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Greenagers out in Town – Collaboration Patterns of Renewable Energy Innovators

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Abstract

We analyze if firms engaged in 'green' innovation (operationalized as innovation in renewable energy) display different collaboration patterns compared to otherwise similar 'non-green' companies. This research question is triggered by the presumption that renewable energy (RE) innovations requires firms to source in knowledge and other resources in a distinct manner, since they are—to a higher extent than other types of innovations—interwoven with other parts of the system and draw upon a broader range of different knowledge bases. We use data from the 2014 special section of the CIS survey in Denmark, which included questions on energy innovation. Our dataset contains 2.087 firms, of which 285 have such activities. Frequency and regression analyses test hypotheses derived from earlier literature. Additionally, a qualitative single-case study illuminates some of the mechanisms that were only indicative in the quantitative analysis. We find that RE innovators are notably more likely to engage in collective innovation activities than non-RE innovators. But we find, counter to expectations, that their collaboration patterns in terms of which actors they interact with are almost exactly as in other firms, only with higher frequency. We further find weak correlation between firm's cooperation diversity and innovative performance, particularly for RE innovation. We ascribe this to the long time-lags between product innovation and market penetration in renewable energy.

Jelcodes:O31,O32

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ABSTRACT

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We use data from the 2014 special section of the CIS survey in Denmark, which included questions on energy innovation. Our dataset contains 2.087 firms, of which 285 have such activities. Frequency and regression analyses test hypotheses derived from earlier literature. Additionally, a qualitative single-case study illuminates some of the mechanisms that were only indicative in the quantitative analysis.

We find that RE innovators are notably more likely to engage in collective innovation activities than non-RE innovators. But we find, counter to expectations, that their collaboration patterns in terms of which actors they interact with are almost exactly as in other firms, only with higher frequency. We further find weak correlation between firm’s cooperation diversity and innovative performance, particularly for RE innovation. We ascribe this to the long time-lags between product innovation and market penetration in renewable energy.

JEL Classification: O31, O32, Q4, L26

Keywords: green innovation, Renewable energy, collaboration capabilities, innovation networks, innovation survey.

1 Introduction

Firms increasingly pursue innovation and entrepreneurship in interactions with external partners in the institutional system in which they are embedded (Powell et al., 1996, Lundvall, 1992, 1993, Audretsch et al., 2011). This paper is concerned with the way this networking is configured, and what is the outcome. We particularly focus on green innovations and entrepreneurship[1] in renewable energy (RE). Our main research question concerns if firms engaged in RE innovation display different collaboration patterns with external partners compared to otherwise similar 'non-RE' companies? We furthermore investigate if there are any patterns in the outcome from collaboration (or other input factors).

These questions are triggered by the presumption that in the context of RE, firms are required to source in knowledge, capabilities and other resources in a distinct manner. Building on previous literature (eg. van Kleef and Roome, 2007; De Marchi and Grandinetti, 2013; Cainelli et al., 2015; Cuerva et at., 2014; Del Rio et al., 2013, Ghisette et al., 2015, De Marchi, 2012)We justify this presumption with three main arguments. First, green innovations are often interwoven with other parts of the system. In renewables, for example, integration with other elements of the energy system is essential for solutions to be successfully taken to market. (Foray and Grübler, 1996, Rennings and Rammer, 2009, De Marchi and Grandinetti, 2013, Horbach et al., 2013). Second, RE innovations involve relatively more complex knowledge bases compared to most other innovations (De Marchi and Grandinetti, 2013, De Marchi, 2012, Marin et al., 2015). Finally, innovations in renewable energy generally involve higher capital costs until they reach a commercial level, which could indicate the need to engage with a multiple of actors for mobilizing necessary resources (Marin et al., 2015). Although much less studied in previous literature, we suggest that that these collaboration patterns also impact firm performance. Some of the above-mentioned literature started addressing these problem areas, but there is need for deeper understanding.

Whereas previous literature almost solely uses quantitative data, we use both quantitative and qualitative data, as our initial quantitative analyses left us with unresolved questions regarding the background and motivations for firms to engage in collaboration. The quantitative data stems from a special section of the CIS survey in Denmark concerning energy related innovation activities. Our dataset contains 2.087 firms, of which 285 indicate to be engaged in research or innovation activities related to the production, distribution, storage or consumption of energy. Our qualitative data consist of a single case study, which naturally does not provide information meant for

[1] In this paper we adopt a view of entrepreneurship that is more aligned with Schumpeter’s ideas of the ones who bring about innovations, be it within established firms or as new firm creation, than with the current use that equates entrepreneurship with firm foundation.

generalisation but nevertheless allows us to dig deeper into understanding the motivations behind our aggregate findings (Welch et al. 2011).

We indeed find that firms that introduce ‘green’ innovations are notably more likely to engage in collective innovation activities than non-green innovators. We find, though, counter to expectations, that their collaboration patterns in terms of with which other actors they interact are almost exactly as in other firms, only the frequency of listing particular partners are higher. The exception from this pattern is that entrepreneurial innovators in renewable energy have a higher propensity to collaborate with universities, something also found in earlier studies (e.g. Triguero et al., 2013). We fail to find any correlation between the innovation inputs and output in terms of share of innovative products in turnover. If anything, there seems to be a propensity for larger RE firms to reap benefits from collaboration to innovate, whereas smaller firms are less innovative, yet more prone to collaboration.

Hence, our findings indicate that in contrast to an innovation process characterised by what Hockerts and Wüstenberger (2010) termed ‘Davids’ challenging the ‘Goliaths’ (incumbents) of the energy industry and where entrepreneurs are primary driving forces (Wagner and Llerana, 2011) we propose that in reality a large share of innovation in the industry takes place in large, entrepreneurial firms who collaborate and integrate their solutions in a complex web that constitute the foundation for the industrial evolution of this industry. In a similar vein, Beveridge and Guy (2005) argue that what in the literature in the early 1990s came up as ‘eco-entrepreneurs’ or ‘green entrepreneurship’, or ‘environmental entrepreneurs’ has produced a mis-conception of what drives green entrepreneurial processes as it brings too much focus on the personality and actions of individuals, at an expense of a more realistic perception where green entrepreneurs interact in a broader system of different actors in specific contexts and often with the point of departure in the intrapreneurship processes of large firms.

The paper proceeds with a theoretical, literature-based discussion on why and how firms collaborate on innovation leading to a further discussion of the question, if and why we should expect differences in the collaboration on innovation if firms are engaged in RE innovations. We also elaborate on the issue of a possible link between various input factors and innovation outcomes. Section three explains our approach and data. The fourth section has our findings from work on survey data followed by section five, which presents our case study. Discussion on the results, conclusions, and implications are laid out in the final section six.

2 Theoretical background and hypotheses

We indicated above that the majority of green innovations are pursued through entrepreneurial activity from established firms. Later in this paper we substantiate empirically this statement but theoretically, this understanding is aligned with traditional definitions of 'entrepreneurship' (Schumpeter, 1934, see Schaper, 2010 for application to green entrepreneurship), which usually encompass entrepreneurial processes within firms (intrapreneurship). Our data allows us to apply more fine-grained definitions of entrepreneurial in the analysis such as separating firms using the innovation intensity as a yardstick. A third, additional operationalization, is that they could be defined as being both innovative and young/small to be termed entrepreneurial. However, these additional definitions are only used in robustness checks of the results, not reported here.

In the following, we survey the literature discussing how, when, and why firms collaborate with other organisations in their innovation activities. The general idea behind this is to arrive at some expectations on the case of RE, entrepreneurial firms: could they be expected to differ from 'ordinary' firms? If so, how? Hence, we consider 3 issues in this theoretical background: (i.) How innovation is now understood as taking place in an interaction with other actors and the institutional system; (ii.) what drives collaboration, in terms of the actors' need for knowledge, and the consequences of this for the number and types of collaboration partners; and finally (iii.) why (if) the case of 'green' innovations should require other resources than conventional innovations. This leads to the hypotheses we investigate.

2.1 Innovation in interaction

Over the past few decades, there have been considerable developments in the perception of innovation processes. One key insight is that innovation is often a result of a collaborative effort. Nowadays there is consensus that technological innovation takes place in an interactive learning process between various actors at all levels in the economy (Lundvall, 1992) and increasingly so (Contractor and Lorange, 2002). Moreover, multiple sources of information and pluralistic patterns of collaboration seem to be the rule rather than the exception. The data from the Community Innovation Survey (CIS) have been used to demonstrate that firms often find their sources of inspiration for innovation from other organisations, and even that they find these sources of inspiration with a multitude rather than with a single external partner (Smith, 2001). Likewise, work on innovation systems done at the OECD (1999), revealed that there is in fact a considerable variation between national innovation systems and industries in terms of the extent to which firms interact with different collaboration partners, and in terms of whether collaboration is pursued with domestic or international partners. On a more general level, Freeman (1996) illuminated how the progress in the understanding of the innovation process also informs the role of interactions in the 'green' economy.

Generally, earlier literature points out that networks impact the innovative performance of firms (Pittaway et al., 2004, Najfian and Colabi, 2014, Huggins et al., 2012, Hao and Yu, 2012, Powell et al., 1996, Hewitt-Dundas, 2006), why they collaborate (Tether, 2002, Miotti and Sachwald, 2003), and what different partners may mean in innovation activities (Nieto and Santamaria, 2007, Laursen and Salter, 2006). These works provide relevant insights on innovation and collaboration, however, the findings in this literature cannot be directly applied to the case of green innovators because of the special characteristics of these innovations (eg. van Kleef and Roome, 2007; De Marchi and Grandinetti, 2013; Cainelli et al., 2015; Cuerva et at., 2014; Del Rio et al., 2013, Ghisette et al., 2015, De Marchi, 2012). Therefore, we take differences between 'ordinary' innovations and RE innovations as a point of departure for further theorizing and to developing hypotheses in section 2.3.

2.2 Types of knowledge and collaboration partners

Huggins and Thompson (2015) propose that the relationship between entrepreneurship, innovation and (regional) growth depends on the network dynamics related to the nature of: the characteristics of the firms, the knowledge used for innovation and the spatial nature of the networks between providers and users of knowledge. In this paper we do not undertake studies of the regional dimension but argue, similarly, that the two first-mentioned dimensions are essential to understanding the 'green' network dynamics. A resource-based view of the firm (Barney, 1991, Wernerfelt, 1984) would suggest that firms substituting internal build-up of capabilities with external collaboration due to constraints on availability of resources. In a dynamic perspective the types of collaboration partners are likely to change over the life cycle of technologies (Pyka, 2000). In line with numerous studies of innovation collaboration and information sources for innovation based upon CIS we expect that 'upstream' sources/collaboration partners (universities, research organisations) are relatively more important in the early stage of development whereas 'downstream' sources are more important when the technology gets more mature and closer to market (Laursen and Salter, 2006). Consequently, the number of different collaboration partners at specific points of time over the technology evolution might remain constant but take a very different configuration. It is likely that the number of collaboration partners will be highest when firms are in a 'middle' position between still exploiting upstream sources while at the same time starting to orient themselves towards sources closer to market.

2.3 Application to RE innovation and hypotheses

Several of the features of collaboration discussed in the literature apply generally to any (small) firm. However, we expect that for green firms, especially in RE, the above-mentioned effects will be both amplified and different in some respects.

First, we expect that the energy industry structure has an impact on the collaboration activities of players. Switching to a renewable energy paradigm is a gradual process, and therefore innovations need to be integrated with existing structures of the energy system. This builds to the interconnectivity that represents the systemic character of innovations in general. The energy sector is often described as a dual structure (Hockerts and Wustenberger, 2010) where a number of incumbents and large infrastructures dominate, producing a lock-in of technological evolution, whereas there are a number of entrepreneurial small innovators. In this situation, we would expect the small, entrepreneurial firms engaged in RE innovations to have a high propensity to collaborate with external partners in order to compensate for the lack of economies of scale. But even existing, large firms will be inclined to collaborate as the context in which innovations should be implemented is characterised by a complex and interwoven web of infrastructures and need for compatibility with existing products and processes.

We hypothesize: 1. RE innovative firms will have a higher propensity to collaborate with external partners than non-RE innovators.

Along these lines, we expect a difference between RE innovators, and non-RE innovators regarding who they collaborate with. This propensity to collaborate is reinforced by the fact that RE innovations often interact with several, complimentary knowledge bases (Horbach et al., 2013, De Marchi and Grandinetti, 2013, Marin et al., 2015). Nevertheless, RE innovative, entrepreneurial firms are at the outset often built around a single-product or technology, meaning that their competences are narrowly built around a particular knowledge base. Hence, in order to thrive in a complex system, they may need to collaborate with a set of diverse types of partners.

We hypothesize: 2. RE innovative,, firms will have a more diverse set of collaboration partners than their non-RE counterparts.

Third, we posit that RE innovations' often suffer from the double externality problem (Rennings 2000) which refers to the sum of externalities described in environmental economics, and R&D economics. That is, RE innovators face both the challenges of firms lacking incentives do adopt environmentally friendly solutions, as well as concerns with their ability to capture rents from developing these innovations due to spill over effects and their public goods nature. Because of the double externality problem, firms tend to 'underperform' initially when compared to existing non-RE solutions. The implication from this is that we expect to find non-linear and different performances in firms involved with green innovations than in otherwise similar firms. The link between environmental and economic performance of firms has been extensively explored on a general level with the point of departure in the debate on the Porter-Linde hypothesis (1995) (e.g. Wagner et al., 2002, González-Benito and González-Benito 2005). Mixed conclusions have been reached, som of which falls back to the problems associated with defining a relevant performance measure (González-Benito and González-Benito 2005). Using innovation survey data for Germany Rennings and Rammer (2009) found no differences in shares of sales with new products between energy innovators and a matched sample of other innovators. Likewise, their economic output in terms of profit margins was similar. Their study did though, in line with Triguero et al., 2013) find differences in cooperation partners and upstream sources for innovation (universities, public research institutions, conferences, publications) the latter being used more intensively in energy innovators. Furthermore, in many cases, young entrepreneurial firms engaged in green innovations are more project-based or technology-based as opposed to firms who encompasses a broader range of the value chain. These types of firms will often have little turnover— if at all—and be reliant in their business model on being acquired by firms who are in the manufacturing part of the value chain. In some respects, they resemble firms in pharmaceuticals who typically face long time-lags between input and output (R&D and market), and likewise often do not have a product ready for the market before being acquired. This jeopardizes a linear relationship between input factors we would normally consider relevant for spurring output factors.

We hypothesize: 3. Re innovative*, firms will, to a higher extent, have non-linear or absent correlations between input factors and output compared to non-RE innovators.*

It is clear that many of the variables we discussed so far need closer operationalization and definition. In the following, we explain our data and empirical approach for analysing these questions.

3 Empirical quantitative setup

Our basic research approach is to identify entrepreneurial firms who introduced RE innovations, and compare interaction patterns with external partners in these firms with collaboration patterns displayed by non-energy innovating, firms. ‘Green’ firms generally are hard to identify (Shapira et al., 2014). Using industry classification codes, such as NACE, generally renders a very incomplete and biased picture. Because ‘green’ activities span across all industries, it is necessary to filter out from all firms the ones engaged in innovation activities of the kind we are after. Survey-based approaches to identify them entail disadvantages such as low response-rates, difficulties in defining the relevant sample etc. (Shapira et al., 2014, NN, 2016) but they also have advantages over the alternatives.

3.1 Data sources

In our case, the data stems from a special section of the 2013 Community Innovation Survey (CIS) (OECD, 1997) survey in Denmark, including a set of additional voluntary questions on energy related innovation, formulated by the authors. In detail, we included – among others - a set of questions addressing the firm's research and innovation activities related to the renewable energy area, enabling us to delineate the subset of 'green' firms based on their activities. Our initial dataset contains 4,786 firms. However, only firms indicating to be involved in R&D or innovation projects or processes are asked for further detailed questions related to the nature of their innovation activities. Consequently, 2,174 firm indicating to be engaged in innovation activities qualify for the further analysis.[2] Among these innovating firms, 290 indicate to be engaged in research or innovation activities related to the renewable energy sector. This includes both firms producing and distributing energy, firms involved in the supply chain, doing industrial products and processes that enable the building of energy production facilities, as well as firms offering services for this sector (O&M, logistics, installation, engineering and design etc.). The sample includes both firms that actually introduced RE innovation (154), and firms that started but did not complete RE innovation projects (136) and firms that considered RE innovation but did not start such projects (230). The latter group is, however, excluded from the analyses as we cannot expect firms who did not actually engage in innovation and collaboration to be well informed about choices of collaboration partners.

Additionally, we complemented the CIS data with information from the Danish firm register database (FIDA) provided by Statistics Denmark, including the firms location, industry affiliation, number of employees, turnover *et cetera*.

3.2 Empirical Strategy

In order to investigate our hypothesis, we choose to follow different empirical strategies. In hypothesis 1 and 2, we are interested in the characteristics of RE compared to non-RE innovators in terms of their cooperation pattern. However, we here do not impose a causal relationship. Consequently, we choose to answer these questions with a comparative frequency analysis, which we carry out in section 4.2. In contrast, hypothesis 3 claims a different causal relationship between innovation input and output for RE and non-RE innovators. This question will be further investigated in a comparative split-sample regression analysis in section 4.3.

[2] However, since non-innovative firms can be expected to be systematically different from their innovative counterpart, we later apply in our econometric analysis a two-step procedure to adjust for sample bias caused by endogeneous selection.

3.3 Variables in the Regression

3.3.1 Dependent variable

Our dependent variable of main interest is the firm's share of turnover of new products (at least new to the firm) in 2013, which is a part of the standard CIS questions.

3.3.2 Independent variables

As argued before, we expect the pattern through which a firm connects and interacts with other institutions to positively affect their innovation performance (hypothesis 3). Generally, it can be assumed that a broader set of cooperation partners will lead to access to a higher amount, as well as more diverse external knowledge, thereby making the firm more likely to create novel products. We operationalize the degree of cooperation diversity (*Coop div*) as a measure indicating the diversity of other actors and institutions a firm cooperates with, which takes a value of zero in case of no cooperation activity and 1 for cooperation with all possible groups of actors.[3]

3.3.3 Control variables

We further control for the firms' age (*age*), size measured by the number of employees (*empl*), and annual turnover (*turnover*). Due to the high skewedness of both variables, and our assumption of decreasing marginal effects of size and age, both variables enter the regressions in their natural logarithm. To avoid endogeneity issues with the firm's innovation and cooperation activities, we lag both variables by one year.

The pattern of innovation as well as cooperation activities differ between sectors and industries (Pavitt, 1984), especially between manufacturing and service oriented sectors. This effect will be captured by a dummy variable (*industry*), indicating the firm to be active in manufacturing.

Firms in industrialized urban regions are generally said to be more innovative than the ones in rural areas (Storper and Venables, 2004), so we also control for if the firm is located in one of the more densely populated regions of Denmark (*region urban*), namely the larger Copenhagen area as well as East Jutland.

Finally, we control for the legal status of the firm with a dummy variable (*legal*), indicating if the firm is listed on the stock market, or has other legal forms.

[3] The CIS data explicitly asks if the firm cooperates with (1.) competitors, (2.) firms from other sectors, (3.) consultants and other private business service, (4.) research institutions, (5.) public service institutions, (6.) other public sector institutions, (7.) public sector customers, (8.) private sector customers.

4 Quantitative analysis

4.1 Descriptive statistics

Table 1 provides descriptive statistics on basic firm characteristics, where we compare RE with non-RE innovators in our sample. On average, RE innovators appear to be slightly (~4 years) older, and employing about twice the number of employees.

Table 1: Descriptive Statistics: RE vs non RE Innovators

	All				Non-RE				RE			
Variable	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
industry	0.31	0.46	0	1	0.29	0.45	0	1	0.45	0.50	0	1
region	0.37	0.48	0	1	0.38	0.49	0	1	0.31	0.46	0	1
legal	0.69	0.46	0	1	0.68	0.47	0	1	0.76	0.43	0	1
age	22.32	19.34	1	189	21.80	19.01	1	189	25.75	21.12	1	112
empl	203.08	781.99	1	17,900	191.26	795.98	1	17,900	281.55	677.87	1	6,201
R&D basic	3.29	11.17	0	100	3.31	11.54	0	100	3.19	8.60	0	70
R&D applied	20.51	30.55	0	100	20.05	30.99	0	100	23.31	27.64	0	100
R&D dev.	52.30	42.24	0	100	51.15	42.98	0	100	59.30	36.67	0	100
Coop. divers	0.12	0.21	0	1	0.11	0.20	0	1	0.21	0.27	0	1
N	2,216				1,926				290			

4.2 Cooperation intensity and diversity – Frequency analysis and propensity score matching

In the first step in our data analysis, we are particularly interested in different cooperation pattern, intensity and diversity. Informed by our hypothesis 1, we investigate if RE and non-RE innovators are different in their propensity to collaborate with external partners, where the results of a frequency analysis is reported in Table 2.

To focus on this difference, we decided to compare only RE and non-RE firms similar in their other characteristics. Therefore we employ a propensity-score matching procedure, where we matched every RE innovator with an non-RE counterpart similar in number of employees, age, R&D expenses per employee, as well as with the same industry affiliation and regional location.

	All	Non-RE	Non-RE (PSM)	RE
coop	0.35	0.32	0.35	0.52
coop divers	0.12	0.11	0.12	0.21
Cooperation Partner				
coop firm	0.10	0.09	0.10	0.19
coop research	0.08	0.07	0.12	0.16
coop comp	0.11	0.10	0.09	0.20
coop cons	0.19	0.16	0.18	0.33
coop pubs	0.05	0.05	0.05	0.07
coop pubo	0.05	0.04	0.05	0.11
coop uni	0.18	0.16	0.22	0.33
coop cuspub	0.11	0.10	0.10	0.17
coop cuspriv	0.22	0.20	0.19	0.35
N	2,216	1,926	290	290

Table 2: Cooperation Pattern RE vs. Non-RE firms - Means

Note: We distinguish between cooperations with: firms from other sectors (firm), competitors (comp), research institutions (research), consultants and other private business service (cons), public service institutions (pubs), (6.) other public sector institutions (pubo), public sector customers (cuspub), private sector customers (cuspriv).

In line with De Marchi (2012), RE firms also show substantially higher cooperation diversity. While RE firms generally cooperate more often with a more diverse set of actors, their cooperation pattern roughly matches the ones of non-RE innovators, as also illustrated in Figure 1.

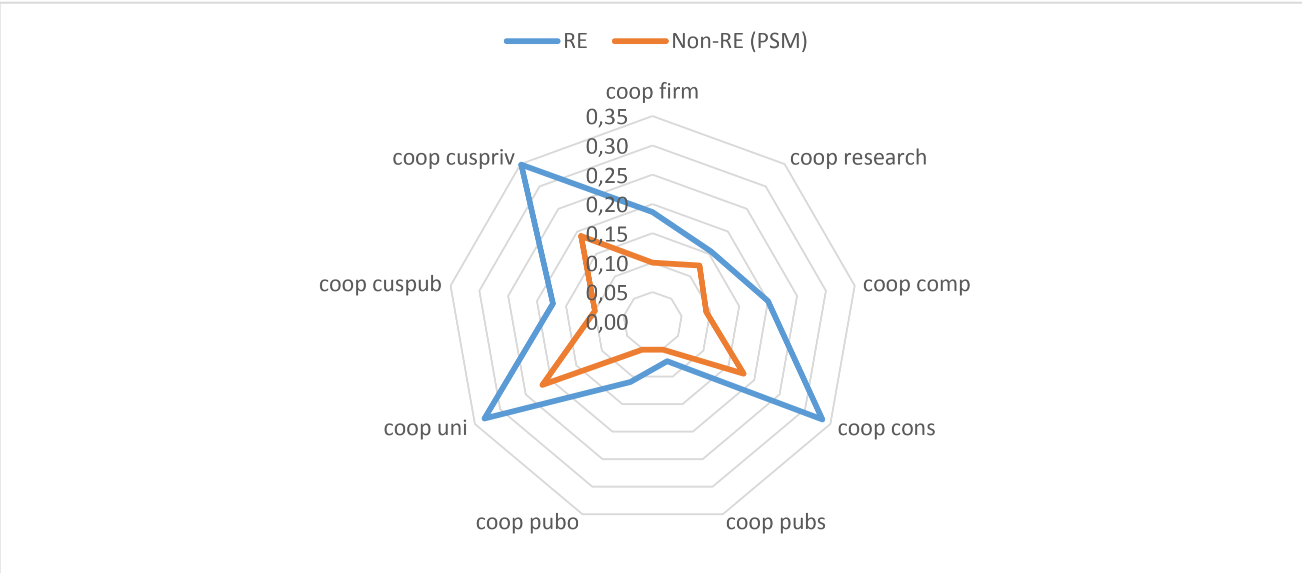

Figure 1: Cooperation Pattern: RE vs. Non-RE (PSM) Innovators

While they about twice as often cooperate with particular actors, the only divergence of this pattern can be found in the cooperation with public service institutions, which is only slightly higher for RE innovators. In summary, RE innovators appear to – in line with hypothesis 1 – cooperate more often with other institution to develop their innovation. As suggested by hypothesis 2, they also tend to cooperate with a more diverse set of different institutions at the same time.

4.3 Collaboration and performance: Examining hypothesis 3

In hypothesis three we posit that it is likely that there are differences in how input factors links to performance in RE and non-RE firms. To test this we proceed with a regression analysis linking innovation performance – measured as the share of new products and services in turnover – to innovation diversity and a number of other input factors and controls.

In the CIS survey structure, only firms that initially indicate to be engaged in R&D or other innovation activities are asked the full set of questions. To control for possible bias arising from the exclusion of non-innovative firms, we apply a standard two-stage Heckman selection model (Heckman, 1979), where we first fit a logit model estimating if the firm accounts for innovation activity, and insert the predicted inverse mills ratio (λ) in the 2^{nd} stage model. In the first stage, the probability to be engaged in innovation activity is calculated as a function of the variables available for all firms, which are their number of employees, turnover, age, legal form, industry and region.[4] Table 3 presents the results of the second stage of the OLS regression model adjusted for endogenous selection, with the firm's share of turnover in new products as dependent variable, serving as a measurement for innovation performance.

First, we run a model (i.) with all control variables plus *coop divers* on the whole sample. Here, the firms size (*empl*) shows a negative coefficient, significant at five percent level, indicating our Danish sample of all innovators, both RE and non-RE innovators to act more in a Schumpeter MARK I model, where small entrepreneurial firms are the main carrier of innovation (the coefficient of the firms age also shows a negative sign, yet remains insignificant). Cooperation diversity shows a high positive coefficient, significant on one percent level, suggesting cooperation with a diverse set of institutions to indeed serve as an important input for firm level innovation processes. We also include our identifier for RE innovators (*RE inno*) to test for general systematic differences in innovation output in RE firms. It up to now remains insignificant. In model (ii.) we include an interaction effect between this identifier and the firms cooperation diversity, (*RE inno * coop divers*), which shows a high negative coefficient, significant on five percent level, but also causes other interesting changes in the model dynamics. First, the magnitude of cooperation diversity increases, and second, the RE identifier turns positive and significant at ten percent level.

[4] Since not main part of the discussion and analysis, the results of the first stage remain unreported, yet available on request.

Table 3: Regression Model: 2nd stage. Dependent variable: Firms share of new products and services in its 2013 turnover

	All		All (PSM)		Non-RE (PSM)		RE	
	(i.)	(ii.)	(iii.)	(iv.)	(v.)	(vi.)	(vii.)	(viii.)
region	2.17	2.16	1.10	1.18	5.05	4.96	-2.57	-2.60
	(1.66)	(1.66)	(3.27)	(3.26)	(4.20)	(4.19)	(4.99)	(5.00)
legal	3.51	3.50	8.54*	9.36*	8.43	8.17	7.51	7.49
	(1.93)	(1.93)	(3.80)	(3.80)	(4.75)	(4.75)	(6.05)	(6.06)
industry	1.40	1.29	7.36	7.03	-0.74	-1.79	14.34*	14.57*
	(2.05)	(2.05)	(3.81)	(3.80)	(4.83)	(4.89)	(5.84)	(5.89)
age_{ln}	-1.47	-1.53	2.64	2.44	3.06	3.26	2.85	2.83
	(1.17)	(1.17)	(2.11)	(2.10)	(2.72)	(2.72)	(3.19)	(3.20)
$empl_{ln}^{t-1}$	-1.92**	-1.92**	-2.33	-2.24	-5.17**	-5.45**	0.22	0.29
	(0.66)	(0.66)	(1.35)	(1.34)	(1.81)	(1.82)	(1.95)	(1.96)
$turnover_{ln}^{t-1}$	0.16	0.17	0.35	0.32	0.72	0.80	0.08	0.06
	(0.19)	(0.19)	(0.45)	(0.44)	(0.61)	(0.61)	(0.64)	(0.64)
Coop divers	29.69***	34.91***	24.72***	41.26***	41.54***	70.47**	12.99	6.27
	(3.78)	(4.27)	(5.96)	(9.37)	(8.67)	(24.03)	(8.18)	(23.58)
RE inno	-0.81	3.65*	4.26	8.567*				
	(2.40)	(1.54)	(2.98)	(3.52)				
RE inno * coop divers		-23.47**		-27.20*				
		(8.95)		(11.93)				
Coop divers^2						-41.44		8.73
						(32.10)		(28.69)
λ	-9.88	-9.99	0.95	0.58	-3.46	-4.05	1.83	1.88
	(5.30)	(5.29)	(11.54)	(11.50)	(14.87)	(14.86)	(17.60)	(17.63)
N	2,176.00	2,176.00	570.00	570.00	285.00	285.00	285.00	285.00
R^2	0.037	0.04	0.062	0.071	0.112	0.118	0.07	0.07

***, **, * indicates significance on one, five and ten percent level

Overall, this suggests the relationship between cooperation diversity and innovation output to broadly differ between RE and non-RE innovators, as suggested in hypothesis 3. While the relationship in general tends to be positive, this pattern appears to be reversed for RE innovators. As indicated in Table 1, our sample contains about ten times more non-RE than RE innovators, where some of their firm level characteristics systematically differ.

To rule out that our results are driven by these inequality and differences, we in model (iii.) and (iv.) replicate the same setup on the sample generated by the propensity score matching. This now contains an equal (285) number of RE and non-RE innovators similar in their basic firm-level characteristics (region, legal form, industry, age, size, turnover). Here, the results depicted for model (i.) and (ii.) are replicated in the results from model (iii) and (iv).

Finally, we run separate models for non-RE (PSM sample) and RE innovators. For the non-RE innovators, we find patterns in line with the previous models. Small as well as firms with a high cooperation diversity tend to have higher innovation output. In model (vi.) we also introduce a squared term of cooperation intensity to test for a non-linear relationship between cooperation diversity and innovation output, where too little as well as too fragmented cooperation pattern might not be beneficial. However, this seems not to be the case in our sample. In model (vii.) and (viii.) we replicate the exercise for RE innovators. The results here are very sobering in a way that we barely find any significant effect, besides a weak significance of the dummy for manufacturing firms (*industry*). If anything, then the results suggest the pattern of RE innovation to indeed be very distinct compared to other sectors. Testing for an inverse U-shape of this effect did also not deliver statistically significant results.[5] Further, small firms as carriers of innovation observed as a tendency for non-RE innovators does not hold true in the case of RE innovations indicating an innovation process relatively more in line with a Schumpeter Mark II model than Mark I.

4.4 Summary of Results

Overall, the results suggest substantial differences between cooperation intensity between RE and non-RE innovators, as stipulated in hypothesis 1. Further, in line with hypothesis 2, RE firms appear to generally maintain cooperation with a more diverse set of partners, indicating the systemic nature of RE innovation processes that demands inputs from a broad set of sources. However, we cannot confirm hypothesis 3, indicating a (non-linear) relationship between cooperation intensity and diversity, and innovation output for RE firms. We can up to now – within the limits of our sample and econometric strategy – only provide first evidence, that if any relationship exists, it is neither a linear nor an inverse U-shape. This highlights our yet underdeveloped understanding for the systematic differences of innovation processes in RE firms, and the role of cooperation. Albeit RE innovators show a high tendency to cooperate with a diverse set of actors, this does not seem to transfer to innovation output. In line with this result Cuerva et al. (2014) fail to find a correlation between collaboration and environmental innovative performance. A reason suggested is the often long development times in RE projects (Kenney, 2011), which are in need of different partners at different points of time. The nature of our dependent variable here does not allow us to capture direct effects of cooperation on innovation performance (which is true for most commonly used measures, such as patents etc.), and the cross-sectional nature of our data does not allow to disentangle life-cycle effects. The following case study of an entrepreneurial RE firm aim to shed light especially on the up to now unexplained patterns, in particular the missing longitudinal component of the quantitative analyses that might contribute to a better understanding of the portfolio of collaboration partners over time and of the possible outcome of the processes we study.

[5] In further unreported models, we also test for various other interactions with cooperation diversity of RE innovators, for example with the firm's age and size. Yet, they all remained insignificant.

5 Networks and collaboration: A case from offshore wind

The purpose of adding a case study to the analysis is to investigate issues that are suggested by the results of our quantitative section but not explained regarding the underlying motivations and reasons. The case study allows for a contextually richer understanding of the mechanisms in place when RE entrepreneurial firms collaborate (Welch et al., 2011). It also enables capturing a longitudinal perspective on issues such as how partnerships change as the firm matures, and the long and uncertain time span between initiating RE innovation processes and their outcome, which are part of the rationale for hypothesis 3.

We selected a company within the offshore wind value chain, namely Universal Foundation A/S. Four interviews[6] were conducted with people involved in different functions. Three of the interviewees have been involved from the very beginning of the establishment of the company, and one has joined the company more recently. Although four interviews is not an exhaustive number, this is a small firm, with about 20 employees, hence the four interviews provide a good coverage of possible information and opinions on the story. Analysis of archival data, such as firm documents and news concerning the company provided supplementary information sources as preparation for the interview. We proceed by outlining the background of the offshore wind industry, as this context is essential for the analysis.

5.1 The offshore wind industry and supply chain

Denmark has been a pioneer in developing wind energy facilities, and industries associated with it, both onshore and offshore. The sector is vital to the Danish economy—it generated a turnover of EUR 11 billion in 2013[7], of which 60% refer to exports (DAMVAD, 2014). There are more than 500 firms dedicated to various areas of the wind industry in Denmark, employing 28 thousand people (DWIA, 2014; DAMVAD, 2014).

The Danish wind industry developed by employing an approach characterized as bricolage (Garud & Karnøe, 2003). This refers to that a path was created based on the collaboration of diverse actors who employed low-technology knowledge bases and small-scale craft capabilities, such as carpentry and machinery (Andersen et al., 2014; Garud & Karnøe, 2003). Thus networks and collaboration have been at the heart of the industry for several decades. This was followed by a public opinion that advocated for wind, the establishment of research and industry networks, and the design of policies to support the industry (ibid.). In the early stages this opinion took form of a grassroots movement. The involvement of all these actors has been instrumental in developing wind

[6] Interviews were conducted from April to June 2015 and lasted from 45 minutes to 90 minutes each.

[7] Offshore wind accounts for about one third of this turnover (DWIA, 2014).

power as it was crucial in order to advance a paradigmatic change from a planned but not realised nuclear alternative to wind power(Andersen & Drejer, 2008).

With the expansion of technological possibilities, wind farms started to be placed offshore in the 1980s, although only in the early 2000s they became more widespread (Andersen et al., 2014). Together with the advantages of placing wind turbines offshore came several challenges. These included simplifying the cost structure, and achieving more standardization and efficiency in the supply chain.

Offshore turbines need an underwater foundation structure for installation. Foundations are significant in the supply chain for several reasons. The complexity of civil works account for an essential difference between onshore and offshore (EWEA, 2011). Things such as the maritime environment, conditions of the seabed soil and logistics present a higher technical challenge for offshore wind in relation to the traditional onshore installations. This is reflected in costs—up to 30% of the total capital costs are attributed to the supply and installation of substructures (EWEA, 2011).

5.2 Innovation in the company

Universal Foundation A/S is a company that offers an innovative solution for the foundation substructures supporting wind turbines in offshore parks. There are different activities to be carried out in relation to substructures, which require substantially different capabilities. Universal Foundation is focused on engineering and design[8].

The innovation brought about by Universal Foundation is the use of a technology known as suction buckets. This technology itself was widely used in the offshore oil and gas industry, and the innovation lies in its application to the context of offshore wind, besides the complementary improvements and systems that made it technically viable as a foundation. This is a classic case of new combinations of existing knowledge that result in innovation (Schumpeter, 1934). The bucket foundation presents several advantages to the existing substructures: it requires less steel, which makes it cheaper; its installation has lower environmental impact; and it can be removed without leaving parts behind in the seabed[9]

5.3 The company as the result of a collaborative effort

The motivation behind the founding of MBD offshore—as the company was known initially—was the closing of the Frederikshavn shipyard, in northern Denmark. An initiative was established with the purpose of exploiting the remaining competences, and putting qualified workforce and other

[8] Other activities concern studies of soil and seabed conditions, the fabrication of steel structures, logistics and installation.

[9] As opposed to monopiles—the most widespread solution.

resources to a new use. The entrepreneurs behind Universal Foundation identified opportunities in offshore wind, and partnered with an engineering professor from Aalborg University. Together they attempted to establish the company, firstly by seeking partnership with turbine manufacturers. When they were turned down, they pursued different partners in their network.

As a result, the original, early ownership of Universal Foundation consisted of a company with expertise in steel design structures (MarCon), a shipyard (Ørskov), a steel infrastructure manufacturer (Bladt Industries), a park developer (ELSAM—currently DONG Energy), and a company that concentrated the interests of the entrepreneurs as shareholders (Novasion). Each of these partners had 20% ownership. The investment from these diversifying incumbents was essential, as the wind power sector is competitive and capital intensive. Access to the expertise and networks of these partners also widened the range of partners with whom the infant company could collaborate, extending the competences and resources it could tap into.

Armed with an innovative product and engaged partners, it was essential for the newly established firm to prove its concept in a commercial context. In order to achieve this, in 2002, a prototype was installed in Frederikshavn, upon which one of the largest turbines at that time was mounted[10]. This demonstration project was realized through the competences of different partners, both shareholders and otherwise. For instance, Bladt Industries manufactured the steel structure, Aalborg University was involved with the design and engineering, ELSAM provided the site. The project represented a first test of the concept, and enabled the monitoring and collection of various types of relevant data concerning the soil, ocean and wind, which contributed not only to the improvement of the product, but also to academic research in the field.

5.4 Firm–university partnership and other collaborations

Universal Foundation is a typical case among RE innovators, in the sense that collaboration is intensive and with diverse partners, with special engagement with universities, as suggested by our quantitative analysis. Since the very beginning Aalborg University has been a key partner to Universal Foundation, providing access to specialists in diverse knowledge bases (geotechnical, construction, materials, robotics etc.). Although the company has gained its own R&D capabilities, the university still plays a role in this regard, albeit minor.

Cooperation has also been important in terms of research. To date, seven PhD projects have been completed in relation to mono-buckets, three are currently ongoing, as well as a number of master level projects. The engineering professor involved since the early research is still a minority shareholder, he is actively involved as a consultant, and serves the board of directors. The Director of the Faculty of Engineering is also a member in the Board of Directors. Data collected from the

[10] Vestas V90 3 megawatt; the installation is still in operation.

experimental installations have also fed academic research. In the words of an interviewee: *"Actually I do believe that it goes well hand in hand. We would not be here, where we are today, if we hadn't had help from the university, but I also think that the business (industry) is benefiting greatly from our findings and the cooperation we have with the university"*.

The firm–university collaboration went well beyond access to knowledge and research. For instance, Aalborg University offered support when some of the shareholders went bankrupt after the 2008 crisis, and other wanted to leave the partnership. The University's lawyers were involved in negotiating IPR agreements so that the firm could ensure ownership of its key technology. Moreover, and unusually, in the midst of this crisis, the University invested as a shareholder, and assisted in searching for another investor. After the entry of Fred Olsen[11] in the partnership, MBD Offshore was renamed Universal Foundation.

The role of Aalborg University in the trajectory of Universal Foundation has changed. Although the university is still a shareholder, other partners become more central, as the firm goes through different stages of development. At this point, certification of the concept and access to markets are crucial. In parallel, is the development of a supply chain to manufacture the bucket–foundation. Key partners here are other companies in the Fred Olsen group.

The main challenge of Universal foundation has been acquiring legitimacy in a market that is paradoxically is simultaneously pioneering and conservative. It is pioneering in the sense that wind power is a RE technology, representing a break from fossil fuel energy sources hence a shift that causes large–scale systemic breaks (Jacobsson & Karltorp, 2013; Unruh, 2002; Kaldellis & Kapsali, 2013). At the same time it is conservative in the sense that actors are risk averse and resistant to adopting innovations. It can be costly to experiment with solutions in this market, especially because of the large scale of projects, their complexity and capital intensity.

This combination of systemic paradigm shift and industry conservatism results in increased barriers for small players and *de novo* entrants. In the context of RE innovation, partnering with both established incumbents (such as DONG) and diversifying incumbents (such as Fred Olsen) is crucial for small start-ups (Chen et al., 2012). This is in line with our findings in the regressions, which suggest Schumpeter's MARK II model to be governing the dynamics of RE.

5.5 Key performance indicators

Universal foundation is a 14 year–old company. In many other sectors this could be perceived as a mature company; this is, however, not the case in RE. Universal foundation remains small and entrepreneurial. Their innovation still requires acceptance from the market. Although now a part of a

[11] Fred Olsen in a Norwegian group with activities in diverse business areas. The group has grown its portfolio in renewables, with businesses in assessment and planning, construction, operation and maintenance etc.

larger group, the firm still operates as a separate entity. Other innovative foundations have been proposed in the industry, but none has been able to challenge the dominant design of monopiles yet—even though some argue monopiles are also not the optimal foundation.

This case illustrates the long time–lags from R&D to market, as discussed in hypothesis 3, and the problems with establishing a clear relationship between inputs and outputs. It is difficult to measure innovation performance in cases like this with traditional measures, such as revenues, products brought to the market, and patents.

In terms of patents, Universal Foundation owns two patents that encompass the concept of buckets as offshore foundations, plus the methods of installation. In terms of income, the company has not registered a steady stream of revenues, and this being a project–based market is an additional complication. Any income the firm has had refers to grants for R&D from donor agencies, and funds from the major shareholder. Equity has now been spend, and it is the parent company that has kept the business going while they go through what in the literature (Wüstenhagen and Menichetti, 2012, Grubb, 2004) is termed 'the valley of death'. While this problem is well documented in several sectors the length of development processes observed in RE innovations is exceptional. As a result, revenues, share of innovation in total sales, or patents, are insufficient indicators for innovative performance in this context.

The case suggests that RE entrepreneurial firms may require longer periods to penetrate the market and their revenues are often relatively de-linked from input factors due to the technological, market, and financial uncertainties and the long time span between input factors and output. This observation is aligned with our third hypothesis. It also suggests indication of a MARK II model, in which established firms are essential for carrying out innovations to market. In the case of Universal Foundation, the long time–lags between R&D and market would have caused the firm to fail, had they not been acquired by a diversifying incumbent.

6 Discussion, conclusions, implications

In line with a range of other recent studies we found that entrepreneurial RE firms have higher cooperation intensity than otherwise similar firms. We ascribed this finding to the systemic character of 'green' (RE) innovation and the broader knowledge base in use for carrying these innovations through. Earlier studies pointed to entrepreneurship as being particularly important for eco-innovations (Wagner and Llerena, 2011). A resource-based view of the firm (Barney, 1991) argues for the importance of collaboration, as means for coping with the challenges of entering a scale-intensive energy sector dominated by sunk investments into large infrastructures (Hewitt-Dundas, 2006). Our findings support the idea that firms engaged in renewable energy innovation need to collaborate to a higher extent than non-RE innovators. However, when Beveridge and Guy (2005) talk about an over-exposition of small start-ups and the individual entrepreneur in eco-innovations (‘ecopreneurs’) our results are largely in line with their arguments. We found that the entrepreneurial activities are particular pronounced in large RE firms. This is not to belittle the important role of small firms. These firms were found to be important carriers of innovation in the total sample of firms and are still important for business churning and have a role in the RE innovation supply chain. But intrapreneurship seem relatively more important to RE innovation.

We also expected that RE innovators would display a broader and different range of partner types in their pattern of external collaboration. Once we isolated behavioral differences from characteristics, we found, contrary to expectations, the same patterns in the use of types of partners in the two groups of firms. An exception from this was the collaboration with ‘upstream’ sources, for example universities, whom RE innovators are more prone to engage with; a result in line with a number of other studies (e.g. Triguero et al., 2013).

We also proposed that it would probably be difficult to find a linear correlation between input factors and output factors in RE firms (Rennings and Rammer, 2009, Cuerva et al., 2014). The character of RE entrepreneurial firms and the industry they operate in explains why these firms do not achieve rapid innovation output corresponding to the investments. Our regression analyses both indicated this and left us with unsolved questions regarding the mechanisms behind our findings. This made us conduct a case study in order to get closer to an understanding of the patterns we saw in the quantitative analysis. The case study informed many of the presumptions we build our design of the quantitative analyses on, and made us more confident in the way hypotheses and interpretations of results were made. It also illuminated some of the motivations behind collaboration and choices of collaboration partners, something we could only map in our quantitative studies. It therefore provided valuable information on the mechanisms behind our story. Specifically, it became clearer how the type and number of collaboration partners changed over time. The case study also offered additional insight into the uneven and unpredictable nature of the outcomes from RE innovations.

The fact that RE innovators are more intensely involved in interaction with outside partners has implications for both firms and policy. For RE innovators we point to the need for these firms to actively engage in networks to obtain information on which partners for innovation are the most appropriate to broaden their knowledge base, and access a variety of capabilities and resources that are indispensable to the organization. This, however, requires search for finding and configuring the networks and it requires skills to manage network participation in a productive manner (Ritter and Gemunden, 2003, Hao and Yu, 2012). Therefore, we propose that networking capabilities should be enhanced in greenagers and other small firms. This is worth considering in relation to policies but also in connection with the curriculum of business schools. Both in policies generally, and in teaching business students it is often emphasized how important networking is. However, it is rarely explained how to pursue networking effectively. Network search, creation, management is nowadays a discipline in itself but rarely unfolded in an explicit manner.

We furthermore propose that modern innovation policies, which are today often aimed at correcting systemic failures rather than market failures, should be more intensely geared towards facilitating the creation of links between partners in RE innovation processes (Triguero et al., 2013). We showed that while RE innovators already collaborate relatively more, this is needed to get RE innovations to the market. Our results may also be read as indicating that policies for enhancing links between firms engaged in green innovations need not be different than other policies, even though special policies tailored to the context of green entrepreneurship[12] may fulfill several other meaningful goals. This is implied by the fact that types of collaboration partners are roughly the same among the two groups of firms analyzed. Finally, policy should recognize the time–lag and non-linear relationship between input and output factors in RE innovation. This complicates evaluation of policies. Network policies are generally difficult to evaluate due to their indirect effects, difficulties in estimating time-lags between networking and effects, and numerous problems relating to isolating cause and effect and pre-selection (Arnold, 2004, Georghiou, 2007). Collaboration on innovation was in this and earlier papers shown to be particular important. Failure to show effects from policies to enhance innovation collaboration between RE, entrepreneurial firms may mistakenly lead to abandoning policies, which in turn may harm the greenagers.

[12] A number of green innovation policies are implemented in various countries but according to Hamdouch and Depret (2012) these policies are generally not targeted towards the ’Davids’, rather the ’Goliaths’ in Hockerts and Wustenhagen (2010) terms.

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