [ ] Nigeria
- [ ] N. Mariana Islands
- [ ] Norway
- [ ] Oman
- [ ] Pakistan
- [ ] Palau
- [ ] Panama
- [ ] Papua New Guinea
- [ ] Paraguay
- [ ] Peru
- [ ] Philippines
- [ ] Poland
- [ ] Portugal
- [ ] Puerto Rico
- [ ] Qatar
- [ ] Reunion
- [ ] Romania
- [ ] Russia
- [ ] Rwanda

- [ ] Saint Helena
- [ ] Saint Kitts & Nevis
- [ ] Saint Lucia
- [ ] St Pierre & Miquelon
- [ ] Saint Vincent and the Grenadines
- [ ] Samoa
- [ ] San Marino
- [ ] Sao Tome & Principe
- [ ] Saudi Arabia
- [ ] Senegal
- [ ] Serbia
- [ ] Seychelles
- [ ] Sierra Leone
- [ ] Singapore
- [ ] Slovakia
- [ ] Slovenia
- [ ] Solomon Islands
- [ ] Somalia
- [ ] South Africa
- [ ] Spain
- [ ] Sri Lanka
- [ ] Sudan
- [ ] Suriname
- [ ] Swaziland
- [ ] Sweden
- [ ] Switzerland
- [ ] Syria
- [ ] Taiwan
- [ ] Tajikistan
- [ ] Tanzania
- [ ] Thailand
- [ ] Togo
- [ ] Tonga
- [ ] Trinidad & Tobago
- [ ] Tunisia

- Turkey
- Turkmenistan
- Turks & Caicos Is
- Tuvalu
- Uganda
- Ukraine
- United Arab Emirates
- United States
- Uruguay
- Uzbekistan
- Vanuatu
- Venezuela
- Vietnam
- Virgin Islands
- Wallis and Futuna
- West Bank
- Western Sahara
- Yemen
- Zambia
- Zimbabwe

8. 1.1b How many branches/plants do you have?

_____

9. 1.1c If your firm is a multi-national, in how many countries are you operating? Also provide the names of the countries

_____

10. 1.2 In what year was your firm established?

_____

11. 1.3 Number of Employees when established?

_____

12. 1.3a What percentage of employees in your firm have a third level qualification (a qualification from a Higher Education Institution i.e. a university, college)?

_____

13. 1.3bWhat was your organisation's average number of employees in2017?

_____

_____

_____

_____

_____

14. 1.3cWhat was your organisation's average number of employees in 2019?

_____

15. 1.4 What situation best describes your current situation:

Check all that apply.

- ☐ You are an offshore energy company
- ☐ You could be an offshore energy company in the future
- ☐ You are a supplier to the offshore energy sector
- ☐ You could be a supplier to the offshore energy sector in the future
- ☐ You are a consultant for the offshore energy sector
- ☐ You could be a consultant to the offshore energy sector in the future

Other: ☐ _____

16. 1.5 If we were to categorize your organisation's involvement in the offshore renewable energy sector which of the following categories would apply? Tick all that apply.

Check all that apply.

- [ ] Asset owner operator/utility
- [ ] Project/asset developer (from planning to installation)
- [ ] Technology supplier (devices or supply chain)
- [ ] Service or consultancy

Other: [ ] _____

17. 1.5a Your organisation is active in which of these energy sectors? If your firm is active in more than one then tick all that apply. Also indicate stage of following energy sector where TRL refers to technological readiness level:

Check all that apply.

	Yes	No	Early R&D Phase (TRL 1-5)	Demonstration Phase (TRL 6-9)	Early Commercial Sales & Scale up	Established Sales & Market Share
Onshore wind	☐	☐	☐	☐	☐	☐
Floating offshore wind	☐	☐	☐	☐	☐	☐
River or estuary in–Stream Energy	☐	☐	☐	☐	☐	☐
Offshore wind Wave energy Solar	☐	☐	☐	☐	☐	☐
Salinity gradient energy	☐	☐	☐	☐	☐	☐
Biomass	☐	☐	☐	☐	☐	☐
Ocean thermal energy	☐	☐	☐	☐	☐	☐
Tidal (current) energy	☐	☐	☐	☐	☐	☐
Tidal (barrage) energy	☐	☐	☐	☐	☐	☐

18. 1.6 How long have your organisation been involved in the offshore renewable energy sector? (answer in years)

19. 1.7 Can you share your thoughts on why (or if) you see unique reasons why offshore energy should play a role in Ireland/Wales/UK/Europe's energy market into the future?

20. 1.8 In order for your company to start supplying products/services, or to improve supply into the offshore renewable energy sector, what capability would you need to add to your company? (please write the most important one first)

21. 1.9 What are the current external barriers impacting your company selling products into the offshore renewable energy sector? (tick all that may apply)

Check all that apply.

- [ ] Lack of financial support and assistance from traditional sources (like banks/credit unions)
- [ ] Initial set up cost
- [ ] Directors and/or shareholders not interested in renewable energy
- [ ] Lack of knowledge
- [ ] Lack of University support and engagement with the sector
- [ ] Our products not competitive in renewables sector
- [ ] Not enough government support and engagement with the sector
- [ ] Lack of government subsidies
- [ ] Other: _____

22. 1.10 Which of the following university R&D support activities would help you to increase supply into the offshore renewable energy sector (tick all that may apply):

Check all that apply.

- [ ] Local Industry-University collaborative R&D knowledge networks (for example Selkie)
- [ ] Cross border Industry-University networks consisting of Ocean Energy SME's and supply chain companies
- [ ] Multi use engineering tools
- [ ] Sensor Optimisation and Data Analysis
- [ ] Physical and Numerical offshore renewable Array Modelling
- [ ] GIS Techno-Economic Models
- [ ] Business and commercialization plans
- [ ] Access to economic advice
- [ ] Scenario planning advice
- [ ] Other: _____

23. 1.11 What was your organisation's total turnover for 2017?

24. 1.11a What was your organisation's total turnover for 2019?

25. 1.11b Which activity or product/service represents the largest proportion of your annual sales 2019?' (Please still report the activity or product/service even if it is not related to the offshore renewable sector)

26. 1.12 Approximately, what was the percentage of turnover (to understand regions, have a look at the image below) in 2019 from:

Check all that apply.

	0 to 25%	26% to 50%	51% to 75%	76% to 100%
Customers located in Ireland (yellow colored region)	☐	☐	☐	☐
Customers located in Ireland (green colored region)	☐	☐	☐	☐
Customers located in Wales (yellow colored region)	☐	☐	☐	☐
Customers located in Wales (green colored region)	☐	☐	☐	☐
Customers located in rest of UK	☐	☐	☐	☐
Customers located in other EU or EFTA (European Free Trade Association)	☐	☐	☐	☐
Customers located in countries not included above	☐	☐	☐	☐

Section 2

Goods/Service Innovation

27. Do you think your organisation have been involved in any innovation activities from 2017 to 2019? (Examples include: research and development activities, the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations).

Mark only one oval.

- ◯ Yes *Skip to question 28*
- ◯ No *Skip to question 38*

28. 2.1 During the three years 2017 to 2019, did your organisation introduce Goods Innovation?

Goods Innovation: is bought by and then owned by a customer. A tangible product has one or more functions and it can be seen and touched. Thus, Goods innovation commonly improves functionality or physical appearance.

Mark only one oval.

- ◯ Yes *Skip to question 29*
- ◯ No *Skip to question 30*

29. 2.1a Who developed these Goods innovations? (Select all that apply)

Check all that apply.

- ☐ Enterprise by itself
- ☐ Enterprise together with other enterprises or organisations
- ☐ Enterprise by adaption or modifying goods or services originally developed by other enterprises or organisations
- ☐ Other enterprises/institutions

111

introduce Service Innovation?

Service Innovation: is an intangible process that is performed for a customer. Thus, service innovation commonly focuses on improving attractiveness (marketing) or performance (faster, cheaper, more consistent).

Mark only one oval.

- ◯ Yes *Skip to question 31*
- ◯ No *Skip to question 32*

31. 2.2a Who developed these service innovations? (Select all that apply)

Check all that apply.

- ☐ Enterprise by itself
- ☐ Enterprise together with other enterprises or organisations
- ☐ Enterprise by adaption or modifying goods or services originally developed by other enterprises or organisations
- ☐ Other enterprises/institutions

32. 2.3 Were any of your product innovations (goods or services) during the three years 2017 to 2019: New to your market (i.e. your enterprise introduced a new or significantly improved product onto your market before your competitors (it may have already been available in other markets))

Mark only one oval.

- ◯ Yes *Skip to question 33*
- ◯ No *Skip to question 34*

33. 2.3a New to market % of turnover: 0-100

_____

34. 2.4 Were any of your product innovations (goods or services) during the three years 2017 to 2019: Only new to your enterprise

Mark only one oval.

- ◯ Yes *Skip to question 35*
- ◯ No *Skip to question 36*

35. 2.4a New to enterprise but not new to the market % of turnover: 0-100

_____

36. 2.5 Percentage of goods and services unchanged or only marginally modified%: 0-100

_____

37. 2.6 How did the new or improved products, introduced during 2017 to 2019 meet your enterprises expectations by the end of 2019? (Dropdown – Select one option)

Mark only one oval.

- ◯ Expectations were exceeded
- ◯ Expectations were adequately met
- ◯ Expectations were not met at all
- ◯ Too early to assess

Skip to question 39

Non-Innovators

Section 3

38. 3.1 If your enterprise had no innovation activity during 2017 to 2019, please indicate why it has not been necessary or possible to innovate.

Mark only one oval per row.

	Yes	No
No need due to previous innovations	◯	◯
No need due to market conditions	◯	◯
Factors constraining innovation	◯	◯
Other	◯	◯

Skip to question 76

Section 3

Product, process, organisational and marketing innovations

39. 3.1 During the three years 2017 to 2019, did your enterprise introduce:

Mark only one oval per row.

	Yes	No
Methods for producing goods or providing services (including methods for developing goods or services)	◯	◯
Logistics, delivery, or distribution methods	◯	◯
Methods for information processing or communication	◯	◯
Methods for accounting or other administrative	◯	◯

40. 3.1a Who developed these process innovations? (Select all that apply)

Check all that apply.

- [ ] Enterprise by itself
- [ ] Enterprise together with other enterprises or organisations
- [ ] Enterprise by adapting or modifying processes originally developed by other enterprises or organisations
- [ ] Other enterprise/institutions

41. 3.1b How did the new or improved processes, introduced from 2017 to 2019, meet your enterprises expectations by the end of 2019? (Dropdown – Select one option)

Mark only one oval.

- ◯ Expectations were exceeded
- ◯ Expectations were adequately met
- ◯ Expectations were not met at all
- ◯ Too early to assess

42. 3.2 During the three years 2017 to 2019, did your enterprise introduce:

Mark only one oval per row.

	Yes	No
Business practices for organizing procedures	◯	◯
Methods of organizing external relations with other firms		
Methods of organizing work responsibility, decision making or human resource management	◯	◯

43. 3.2a Who developed these organisational innovations? (Select all that apply)

Check all that apply.

- [ ] Enterprise by itself
- [ ] Enterprise together with other enterprises or organisations
- [ ] Enterprise by adapting or modifying processes originally developed by other enterprises or organisations
- [ ] Other enterprise/institutions

44. 3.2b How did the new or improved organisational innovations, introduced from 2017 to 2019, meet your enterprises expectations by the end of 2019? (Dropdown – Select one option)

Mark only one oval.

- ◯ Expectations were exceeded
- ◯ Expectations were adequately met
- ◯ Expectations were not met at all
- ◯ Too early to assess

45. 3.3 During the three years 2017 to 2019, did your enterprise introduce:

Mark only one oval per row.

	Yes	No
Marketing methods for promotion, packaging, pricing, product placement or after sales services	◯	◯

46. 3.3a Who developed these marketing innovations? (Select all that apply)

Check all that apply.

- [ ] Enterprise by itself
- [ ] Enterprise together with other enterprises or organisations
- [ ] Enterprise by adapting or modifying processes originally developed by other enterprises or organisations

43. 3.2a Who developed these organisational innovations? (Select all that apply)

Check all that apply.

- [ ] Enterprise by itself
- [ ] Enterprise together with other enterprises or organisations
- [ ] Enterprise by adapting or modifying processes originally developed by other enterprises or organisations
- [ ] Other enterprise/institutions
- [ ] Other enterprise/institutions

47. 3.3b How did the new or improved marketing innovation, introduced from 2017 to 2019, meet your enterprises expectations by the end of 2019? (Dropdown – Select one option)

Mark only one oval.

- Expectations were exceeded
- Expectations were adequately met
- Expectations were not met at all
- Too early to assess

Section 4

Ongoing or abandoned innovation activities for product, process, organisational and marketing innovations

48. 4.1 During 2017 to 2019 did your enterprise have any innovation activities that did not result in a product, process, organisational, or marketing innovation because the activities were:

Check all that apply.

- [ ] Abandoned or suspended before completion
- [ ] Still ongoing end 2019

Section 5

Innovation activities and expenditure for product and process innovations

49. 5.1 During the three years 2017 to 2019, did your enterprise engage in In-House R&D activities?

Mark only one oval.

- Yes *Skip to question 50*
- No *Skip to question 52*

50. 5.1a Did your organisation perform R&D during the three years 2017 to 2019?

Mark only one oval.

- ◯ Continuously
- ◯ Occasionally

51. 5.1b How much did your organisation spend (to the nearest € '000) on In-House R&D activities in 2019 only?

_____

Skip to question 53

52. 5.1a Why not?

_____

53. 5.2 During the three years 2017 to 2019, did your organisation engage in External R&D activities?

Mark only one oval.

- ◯ Yes *Skip to question 54*
- ◯ No *Skip to question 55*

54. 5.2a How much did your organisation spend (to the nearest € '000) on External R&D activities in 2019 only?

_____

Skip to question 56

55. 5.2a Why not?

_____

56. 5.3 During the three years 2017 to 2019, did your organisation engage in any other innovation activities? (including design, training, marketing and other relevant activities)

Mark only one oval.

- ◯ Yes *Skip to question 57*
- ◯ No *Skip to question 62*

57. 5.3a How much did your organisation spend (to the nearest € '000) on acquisition of machinery, equipment, software & buildings activities in 2019 only?

_____

58. 5.3b How much did your organisation spend (to the nearest € '000) on acquisition of existing knowledge from other enterprises or institutions activities in 2019only?

_____

59. 5.3c How much did your organisation spend (to the nearest € '000) on testing activities in 2019only?

_____

60. 5.3d How much did your organisation spend (to the nearest € '000) on all other innovation activities (including design, training, marketing and other relevant activities) in 2019only?

_____

61. 5.3e How much did your organisation spend (to the nearest € '000) on total expenditures on innovation activities in 2019 only?

_____

Organisation and CEO educational background and experience

62. 5.4 Please specify the number of female staff in each category involved in in- house R&D during2019

Mark only one oval per row.

	0 to 20%	21% to 40%	41% to 60%	61% to 80%	81% to 100%
PhD Qualified Researcher					
Other Researchers					
Technicians Support Staff					
Others					

63. 5.5 As staff may share their time between R&D and non-R&D activities, please estimate the average percentage of time spent on R&D for each of these categories of staff.

Mark only one oval per row.

	0 to 20%	21% to 40%	41% to 60%	61% to 80%	81% to 100%
PhD Qualified Researcher					
Other Researchers					
Technicians Support Staff					
Others					

64. 5.6 Recruitment of Researchers: At what level of qualification are you likely to increase R&D personnel(researchers) over the period 2021 - 2026? If yes, then please indicate the importance level of these(1 not important at all to 5 most important)

Check all that apply.

	Yes	No	1	2	3	4	5
Diploma	☐	☐	☐	☐	☐	☐	☐
Bachelor's Degree	☐	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐	☐
Master's Degree PhD	☐	☐	☐	☐	☐	☐	☐

65. 5.7 What is the highest level of education achieved by the CEO or highest- ranking officer of the firm (Select one)

Mark only one oval.

- ◯ Secondary School Graduate
- ◯ Associates Degree/ Diploma
- ◯ Bachelors Degree (BA, BSc)
- ◯ Masters Degree (MA, MSc, MEng, MBA)
- ◯ Doctorate Degree (PhD)

66. 5.8 Which of these options best represents the discipline of the CEO's (highest ranked officer) education?

Mark only one oval.

- ◯ Technology based (Engineering or Science/STEM)
- ◯ Management related (Management, Finance, Economics, Commerce, Accounting)
- ◯ Others (Arts, Design, History, Geography, Politics)

67. 5.9 Which of the options below best represents the CEO's (or highest-ranking officer of the firm) area of prior work experience (Select all that apply)

Check all that apply.

- [ ] Research and Development
- [ ] Sales/Marketing
- [ ] Production
- [ ] Planning/Strategy
- [ ] Other areas

Section 6

Co-operation for product and process innovations

68. 6.1 During the three years 2017 to 2019 did your organisation co-operate with other enterprises or organisations?

Check all that apply.

- [ ] On R&D
- [ ] On other innovation activities excluding R&D
- [ ] On other business activities

69. 6.2 Please indicate the type of innovation co-operation partner (s) (Kindly, to understand regions, have a look at the image below) by location. (select all that apply)

Check all that apply.

	Ireland (yellow colored region)	Ireland (green colored region)	Wales (yellow colored region)	Wales (green colored region)	Rest of UK	EFTA or other EU
Consultants, commercial labs or private research institutions	☐	☐	☐	☐	☐	☐
Suppliers of equipment, materials, components or software	☐	☐	☐	☐	☐	☐
Enterprises that are your competitors	☐	☐	☐	☐	☐	☐
Other enterprises	☐	☐	☐	☐	☐	☐
Enterprises within your enterprise group	☐	☐	☐	☐	☐	☐
Universities or higher education institutions	☐	☐	☐	☐	☐	☐
Government or public research institutes	☐	☐	☐	☐	☐	☐
Clients or customers from the public sector	☐	☐	☐	☐	☐	☐

Clients or customers
from

The private sector

☐ ☐ ☐ ☐ ☐ ☐

Non–profit

Section 7

Green Innovation

Green innovation consists of new or improved products (goods or services) and processes (including organizational changes) that differ significantly from the products or processes previously on offer or in use and which—with or without intent—lead to environmental improvements compared to

70. From the above definition, do you think your organisation has been involved in any green innovation activities?

Mark only one oval.

◯ Yes *Skip to question 72*

◯ No *Skip to question 76*

71. Does your organisation have any of the following ISO Certifications (Check all that apply).

Check all that apply.

- ☐ ISO/TC 265, Carbon dioxide capture
- ☐ ISO 50001 on energy management systems
- ☐ ISO 14001 for environmental management
- ☐ ISO 14064 on the quantification and reporting of greenhouse gases
- ☐ ISO 14025 on environmental labels and declarations
- ☐ ISO/IEC 13273-1:2015 Energy efficiency and renewable energy sources

Other: ☐ _____

72. 7.1During the years 2017–2019, did your organisation introduce a product or process innovation with any of the following environmental benefits?

Check all that apply.

	Yes	No
Reduced material use per unit of output	☐	☐
	☐	☐
Reduced energy use per unit of output	☐	☐
	☐	☐
	☐	☐
Reduced CO2 footprint(totalCO2 production) of your enterprise	☐	☐
Replaced materials with less–polluting or–hazardous substitutes		

73. 7.2 During the period from 2017 to 2019, did your organisation introduce green innovation due or in response to the factors listed below. If yes, please indicate the level of importance (1 not important at all to 5 being the most important)

Check all that apply.

	Yes	No	1	2	3	4	5
Existing environmental regulations or taxes on pollution?	☐	☐	☐	☐	☐	☐	☐
Environmental regulations or taxes that you expected to be introduced in the next five years?	☐	☐	☐	☐	☐	☐	☐
Availability off government grants, subsidies, or other financial incentives for green innovation?	☐	☐	☐	☐	☐	☐	☐
Current or expected market demand for products or processes with reduced environmental impacts?	☐	☐	☐	☐	☐	☐	☐
Voluntary codes or agreements for environmental good practices within your sector?	☐	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐	☐

standards?

Supplier ☐ ☐ ☐ ☐ ☐ ☐ ☐

pressure?							
Competitor pressure?	☐	☐	☐	☐	☐	☐	☐
Personal reasons?	☐	☐	☐	☐	☐	☐	☐
Associated technological advances?	☐	☐	☐	☐	☐	☐	☐
Positive experience Of previous green innovation within the company?	☐	☐	☐	☐	☐	☐	☐
Intention to improve	☐	☐	☐	☐	☐	☐	☐

74. 7.3 Between 2017 and 2019, did you encounter any of the following problems in adopting green innovations? if yes than please indicate importance level (1 not important at all to 5 most important)

Check all that apply.

	Yes	No	1	2	3	4	5
Difficulties in obtaining financing	☐	☐	☐	☐	☐	☐	☐
Start up problems With the use of technology for green innovations	☐	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐	☐
Inadequate skills	☐	☐	☐	☐	☐	☐	☐
Inadequate infrastructure	☐	☐	☐	☐	☐	☐	☐
Problems with obtaining permits	☐	☐	☐	☐	☐	☐	☐
Repeated malfunction Of product or process innovations	☐	☐	☐	☐	☐	☐	☐

75. 7.4 Which of the following types of support is likely to be the most relevant for your organisation's investments in green innovation over the next five years? if yes than please indicate importance level (1 not important at all to 5 most important)

Check all that apply.

	Yes	No	1	2	3	4	5
Financial support from government	☐	☐	☐	☐	☐	☐	☐
Financial support from non-governmental sources	☐	☐	☐	☐	☐	☐	☐
Non–financial support from any sources	☐	☐	☐	☐	☐	☐	☐
Affordable technical assistance	☐	☐	☐	☐	☐	☐	☐
Ease of obtaining a permit	☐	☐	☐	☐	☐	☐	☐
Information support	☐	☐	☐	☐	☐	☐	☐
Collaboration with any	☐	☐	☐	☐	☐	☐	☐

Section 8

Factors hampering innovation activities

76. 8.1 During the three years 2017 to 2019, how important were the following factors in hampering your organisation's decision to start innovation activities, or its execution of innovation activities?

Mark only one oval per row.

	High	Medium	Low	Not a constraint
Lack of internal finance for innovation				
Lack off credit or private equity				
Difficulties in obtaining public grants/subsidies				
Costs too high				
Lack of skilled employees within your enterprise				
Lack of collaboration partners				
Lack of access to external				
Uncertain market demand for your ideas				

Section 9

Intellectual property rights

77. 9.1 During the three years 2017 to 2019, did your organisation do any of the below activities: Please indicate the importance of each activity to your firm's performance (1 not important at all, to 5 most important)

Mark only one oval per row.

	Yes	No	1	2	3	4	5
Apply for a patent							
Register an industrial design right							
Apply for a trademark							
Claim copyright							
Use trade secrets							
Establish a market lead time							

Section 10

Networking

78. 10.1 Doesyourorganisationcurrentlymaintainrelationswithotherorganisations with the aim of exchanging or acquiring knowledge to support innovative activities? These organisations may be foreign or domestic, Universities, Industry, government etc.

Mark only one oval.

- Yes *Skip to question 79*
- No *Skip to question 82*

79. 10.1a List the five most important organisations

80. 10.1b Please indicate the importance level (1 not important at all to 5 most important) of the above-mentioned networking organisation

Mark only one oval per row.

	1	2	3	4	5
Organisation 1	◯	◯	◯	◯	◯
	◯	◯	◯	◯	◯
Organisation 2	◯	◯	◯	◯	◯
	◯	◯	◯	◯	◯
Organisation 3	◯	◯	◯	◯	◯
	◯	◯	◯	◯	◯

81. 10.2 Please explain your organisation relationships with other network members

Skip to question 83

82. 10.2 What are constraints or factors for networking that inhibit innovation?

Check all that apply.

- [ ] Lack of time
- [ ] lack of funding
- [ ] Resistance to change
- [ ] Lack of key competences
- [ ] Hindering government regulations
- [ ] Costly

Other: [ ] _____

Skip to question 91

44. 10.3 Concerning the improvement of strategic linkages in renewable energies in the country your firm is based between
(a) Higher Education Institutions (Universities, College, Institutes of Technology) (b) Industry and (c) Government, there is:

Mark only one oval per row.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Need of Organizing and delivering training sessions					
Increased provision of grants and subsidies					
Joint participation in conferences and seminars					
Committees with re presentation across government--industry—HEI's					
Joint curriculum designs and evaluations					
Increased provision of research fellowships and internship programs					
Joint research work and publications					
Support of HEIs activities and infrastructure					
A collaborative research agreement should be put in place					
The government should set out a plan for addressing the specific needs of industry and HEIIs					
Evidence--based practices should be put in place					
Debates with respect to the crucial issues					

44. 10.4 Concerning the barriers of strategic linkages in renewable energies in the country your firm is based between (a) Higher Education Institutions (Universities, College, Institutes of Technology) (b) Industry and (c) Government, there is:

Mark only one oval per row.

	Strongly Disagree				
Inability to formulatea workingplan among the actors	◯	◯	◯	◯	◯
Absence of a common operating goals and lack of common understanding	◯	◯	◯	◯	◯
Lack of co-ordination	◯	◯	◯	◯	◯
Lack of knowledge of industrial needs by HEI's	◯	◯	◯	◯	◯
Poor experience of HEI's in commercializing research and IP registration	◯	◯	◯	◯	◯
Absence of decision--making, particularly to foster partnership	◯	◯	◯	◯	◯
Delay indecisions finalizedfrom government partners	◯	◯	◯	◯	◯
Absence of mechanisms and links to facilitate establishment of linkages	◯	◯	◯	◯	◯
Absence of research--based evidence programs	◯	◯	◯	◯	◯
Lack of technological resources for strengthening the weak partnership	◯	◯	◯	◯	◯
Risk factors and societal problems	◯	◯	◯	◯	◯
Needs and demands of various	◯	◯	◯	◯	◯

Partiesnotfulfilled

Disagree	Neutral	Agree	Strongly Agree

Lack of interest by industry to collaborate

45. 10.5 Which of the following data sources are considered for your firm's innovation? Tick all that apply

Check all that apply.

- [ ] Conferences, trade fairs, exhibitions
- [ ] Scientific journals and trade/technical publications
- [ ] Professional and industry associations
- [ ] Other: _____

46. 10.6 Most important partner is:

Mark only one oval.

- ◯ Local *Skip to question 87*
- ◯ Foreign *Skip to question 88*

47. 10.6a How far (in kilometer) is most important local partner?

Mark only one oval.

- ◯ 0 to 50
- ◯ 51 to 100
- ◯ 100 to 200
- ◯ Above

48. 10.7 How did the relationship with your organisations most important partner first come into being?

Mark only one oval.

- By coincidence or by an informal meeting *Skip to question 89*
- As a result of deliberate targeting of this particular partner *Skip to question 90*

49. 10.7a If this relationship emerged by coincidence or through an informal meeting was it the result of:

Mark only one oval.

- ◯ A casual encounter at a conference
- ◯ Trade fair
- ◯ Congress or other work-related event
- ◯ The result of personal contacts or meeting outside of work (e.g. at a social event)
- ◯ Other: _____

Skip to question 91

50. 10.7a If this relationship had been purpose-built, was the result of:

Mark only one oval.

- ◯ As a result of in-house research
- ◯ Following advice from customers or suppliers
- ◯ Following advice from consultants or external researchers
- ◯ Following advice from others with no business relationship to the firm
- ◯ Other: _____

Section 11

Policy mix characteristics for low-carbon innovation

51. 11.1 During the three years 2016 to 2019, did your enterprise receive any public financial support for acquiring knowledge or innovation activities from the following levels of government? (Check all that apply)

Check all that apply.

- ☐ Local
- ☐ Regional
- ☐ National
- ☐ European Level

52. 11.2 Concerning the increase in renewable power generation in the country your firm is based, there is:

Mark only one oval per row.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
A broad consensus across all political parties					
A firm political will					
Strong support from the Irish/UK/European government					
Strong support from municipalities					
Important flanking policies are missing that push the expansion of renewables (e.g., on power market design or for grid expansion)					
There is a continuous exchange of information between policy makers and manufacturers					
Policy makers are well informed about developments in the renewable energy branch					
Emerging problems are spotted early on by policy makers					
The search for solutions to problems takes place in a constructive exchange between policy makers and representatives of the renewable energy branch					
The responsibilities for the renewable energy branch are clearly defined for the relevant ministries					

COVID-19 effect 2020 targets

Section 12

53. 12.1 What was % growth or decline on following activities during 2020?

Check all that apply.

	N/A	Growth (0 to 50%)	Growth (50% to 100%)	Growth (over 100%)	Decline (0 to 50%)	Decline (50% to 100%)
In--House R&D	☐	☐	☐	☐	☐	☐
External R&D	☐	☐	☐	☐	☐	☐
Acquisition machinery, equipment, software & buildings	☐	☐	☐	☐	☐	☐
Acquisition of existing knowledge from other enterprises orinstitutions	☐	☐	☐	☐	☐	☐
Spending on testing	☐	☐	☐	☐	☐	☐
All other innovation activities(including design, training, marketing and other relevant activities)	☐	☐	☐	☐	☐	☐
Total expenditures on innovation activities	☐	☐	☐	☐	☐	☐
Decreased/increased annual sales	☐	☐	☐	☐	☐	☐
Proportion of establishment's online sales out of total sales	☐	☐	☐	☐	☐	☐
Domestic sales	☐	☐	☐	☐	☐	☐
Sales on Credit	☐	☐	☐	☐	☐	☐
Purchase on Credit	☐	☐	☐	☐	☐	☐
Currentproportion of workforce working remotely	☐	☐	☐	☐	☐	☐

Total number of workers

Liquidity or cash flow availability	☐	☐	☐	☐	☐	☐
Loans from banking financial	☐	☐	☐	☐	☐	☐
Loans from non-banking financial institutions	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐	☐

Section 13

Comments and Measuring Administrative Burden

54. 13.1 Additional Information: Please add any comments that would help us to interpret the data provided and avoid further enquiries: (1000 characters)

55. 13.2 What prompted your engagement?

56. 13.3 How many minutes did it take you to collect the data for this form? (0-999)

57. 13.4 Eircode or Postcode (optional)

_____

58. 13.5 Please indicate which option best describes the main respondent's position:

Mark only one oval.

- ◯ Owner
- ◯ President, Executive Director, or CEO
- ◯ Chief Financial, Chief Operational Officer (CFO/COO)
- ◯ Operational or plant manager
- ◯ Sales or marketing manager
- ◯ Accountant
- ◯ Lawyer
- ◯ Other Administrative
- ◯ Other Management
- ◯ Other: _____

Survey Feedback

59. How would you rate this survey, in terms of:

Mark only one oval per row.

	Very Dissatisfied	Not Satisfied	Neutral	Satisfied	Very Satisfied
Comprehension	◯	◯	◯	◯	◯
Logic and flow	◯	◯	◯	◯	◯
Length and adherence	◯	◯	◯	◯	◯

60. What questions did you think were most difficult to answer? (please mention question number)

61. Any Suggestion?

Thank You for giving your valuable insight

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