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Green Innovation Processes in SMEs: Anatomy of a Learning Journey

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Established small and medium-sized enterprises (SMEs) can seize business opportunities in new, emerging sustainability-related markets. However, in contrary to start-ups dedicated to a green mission, expanding a firm's conventional product portfolio with green products has proven to be very challenging. Indeed, green innovation processes are new to many firms and adapting to green technology, product and market contexts requires important learning efforts. This paper aims at gaining insights into the underlying process and the learning outcomes. We examined innovation processes at the micro-level using the Fireworks innovation process model and found that top management had to a) better understand its own assets and competences and b) to develop new innovation management routines related to search, selection and implementation of the innovations to be developed. However, this is not a straight-forward task as it often happens in a long-term exploratory process without guarantee for (quick) success and can involve important setbacks. Therefore, for conventional technology SMEs, a central difficulty is to engage on this trial-and-error learning journey to better understand how it can, based on its assets and competences, develop green product innovations.

1. Introduction

Even though the number of management publications on eco, green or sustainability-oriented innovations are strongly increasing (Schiederig, Tietze, and Herstatt 2012), the *processes* underlying the development of these innovations in organizations are still only marginally understood. This is particularly the case in small and medium-sized enterprises (SMEs) – not entrepreneurial firms founded with a green mission, but conventional firms diversifying themselves into green markets.. Indeed, green product innovations are often radical for established organizations as they significantly differ from the current business in terms of technology and markets and involve large unknowns. Some authors argue that developing new methods for search (of new technologies and markets), selection (of the product that ought to be developed) and implementation is a major challenge these firms (Seebode, Jeanrenaud, and Bessant 2012). Others also highlight the need for new knowledge, which often needs to be acquired from outside the firm (Clarke and Roome 1995;

Hansen and Klewitz 2012). As green innovation processes are new to many firms, adapting to green technology, product and market contexts requires important learning efforts; a process that is presently not well understood and often hindered by old beliefs about success.

This paper aims at gaining insights into learning processes of technology SMEs previously operating in conventional markets, engaging in radical innovation by pursuing green technology innovations. We examined innovation processes at the micro-level in a business-to-business engineering SME, which has developed components for sustainable energy technologies in the context of a new business unit. We considered three intertwined, emergent and interdependent innovation paths that ended without successful market introduction. These paths and the related innovation processes form an innovation journey. We studied this journey with the Fireworks innovation process model (Van de Ven, Angle, and Poole 2000/1989), which allows to study the complex interactions between the related processes, and with internal and external phenomena that influence their course. The model pays particular attention to events such as the occurrence of setbacks, shift of innovation performance criteria, fluid participation of personnel, involvement and role of top-management, alteration of relationship among personnel and the role of other industry actors (Van de Ven and Poole 1990). Interesting is that each path can induce learning outcomes. We analyzed these learning outcomes from an organizational learning perspective (Levitt and March 1988; Levinthal and March 1993; Nonaka and Takeuchi 1995) with a strong focus on the role of cognitive representations.

2. Literature review

2.1 Green innovation and SMEs

Even though the number of management publications on eco or green innovations are strongly increasing (Schiederig, Tietze, and Herstatt 2012), the processes underlying the development of green innovations are still only marginally understood (Klewitz and Hansen 2014). Green innovations include new products, services or business models (NBS 2012). Green technology innovation share many similarities with conventional technical innovations, but differ in purpose, direction of search and complexity (Noci and Verganti 1999; Paech 2007; Bos-Brouwers 2009). Indeed, on top of commercial success, green innovations embrace the explicit double-aim of improving the firm's sustainability performance and to contribute to solving societal issues (Hansen, Große-Dunker, and Reichwald 2009). To fulfil this purpose, firms need to search in a specific direction to assure that the innovation outcome will eventually have a positive impact on the environment and society, which increases complexity and decrease the number of available options (Fichter, Paech, and Pfriem 2005).

Notwithstanding the significant managerial complexity, empirical investigation demonstrated that some SMEs are highly committed to the development of green innovations (Noci and Verganti 1999). In many ways small business are particular and are not just little big businesses (Welsh & White 1981). These differences are reflected in the rich academic discussion on the differences between small and large firms. The most frequently discussed difference include: a) the amount of resources available, b) SMEs, unlike large enterprises, often compete in clusters where competitors are prone to price cutting, c) fewer resources are available to hire manager and qualified personnel, as the owner-manager salary represents a much large fraction of the revenues and d) external forces tend to have a more determining impact on SMEs (Welsh & White 1981). However, compared to their larger counterparts, SMEs have the advantage of greater flexibility and can therefore react much faster to a changing technological, market and regulatory situation (Welsh and White 1981). And when it comes to innovation management, no innovatory advantage is unequivocally associated with neither large nor small firms (Schumpeter 1934). In fact, some authors argue the advantage of SMEs is mainly behavioral and the one of large firms material (Rothwell 1989; Nooteboom 1994). We focus on this paper on innovation processes related to the development of green innovation in the SME specific context.

2.2 Fireworks innovation process model

In the literature on innovation studies, a conceptual difference is made between the *process* and *outcome* dimension of innovation. According to Crossan, Maurer, and White (2011), scholars studying the process of innovation aim to answer the question "how" an innovation occurred. Internal as well as external drivers and barriers to the development of the innovation are typically analyzed. The process is considered at different levels: individual, team, organizational and inter-organizational levels.

The term *innovation process* refers to the sequence of activities that led to the birth of an innovation. Frequently used in innovation management and in the design literature, so-called flow models represent the archetypical development of an innovation in the form of a linear process that ranges from the idea to the launch of the new product (Verworn and Herstatt 2000). The development stages are often separated with "go – no-go" decisions gates (Cooper 1990). Thus this prescriptive view is of great use to simply represent an innovation process and for communicating about it. Yet, it yields limited usefulness for empirical analysis. Indeed, in reality the innovation process is rather fuzzy: stages occur in parallel, often overlap and are iterative. Based on an in-depth qualitative study of 30 British industrial firms known to be active in R&D, Cooper (1983, 12) concludes that:

> *"[T]he new product process is not the sequential or series process so often portrayed in the literature. Rather, we see a more complex process, with many activities overlapping or undertaken in parallel. Indeed there appear to be certain efficiencies in adopting this parallel approach. The usual normative models, in contrast, propose a stagewise (series) set of activities for new product managers to follow. Such models are clearly unrealistic: product innovation simply does not occur that way, and normative guides that do not recognize either the differences in processes or the overlapping nature of activities will probably meet with little success."*

We adopt the "fireworks" innovation model (depicted in Figure 1) to embrace the complexity of the innovation process (Van de Ven, Angle, and Poole 2000/1989). The framework is used to gain insights into how and why innovations develop over time from concepts to implementation (Van de Ven et al. 2008).

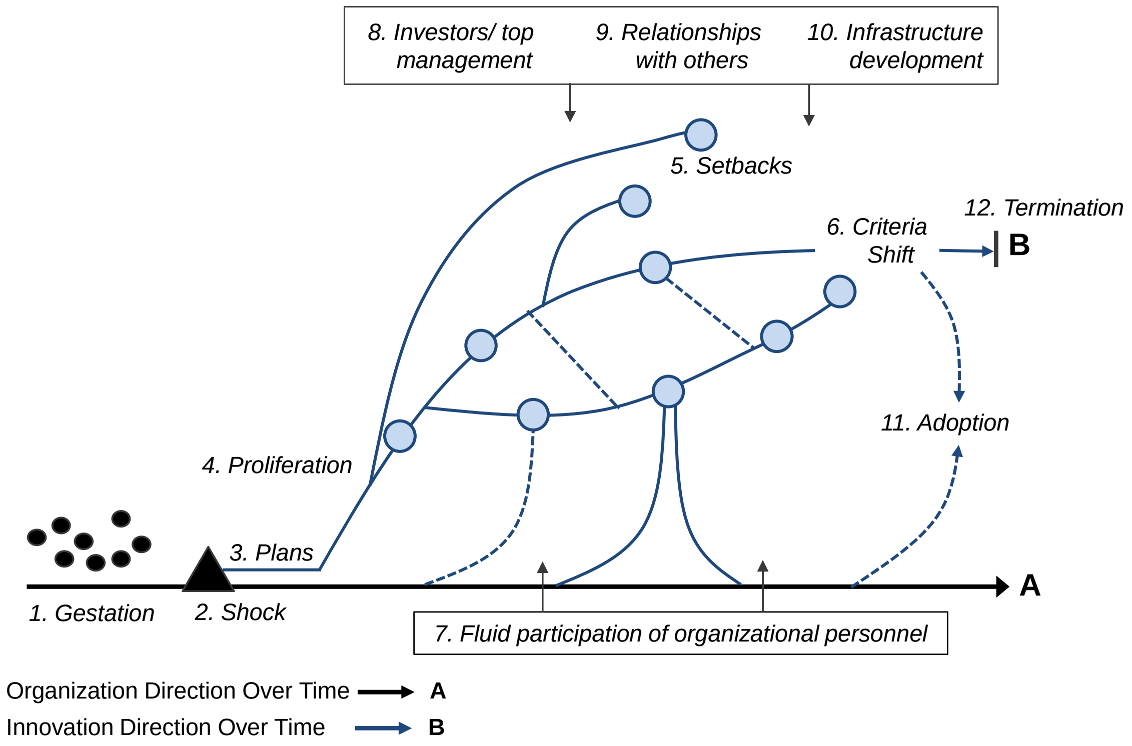

Figure 1. The Innovation Journey and its key components (source: Van de Ven et al. 2008)

These innovation processes, taken together, form an innovation journey that can be divided into four phases: the initiation, the development and the implementation and termination. The initiation is characterized by a long period of time where ideas are in gestation. It is separated from the second phase by a shock, which triggers the attention of managers. The shock signals managers that it is urgent to develop something new to guarantee the survival of the organization. The shock is followed by the development phase that is characterized by the proliferation of ideas into different pathways. The study of the innovation journey largely focuses on this phase of the innovation process. Elements to study in this phase are the occurrence of setbacks, the shift of innovation performance criteria, the fluid participation of innovation personnel, the involvement and role of top-management, the alteration of relationship among personnel and the role of other industrial players (Van de Ven et al. 2008). The last phase deals with the adoption of innovations by the receiver organization and the termination of innovation, in case of failures. Overall, the fireworks model describes how innovation processes occur along various (partial) pathways, influencing each other but also facing dead ends sometimes. While in a short-term perspective, a dead end could be considered innovation failure, from a longer time perspective, it may become clear that it was just a setback part of a longer development process ultimately leading to success. Our aim is to get a longitudinal understanding of these individual process elements and their role in the overall innovation journey from a perspective of organizational learning.

2.3 Management cognition and organizational learning

In management, cognition is about the ability of top management to perceive and understand the firm environment and the situation of the firm. This cognition starts with the ability to identify a firms’ current core competencies and the evolving competitive environment (Hamel and Prahalad 1994). In that sense, management cognition is a pre-requisite for long-term firm survival (Hamel and Prahalad 1994) and is closely related with management’ ability to sense the environment. To adapt to a new firm environment, organizational learning is necessary to transform and adapt competences, routines and perception of the environment. However, organizational learning is a long-lasting and challenging process.

Within organizational learning, we focus on the concept of cognitive representation that help explain management changes along the innovation journey. Considering that managers are bounded in rationality (Simon 1991), cognitive representations in essence allow to simple information processing and thereby increase the efficiency of management decision making. They are typically based on historical experience (Tripsas and Gavetti 2000) and are also referred to as set of believes, dominant logic, management frames (Prahalad and Hamel 1990) or assumptions about success in business. They are essential for performance in a mature business that aims at drawing optimal commercial benefits of existing technologies or products (Benner and Tushman 2003). However, cognitive representations are difficult to unlearn or be reinvented, which is however necessary in the context of strategic renewal or when the firms needs to develop new products for new markets (Crossan and White 1999). They are in this sense a major cause for inertia. Further, (Levinthal and March 1993) speak of managerial traps when managers face difficulties steeping out of old thought structures. For instance, the term "learning trap" relates to the situation of a manager that cannot step out of exploitative thought structure even though new, radical steps in innovation are needed. As cognitive frames often have a strong influence on the accumulation of competences and eventually on a firms' ability to adapt to a changing environment, difficulties in learning can have an impact on the development of new competences. Leonard-Barton (1992) speak of "core rigidities" when core competences of the old business prevent the development of new business areas and holds back the development of the company. While – within the timeframe covered in the longitudinal analysis – we examine a case of unsuccessful technology innovation (i.e. innovations either did not enter commercialization or were discontinued subsequently), we find that individual and organizational learning occurred during the complex innovation journey by overcoming some of the core rigidities – ultimately, enabling more successful innovation processes in the future.

3. Methodology

The research presents an in-depth longitudinal case study (Yin 2014) of a well-established engineering SME in Germany successfully operating in the electronics industry. The firm – subsequently referred to as TechLtd – has engaged in the development of green technologies as components for renewable and sustainable energy technology solutions. The case focuses on the learning outcomes that occurred within a new business unit dedicated to the exploration of these sustainable energy technologies. While we are interested in understanding the overall innovation process, the case features three embedded units corresponding to interrelated paths focused on specific products and related technologies: a) turbomachinery, b) small wind turbines and c) flywheel energy storage. Analysing such dynamic processes over long periods of time is prone to single case study research (Siggelkow 2007).

For data collection, we utilized a combination of retrospective and real-time approaches (Pettigrew 1990) covering a period of 15 years (2000-2015), of which we were able to observe the last three as an on-going process. We triangulated various data sources (Babbie 2013) including semi-structured interviews with top-management, middle-management and value network actors (31 interviews), participatory observation (19 meetings), two industry workshops, and extensive desk research. Interviews were transcribed, meetings protocolled, and both coded and analyzed (Babbie 2013). We also used triangulation and reflexive interpretation for integrating diverse and partly contradicting perspectives from various internal and external informants (Alvesson 2003; Shenton 2004). We assured 'trustworthiness' by providing for a triangulation of data and informants, multiple investigators, transparency of the methodological approach, rich description of the phenomena and context, and consideration of alternative explanations (Shenton 2004). The data is analyzed with the Fireworks innovation process model (Van de Ven, Angle, and Poole 2000/1989) in line with the recommendations for longitudinal case studies (Huber and Van de Ven, 1995; Yin 2014).

4. Case description

4.1 Introduction to the case study company

This paper examines TechLtd, a medium-sized German engineering firm that is operating in business-to-business markets in the electronics industry. The family business founded in 1962 is owner-managed in the second generation and employs about 200 people. Over the past 50 years, it has accumulated extensive knowledge in the control and steering of high-speed engines and generators and has become a global leader with a global market share of about 40 percent. It has typical characteristics of 'hidden champion' (Simon 2009) and is representative of the German 'Mittelstand'.

The firm, driven by a strong engineering culture, develops and produces electronic components (computerized numerical control (CNC) system, high-speed motor and generator control devices) that are sold to system integrators – machine-tool, turbine or various industrial machine manufacturers. Machine-tools are its primary market. Within this, the firm focuses on the niche of circuit-board drilling. Product development takes several months and is characterized by intensive R&D collaboration with customers and trust-based, long-term relationships. Production is characterized by small batches and is, contrary to industry trends, located in Germany. Sales offices exist in Europe, the USA, and Asia.

Top-management, knowing that new, path-breaking technologies might disrupt its main market segment (representing 80% of sales) sometime in the future, recognized the urgency for diversification of their business. Inspired by their intrinsic motivation for sustainability, top-management searched for new applications for its core competences and found several in the emerging market for sustainable energy technologies (SET). A new business line dedicated to the exploration and development of technologies related to the feed-in of renewable energy into the power grid was created.

In terms of structure, TechLtd is a rather flat hierarchical organization (Figure 2). Top management is represented by the owner-manager (i.e. CEO) and the chief technology officer (CTO). Due to the flat organization, no formal departments (e.g. R&D) or business units (e.g. CNC) exist, but the individual units report directly to the top management; an exception is the production department which serves all three business lines.

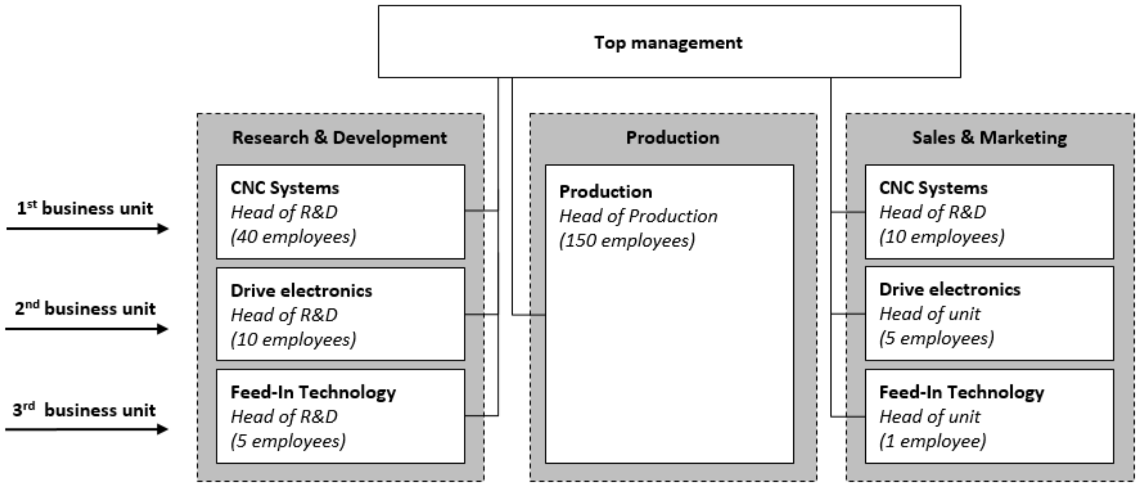

Figure 2. Organizational structure of TechLtd

The firm is organized in three business lines. The first deals with computerized numerical control (CNC) systems, which represents the core of the company with regard to its historical roots, size and sales. The second business line, drive electronics, was created thirty years ago as a spin-off and contributes about 20 percent of total sales. Instead of control systems for engines, this unit commercializes systems for high-speed generators and is responsible for one of the core competencies of the firm, i.e. the analysis and control of high-speed rotation. These two business lines are characterized by an exploitation rationale focusing on continuously improving the existing products based on small, incremental innovation with the aim to create short-term productivity gains for their customers. The focus of this paper is the third business line, feed-in technology, which is characterized by an exploration rationale and was formally created in 2003 (12 years ago) to explore how the company could use its engineering competencies for developing new applications for the market of renewable energy technologies (particularly small wind turbines).

4.2 Description of the innovation processes

The findings describe how three distinct innovation paths emerged after a period of general exploration on possible new applications of the firm's core technology. Interestingly, these three paths also induced innovation and learning in the core business. The general exploration, the three paths and their effect on the core business are described in the subsection below. An overview of the three innovation paths is given in Table 1 and a visual overview in Figure 3.

4.2.1 Initiation and overview of innovation process

In early 2003, top management employed an external engineer as head of the new feed-in business line. By searching for synergies with the existing core competences, exploration and networking aimed at finding applications in the area of 'rotation-based' renewable energy technologies, mostly different forms of turbines.

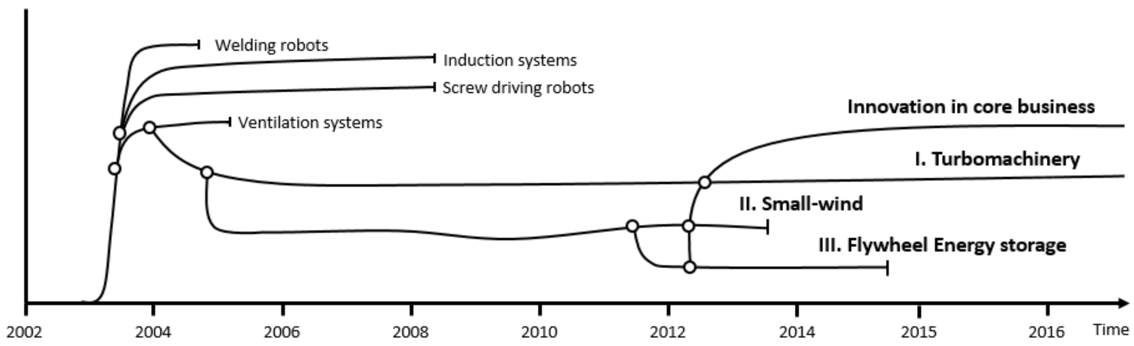

Figure 3. Innovation paths as viewed from a Fireworks innovation model perspective

This general technological exploration began with applications quite close to the core business. The first exploratory innovation projects were in the range of control system for welding and screw driving robots as well as induction systems. They did not have a sustainability-related character. However, during this exploration, TechLtd came in contact with a technical university that was developing new technologies centered on fuel cells in collaboration with regional industrial actors including a large automotive player. In this setting, the firm for instance came to develop a control system for the ventilation of a micro-fuel cell. Given the small size, a high-speed ventilator was necessary for oxygen supply. This is one example of early exploration that was followed by other projects, together forming the very early phase of the innovation journey.

Learning outcomes occurred already in this early phase. TechLtd became aware of aspects of its own business such as its core competences and how they can be of value to other firms in innovation projects. It also gained experiences in participating in collaborative R&D projects and thus in splitting tasks among firms based on what each partner can do best. In this context, it also explored how to use standard technical components available on the market instead of developing the entire product on their own.

Table 1. Overview of the three innovation paths

	Innovation path 1 Turbomachinery	Innovation path 2 Small Wind	Innovation path 3 Flywheels
Duration	2003-2016	2003-2013	2011-2014
Product/Technology	Controller for high-speed generator	Controller for high-speed generator and inverter	Controller for high-speed generator and inverter
Degree of innovation*	Low	High	High
Market	Micro gas turbines, combined heat and power plants, heat and cold conditioning system, etc.	European small wind market	Global flywheel energy storage market
Staff	- Top-Management (CEO and CTO) - Project managers - Development staff	- Top-Management (CEO and CTO) - At first: project manager - Later stage: R&D and sales manager - Development Staff (3-7 people)	- Top-Management (CEO and CTO) - Project manager - Development staff (< 3 people)
Costs	n/a	3-4 million (only staff)	< 0,5 million (only staff)
Believe in future customers	High	Medium (Low towards project end)	Low
Main market exploration format	- Trade fairs - Personal contacts and case by case approach (with product development based on customer needs)	- Partner with market access - Market research - Product presentation at trade fair	- Participation in industry workshop - Exploration of potential future sales contracts with flywheel end-user - CTO "Roadtrip" to leading flywheel manufacturers - Market research
Market knowledge	Low	Medium-low	Medium-high
External support	R&D with partners	Partner: access to small wind market and support in product design Institute of the authors: Analysis and reflection about the innovation processes	Institute of the authors: organize industry workshop and support in contacting potential customers

* As estimated by top-management in comparison to the core business

4.2.2 Innovation path I: Turbomachinery

Based on the first short-term R&D project on fuel cells as part of the initial phase, TechLtd engaged in a first longer term innovation project with the same partners. This time it did not only develop a prototype for a ventilation control system, but also to develop the component that transforms the electricity generated from the fuel cell so that it can be fed-in to the electricity grid (in this case of vehicles). TechLtd decided to engage on this project largely by opportunity and because they realized that they can contribute with their expertise to this project. This fits the way the firm previously innovated their products: innovation was essentially driven by the demands of their existing customers. It thus made sense to engage on a further project with the same partners. What's more is that top-management sensed an interesting market opportunity: working with a large automotive player can promise access to the global car market. Further, it also fitted with top-management intrinsic believe in sustainability. For an engineering firm, participating in fuel cell development and possibly become supplier to clean vehicles appeared to be a very interesting prospect. As it turned out, the development of this electricity inverter was a decisive step for the TechLtd as it enlarged its technology base and prepared it for the renewable energy technology market, in which inverters are central components.

Among the important learning outcomes, top-management realized that new projects needed to fit the capacity of the in-house production facility. Indeed, if TechLtd had become supplier to the automotive industry (here private cars), the yearly production numbers would have by far exceeded its production capacity. Consequently, TechLtd could have only done the engineering but not the production of these components. This was not seen as an option as top-management realized that their revenues were drawn from production and not R&D activities. This is the main reason why top-management decided to withdraw from this innovation project. Overall, the outcome was nevertheless rather positive as it developed a new technological component and came to understand better what kind of products/markets fit the existing organizational structure.

After this first project, TechLtd pursued the turbomachinery innovation path and explored further related applications in the area of micro-gas turbines, expansion turbines and organic-ranking cycles (ORC). The commonality of these applications is the high-speed component. The efficiency of those energy conversion methods increases when the turbines rotate faster. A major barrier to higher turbine velocity is the control system, which lies in TechLtd's area of expertise. Seeing an opportunity to value the core competence, these applications appeared appealing to top-management. Further, they were also in line with their motivation for sustainability. As increasing the efficiency of energy conversion technologies is an important technical challenge in the energy transition. TechLtd fully developed the technology and worked over the years in selling it to manufacturers of these machines.

The markets in which these applications are used share several characteristics with the markets of their core business. They are all small, business-to-business and very mature (with well-established market rules and actors). As such, the technology as such is also well-know and is mainly being improved incrementally (with high-speed representing possible important progress in technology development). Product development is largely customer specific (made-to-order). Customers are mainly well-established large firms. Commercial relationships are long-term and based on trust. Therefore, the market for turbines is relatively close to the markets of the core business. Considering both the technological and market similarity to the core business, this innovation path generated less radical learning outcomes in the subsequent years.

4.2.3 Innovation path II: Small wind

In the context of the R&D networking activities related to the fuel cell, other collaborations with universities were initiated. TechLtd came in contact with an engineering-minded university spin-off that had knowledge in and access to the small-wind market. Small-wind turbines are typically sized below 10 kilowatt output power – whereas modern large turbines exceed one megawatt – and are characterized by unpredictable and turbulent high-speed rotation. In partnership with this firm (hereafter names 'WindUp', TechLtd began exploring the small wind application.

Early 2000, small wind turbines were an emerging niche market with globally around 300 manufacturers (BWE 2011; Gsänger 2013). At that time approximately 30 firms manufactured small wind turbines in Germany, with a typical turbine size below 100 kilowatt (BWE 2010). The total installed capacity represented less than 100 megawatts (Brück 2013). Even though the market had been developing rather slowly, industry associations predicted very optimistic growth figures and forecasted global installed capacity of over one gigawatt by 2020 (Gsänger 2013). Many industry experts foresaw similar growth patterns as in the traditional wind (working with large scale turbines) and solar industries (Luethi 2010).

TechLtd became interested in small-wind application for several reasons. First, because it appeared that many start-ups were successful in this emerging industry. Second, a positive and optimistic growth atmosphere reigned in the industry at that time. The, the relatively small-sized market fitted its niche market strategy. Finally, it perfectly fitted the motivation for sustainability, as by developing a good inverter (which was an important bottleneck at that time), the firm could contribute to develop the small-wind market and support the diffusion of renewable energies. Given their complementary expertise and assets, TechLtd saw an opportunity in collaborating with WindUp, who lacked production and commercial capabilities but had access to the market. Negotiating the nature of possible collaborations, they eventually decided to jointly develop control system, WindUp would market it, TechLtd produce it and formally organize sales, shipping and after-sales.

A phase of intensive R&D collaboration followed. The two firms jointly designed the inverter, constructed prototypes, tested the product with pilot users, improved it, and tested it again, presented it at trade fairs and obtained many purchase intentions from turbine manufacturers across Europe. Based on this positive outlook, TechLtd began with small-series production and further improved the product. Unfortunately, after market introduction sales figures did not increase as expected. About a year later, the first end-users (landlords, farmers, small businesses striving for energy autarky) began complaining about the low yields. Only at that time TechLtd began to realize that most wind-turbines were actually not technologically mature and that some manufacturers even lacked basic competences for turbine design. It subsequently decided to work with manufacturers and built new functions into the inverter to compensate for poor turbine design, therefore taking over turbine management functions. As sales were still not increasing, top-management began reducing the size of the business line and ordered new market research that revealed that the small-wind market is poorly organized, very volatile (with many firms entering and leaving the global market every year), that many manufacturers were working unprofessional in bricolage styles, with some even selling unviable turbine concepts to customers located in areas with poor wind conditions. WindEnergy, who had a better knowledge of the market, suggested much earlier project should be abandoned. When top-management also realize the situation, production was stopped and R&D resources were reallocated to other projects. A final intensive marketing attempt reveal that in the meanwhile the inverter was not adapted anymore to the need of the more professional turbine manufacturers and twice the price of the competitors'. The project was finally terminated mid-2013 with a financial loss of several million euros.

Whereas this project can be seen as a failure, our analysis revealed that it also triggered important learning outcomes that were useful for the next innovation paths. First, top-management realized that this project was too complex as it involved uncertainties at various levels (new product, new market, dependence on uncertain regulatory frameworks). Second, it realized that emergent markets function in a very different way than mature ones. Third, that both product development and sales and marketing needed to be adapted to the new market context. Finally, it realized that in terms of organizational structure and staffing, a separation needed to be implemented to allow the new, exploratory business line to develop innovations without being hold back by cognitive representations and routines of the core business.

4.2.4 Innovation path III: Flywheel energy storage

The flywheel innovation path emerged in the context of another collaboration with a technical university involved in developing high-performance flywheel energy storage system with regional partners. TechLtd developed a control system and inverter for this flywheel installed in the university laboratory. Given that this flywheel also relied on high-speed, it was technologically close to the controller of a small-wind turbine. High-speed flywheels represent an environmentally-friendly energy storage technology that allows storage in kinetic form over a short time period. Similar to small-wind turbines, this application fits both TechLtd's core competence and motivation to use it in the renewable energy technology markets.

Generally speaking, the high-speed flywheel industry is also at an emerging stage. The technology is not mature yet, industry actors are poorly organized and many of them lack resources and commercial competences. High-speed flywheels find many applications but only a new markets are really known by industry actors. Broad speaking, two fields of applications can be distinguished: first for vehicles, in which case high-speed flywheel are primarily used to store recovered breaking energy in hybrid busses, trucks, trams, trains or cars that operate with stop-and-go drive cycles. Second, larger high-speed flywheels can be used as in the grid-context, as storage to compensate for the intermittency of renewable energy sources, as components of uninterrupted power supply systems, and in smaller formats for instance to store locally produced renewable energy at the household or energy community levels.

After this initial project with the university, TechLtd sought for other actors in the value chain (i.e. solution providers, end-users) who could possibly be interested in the control system before investing significant amounts into application-specific development of the component. They considered mobile applications, particularly duty vehicles as developed by a major local firm, as fruitful focus. In collaboration with the authors' institute, an innovation network was planned intended at involving flywheel R&D and manufacturing firms, suppliers, system assemblers (who build the flywheel into a larger machine or storage system) and end-users. However, this market foresight activity was abandoned when the duty vehicle producer, the system-assembler (acting as market gate-keeper), could not be involved. Working on this innovation network showed that industry actors had limited knowledge about commercial attractive applications of flywheels and promising markets. Later, a second foresight activity was organized: an industry workshop bringing together the actors of the regional technology innovation system to remediate this lack of knowledge and support networking among industry members. The event was successful in that the firm gained intimate access to various actors of the system and could considerably extent it's technology and market insights – however, resulting in a rather pessimistic outlook. The workshop revealed a stagnating situation (in large parts of the industry) in R&D commercialization of the technology. Overall, the dynamics within this technology centered innovation system and the market outlooks were rather negative. In parallel, the CTO undertook a business trip to the USA to visit prospective clients including leading American flywheel manufacturers. Whereas the US flywheel innovation system appeared more advanced, he discovered that even industry leaders are not performing so well and that their business model is commercially still not viable, even after several years in the business. The market foresight activities that were undertaken allowed to build a better picture of the industry and given the negative outlook, TechLtd decided to end this innovation paths, only 3-4 years after begin.

In this third innovation path, TechLtd came to understand the value of involving end-users upfront. Indeed, by being in contact with a vehicle manufacturer, it learned about the end-user's technology needs, which could then be integrated in early-on in product design. In this particular case, involving the end-user upfront also revealed that he was not interested in technology for safety issues, which not only avoided TechLtd to invest in expensive prototype development but also gave an important market signal about the (lack of) acceptance of the technology. Next, through the participation in the industry workshop, TechLtd could better sense the overall atmosphere in this industry and develop contacts with potential customers. Finally, it developed a way to dealing with the uncertainty typical of emerging markets by testing the reaction of actors and learning how to read signal of early-stage markets. In other terms, it developed industry foresight approaches to decide whether to further develop an innovation project or not. This learning is visible in the fact they decided to abandon the flywheel project much earlier than it did for the small-wind project.

4.2.5 Innovation spill over to core business

Towards the end of the studied innovation journey, new approaches to innovation management also spilled over to the core business. In the two core business lines, innovation took to form of many incremental improvements, often demanded by the customer. However, the innovation degree (in terms of distance to existing technology) was small. A sign for this spill over is top-management's decision to set a group for more radical innovation in the core business. The objective of this structurally separated group was to explore a new kind of software tool. Instead of controlling a single high-speed-machine, this software is intended to manage a machine park (of typically 20-200 machines operating in parallel). Thanks to this software, a production manager could have data about the machine in a single control center and therefore be able to intervene more rapidly and effective in case of problem. This innovation could possibly open new commercial possibilities as a breakthrough could move the firm from supplier to machine tools to software-based service developer for the management of various machine parks, possibly also for other type of machines and applications.

This more radical innovation in the core business is highly interesting for the study of the learning journey, even though it does not relate to green innovation, as it demonstrates that the high degree of learning even spilled-over to the core business units. Indeed, it demonstrates that top-management was able to drop important assumptions about the success of the firm: it has previously always argued that an innovation need to be in the form of physical products. It also shows that top-management changed is perspective on its position in value chain, as this new software is not intended to machine manufacturers but machine operators.

5. Preliminary analysis

We adopted the perspective of cognitive representation as conceptualized by Hamel and Prahalad (1994) and Tripsas and Gavetti (2000) to analyses the learning outcomes of the three innovation paths and the overall innovation endeavor. We found five central cognitive representations at top and middle management level that evolved over time. This evolution demonstrates important organizational learning that created mental space that in turn conducive to more radical forms of innovation, as needed for green technology innovation.

5.1 Position in the value chain: suppliers to system integrators

For the top-management, TechLtd is supplier to system-integrators (i.e. machine manufacturers that assemble components and sell machines to end-users). This believe strongly influenced the kind of innovation that was sought for and the competences developed. For instance, the firm developed a very specific approach to marketing and sales. Sales managers were typically recruited among former R&D managers with over 10 years of experience in the business. The established and care long-lasting relationships with customers. Relationships were largely based on trust and expertise. The absence of classical sales departments was perceived as decisive advantage as customers could directly deal with experienced engineers instead of contacting the commercial department. However, given this approach to sales and marketing, TechLtd was not adapted to deal with large sales numbers nor to do business in a business to consumer market.

While useful in the conventional business, the strict adherence to the belief that TechLtd is a supplier to system-assemblers strongly influenced its set of competences and thereby also limited the scope of possible innovations. Indeed, in the context of a new product, the firm might have benefitted from adopting a different position in the value chain. This is particularly true as innovation is often driven by manufacturers, who play a key role in the machine value chain. This can become a disadvantage when changed in the manufacturers business negatively influences suppliers. Suppliers therefore gain in reducing there dependency to this key player. This believe was for instance visible in the small-wind case, were TechLtd refuse to sell inverter to turbine users, which might have avoid complaints about low yields. Further, TechLtd could have purchased selected high-quality turbines and sold them in combination with its inverter to installers. This option might have contributed to solve the important trust issue in the industry (as TechLtd was a very trusted firm).

This cognitive representation changed towards the end of the studied time period when TechLtd also began innovating in its core business by exploring the possibility of producing machine park management software directly intended to the end-users of the CNC drilling machines, thus an actors positioned one level lower in the value chain.

5.2 Rapid prototyping instead of intensive upfront R&D processes

Based on the marketing experiences gained in the core business, top management believed that only finished and well-tested products should be brought to the market. This has the advantage to foster trust as it guarantees that the new product presented by TechLtd is already mature and tested. While this believe probably holds for mature markets, TechLtd learned that this product development approach is not effective in emerging, rapidly evolving markets. Intensive upfront R&D processes simply take too long in a rapidly evolving environment. For instance, in the small-wind case TechLtd developed the product over several years and shortly after market introduction the demand already changed and the product became quickly obsolete. Second, this approach is also too costly. In an uncertain environment, the chances for market success are not high and a firm cannot afford to repeatedly fully develop products without yielding commercial success.

This cognitive representation changed when top-management realized that the approach to product development and marketing needed to be adapted to the market context. In the flywheel case, TechLtd adopted rapid prototyping (by only developing the prototype for the technical university and waiting for gaining a better market understanding before fully developing the product). Rapid prototyping became the standard way of exploring new products for emerging markets in the company.

5.3 Innovations as in-house manufactured products

Top-management initially believed that the entire production needed to take place in-house. The most important reason for that is TechLtd generates revenues not by selling their engineering expertise, but by manufacturing of technological components and related sales. Therefore new products need to contribute to make full use of the in-house production facility. Other reasons are that outsourcing (for instance to the USA or China) would cause local jobs to be lost, which is incompatible with the owner manager's responsibility taken for local job creation. Further, top-management considered that technology and know-how packed into an in-house manufactured product is the best way to prevent industrial espionage and copy.

Whereas this cognitive representation as advantages in the conventional business, it strongly influence the type of innovations sought for and selected. It limits the scope of innovation to manufactured products that fit the production facility in terms of technology and production numbers. However, the production facility was adapted to the needs of the core business and it is very likely that it will not be adapted to tomorrows' needs. The fuel cell ventilator project was rejected because of this cognitive representation: the production numbers would have by far exceeded the capacity of the in-house production facility. Further, at the beginning of the innovation journey, selling only software was discussed several times and repeatedly rejected for this same reason.

This cognitive representation changed towards the end of the innovation journey when top-management came to realize that it is too narrow to develop only new products that fit exactly the existing production facility. This change was visible in the innovation that happened in the core business, where a group of engineers was set up to explore a machine park management software service, which is radically different from the previous production focus.

5.4 In-house R&D instead of building on standard components

This cognitive representation relates with the idea that the firms needs to have mastery over all components of the product. Following this logic, every single element of the control system was designed and produced in-house. In the past, this philosophy was helpful as it allowed to guarantee a high-degree of quality. However, in industries evolving more rapidly and with pressure on prices, it became increasingly difficult to remain competitive without relying on more cost effective, standard components.

This representation began to change when the son of the founding CEO took over the company, shortly before the innovation journey began. Over time, it also changed in the core business and even at the middle-management level, were it was strongest. However, this change is most visible in the small-wind case: instead of designing the entire inverter, design and development took place in a joint-ventures setting with other firms and a technical university. In current projects, standard components are used whenever possible with technically superior components only being internally developed when a positive business development is likely. Over the years, relying on standard components became part of the established product development routines.

5.5 Innovation project manager for full product development and commercialization

In line with a project management logic, top management assumed that the best way to develop a new products is to recruit an engineer who would explore for new innovation. When a promising option was found, he would be in charge of developing the product and later commercializing it. Eventually, his responsibility would evolve to product and sales managers. This form organic growth around several key product managers reflects the way the company grew so far. However, through the small wind case, top-management came to realize that the exploration of new production options is a very different task than managing a product (or an entire business unit) and requires a very different skill set. The first tasks involves important networking, requires the manager to understand both the firms' assets and competences and new industries and adopt a holistic perspective on the business. More than management, leadership in product development is demanded. On the other hand, product management follows a performance and efficiency rational that aims at best exploiting existing products (Benner and Tushman 2003).

This view on how to best organize the exploration also changed over time. In the flywheel innovation path, exploration managers explored the flywheel industry. When it turned out that the market outlooks are negative, they moved on exploring other innovations. Further, the innovation in the core business also shows an evolution: even though the software project was directly related with the core business R&D activities, a separate group of engineers was set to explore this option. Software production was however not part of their tasks. Top management affirmed that product development and production would be handed over to larger core business team, when the innovation would turn out commercially viable.

6. Discussion and conclusion

While green innovation is often considered to be a straightforward exercise, this paper discusses a central aspect of the difficulty experienced by conventional firms in expanding the product portfolio with green products: how firms learn to develop new, radical green products and successfully commercializing them. We found that this is an exploratory process and a long term task without guarantee for (quick) success. The analysis reveals that many fundamental beliefs about the business needs to evolve in order to create the mental space needed for developing radical innovations.

The findings suggest that changes in the cognitive representations and learning need to happen in at least four aspects.

- First, top management needs to be aware of the scope of innovation. Green innovations often imply radical changes and innovation both in the product and the market area. This is a very ambitious form of innovation. Therefore, it should provide the innovation with sufficient space to unfold.
- Second, a major difficulty is the large uncertainty of emerging, green markets. Established firms are often not used to handle a high degree of uncertainty. However, start-ups and entrepreneurs are found to approach uncertain by experimentation and trial-and-error learning. They navigate the unknown with the large number of small experiments to test the market and industry reaction (Sarasvathy 2001). These experiments should be designed so as to that yield a high "return on failure" (Birkinshaw and Haas 2016), to reduce as much as possible the exploration costs.
- Third, even though managers might know their business very well, the development of green innovations require new knowledge that is often not available in the firm. Therefore, in order to acquire new knowledge, the firm benefits from engaging with so far unknown stakeholders. This allows to develop new ideas, to sense new markets, and to learn about the needs of new customers. The discovery of new knowledge is particularly crucial for established firms exploring sustainability related markets, which are typically unknown to them.
- Fourth, innovation at the level of the business model can contribute to widen the spectrum of possible innovations (Amit and Zott 2010), which is particularly relevant for green innovations as they will likely differ from the conventional business.

Next to these areas of learning, appropriate organizational structure need to be set up to create a space in which the innovation can develop without being influenced by the rational of the old business (O'Reilly and Tushman 2013). Literature suggests that dedicated space is particularly necessary when the logic of the conventional business strongly differs from the new business, which is frequently the case for green innovations.

To practitioners, this papers shows that conventional engineering firms can develop radical green products based on their core competences. But, as green innovation is related with important novelty and uncertainty, significant learning is necessary. This can best be triggered by learning-by-doing, which involves making experiments to explore new technologies, new product development paradigms, new markets and marketing approaches. While many experiments may fail, taken together, they can form a trial-and-error learning journey for green innovation.

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