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University spin-off firms in sustainable energy in five countries: what determines their reaching of the market?

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Abstract

It is widely acknowledged that the transition towards a more sustainable energy production and use needs to be accelerated. Whether young high-tech ventures can contribute to such an acceleration is a matter of debate. To contribute to this debate, this article aims to clarify the conditions under which a specific type of young high-tech ventures, university spin-off firms, bring inventions in sustainable energy to market in a quickly manner. The study draws on a selected sample of spin-offs (37) and four case-studies in Northwest Europe, and applies rough-set analysis to explore the influence of different sets of conditions. We observe that the following conditions provide the highest chance for a quick development, namely, located in an 'Innovation Leader' country and involved in multiple networks. Next important is a combination of practical orientation (founders) and access to substantial investment capital. In addition, we observe that time may be critically important, for example, in a quick financing of a global sales organization and in pay-back time after substantial investment.

Keywords: university spin-off firms, sustainable energy innovation, entrepreneurial orientation, market introduction, time

1. Sustainable energy and young high-tech ventures

Despite progress in introduction of sustainable energy technologies, following the Brundtland Report (WCED, 1987; Shafiee and Topal, 2009), it has been acknowledged in the early 2010s that more structural change is needed to enable an energy transition taking place during the first half of this century (COM, 2014; IEA, 2014; SER, 2013). Today, sustainable energy is one of the Grand Societal Challenges in the EU Horizon 2020 program (EC, 2011), addressed as 'secure, clean and efficient energy'. The emphasis is stronger on a long-term view on sustainability innovations, on the required system changes and on an increased role of universities in such changes, eventually in their city-regions (EC, 2014; Goddard and Vallance, 2013). And together with universities, their spin-off firms enter the scene.

University spin-off firms are independent ventures, established by graduates (Master or PhD) or university staff, with the mission to bring novel knowledge from university to market (Shane, 2004). Though university spin-off firms are by no means the only ‘vehicle’ in commercialization of university knowledge (D’Este and Patel, 2007), they are increasingly acknowledged – based on their young age - for their potential of disrupting current socio-technical systems due to flexibility, willingness to take risk, creativity, responsiveness and forward looking. These advantages also named ‘learning advantages’ of newness (Teixeira and Coimbra, 2014; Zhou and Wu, 2014) have been emphasized specifically in literature on international entrepreneurship. Also, a lack of reputation motivates these firms to work innovatively, eventually aggressively, in gaining competitive advantage. Young high-tech ventures can also better target small niche markets that are unattractive to larger firms and they can better operate under high uncertainty in an economically viable way (Janssen and Moors, 2013). These features are seen as providing spin-offs the potential to contribute to development and implementation of economically viable solutions increasing sustainability (Hall et al., 2010; Alkemade et al., 2011).

However, there is also a contradictory view. First, it is forwarded that resistance in the current energy systems (regimes) to transitional change, as well as lack of insight into impacts from public policies and concomitant uncertainty (Geels and Schot, 2007; Loorbach and Rotmans, 2010; Smith et al., 2010) create a situation in which no single actor can bring about system changes or disruptions to the prevalent regime. Secondly, in entrepreneurship studies, there is the traditional view of the ‘liability of newness’ among young ventures (Stinchcombe, 1965; Freeman et al., 1983) putting an emphasis on lack of resources, among others, lack of reputation which hampers building networks with powerful actors and lack of experience which hampers dealing with complexity in these networks (Sweet et al., 2003; van Geenhuizen and Ye, 2014). In particular, university spin-off firms in their early years, are faced by lack of knowledge about the market, marketing skills and investment capital, potentially causing difficulty to make progress in development (Vohora et al., 2003; van Geenhuizen and Soetanto, 2009). In some cases, namely when up-scaling of production is needed but investment capital is missing, there is the risk of facing the ‘valley of death’ (Auerswald and Brancomp, 2003; Bocken, 2015; van Vooren and Hanemaaijer, 2015).

To our knowledge, only a few studies have addressed market introduction of sustainability products, processes etc. in particular among young university spin-off firms, and this conforms to an overall small attention to firm-specific factors and external factors among young high-tech ventures (Bjørnali and Ellingsen, 2014; Boons and Lüdeke-Freund, 2012; Horbach et al., 2012). An exception is the study by Triguero et al. (2013) as a large scale econometric analysis of ‘drivers’ among European SMEs engaged in eco-innovation, including firm-specific factors and demand-side drivers. However, like other studies on driving factors in eco-innovation, this one does not provide in-depth insights about time and steps in market introduction. An exception is Bocken (2015) specifically in relation to investment of venture capital. Accordingly, success factors are found to be novelty in the business model and collaboration with different types of firms. Reasons for failure are found to be lack of suitable venture capitalists and knowledge, a strong incumbent industry and a short-term investor mind-set. We may conclude that success/failure in young ventures' strategies towards the market is achieving an increased scholarly attention today, most often addressing collaboration and investment issues. However, time in relation to market introduction has seldom received explicit attention. In the context of the debate of potentials of young high-tech ventures, therefore, the current article aims to clarify factors influencing the path to market introduction of sustainable energy inventions/solutions among university spin-off firms, in particular obstacles related to the time-dimension.

The questions we seek to answer are: what factors influence the path (time and steps) involved in bringing sustainable energy inventions to market? What is the role of collaboration and investment capital in market introduction, and of time-related obstacles? And, which perspective is supported, 'learning advantages' of newness or 'liability' of newness?

The current study contributes to the literature in two ways. First, by addressing the time dimension of pathways to market introduction while adopting an in-depth approach to collaboration and investment capital amidst a set of other factors and, secondly, by shedding light on the role of young age, providing learning advantages or, by contrast, causing liability of newness. The study draws on a small and carefully selected sample of 37 spin-off firms which allows for identification of preliminary types of spin-offs, but excludes statistical generalization. These types are 'distracted' from the sample in a quantitative way, using rough set analysis and can be considered as preliminary generalizations based on 'theoretical positions'. Next, we analyze three case studies of spin-off firms in-depth concerning their way to market introduction, and explore the preliminary 'types' and 'theoretical positions'.

The article unfolds as follows. In section 2, energy systems in general and the national innovation system of the countries in the study are discussed. Section 3 encompasses the entrepreneurial perspective, including the design of a model of time/steps in bringing inventions to market. This is followed by methodological aspects, including the sampling and data collection, as well as principles of rough set analysis (section 4). In section 5, the results of the model exploration and case study analysis are discussed. Section 6 provides a reflection on the results and an indication of future research.

2. Energy systems and the national innovation system

2.1 Rigidity of energy systems

Energy systems are a collection of interacting physical elements, such as power plants, distribution grids, technology firms, metering systems, etc. but also of social elements, including individuals, firms, governments, institutions, regulation, standards, pricing-regimes, etc. All these elements together with their linkages constitute the socio-technical system of energy. As a result, bringing about changes in energy systems, particularly substitution, means the involvement of large numbers of actors – on the technical and social sides - along with their networks and interconnections energy systems, while a single actor can only partially influence its own path and its network linkages (Schot and Geels, 2008; Lopolita et al., 2011; Smith and Raven, 2012). For, high-technology ventures this means the need for owning competence and resources in finding the best collaborative partners, like large firms and public actors, and the difficult task to manage complexity in the relationships concerned and extend their influence on the system.

Rigidity to change is specifically connected to the centralization in current energy systems, while renewable energy systems, such as wind and solar, enable to move toward more decentralized production and consumption (Alanne and Saari, 2006; European Parliament, 2010). In a decentralized system, energy is produced on a small scale (a few kWh) and in a distributed pattern, often close to where it will be consumed (Kaundinya et al., 2009). In such a situation, the costs of storage and transport of energy will be reduced which can bring major savings to consumers but the changes may also render part of the grids redundant affecting the central grid providers. Also, prices need to be established if locally produced electricity surplus is fed into the central grid. As a result, changing to a decentralized energy system affects existing institutions and regulations (laws) and vested interests.

2.2 National innovation system

The national innovation system as apparent from various innovation input and output indicators differs clearly between the countries in our study: the Netherlands, Norway, Denmark, Sweden and Finland. In 2015, the Netherlands was qualified an innovation follower, while Norway was qualified as only a moderate innovator (Innovation Union Scoreboard, 2015). By contrast, the other Nordic countries – Denmark, Sweden and Finland - were qualified innovation leader. The selected indicators in Table 1 serve to illustrate these different positions with particular attention to knowledge creation and investment in R&D, and innovation activity and output among SMEs. The Netherlands and Norway clearly differ from the innovation leaders in R&D expenditure, particularly that in the business sector and non-R&D innovation expenditure, which are at a relatively low level. In addition to that, Norway remains behind all other countries in patent application in general and in those addressing societal challenges. Norway also remains behind in innovative behavior of SMEs, including bringing new products/processes to market. In contrast, the Netherlands only remains somewhat behind innovation leaders with regard to introducing market- or organizational innovation among SMEs.

Given the above indicators, we may preliminary conclude that there are no large differences in production of scientific knowledge including R&D expenditure in public sector and venture capital investments. The differences are most pronounced concerning business sector R&D expenditure and non-R&D innovation expenditure, as well as introducing other than technology innovation among SMEs, which may point to some differences in developing the soft side of innovation in the Netherlands and Norway.

Table 1 Selected innovation input- and output indicators

	NL	Norway	Denmark	Sweden	Finland
-Intern. scientific co-publications	420	508	527	493	410
-Most cited scientific publications	142	104	133	116	104
-Public-private co-publications	238	154	384	279	174
-R&D expenditure in public sector	117	113	144	140	140
-Venture capital investments	110	137	158	126	135
-R&D expenditure in business sector	***88***	***69***	154	170	178
-Non-R&D innovation expenditure	**26**	**35**	54	115	55
-PCT patent application	159	***74***	183	242	248
-idem application, societal challenges	176	***58***	273	192	168
-SMEs innovating in-house	136	***71***	106	134	127
-Collaboration among innovative SMEs	140	***77***	167	123	138
-SMEs introducing product/process innovation	134	***74***	111	130	131
-SMEs introducing market/ organizational innovation	***97***	***90***	112	106	102
- General: Sales of innovations new to market/ firm	95	***42***	178	49	90

Source: Innovation Union Scoreboard 2015 (EU-27 = 100)

3. Entrepreneurial perspective: A model of time and steps to market introduction

Our model on bringing sustainability inventions to market encompasses three sets of factors, first, firm-specific factors connected to entrepreneurial orientation (EO) and secondly, firm–specific factors connected to capabilities of founders, including that of establishing networks to access to external resources (Figure 1). The model includes as a third set of factors, external factors (facilitators), of which one is availability of financial capital and the other is a broader set of influences of the above discussed national innovation system.

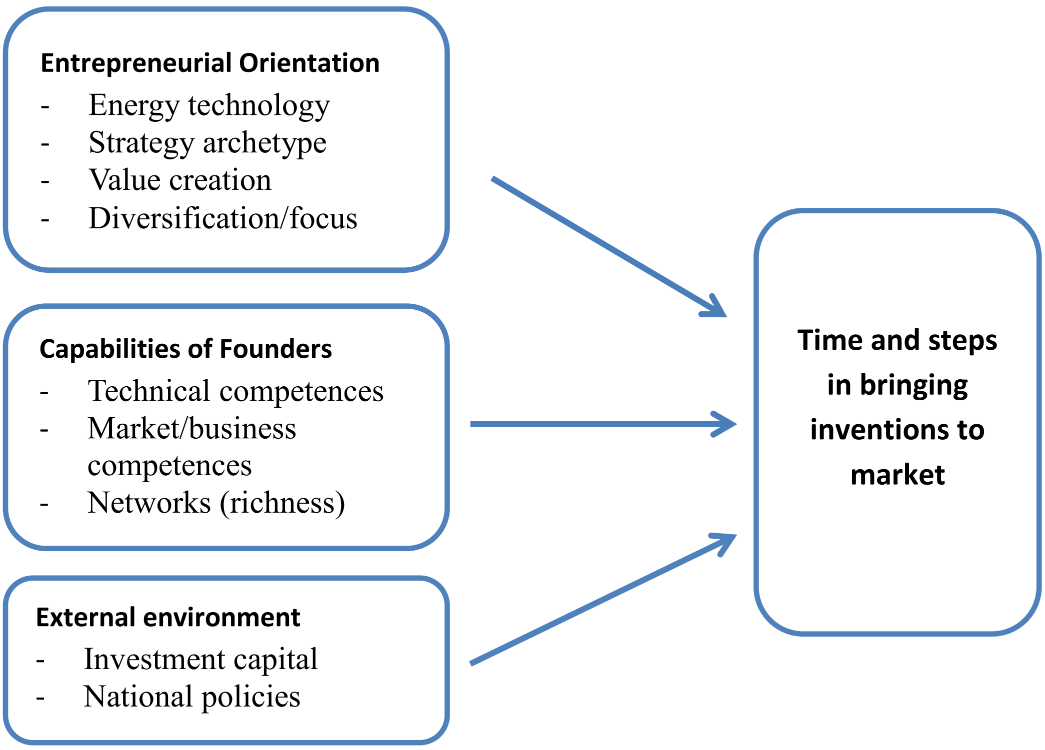
The intention to bring sustainability inventions to market encompasses various critical decisions by entrepreneurs which can be summarized in entrepreneurial orientation (EO). The concept of entrepreneurial orientation refers to the organizational processes, methods, practices, and decision-making activities that firms use to act entrepreneurially. In other words, entrepreneurial orientation reflects dimensions like autonomy, innovativeness, risk-taking, pro-activeness, and competitive aggressiveness (Lumpkin and Dess, 1996).

With regard to energy technology and risks taken, there is an array of possibilities, including solar (photovoltaic and thermal), wind, hydro (falling water and waves), fuel cell (hydrogen), geothermal and new biofuels. Wind and solar (photovoltaic and thermal) seem most accepted across the world, but face resistance in being placed in densely populated areas. Importantly, firms may also differ in position in the market, level of innovativeness and concomitant risk-taking, namely, whether to act as first-mover, follower, customer-intimate, or cost-leader thereby addressing different market segments (strategic archetype) (Mohr et al., 2010). It seems that first-movers take relatively high risks while followers may easily learn from first movers' failures but eventually need to share the market. With regard to cost-leadership, entrepreneurs develop new solutions by using cheaper manufacturing processes, like thin-film technology in solar cell production. In addition, firms may also differ in type of value creation, like in the core of efficiency of energy conversion, e.g. in solar cells (better materials). Extending existing solutions with functional improvement is another type of value creation, like adapting the color and shape (curving) of solar cells to apply them as roof tiles or wall covering, and designing a construction in which solar panels can cover parking places and other open-air area. Another main entrepreneurial decision is whether to remain focused on the specific new energy solution or using the same or similar technology for other products/services in different markets. If the new technology is a platform technology, diversification is relatively easy, like in the case of specific thin-film technology used in manufacturing of solar cells but also in manufacturing of computer screens. Diversification constitutes an important way of reducing risk in a competitive environment or environment in which national policy support is instable (Chang and Thomas, 1987), but it may also deter attention from the energy invention. Many of the above decisions are summarized in the firms' business model.

We next include important capabilities of the founders in the model (Barney and Clark, 2007). Founders of spin-offs often lack market/business education and market experience in their team (Clarysse and Moray, 2004; van Geenhuizen and Soetanto, 2009) while a good match between market abilities and entrepreneurial ambitions strongly contributes to performance of spin-offs (Pérez and Sánchez, 2003). But some spin-offs do have experience from previous work or from having started a prior firm, and these aspects of management team composition are acknowledged as a factor of influence (Colombo and Grilli, 2005, 2010; Visintin and Pittino, 2014; Diánez-González and Camelo-Ordaz, 2016). In addition, most founders in sustainable energy have a technical background, but there is a difference in depth of technical knowledge as reflected in a PhD or not and in important knowledge on practical application. Further, networking in order to gain resources that are not owned, is included in the model (Lavie, 2006; Barney and Clark, 2007; Kozlenkova et al., 2014). Building and maintaining networks is not easy. At young age these networks include relations with friends, family and colleagues at university or in the incubator, but sooner or later, these networks have to shift to 'arms' lengths ones', in which rules of business apply, like with established energy providers, car industry, battery industry, turbine manufacturers etc. (Hite and Hesterley, 2001) and eventually policy influence is extended. Selecting the best partners and managing the relationships while considering the partner's interests, is a complicated task for some segments of young firms (Hockerts and Wüstenhagen, 2010; Fontes and Sousa, 2013). Others, on the contrary, may act relatively 'aggressive' or 'pro-active' by collaborating with potential customers as launching customers or even as partners in the development and design process (co-creation) (Prahalad and Ramaswamy, 2004; von Hippel, 2005). We distinguish in the current paper between multiple actors (and rich and influential networks), like customers, policy representatives, financial investors, enabling e.g. niche development and experimentation (Lopolito et al., 2011; Hermans et al., 2013), as opposed to single relationships.

And finally, we include external circumstances with regard to investment capital and national innovation system, as parts of the model. The most often missing resource among high-tech spin-offs is investment capital, particularly after the first rounds of (informal) investment. This is the stage in which the invention needs to be up-scaled and/or tested otherwise, however, without being sufficiently attractive for professional investors, like venture capitalists and banks. This issue is addressed in the literature as the 'valley of death' (Bocken, 2015; van Vooren and Hanemaaijer, 2015). The reasons for not being attractive is the need for large amounts of capital without being able to pay back at the required limited time, this as a result of a market that develops slowly due to higher customer prices and sometimes smaller customer comfort (Mohr et al., 2010; Leete et al., 2013; Marcus et al., 2013). This situation holds particular for firms in hardware, equipment, and materials. With regard to countries' national innovation system as discussed in the previous section, we distinguish between Norway and the Netherlands on one side, and Denmark, Finland and Sweden as 'innovation leaders' on the other side. In addition, we mention here an important aspect of national support for particular types of sustainable energy. Policies need to be supportive over longer periods of time. If policies are subject to discontinuity, like in the Netherlands in recent past with regard to wind energy, SMEs start feeling vulnerable and tend to change their product innovation program, and eventually enter diversification (Horbach, 2008; Triguero et al., 2013).

Figure 1 A simplified conceptual model of path to market introduction



4. Methodological aspects

4.1 Sample and data collection

As indicated above, we carry out the research in the Netherlands and in the four Nordic countries, Denmark, Finland, Norway and Sweden. We composed a selected sample of 37 of university spin-off firms dealing with commercialization of sustainable energy solutions and in their early years, aged between 4 and 10 years. The selection was aimed at creating sufficient variation (contrasting positions) in the database concerning the nine factors in the model. The data were drawn from multiple sources, namely, existing in-depth interviews (Note 1), the firms' website presentation, and internet coverage, e.g. through branch journals, like Nordic Green. All three sources were used to compose a structured data list, which was cross-validated and checked by both researchers (in 2014/15). The data list includes the composition of the founding team (education and experience), important events and years (firm establishment, pilot studies and other testing, introduction to market), networks and network partners, gaining of investment capital, and a set of data on the energy system, value creation of the invention, strategy archetype and focus or diversification.

Using a small sample and applying a specific selection of case studies, of course, does not allow statistical generalization of the results. Instead, the approach enables 'generalization' on the basis of theoretical positions of the spin-offs (Eisenhardt and Graebner, 2007), like a 'typical' combination of country and collaborative networks or a 'typical' combination of an energy technology and failure in gaining investment capital, and their influence on the time to market. These combination are the results of rules derived from rough-set analysis. In a next step, the in-depth analysis of five case studies enables a further exploration of the main factors, to confirm or critically check the results, this as part of iterative learning processes that are common in the framework of 'grounded theory' (Mayring, 2007).

4.2 Database

Table 2 shows how the variables have been measured and categorized as input for the optimal runs of the rough-set analysis. Note that most of them are binary as the result from experimentation outcomes and robustness checks in the preparation stage, aimed at gaining a balance between sufficient classification power and detail that is redundant. The dependent variable – a qualification of time and steps used in bringing inventions to market - is measured as a binary variable, a positive situation (short time to market introduction or successful pilot testing) and a problematic situation (long time but no market introduction, a still problematic pilot testing or failure/bankruptcy). After robustness checks, we took five years as the borderline between positive (short time and many steps) and problematic (long time and few steps). For spin-off firms that are younger than five years (four cases) we evaluated engagement in early steps in more detail. Further, richness in networks was measured on the basis of both interviews concerning important relations and website information indicating single or multiple types of networks, the last including supplier relations, customer relations, pilot experimentation, etc.

4.3 Rough Set Analysis

The limited sample size and low level of measurement of some data, namely categorical, prevent applying regression analysis, instead of which we apply a fuzzy based method, rough-set analysis (e.g. Pawlak, 1991; for details, see Polkowski and Skowron, 1998 and Polkowski, 2002; for a new approach, see Kłopotek et al., 2010). The software we use, is named ROSE. In contrast to multiple regression analysis, no assumption is made in rough-set analysis about a normal distribution of the data.

Table 2. Measurement of variables

Variables	**Categories' share in the sample**
Indicators reflecting entrepreneurial orientation	
Energy system	Solar: 35.1% Wind: 18.9% Automotive: 18.9% Other (biofuels, fuel cells, combination, etc.): 27.0%
Value creation	Core of energy technology: 67.6% Additional application technology: 32.4%
Strategy archetype	First mover: 35.1% Otherwise (follower/customer intimate): 64.9%
Diversification/focus	Diversification: 27.0% Focus: 73.0%
Indicators reflecting founders' capabilities	
Market/business competence	Business experience: 56.7% No business experience: 43.3%
Technical competence (highest level)	PhD: 70.3% Master: 29.7%
Networks	Multiple: 54.1 % Otherwise (no/simple): 45.9%
Indicators reflecting the external environment	
Access to substantial investment capital	No: 54.0% Yes: 46.0%
Countries' profile in innovation (past years)	Finland, Denmark, Sweden (Innovation Leaders): 43.2% Norway: 18.9% Netherlands: 37.8%
Decision attribute (dependent variable)	
Evaluation of time/steps in bringing inventions to market	Positive: 59.5% Problematic: 40.5%

As a first step in rough-set analysis, data on each individual spin-off firm including the dependent variable, namely qualification of development to market (in two categories) and nine independent variables are used to develop the so-called information table, serving as a basis for a systematic analysis of the model. The information table is a matrix in which spin-off firms are arranged on the basis of their independent variables (named condition attributes) and dependent variable (named decision attribute). Next, the basic procedure in rough-set analysis works through attribute reduction, i.e. finding a smaller set of condition attributes with the same or close classificatory power as the original set of attributes. Further, on the basis of a reduced information table, the analysis composes decision rules in various rounds. A decision rule is presented in an 'IF condition(s) THEN decision' format. The procedure leads to 11 of such rules, of which we show the 10 strongest (Table 2).

It is worth notice that we use the following quality checks of the rough-set procedure and outcomes. One of the first steps in the procedure is the determination of condition attributes that are in the 'core', meaning that they have the strongest classification power. These turn out to be energy technology, networks and country. The quality of classification of attributes in the core is 0.84, which is below the maximum of 1.0 but it is still acceptable, whereas the quality of classification of all condition attributes is 1.0 (Annex 1). Next, a validation of the rules is performed by using K-fold cross-validation. This is a technique to evaluate predictive models by randomly partitioning the sample into K subsamples in which one of them plays as validation set for testing the model and the rest of K-1 subsamples are put together to form a training set (Chen, 2009). This test is based on random selection of the validation and training sets, and we repeat the test 50 times. The results have a sufficient level of accuracy (almost 70 per cent in total) for the obtained rules.

It is also worth notice that rough-set analysis is increasingly recognized in the literature as a classificatory method, including elements of causal relations. This holds for comparing performance of firms, development of projects, systems, etc. particularly when it comes to analysing small samples and qualitative data (e.g. Dimitras et al. 1999; Nijkamp et al. 2002; Soetanto and van Geenhuizen 2007; Peters and Skowron 2014; Taheri and van Geenhuizen, 2016).

5. Conditions enhancing positive or problematic development

5.1 Results on the rules

In determining the importance of the decision rules, we use strength and coverage. The strength of a decision rule indicates the share of all spin-off firms displaying the same combination of condition attributes (rule) as well as the same outcome on the decision attribute. The coverage is the absolute number of spin-offs involved. The higher these outcomes, the better the rules describe parts of the sample. Rough-set analysis works stepwise by experimentation. This means that after various rounds of 'estimation' the optimum number of categories become apparent as a balance between useful detail and redundant information.

The results of the final estimation are given in Table 3. We first summarize two overall trends as apparent from the rules. As a first trend, the rules tend to be stronger for a positive development compared to problematic situations, as indicated by the strongest rule's coverage of 11 firms as opposed to seven firms respectively at an almost similar strength (50 and 47 per cent). Secondly, the results of core determination mentioned in section 4.1, indicate that energy technology, networks and country are more often present in the rules than other condition attributes. They appear respectively six, four and four times in the obtained rules and have apparently the strongest influence on time and steps to the market.

Type of energy technology appears most frequently in the rules. However, it appears that merely this attribute does not produce consistency among the rules, meaning it gains importance mainly in combination with another attribute. For instance, Rule 4 (Table 3) indicates that spin-offs in automotive technology with multiple networks face a positive development, while Rule 10 indicates that spin-offs in automotive technology without such networks face a negative development, though at less strength of the rule. Country is the next most repeated attribute in the rules. The results indicate that a positive development appears more often in countries with a higher innovation level. Denmark and Finland emerge twice in the rules and only in positive rules. Norway and Netherlands appear only once and just in a negative rule. Furthermore, networks is repeated four times in the rules, like country, and we observe a strong consistency for this attribute. The most distinguishing rules are Rule 1 and 4 (positive development). In addition, the strongest rule in the negative class (Rule 7) indicates that acting as a follower in the solar technology market, avoiding the highest risks, is nevertheless likely to produce a negative development in the absence of multiple networks. Surprisingly, market/business competence fails to be part of any rule, indicating lack of importance in speed of reaching the market. This can, however, be explained by the fact that high-tech spin-offs that lack such competence often attract a CEO from outside after a couple of years, in particular when achieving large amounts of (venture) capital.

In the remaining section we discuss the strongest rules, first the ones concerning a positive timeline (Rule 1 to Rule 4) (Table 3):

- Rule 1 indicates that the combination of operating in an Innovation Leader country and having developed a multiple network makes a positive development towards the market likely, at a strength of 50 per cent. It points to a combined positive influence of favorable national institutions, regulation and policy measures together with well-developed, rich, networks.
- Similar, but weaker (at a strength of 32 per cent) Rule 2 indicates that the combination of having merely a Master as highest education and gaining of substantial investment capital, makes a positive development time to market likely. As assumed, having a Master only could be an advantage as it is more practical and less scientific in orientation than a PhD (a disadvantage according to Rule 8). In addition, Rule 2 confirms the importance of gaining investment capital overall.
- Somewhat weaker (at a strength of 27 per cent), Rule 3 indicates that the combination of wind energy technology and being a follower in the market makes a positive development likely. The rule indicates a positive impact from taking smaller risks as a follower in an already established market.
- Likewise (at a strength of 23 per cent), Rule 4 indicates that the combination of automotive fuel technology and multiple networks makes a positive development

likely. This rule puts an emphasis on the benefits of multiple networks in a situation of scarce resources and probable resistance from established automotive technology.

The occurrence of a problematic development is somewhat less clear (structured) as appears from a lower strength of the rules and their combination of often three condition attributes:

- Regarding Rule 7, the combination of solar energy technology, a poor collaboration network and being a follower, makes a problematic development likely, at a strength of 47.5 per cent. It suggests that even being a follower, taking less risks, requires strong collaboration in networks in bringing solar energy solutions to market, thereby referring to competition of spin-offs with large Chinese solar cell producers active in the European market at a much lower customer price (Goodrich et al., 2013).
- Rule 8 is less strong (at 27 per cent) and indicates that spin-offs in Norway, with a strong focus and high technical skills (PhD) are likely to develop in a problematic way if insufficient support. This rule suggests problems of more basic research that still needs a long way to be transformed into a practical application.
- And finally, Rule 9 (at a strength of 20 per cent) indicates that spin-offs in the Netherlands in energy technology like fuel cells and alternative biomass (algae), improving efficiency of the new solutions, are likely to develop in a problematic way. This rule suggests that such spin-offs are still engaged with pilot plants and scaling-up of production, calling for substantial financial investment and potentially facing the 'valley of death'.

Table 3. Rules on path to market

	Rules a)	**Decision Attribute**	**Coverage**	**Strength %**
1	Country (Innovation Leader) & Multiple network	Positive	11	50.0
2	Technical competence (Master) & Investment capital (Yes)	Positive	7	31.8
3	Energy technology (Wind) & Strategy archetype (Follower)	Positive	6	27.3
4	Energy technology (Automotive) & Multiple network	Positive	5	22.7
5	Energy technology (Other sustainable energy) & Country (Innovation Leader)	Positive	4	18.2
6	Energy technology (Solar) & Country (Netherlands) & Technical competence (PhD) & Focus	Positive	2	9.1
7	Energy technology (Solar) & Single network & Strategy archetype (Follower)	Problematic	7	46.7
8	Country (Norway) & Focus & Technical competence (PhD)	Problematic	4	26.7
9	Energy technology (other sustainable energy) & Country (Netherlands) & Value creation (in core)	Problematic	3	20.0
10	Energy technology (Automotive) & Single network	Problematic	2	13.3

a) One rule with a coverage of 1 spin-off is not shown.

With regard to the contradiction between liability of newness and advantages of newness, the above rules indicate various situations in which university spin-off firms do not suffer from liability of newness. Rather, some of them may develop a useful practical orientation and build multiple networks to gain resources, including credibility, and to achieve substantial amounts of investment capital. On the other hand, it is also possible that they are not able to establish strong networks and are faced with unexpected competition or with a long way to the market including the need for various capital injections. Overall, the results indicate that the two perspectives are both too simple.

5.2 Case studies

The four case studies are selected in such a way that they allow a further exploration of the main trends and thus represent one of the relatively strong rules (Table 4). The analysis has a focus on networks because these appeared to be consistently important in the rules, and on gaining substantial financial investment.

Case study 1 deals with developing hardware and software of charging stations for electrical vehicles to reduce charging time without damaging the battery. The spin-off represents Rule 2 and suggests importance of a practical Master level approach to an existing invention, as well as acquiring substantial investment capital. The investors were mixed, among others a foreign eco-venture capitalist and a Dutch venture capitalist, and a battery company from Taiwan. Market introduction took place four years after firm establishment and one year after substantial investment started. Note that the invention at university was already quite far developed at the time of firm establishment, which may explain part of the short time to market, but the ability of the firm to organize pilots and niche experimentation and learn from them together with important actors (multiple networks), also needs to be mentioned. However, if we observe the firm later in time, it failed to collect sufficient investment capital to quickly roll-out the market globally (US and China) and decided to be acquired by the MNC with which there was already a long-standing collaboration relationship.

Case study 2 represents Rule 3 and indicates importance of a low-risk follower strategy in a more or less established energy technology (wind). The firm has adopted an integrated approach to wind energy exploitation, and is engaged in preparation and management of wind farms. To increase efficiency in operation and maintenance, the firm outsources specialized services. There is no substantial investment involved, unless the firm acquires an existing wind farm. Market introduction took place in 2010 one year after firm foundation, indicating a relatively large demand for the services.

Case study 3 represents Rule 7 and suggests a negative influence of being active in solar energy and missing multiple collaboration networks. The firm designed an innovative support system (construction) for solar panels, that could be moved with the sun, aimed to be placed over open public spaces in cities, like parking places. The firm however faced institutional obstacles from construction rules and safety protection in public places, while no large firm in the home country was interested in producing solar energy. However, in California (US) large firms were interested in the system, but the spin-off at the time was two years old and employed 2 fte, failing to gain credibility. Accordingly, this spin-off was suffering from liability of newness and smallness while missing the backing of a strong partner which could have increased its reputation but also accelerated adjustments to market wishes and regulation requirements.

Table 4 Selected case studies of spin-off firms

	Case study 1 EV Charging	Case study 2 Wind farm services	Case study 3 Solar application	Case study 4 Biogas membrane
Represent	***Rule 2*** *-Substantial investment* *-Master level*	***Rule 3*** *-Wind energy* *-Follower*	***Rule 7*** *-Solar* *-Single networks* *-Follower*	***Rule 8*** *-Norway* *-PhD level* *-Focus*
Founding Year	2005	2009	2011	2008
Energy technology	Charging System EV	Development/ management of wind farms	Solar	Biogas
Innovation	Quick charging, no battery damage	Integrated approach, high efficiency	New support construction of panels: parking places	Clean gas upgrading using advanced membrane
Path Qualification	Positive	Positive	Problematic	'Borderline'
Collaboration networks	Multiple	Multiple	Single	Multiple
Investment capital	Substantial amount (mix)	Limited needs	Not received	Substantial amount (mix)
Specific situations	Strong collaboration in pilots	n.a.	No credibility (investors) Regulation barriers	Active in traditional sectors
Timeline up to 2014				
Investment capital gain	2008-2010	Limited	Limited	2010 4 million Euro
Pilot success	From 2008 on	n.a.	Weak success	2013
MI*	2009	2010	n.a.	2013
Time-to-market (MI)	4 years after founding	1 year after founding	n.a.	5 years after founding
MG**	2010	n.a.	n.a.	2013
State end of 2014	Acquired by MNC in 2011	Continuing	Ceased in 2013	Continuing

n.a.: not applicable; MI = Market introduction; MG = Expansion in global markets

Case study 4 represents Rule 8, located in Norway with a focus on a highly advanced product - a carbon membrane to upgrade biogas working cheaper and cleaner - and founders' competence at PhD level. The rule indicates a problematic situation, but the development is close to a 'borderline' case. The combination of a highly advanced product and PhD orientation tended to cause a relatively slow development while speed was urgently needed in a situation of large amounts of capital invested in the spin-off (about 4 million Euro in 2010). However, there were important collaborations, for example, with food industry and waste treatment. Next, while building and starting up the pilot combustion site according to all required specifications took a relatively long time, market introduction of the membrane followed quickly, all-in-all five years after firm establishment and three years after the substantial investments. Such a situation may cause a danger of too quick market introduction with a somewhat immature product.

Mainly looking back to the influence of substantial financial investment, the above case studies indicate that situations may quickly change over time, like financial investment may be sufficient for the stage of market introduction but not for rolling out sales globally. In addition, with regard to the 'valley of death', the need for substantial financial investment may cause a negative outcome if the firm is not able to achieve it, but it may also cause a negative outcome if the firm does achieve it but a short pay-back time contributes to premature market introduction. And finally, service firms are also part of the sample, for which substantial financial investment is not critical.

6. Conclusions and Future Research

In this article, we aimed to clarify differences in time length and steps in bringing sustainable energy technology to market by young ventures. To that purpose a selected sample of 37 spin-off firms was drawn from universities in the Netherlands and Nordic countries and a simplified causal model was estimated, followed by in-depth analysis of four case studies. Three conditions in the model (out of nine conditions) tended to have a relatively strong influence, namely, energy technology, country and networks. Energy technology was found to be important only in combination with other conditions, like character of the network. Country was found to enhance a positive development with a higher level of national innovation and innovation support in Nordic countries, except Norway. Furthermore, rich network collaboration (various different partners) tended to work positively and lacking such collaboration tended to contribute to problematic developments. Remarkably, while financial capital and the 'valley of death' have attracted a lot of attention in the literature, the evidence from our analysis was somewhat weak. This situation can be attributed to the presence of service firms and 'research firms' in the sample that avoid the need for substantial capital investment. As a final point, referring to the composition of our model, an external factor representing dynamics in the market, e.g. the emergence of serious competitors and of constraints from regulation needs to be included.

The four case studies produced additional and more nuanced insights into the time dimension. First, pathways may change quickly over time, bringing sometimes unexpected time-related obstacles to light. These include delay and eventually refraining from further pilots if investment capital cannot be gained. However, these also include well-financed pilots and market introduction, followed by an immediate short in capital for building a global sales organization. And serious obstacles arise if well-financed last stage tests and pilots are accompanied by a too short pay-back time while pushing the invention to premature market introduction and causing overall firm failure. A second but different time-related observation is that some spin-offs develop very quickly towards the market on the basis of an invention which was almost ready to market at time of firm foundation. This situation raises the question as to whether the 'state' of the invention at firm foundation should be part of the model, or the timeline of development should be considered to start at the first serious planning of development activity towards the market, instead of time of firm foundation.

The study also contributes to the discussion in literature on whether young high-tech ventures are able to grow quickly on the basis of advantages of newness, including e.g. flexibility, responsiveness, and lack of fear for risk-taking. Our results on relatively young university spin-off firms (four to 10 years old) point to the answer yes, if certain conditions are satisfied, and equally to no, if such conditions are not satisfied or alternative conditions are satisfied. Being involved in multiple networks including different actor types seems one of the strongest positive influences, but the situation is more nuanced as the country (its innovation system) also matters. The combination of these two conditions provides the largest chance for a quick market introduction. This is followed by a combination of practical orientation (indicated by Master graduates as founders) and access to substantial investment capital, the latter preferably without a too strong pressure from pay-back time. Accordingly, a specific part of the spin-off firms is able to bring an invention quickly to market and potentially contributes to an energy transition.

Although our results are preliminary, we may call attention to various points. First, for policy makers in the Netherlands and Norway, to increase understanding of the beneficial circumstances in Denmark, Finland and Sweden and to create ways in which these can be 'transplanted' in the home country. One of them may be to nurture the more basic inventions longer at university (as observed in Sweden) and pay more attention to soft needs of innovation. The next points could be addressed to technology transfer offices (TTOs), incubator management and also spin-off firms themselves. The composition of the founding team is preferably balanced, with practical input at the Master level. To increase practical orientation of PhD students in a pre-start situation, they could be encouraged to already spend time (a thesis chapter) on practical application and a business model, as already occurs at some technical universities in Europe. Further, early engagement in collaboration in multiple networks needs to be enhanced, preferably including a larger firm for co-development. We may suggest to organize interactive meetings and enhance participation of spin-offs in these meetings, but also to improve and train presentation skills and negotiation skills of spin-offs' managers (Lockett et al., 2005; van Geenhuizen et al., 2015). What also calls attention is the time-dimension of substantial investment rounds, particularly the time that is 'granted' for last stage development which should be sufficiently long to allow a mature market introduction. New solutions and models in capital investment, as alternatives for venture capital, are emerging today and are sometimes already in place. We mention crowd-funding and new funding platforms, though coming with their own complications, but also the emergence of ‘new style’ venture capitalists matching the needs of the young ventures, and national government action in providing funds (Bocken, 2015; van Vooren and Hanemaaijer, 2015). A last point of attention is the need for better monitoring of changes in the market and in regulation, enabling to early identify competitors abroad and (changing) EU regulation and to prevent that inventions turn out to be superfluous.

This study is also facing some limitations. First, the current results – as trends and typical situations - cannot be generalized in a statistical sense. Therefore, the sample needs to be extended such that a random sample of sufficient size is achieved and the current outcomes can be rigorously tested. And secondly, in terms of content, our case study analysis revealed the need for a more nuanced and extended interpretation of the time-dimension. This includes, first, the time of establishment of the spin-off firm relative to the time of start of planning to bring the invention to market, secondly, the time needed for market introduction relative to main rounds of investment, and third, the quick changes in financial capital needs while moving from market introduction to global sales. Such time-aspects deserve more attention in next research, based on a larger sample and using event-history analysis.

Note 1.

The two databases used are the Soetanto/Taheri database of spin-offs in Netherlands and Norway (Taheri, 2013) and the Spin-up database of spin-offs including ones in Netherlands and Finland (URL: www.spin-up.eu). In addition, the branch journal 'Nordic Green' has served as an important source of spin-off firms among green high-tech ventures.

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Annex 1 Core determination and quality of classification

The core is the intersection of all reducts which indicates the certain condition attributes that are necessary to explain a feature of the decision attribute. The quality of classification for attributes in the core equals 0.84 which is acceptable. Also, the overall quality of classification and the accuracy of two classes equals one which means the doubtful region is empty and condition attributes provide satisfactory discrimination between the classes.

Quality indicators of the rough-set procedure

Quality of classification for	
- All condition attributes	1.00
- Condition attributes in the core (3)	0.84
Quality of classification (two classes)	
- Accuracy of approximation of positive outcomes	1.00
- Accuracy of approximation of problematic situation	1.00