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# Combining the technological innovation systems framework with the entrepreneurs' perspective on innovation

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## ABSTRACT

For their technological sustainability innovations to become successful, entrepreneurs can strategically shape the technological field in which they are involved. The technological innovation systems (TISs) literature has generated valuable insights into the processes which need to be stimulated for the successful development and implementation of innovative sustainability technologies. To explore the applicability of the TIS framework from the perspective of entrepreneurs, we conducted a case study in the Dutch smart grids sector. We found that the TIS framework generally matches the perspectives of entrepreneurs. For its use by entrepreneurs, we suggest a slight adaptation of this framework. The process 'Market formation' needs to be divided into processes that are driven by the government and processes that are driven by entrepreneurs. There should be a greater emphasis on collaborative marketing, on changing user behaviour and preferences and on the development of fair and feasible business models.

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## 1. Introduction

Societies need to change their current patterns of energy and resource use if they want to make the transition towards more sustainable production and consumption pathways to mitigate climate change (Grin, Rotmans, and Schot 2010). Such a transformation can be accelerated by sustainability technologies (Hargadon 2010), that is, technologies which enable a more efficient use of resources, less stress on the environment and even cleaning of the environment (Weaver et al. 2000). Many ideas for innovative sustainability technologies have already been generated; however, these often fail to enter the market (Caniëls and Romijn 2008). One major obstacle is that competing and established unsustainable technologies are usually supported by the normative and regulatory environment within which they have evolved (Geels, Hekkert, and Jacobsson 2008). In other words, the success of the introduction of new technologies is not only determined by the technology itself, but also by the social system that develops and implements the new technology (Foxon and Pearson 2008).

To overcome these barriers to technology adoption, Musiolik, Markard, and Hekkert (2012) suggest that innovative actors have to develop 'supportive structures' which legitimise and stabilise the emerging technology. The driving forces of those innovative actors are often entrepreneurs who try to implement sustainability technologies in society, and thus stimulate the transition towards sustainable development (Hall, Daneke, and Lenox 2010). Entrepreneurs do not need to wait for such a 'supportive system' to emerge, as they can actively accelerate its development. They can trigger

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social changes and optimise research collaborations and product development (Berkhout et al. 2006). In this way, they increase the chances that their innovation will be successfully implemented and will flourish (Van de Ven 1993). Entrepreneurs can strategically shape the technological field in which they are involved (Garud, Hardy, and Maguire 2007; Musiolik, Markard, and Hekkert 2012), and collectively construct a supportive technological system (Caniëls and Romijn 2008; Musiolik, Markard, and Hekkert 2012). The literature on technological innovation systems (TISs) has generated valuable insights into the process of building a supportive technological system (Markard and Truffer 2008; Musiolik, Markard, and Hekkert 2012). Numerous scientists have tested the TIS framework from a system perspective (e.g. Hudson, Winskel, and Allen 2011), in order to give strategic advice to policy-makers who wish to stimulate the implementation of new technologies (Meelen and Farla 2013). However, so far the framework has not been empirically tested from the viewpoint of a single group of private actors, such as entrepreneurs. This micro-level perspective is missing in the TIS framework (Markard and Truffer 2008), even though it is well known that entrepreneurs play a central role in innovation and commercialisation processes. The aim of this article is to explore the applicability of the TIS framework from the perspective of entrepreneurs, and to answer the question whether the TIS framework matches the perceptions of entrepreneurs on important system-building processes and whether it encompasses all the processes that entrepreneurs claim to be relevant. If so, the TIS framework can be used by entrepreneurs for strategically constructing a supportive TIS around their new technology, which can help to increase the chances of a successful implementation of their technology in society (Van de Ven 1993). In order to empirically explore the applicability of the TIS framework from an entrepreneurial viewpoint, a case study was conducted in the Dutch smart grid field.

## 2. Theoretical background

In this section we explain how we define entrepreneurs, their link to sustainability transitions and the TIS framework we use.

### 2.1. *Entrepreneurs as drivers of sustainable development*

An entrepreneur is 'someone who specialises in taking responsibility for and making judgemental decisions that affect the location, the form, and the use of goods, resources, or institutions' (Hébert and Link 1989, 39). Entrepreneurs are not only actors who set up new start-ups, but can also be managers within companies (so-called intrapreneurs) (Menzel, Aaltio, and Ulijn 2007). It has been acknowledged that it is impossible to understand business landscapes without studying the behaviour of entrepreneurs (Baumol 1990). Entrepreneurs are often the drivers of change processes in society (Shane and Venkataraman 2000), and this also applies to the context of sustainable development. Not only are entrepreneurs involved in the transformation of industries towards sustainable development, but they can also be the drivers of sustainability transitions (Hall, Daneke, and Lenox 2010; Vogel and Fischler-Strasak 2014). They invent and diffuse goods and/or services, which stimulate and enable more sustainable consumption and behaviour (Hall, Daneke, and Lenox 2010). More than only introducing and marketing these products, they also engage in 'proactive entrepreneurial action' by altering or creating institutions (such as norms, property rights and legislation) that support sustainable development (Pacheco, Dean, and Payne 2010). However, little research has been conducted on how entrepreneurs create new markets and institutions which stimulate the transition towards a more sustainable society (Hall, Daneke, and Lenox 2010). We use the literature from transition studies to shed more light on these developments.

## 2.2. The TIS framework

The emerging field of 'transition studies' is concerned with transitions towards sustainability, that is, fundamental technological, organisational and institutional changes in both production and consumption, which will lead to more sustainable development. Within the transition studies literature, these socio-technological changes are analysed from a systems perspective. Such changes are generally initiated by radically new products, services or business models. The following three approaches clarify how societal transitions take place: the multi-level perspective, the transition management approach and the innovation systems approach. In these approaches, there is some overlap in the processes they highlight for building a technological regime. However, the approaches differ in the analytical levels and the perspective they take. To study the build-up of an innovation system by entrepreneurial actors, the innovation systems approach is the most suitable one, as it is used for analysing and improving the conditions for the development of new technologies (Farla et al. 2012). Turning an invention into a marketable product or service involves a number of actors. The innovation systems approach considers the 'business ecosystem' of an innovating firm and analyses the flow of information and technology as well as the interactions and relationships between the actors involved, such as enterprises, research institutions and the government (Edquist 2004). Over the years, different innovation systems approaches have emerged that were based on the different boundaries of the system: the national, regional, sectoral and technological innovation system. As we investigate how entrepreneurs can implement a technological sustainability innovation, the TISs approach is the most suitable of these for our study.

The TISs approach deals with the formative phase of building a system for new technologies. A TIS consists of a network of actors involved in launching a new technology. It contains all the components that influence the innovation process for a newly emerging technology, rather than only the components that are exclusively dedicated to that particular technology. A TIS can be analysed in terms of its structural components and in terms of its functions. Structural components are actors, networks and institutions (Bergek et al. 2008). 'Functions of innovation systems' are the key processes that are important in building an innovation system. They are the dynamic processes between the structural components (actors, networks and institutions) of the system. Each key process contributes to building a favourable 'ecosystem' around the new sustainability technology. More importantly, the interaction between system functions accelerates the emergence and growth of an innovation system in virtuous circles, thus increasing the chance of market success (Jacobsson and Bergek 2011; Musiolik and Markard 2011).

The TIS framework is a suitable approach for exploring how entrepreneurs can stimulate sustainability transition, for three reasons: First, the TIS framework is concerned with emerging environmental technologies (Jacobsson and Bergek 2011). It has been developed by scientists and tested empirically with many case studies in the renewable energy sector (Bergek et al. 2008). Second, the analysis can be conducted during the formative phase (as opposed to ex-post), which is crucial in the context of emerging technologies (Hekkert et al. 2007). Finally, the approach has been empirically proven to be a valid framework to analyse processes of technological change (Hekkert and Negro 2009). Although the TIS framework is typically used as a basis for policy recommendations (Jacobsson and Bergek 2011), Coenen and Lopez state that it has the potential to connect the micro-level theory of firm behaviour with system dynamics and thus to generate 'potentially important insights on the level of individual actors' strategies and behaviour, including networking behaviour and impact' (Coenen and Lopez 2010, 1156).

Based on these arguments, we expect that the TIS framework can also be used by entrepreneurs who want to implement sustainability technologies in the market (and thus stimulate sustainability transitions). To test this assertion, we examine whether the TIS framework is in line with the viewpoints of entrepreneurs.

### 2.3. Key processes of the TIS framework

A number of key processes have been identified that are essential for the proper functioning of a TIS (Bergek et al. 2008). Several variations of the TIS framework have been developed by different authors, ranging from models that differentiate seven key processes to models that identify nine key processes. However, in essence these models have all been based on the same set of seven dynamic processes, which are described below.

**Key process 1: Entrepreneurial experimentation.** Entrepreneurs are key in the TIS as they turn the potential of new ideas into business opportunities. These entrepreneurs can be either new start-ups or incumbent firms (Hekkert et al. 2007), including large, established firms diversifying into the new technology (Bergek et al. 2008). By testing new technologies, applications and markets, social learning processes are triggered and information can be gathered about the way in which the technology functions under different circumstances as well as about the reactions of consumers, government, competitors and suppliers (Hekkert and Negro 2009).

**Key process 2: Knowledge development.** Learning activities such as research and development and learning in a practical context are fundamental to any innovation process. Knowledge can not only be gained about the new technology, but also about markets, networks and users (Bergek et al. 2008; Hekkert et al. 2007).

**Key process 3: Knowledge diffusion.** Conferences, workshops and alliances stimulate the exchange of knowledge. This is important not only for the exchange of R&D-specific knowledge, but also for the exchange of knowledge between government, companies and the market (Hekkert and Negro 2009).

**Key process 4: Guidance of the search.** This key process summarises all the activities and events that convince actors to enter the TIS or to further invest in it. A positive expectation about the development of the technology is the main aspect here. This expectation may be based on changes in customer attitudes, input prices, regulations and policy (Bergek et al. 2008; Hekkert et al. 2007).

**Key process 5: Market formation.** Since new sustainability technologies generally have difficulty competing with incumbent technologies, the creation of temporarily protected niche markets is necessary for the technology to further develop and to gain market share. Such niches can be created with favourable tax regimes, guaranteed consumption quotas, environmental standards and by government procurement policies (Bergek et al. 2008; Hekkert and Negro 2009).

**Key process 6: Resource mobilisation.** Sufficient resources are necessary for the emerging TIS to function properly. Financial and human resources need to be mobilised to enable the building of the innovation system; and complementary assets need to be developed, such as complementary products, services and network infrastructure (Bergek et al. 2008; Hekkert et al. 2007).

**Key process 7: Creation of legitimacy.** Sustainability innovations often struggle with overcoming innovation inertia caused by the incumbent regime, which is reluctant to change. Therefore, advocacy coalitions need to lobby for resources and favourable tax regimes and need to put the new technology on the political agenda (Hekkert et al. 2007).

## 3. Methodology

In order to explore the applicability of the TIS framework for entrepreneurs, a single embedded case study was carried out (Eisenhardt 1989; Yin 2009) that considered the dynamic processes of system-building in the innovation system of the Dutch smart grid sector. The units of analysis were the key processes of the TIS framework.

### 3.1. Empirical setting

The Dutch smart grid case was chosen because it is an emerging technological system with a growing network of public and private actors. A smart grid is defined as an electricity network in combination with an IT network, which is adapted to the introduction of renewable energy sources (Interreg IVB

2011). A smart grid is a complex set of technologies, and we will use the term 'the smart grid technology' for the overall set of technologies. Important actors include businesses in engineering, grid operation, consultancy, IT and energy production (NL Agency 2012).

The development of a smart energy innovation system in the Netherlands is well under way. The combination of an emerging sustainability technology and its systemic nature makes the Dutch smart grid an interesting and relevant case to study the applicability of the TIS framework for entrepreneurs.

### **3.2. Data collection**

Data were collected between December 2012 and March 2013 by means of semi-structured interviews. During the interviews, a three-step approach was taken. First, the interviewees were asked an open question about successful commercialisation of their innovative technology, to find out if they spontaneously mentioned any of the TIS key processes as a required process. In the second step, the TIS framework was briefly presented and explained to the entrepreneurs. They were asked to state whether these processes were or should be in place in the Dutch smart grid field, and to what extent they regarded these processes as important. This step was included to allow a systematic comparison of the answers for all key processes. Finally, entrepreneurs were asked if, from an entrepreneurial viewpoint, any process was missing.

In total fourteen interviews were conducted. For the selection, a list was compiled with 25 key actors of the Dutch smart grid sector based on information provided by one of the major experts in this field. The list was triangulated with the report 'Who is who guide – players in the Dutch smart-grid sector' (NL Agency 2012). All 25 people on this list were requested to participate. Ten immediately agreed to be interviewed. These 10 people worked for several companies of the smart grids value chain – such as energy companies, IT companies, suppliers of input materials and consultancies – and represented the broad field of the smart grids sector. During the interviews, four additional actors were frequently mentioned as significant players in this field. These 4 were also on the list of the 25 key actors mentioned above, but they had not yet replied to our initial request. These four individuals were approached again and were interviewed. During the interview process, a saturation point became apparent: at a certain moment, the interviews no longer revealed any new insights.

All interview partners held senior positions such as senior director, executive partner, business developer, division manager smart grids or senior project development manager. This enabled them to reflect upon the TIS framework. The interview partners were all entrepreneurs in the emerging TIS, according to the definition of entrepreneurs given by Bergek et al. (2008) and Hekkert et al. (2007). Of the 14 interview partners, 2 were entrepreneurs in the narrow sense, and 12 were entrepreneurs in the broad definition of the term.

### **3.3. Data analysis**

All interviews were transcribed and analysed using ATLAS.ti software. The analysis process entailed two steps. First, we coded the data, predominantly according to the TIS processes derived from the literature review. To avoid ending up with only very general codes for the key processes, we also acknowledged the different elements that are part of the key processes as described in the theoretical framework. If it appeared that a text fragment could not be linked back to one of the processes of the TIS framework, we used an open coding procedure. This enabled us to identify any missing processes. The second step was the comparison of these empirical findings with the TIS framework.

## 4. Findings

This section describes the results of the interviews per TIS key process. The abbreviations [P1] to [P14] after a quotation refer to the interview partner. The analysis of the answers to the open question 'What is important to commercialize their innovative technology?' made clear that some of the entrepreneurs interviewed knew of all the key processes to build a TIS. Other interviewees mentioned only some of the TIS key processes spontaneously. However, each key process was mentioned by one or more interviewees. The results of the systematic discussion of the TIS key processes with the interviewees are described below.

### 4.1. Key process 1: entrepreneurial experimentation

All interviewees stated that 'Key process 1: entrepreneurial experimentation' is a crucial process and is evidently present. Another element mentioned as essential for the success of the smart grid technology was the development of commercial products, user-friendly products or services that have added value for the consumer. Here, several interviewees used the analogy of the launching of the iPad to illustrate that the product itself should be so tempting that it is pulled into the market. Sustainable technologies should not be purchased by users for ideological reasons or because of subsidy schemes, but because they are just better than their unsustainable substitutes:

If we really want to change things in this world, we need to make products that people need and want, which basically means these products need to be economically viable. So we need to make sustainable new concepts that are better in every way, so that the product is not only sustainable, more flexible, and cheaper; it simply needs to be better. [P1]

### 4.2. Key process 2: knowledge development

Interviewees also stated they perceived 'Key process 2: knowledge development' as a crucial process in building an innovation system. Moreover, they highlighted the importance of knowledge of user behaviour and user preferences: entrepreneurs need to gather more of such knowledge, so that they can improve the implementation in the technological development process. A better understanding of societal changes is necessary to comprehend which changes are acceptable to users, and how these changes can be initiated. Some respondents stated that too much research focuses on the technical aspects and that more research is needed to understand the social and societal aspects of the transition process.

### 4.3. Key process 3: knowledge diffusion

The interviewees mentioned that it is not enough to only generate knowledge. They also perceived knowledge diffusion as a prominent and very important process: *'We want to have an impact on society or on the economy. We have the knowledge, but we won't have any impact if we don't share it with other people' [P4]*. This sharing occurs by means of demonstration projects, workshops, conferences and publications. Knowledge diffusion is often carried out by actor networks: *'Yes, the [network name] does quite a lot of that. We try to be present at most relevant conferences, and regularly organize workshops both formally and informally' [P6]*.

### 4.4. Key processes 1–3: interrelatedness

Moreover, it became apparent from the viewpoint of entrepreneurs that Key processes 1–3 are highly interrelated and interdependent when building a system as complex as a new decentralised energy system. Especially in open innovation processes, knowledge development, knowledge sharing and testing are interwoven, and therefore the interviewees usually do not make clear distinctions

between these processes: *'Most people try to combine this with demonstration-type projects, so they combine entrepreneurial activities with their knowledge-development activities' [P6]. 'If we combine certain things, this may create future possibilities. So, together with other companies, let's test whether this will fit in the new system, or will suddenly even open up new possibilities' [P5].*

#### **4.5. Key process 4: guidance of the search**

In order to stimulate more financial investments in the development of the new technology and its infrastructure, the entrepreneurs interviewed deemed it necessary that the sector has a common vision: *'It is necessary to know in which direction the market is moving' [P6].* Clear government guidelines will stimulate investment. Similarly, economic incentives may motivate companies and financial investors: *'Governments do not really provide any perspective of where we're going and in which areas we should invest. [...] It's difficult for companies to really invest' [P1]. 'A clear economic need or a government guideline is very important for that step' [P5].*

#### **4.6. Key process 5: market formation**

Entrepreneurs agreed that market formation was important. The data showed that from an entrepreneurial point of view, it is important to distinguish between processes that are driven by government actors and processes that are driven by entrepreneurs.

##### **4.6.1. Key process 5a: market formation by the government**

The first process is driven by the government. The government already supports the development of smart grids in a limited way: it provides subsidies and some limited tax incentives. However, the interviewees stated that the government should accelerate the development of the innovation system by changing regulations, rather than by providing subsidies, favourable tax regimes or procurement policies: *'You need the government as a partner for regulations but not for tax regimes, subsidies, loans or such like. The market should do that. But the government could help with regulation' [P7].*

Current regulations, however, do not stimulate but actually block the implementation of new technologies: *'At the moment it is the other way around. They may not do it on purpose, but the public authorities still block the way in which the market can develop' [P14]. 'It is not about technology, but rather about the regulatory framework. That is the most important constraint' [P13].*

The entrepreneurs stated that the government should allow pricing mechanisms (e.g. real-time pricing) and new business models which enable the adoption of the technology, which would allow companies to reap financial benefits from applying smart grid technology and which would stimulate changes in user behaviour. Several interviewees mentioned the generation of fair and feasible business models as important for system-building. The market should be designed in such a way that economic incentives are provided to the people who have to make the investments:

So the first thing that is necessary is that there is at least some economic value. And secondly, that the economic value goes to the people who make the decisions and who make the investment. And it is especially the second thing that is so terribly difficult. [P5]

Cooperation is necessary between private actors (who have the necessary knowledge) and public actors (who have regulative power) to design and facilitate feasible business models, so that the market forces can come into play.

##### **4.6.2. Key process 5b: market formation by entrepreneurs**

The second process is mainly driven by entrepreneurs. All interviewees agreed that developing the market, raising user awareness and creating demand were essential processes in the

commercialisation of the technology. Still, most interviewees were not yet active in this process, and some only to a limited extent. User awareness was mainly generated through pilot projects, involving a limited number of users. So far, no large-scale marketing efforts such as nationwide campaigns to raise awareness for the new energy system have been conducted or planned: *'We need to incentivize the customers because if they don't want to participate in this new energy system, it is not going to happen'* [P11].

To this point, user awareness and knowledge of smart grid technology have been too low to generate a demand pull. End users need to be motivated to change their behaviour: *'The biggest problem is not so much technical, but rather how to get the customers and the end users willing and active in this new energy system'* [P11].

Interviewees suggested that demand pull needed to be created, but acknowledged that so far the sector did not know how to achieve this: *'So it is not about forcing, it is about seducing these customers. But as a sector we have no idea how to do this'* [P11].

To raise user awareness and change user preferences, some interviewees found a collaborative marketing approach with other key actors in the innovation system most effective, as many resources are required to create user awareness and demand at such a large scale: *'This should be done in close interaction with key players in the market'* [P14].

Moreover, some interviewees criticised companies for focusing too much on optimising the technology, while neglecting the societal part. They advised end users and their preferences to be further integrated into the development process of the technology: *'It is not just about technology. [...] The product has to improve people's lives'* [P7]. Products and services should be developed keeping in mind the often unaware and inexperienced end user, who has to be willing and able to use them.

#### **4.7. Key process 6: resource mobilisation**

Entrepreneurs were involved in different forms of resource mobilisation. Whereas the mobilisation of resources was considered important for system-building, some entrepreneurs remarked that resources are necessary for all TIS key processes, and therefore questioned whether Key process 6 was a separate key process.

#### **4.8. Key process 7: creation of legitimacy**

Lobbying to create legitimacy and acceptance of the new technology is a common process in the innovation system. Most actors had undertaken lobbying activities both individually as a company and collectively through networks and branch organisations, which resulted in subsidies for the new technology. Lobbying is seen as an essential process for convincing the government to change legislation and to invest in or to provide subsidies for the new technology. These activities ultimately help stimulate investment in the new technology by suppliers as well as consumers: *'It helps the market move in the right direction'* [P13].

#### **4.9. Missing key processes**

After having discussed the TIS key processes with our interviewees, we asked them whether they thought that an important process was missing. Several entrepreneurs stressed that it is important not only to develop and exchange knowledge, but also to orchestrate these activities, as a great deal of overlap was observed: *'People are reinventing the wheel'* [P9]. It was suggested that better coordination of the activities related to knowledge building, testing and diffusing would accelerate the optimisation and implementation of the technology.

## 5. Discussion and conclusions

The aim of this research was to explore to what extent the TIS framework is also applicable from an entrepreneurial perspective. The findings show that entrepreneurs intuitively carry out the dynamic system-building processes described by the TIS framework. The TIS framework widely matches the perspectives of entrepreneurs.

The findings further show that entrepreneurs find Key processes 1–3 very important and that these are prevalent in the system, but that from an entrepreneurial point of view they were actually perceived as one key process. This underlines the importance of collective actions, combined resource use and knowledge exchange.

From an entrepreneurial point of view, it is moreover important to highlight that, for the technology to be successful, commercial products need to be developed. This underlines the need for entrepreneurs not only to optimise the technology, but also to develop economically viable products which are attractive for end users. Furthermore, entrepreneurs stressed the importance of obtaining knowledge about user behaviour and integrating this knowledge into the product development process. Although developing knowledge about users is mentioned in the TIS theory (Hekkert et al. 2007; Jacobsson and Bergek 2011), its integration in the development process has not been described explicitly. In previous empirical studies, this topic received less attention due to the characteristics of the technology in focus (Negro, Hekkert, and Smits 2008).

The findings for 'Key process 4: guidance of the search' are in line with the TIS framework. To a large extent, this also applies to 'Key process 5: market formation'. The interviewees acknowledge the importance of the government, which can support market formation by implementing favourable tax regimes, minimal consumption quotas and environmental standards, or by generating demand, for example, through government procurement policies (Bergek et al. 2008; Jacobsson and Bergek 2011). In a common effort by private and public actors, fair and feasible business models need to be generated, so that market forces can come into play. The government needs to create a regulatory framework for the new technology, which enables and supports these new business models. From an entrepreneurial point of view, this is perceived as more important for technology implementation than the creation of niche markets and the introduction of tax incentives. This finding is in line with the literature on sustainable entrepreneurship and business models (Bocken et al. 2014; Boons et al. 2013).

In addition, market formation processes can also be carried out by entrepreneurs. Entrepreneurs can raise user awareness and stimulate changes in user behaviour, in order to develop a market for their innovative technology. So far, market creation by entrepreneurs has received little attention in the TIS literature (Bergek, Jacobsson, and Sandén 2008). Possibly because in the energy technologies studied before, consumer preferences play a smaller role than in the case of smart grids technology.

Entrepreneurs can join forces and try to stimulate changes in user behaviour and preferences. Most potential users and the general public often need to go through a lengthy process of persuasion before they embrace a new technology that requires a change in behaviour. Entrepreneurs should consider end user behaviour and contemplate changing user preferences in the early phases of product development. These findings are supported by the transition studies literature. To change a technological regime, gradual processes are necessary that fundamentally change both society and societal subsystems (Kemp and Loorbach 2003). New institutions need to be established and existing ones changed (Voß, Smith, and Grin 2009). Ultimately, the rules and norms in society determine collective action, such as embracing a new technology (Van de Ven 1993). Institutional change, such as a change in regulations and user preferences, is an important factor to be considered by system-building entrepreneurs. Changes in user behaviour and preferences require changes in values, attitudes and beliefs that are deeply rooted in society (Kemp and Loorbach 2003). Furthermore, collaborative marketing efforts are considered more effective than individual efforts. These findings are supported by Van de Ven (1993), whose theory describes collaborative market creation as an essential element for a supportive entrepreneurial infrastructure of a new technology.

While 'Key process 6: resource mobilisation' is prevalent in the system, it can be debated whether from an entrepreneurial point of view this should be regarded as a separate key process: entrepreneurs know that they have to mobilise resources for all their activities. However, as a whole the sector can also mobilise resources for system-level activities (Musiolik and Markard 2010). The findings for 'Key process 7: creation of legitimacy' were also in line with the TIS framework.

Additionally, the analysis revealed that several entrepreneurs were missing one important element that had not yet been explicitly mentioned in the TIS framework: coordination. They stated that coordination at the system level contributes to more efficient resource use and to fewer redundant activities. In the general innovation management literature, collaboration in the value chain has been mentioned as a success factor in launching innovations (Cormican and O'Sullivan 2004), and the emergence and coordination of specialised goods and service providers are also considered of importance for a well-functioning innovation system (Bergek et al. 2008). Recently, Musiolik and Markard stated that the coordination of actors and activities in the value chain is a key process which enhances the overall functioning of the innovation system, which 'has not been mapped yet' (Musiolik and Markard 2011). However, it may be argued that coordination is not a key process, but that it simply accelerates all other key processes. Moreover, 'Key process 4: guidance of the search' also gives some direction to actors in the system. Yet, several entrepreneurs mentioned coordination as missing, and thus it seems to be an important element in the process of building a technological system from the viewpoint of entrepreneurs. It should be explored further.

To conclude, the TIS framework gives entrepreneurs valuable insight into the processes that are important for the successful development and implementation of their innovative sustainability technology. Based on our findings, we suggest a small adaptation of the TIS framework to enhance its applicability by entrepreneurs. We deem it necessary to separate 'Key process 5: Market formation' into processes driven by government actors and processes driven by entrepreneurs. The latter category has as yet been under-represented – or not explicitly stated – in the TIS literature, which mainly focuses on advice for policy-makers and on different types of empirical cases. From an entrepreneurial point of view, there should be greater emphasis on collaborative marketing, on changing user behaviour and preferences and on the development of fair and feasible business models.

The findings of this research contribute to the field of innovation systems literature by providing a stronger entrepreneurial foundation. So far the innovation system literature has been aimed at scholars and policy-makers (Meelen and Farla 2013). Entrepreneurs are at the centre of cyclical innovation and ultimately stimulate societal changes by collaborating with governmental actors and scientists, and by creating markets (Berkhout et al. 2006). The TIS framework matches the perspectives of entrepreneurs, and this makes the TIS literature and the broader innovation systems literature interesting to entrepreneurship scholars. The insights from this study can contribute to closing the gap in the entrepreneurship literature on how the processes that drive sustainability transitions unfold when entrepreneurs try to seize business opportunities in new markets (Hall, Daneke, and Lenox 2010).

Our study has some limitations. First, it was based on only one case, namely the smart grids field in the Netherlands, which limits its generalisability. The complexity and interdependency of the smart grid technology increase the need for coordination. Therefore, the applicability of the TIS framework by entrepreneurs should also be tested for a less complex technology.

Second, it may be argued that the results are influenced by the use of the broad definition of entrepreneurs, that is, including intrapreneurs. Despite differences in the organisations of the two distinct types of entrepreneurs (small start-ups vs. larger and incumbent firms), both types of entrepreneurs share the common objective to seize new business opportunities (Bergek et al. 2008). Therefore, it is unlikely that the two types have a different perception of the importance of the key processes and, furthermore, no indication for this was given during the interviews.

Finally, we only considered the key processes separately, and we disregarded the dynamics between them. Given the systemic nature of building a TIS, and the cyclicity and importance of feedback loops described in the entrepreneurship literature (e.g. Berkhout et al. 2006) and in the TIS literature (e.g. Bergek et al. 2008; Suurs 2009), it would be interesting to examine how the

emerging processes influence each other. Our exploratory study took place at one moment in time, and it was not possible to observe the development of and dynamics between the key processes over time. The dynamics between emerging key processes from an entrepreneurial point of view constitute an interesting field for future research.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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