Technology Analysis & Strategic Management, 2013
Vol. 25, No. 8, 957–970, http://dx.doi.org/10.1080/09537325.2013.823146

Routledge
Taylor & Francis Group

Towards an integrated framework for analysing sustainable innovation policy

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An integrated framework for the analysis of sustainable innovation policy was developed, based on a combination of the transition management (TM) framework, the strategic niche management approach, and policy recommendations, resulting from technological innovation system (TIS) studies. In the framework, the multi-level view from TM has been integrated with the functions approach from the TIS literature. The integrated policy framework shows that specific policy goals and measures can be found at the specific points of intervention related to (the interfaces between) landscape, regime, TIS and niches. The integrated framework suggests that stimulation of a TIS only makes sense when this action is well aligned with landscape and regime developments. The framework should be used in empirical studies for further testing and refinement.

Keywords: transition management; strategic niche management; technological innovation systems; sustainability; innovation policy

Introduction

Climate change, air pollution, and the dependency on finite fossil fuel resources are seen as persistent sustainability problems. To overcome such problems, the introduction of specific, radical innovations is advocated (like for instance electric vehicles or photovoltaic solar panels). However, implementation of such 'sustainable' innovations is difficult because fossil-fuel-related technologies benefit from many years of experience, economies of scale, optimal institutional arrangements and are supported by vested interests (Unruh 2000). Smith and Raven (2012) show that path-breaking sustainable innovations are at a structural disadvantage because of the existing selection environment. Van den Bergh, Truffer, and Kallis (2011) argue that the double externality problem of sustainable innovations make policy action necessary to introduce sustainable innovations. They state that research is needed about which policies (or policy packages) are most suitable for escaping the current lock-in. Recently, several authors (Hillman et al. 2011; Markard, Raven, and Truffer 2012; Van den Bergh, Truffer, and Kallis 2011; Wieczorek and Hekkert 2012) have emphasised the importance of a better understanding of the possibilities to steer innovations in a more sustainable direction. Proper analysis and understanding of policies that can support radical innovation and system transformation is required before any policy (package) can be

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chosen. This paper proposes a heuristic framework for analysing policies that support radical innovation and system transformation, based on the combination of two complementary bodies of literature: related to the multi-level perspective (MLP) and related to technological innovation systems (TISs).

In the past decades, we have witnessed the emergence of these two major approaches for analysing the dynamics of radical innovations related to (environmental) sustainability problems (Markard, Raven, and Truffer 2012). The MLP on technological change (Geels 2002; Rip and Kemp 1998) is based on co-evolutionary development of technologies, institutions and social and economic subsystems. The TIS approach is based on the systems of innovation perspective (Edquist 1997; Lundvall 1992). Studies on sustainable innovations that start from an innovation system perspective, often have taken the development of a specific technology as a starting point. The TIS literature describes how different actors, networks and institutions form a system around a technology (Bergek et al. 2008; Carlsson 1995; Carlsson and Stankiewicz 1991; Hekkert et al. 2007). The success of a new technology can then largely be explained on the basis of the growth and performance of this TIS.

Two approaches based on the MLP have been described that can support the development of radical and path-breaking innovations: strategic niche management (SNM) and transition management (TM).[1] SNM focuses on the (policy) actions that can help the development of radical innovations in technological or market niches, in relation to the development of new institutional arrangements, user preferences, etc. (see for instance (Hoogma et al. 2002; Kemp, Schot, and Hoogma 1998; Raven 2005; Smith and Raven 2012; Van der Laak, Raven, and Verbong 2007)). TM takes a broader perspective and includes the developments outside the niches in which technologies are nurtured (Kemp and Loorbach 2003, 2006; Rotmans, Kemp, and Van Asselt 2001). From studying the system dynamics in many empirical case studies, the innovation system literature has provided policy-makers with tools for identifying system weaknesses (Bergek et al. 2008; Klein Woolthuis, Lankhuizen, and Gilsing 2005; Negro, Alkemade, and Hekkert 2012), which could then be corrected for by environmental regulation and technology-specific policies (Johnson 2001). However, Weber and Rohracher (2012) argue that such policies may not be a sufficient basis for transforming broader systems of production and consumption.

Even though the analytical framework of the MLP and TIS has developed quite separately in the past decade, they largely share the same conceptual basis. Both are rooted in evolutionary economics and use concepts like path dependency, lock-in and nonlinearity. Moreover, the approaches are complementary, as important shortcomings of each of the two analytical frameworks are covered by concepts of the other framework (Coenen and Lopez 2010). Markard and Truffer (2008) therefore use the commonalities of the two frameworks to suggest an integrated framework. This integrated framework is interesting for analytical purposes, but also gives the opportunity to bridge another important gap in the innovation literature: it enables us to integrate policy approaches related to the MLP (TM and SNM) with the policy recommendations that result from the many analyses based on the TIS framework. An integrated policy framework could make use of the complementarities of both models and, therefore, be valuable for policy analysis.

The aim of this paper is thus to integrate the policy approaches related to TM and SNM with the policy recommendations resulting from the TIS literature into one framework for policy analysis. The purpose of the proposed framework is that it can be used as a heuristic model with which existing or planned (sustainable innovation) policy interventions can be analysed. The framework can thus be of use in (future) empirical studies related to the purposeful guidance of innovations in a more sustainable direction.

At this point, however, we should warn against an overly optimistic view on the possibilities of purposeful steering and guidance of radical innovations. The reason why we think that our analytical policy framework will be useful is because the successful steering of radical innovations and transitions is still a rather uncharted area; much more empirical work will be needed in the next years to increase our understanding on this topic. The TM and SNM literature emphasise that a transition is a multi-actor process in which governments can only play a limited role. Policy problems in relation to guiding transitions relate to the different perspectives on the (nature of) problems and solutions, to the distributed nature of control, the fact that it is unclear how short-term steps can lead to long-term structural change, the danger of lock-in to non-optimal solutions, and the short-term focus of politicians and policy-makers (Kemp, Loorbach, and Rotmans 2007). Nilsson, Hillman, and Magnusson (2012) summarise the questions in relation to sustainable innovations with 'who governs' and 'how to govern', indicating that other actors than public actors can steer, with other governance mechanisms than regulative or market-based policy measures. In contrast, some authors from the TIS literature have (implicitly) given the (central) government a very influential role in steering sustainability transitions, which cannot be supported by current insights from political science studies (Flanagan, Uyarra, and Laranja 2011).

The starting point for this study is thus the integrated framework by Markard and Truffer (2008). Based on that framework and a critical review of (a part of) the TIS literature, we will develop a policy analysis framework that matches the integrated analytical framework by Markard and Truffer (2008). This paper is a theoretical contribution to the 'sustainable transitions' literature, and is a starting point for empirical case studies. Schematically, our contribution can be positioned in the literature according to Figure 1.

The left-hand side of Figure 1 shows the analytical framework, with the integrated framework by Markard and Truffer (2008) at the bottom. On the right-hand side, the related policy recommendations are integrated; the double-framed box at the bottom of Figure 1 indicates the contribution of this paper.

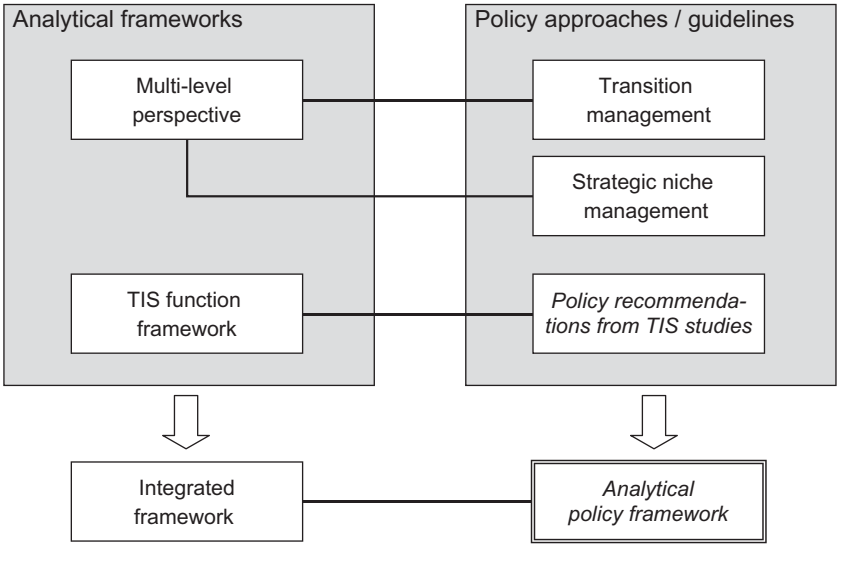

Figure 1. Schematic presentation of the work in this paper.

The paper is structured as follows. First an overview of the TIS framework and the policy recommendations given by TIS scholars will be provided. The policy recommendations were derived from a sample of empirical TIS studies that use the functions approach. Second, the MLP framework and the related policy approaches TM, and SNM are briefly discussed. We then integrate the different policy approaches into one comprehensive analytical policy framework. In the final section, the application possibilities and limitations of our model are discussed and suggestions for further research are given.

Theoretical background

TISs and related policies

Innovation system theorists state that companies do not innovate on their own, but in the context of a system (Lundvall 1992; Nelson 1993). Companies innovate together with other companies, universities and research institutes. Furthermore, laws, rules and routines can stimulate or hamper the innovation process (Edquist 2005). A distinction can be made between national (Freeman 1995; Nelson 1993), regional (Braczyk, Cooke, and Heidenreich 1998; Cooke and Uranga 1997), sectoral (Breschi and Malerba 1997; Malerba 2002) and technological innovation systems (Carlsson 1995; Carlsson and Jacobsson 1997). Carlsson and Stankiewicz (1991) define a TIS as 'a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion and utilisation of a technology'. The TIS approach is suitable for investigating emerging technologies like, for instance, the electric car (Hekkert and Negro 2009).

It is essential for the success of a TIS that certain activities take place in the system. These activities are often called 'functions' of innovation systems and contribute to the development and diffusion of the innovation (Bergek et al. 2008; Hekkert et al. 2007; Johnson 2001). Functions of Innovation Systems have become accepted and widely used in innovation system research in the past decade, and have been applied in many empirical studies. Although broad agreement seems to exist about which functions are important, the naming and definitions of these innovation system functions differs between authors. In this paper, we use the list of functions from Hekkert et al. (2007) which has been verified by extensive empirical research (Hekkert and Negro 2009).

The first function 'entrepreneurial activities' (F1) stresses the importance of risk-taking actors to perform commercial experiments and try and exploit business opportunities. The second function (knowledge development; (F2) and third function (knowledge diffusion in networks; (F3) emphasise the central importance of learning in all its forms for innovation. The fourth function 'guidance of the search' (F4) relates to the selection process of new technologies, in which expectations and policy goals may stimulate the development of technology in the TIS. The fifth function (market formation: F5) stresses the need for niche markets in which new technologies can grow. The sixth function is 'resource mobilisation' (F6), and indicates that financial, material and human factors are necessary for the development of a TIS. Finally, the seventh function (creation of legitimacy; (F7) indicates the necessity to counteract the resistance from the current socio-technical regime. Lobbying is necessary to create legitimacy for the technology in the TIS.

When a TIS grows, the development of the seven functions is monitored (e.g. by event analyses (Negro, Suurs, and Hekkert 2008)) and the results of these analyses can be used for the development of policies aiming at the improvement of weak system functions (Bergek et al. 2008). TIS scholars have stressed the need for empirical analysis of many different TISs before policy recommendations can be given, because of the large differences between TISs (Hekkert 2010).

Policy recommendations found in TIS studies

In articles using the TIS (functions) approach, policy recommendations are given for almost all of the functions of the innovation system. A notable exception is entrepreneurial activities (F1); these will result when the other functions are stimulated (Hekkert et al. 2007). However, it is acknowledged that entrepreneurs should be more involved in innovation policy-making because their interests are often neglected (Hekkert 2010).

Knowledge development (F2) can be stimulated by financing and facilitating R&D (Negro, Hekkert, and Smits 2008) and by learning from (niche) experiments (learning-by-doing) (Negro, Hekkert, and Smits 2008; Van Alphen, Hekkert, and Turkenburg 2009). Van Alphen et al. (2010) advise demonstration of technologies on a commercial scale to trigger learning-by-doing instead of learning-by-planning.

For the diffusion of knowledge in networks (F3), cross-linking platforms can be stimulated (Smits, Kuhlmann, and Teubal 2010). International collaborative networks may have an important role (Van Alphen et al. 2010). Van Alphen et al. (2010) also state that intellectual property rights sometimes hinder knowledge diffusion; coordination in the network is mentioned as a solution. Van Alphen et al. (2010) mention full-scale demonstrations as a means to make hidden knowledge deficits visible. The issuing of best practices by a public or private coordinating organisation is another means to stimulate knowledge diffusion (Van Alphen et al. 2010).

Bergek, Hekkert, and Jacobsson (2008) state that governments can provide guidance of the search (F4) by setting short-term and long-term policy goals in relation to the technology and by expressing positive expectations about the technology. The same is argued by Van Alphen et al. (2010) under the heading 'regulate and communicate', in which they also include standard setting. On the one hand, Van Alphen et al. (2010) propose regulatory flexibility around demonstration projects; on the other hand they propose a 'strong regulatory framework' to minimise concerns in the public at large (related to F7: legitimacy).

Function five, the creation of markets can be supported by the installation of favourable tax regimes or minimal consumption quotas (Hekkert et al. 2007). Van Alphen et al. (2010) state that temporal subsidies and tax credits can be a first step, but that this should be done in combination with changes in the institutional infrastructure: [. . .] government [. . .] should change 'the rule of the game'.

The provision of resources (F6) is a general activity to support the other functions. Van Alphen et al. (2010) argue that public–private partnerships may be a means of providing certainty for investors. Hudson, Winskel, and Allen (2011) mention support for training activities as a means to increase the skills of technicians related to a specific technology.

Function seven of the TIS framework, the creation of legitimacy can be supported by changing institutions (laws, rules, routines, etc.) in order to make them more compliant with the technology of the TIS (Bergek, Hekkert, and Jacobsson 2008). Also, open communication about a technology can help creating legitimacy for the technology (Van Alphen, Hekkert, and Turkenburg 2009). Hudson, Winskel, and Allen (2011) argue that setting technology-specific targets may increase legitimacy and that technology-specific (trade) organisations may be used to focus and unite interests.

In addition, Hekkert (2010) gave more general policy recommendations after empirical analysis of emerging TISs. He makes a plea for consistent and long-term innovation policies that put pressure on (the lock-in of) the current technological regime. Furthermore, the need for international collaboration for effective stimulation of innovations is stressed, because TISs cross national boundaries. Finally, Bergek, Jacobsson, and Sandén (2008) state that policy-makers can make use of the positive externalities between TISs, by stimulating complementary TISs in parallel.

MLP and TM

The MLP provides a (heuristic) model of how innovations in niches can enter the existing socio-technical regime with the help of societal pressure on the so-called landscape level (Rip 1995). The successful introduction of an innovation that leads to a major change in the existing socio-technical regime is called a transition in the MLP. As innovations can enter the current socio-technical system in various ways, transitions may follow different pathways (see (Geels and Schot 2007)).

From historic transitions described with the multi-level framework, the idea of TM was deduced (Loorbach 2007; Rotmans, Kemp, and Van Asselt 2001; Smith, Stirling, and Berkhout 2005). TM theory states that transitions towards sustainable development may be initiated, sped up and steered 'by coordinating and enabling the processes that occur at different levels in a more systemic and evolutionary way, which gives room for variation, selection and innovation' (Kemp and Loorbach 2006). In TM, measures can be taken at three different levels: the strategic, tactic, and operational level (Loorbach 2007, 2010; Rotmans, Kemp, and Van Asselt 2001).

At the *strategic level*, the creation of visions and setting of long-term goals is important (Voß, Smith, and Grin 2009). TM argues that normal policy-making is focusing too much on short-term and mid-term goals because of political cycles. TM tries to incorporate long-term processes more actively in policy development with the creation of the so-called transition arenas in which innovative people from governments, NGOs, academia and industry work together on long-term visions. Eventually, these transition visions should lead to the formulation of different transition paths to reach the transition vision (Loorbach 2007). For instance, hybridisation of cars can be formulated as a transition path in a vision to reach sustainable mobility (Farla, Alkemade, and Suurs 2010).

At the *tactical level*, a so-called transition agenda should be defined with intermediate policy objectives (Kemp and Loorbach 2003). At this level, the complex task is to prepare the existing socio-technical regime for the introduction of a technology from a niche. Structures of the old socio-technical regime, which may hamper the introduction of the innovation, should be adapted. These structures include predominant rules, institutions, organisations, infrastructures, routines and habits (Loorbach 2007). Furthermore, at this level, the pressure on the current regime should be increased, making use of landscape developments and internal regime contradictions (Kemp and Grin 2009). Landscape developments can – for instance – support actions aimed at reducing climate change. An example of an internal 'regime contradiction' is a high oil price that can disturb the current socio-technological regime of gasoline cars.

At the *operational level*, experiments should be carried out. These experiments are innovation projects that have to be in strong accordance with the vision defined at the *strategic* level and the transition paths chosen at the *tactical* level (Loorbach 2010).Critical reflection on and monitoring of both the transition process and TM itself at the different levels is of foremost importance. Evaluations should be done in such a way that transition policies can be adapted to the ongoing transition developments (Kemp and Loorbach 2006; Taanman 2008).

Strategic niche management

SNM is a steering approach that is also related to the MLP (Kemp, Schot, and Hoogma 1998; Schot and Geels 2008). SNM specifically describes how protected spaces can be created in which experiments with a promising technology can be carried out. The knowledge resulting from the experiments is used to scale up the niche experiments in such a way that the technology is eventually ready to diffuse from the niche into the prevailing socio-technical regime.

In the basis, SNM consists of five phases (Kemp, Schot, and Hoogma 1998): (1) the choice of the technology; (2) the selection of the experiment; (3) the set-up of the experiment; (4) scaling up the experiment, and (5) breakdown of the protection. For each of the five phases, guidelines have been developed. In the first phase, the choice should be made for a technology that (a) has large possibilities for future technological development, (b) has learning economies, (c) is compatible with the actual institutional structure and user needs, and (d) is already attractive in certain applications where the disadvantages of the technology count less and its advantages are highly valued. With regard to the selection of an experiment (phase 2), an experiment setting should also be chosen in which the advantages of the technology are highly valued, and the disadvantages are of less importance. For the set-up of an experiment, a balance should be found between protection and selection pressure. Activities should focus on the barriers that hinder the introduction of the technology, which can either be technical, economic or institutional (Kemp, Schot, and Hoogma 1998). In the phases (4) and (5), the experiment should be scaled up and make its way into the current socio-technological regime. In later SNM literature, more attention is given to the interaction of niches from the same technology, which can reinforce each other due to mutual influences on the so-called global niche level (Geels and Raven 2006). Furthermore, more detailed recommendations were given, based on empirical case studies (Van der Laak, Raven, and Verbong 2007).

The goals of SNM are to learn about the social desirability of a specific technology, to stimulate its development (by achieving cost efficiency and alignment with the institutional framework), and to build a constituency – of firms, researchers and public authorities – behind a technology (Kemp, Schot, and Hoogma 1998). Another important aspect of SNM (as well as TM) is higher order learning: in higher order learning processes, the ideas about a technology, user demands, regulations, etc. are not tested, but questioned and explored (Hoogma et al. 2004).

Combination of the MLP, TM, SNM and TIS perspectives

In their effort to integrate the 'TIS' and the 'MLP' approaches, Markard and Truffer (2008) came up with an integrated model in which one TIS interacts with existing regimes, with other TISs and with the landscape. Within the TIS, several niches can be found. For example, in the electric vehicle TIS, niches may exist for the application of electric cars as taxis and as vehicles for inner city mail delivery.

The strength of the combined model is the complementariness between the approaches. In the MLP, the roles and strategies of the different actors, the interactions between actors and institutions and the agency of the different actors are given less attention (Farla et al. 2012; Smith, Stirling, and Berkhout 2005). The TIS approach claims to be more powerful for analysing the dynamic processes with the function framework (Hekkert et al. 2007). However, the TIS approach may have a perspective that is too much inward looking (Coenen and Lopez 2010; Geels, Hekkert, and Jacobsson 2008).

In the TIS approach, the current socio-technical regime and landscape and their influences on the TIS are less rigorously analysed, whereas this is one of the strengths of the MLP (Markard and Truffer 2008). The combined model by Markard and Truffer (2008) is used by us as a basis to combine policy concepts derived from both the TIS and MLP perspectives.

The MLP and TIS approaches differ on the point of incremental and radical innovations. In the MLP, radical innovations come from niches, whereas incremental innovations originate from the regime. In the original literature on technical innovation systems, no difference is made between radical and incremental innovations. Our policy framework, however, is based on articles

related to the dynamics of a growing TIS and is thus specifically applicable to more radical innovations.

TM, SNM and TIS approaches have all been criticised for paying limited attention to users (see e.g. Shove and Walker 2007; Spaargaren 2011). This lack of attention cannot be fixed in this article, but it implies that our combined policy approach framework will also lack the specific attention to users in sustainability transitions.

The integrated policy framework

In this paragraph, we integrate the goals and policy advices from the previously described approaches. Our effort cumulates into a new, combined model in Table 1.

In the model by Markard and Truffer (2008), system innovations are (as is the case in the MLP) supported by developments at the landscape level. Landscape developments may open 'windows of opportunity' for promising technologies. For the identification of promising technologies, transition managers should thus be aware of the trends at the landscape level. The TM literature stresses the need for a long-term vision that is in accordance with the slow trends at the landscape level. The 'transition arena' is a platform where such a vision can be arrived at (Loorbach 2010). TM scholars state that after the creation of a transition vision, transition paths can be created: possible routes starting from the present which can realise the transition vision. The choice of a transition path thus implies the choice for stimulating specific technologies/TISs. In the transition path, (positive) expectations and short-term and mid-term policy goals regarding the use of the technology of the TIS are included. So the transition path contributes to the fulfilment of function four of the TIS framework: guidance of the search. Following the policy recommendations resulting from the TIS framework, entrepreneurs should take part in developing the transition path(s) (Hekkert 2010). An example of the implementation of TM was the Fourth Dutch environmental policy plan, launched in 2001. It aimed at long-term solutions for persistent problems like climate change. The transition towards a sustainable energy system was one of the transitions described in the environmental policy plan. For this energy transition, the 'Platform Sustainable Mobility' was created (among others). This platform can be described as a transition arena in which government, industry, research institutions and NGO's work on visions and plans for sustainable mobility (Farla, Alkemade, and Suurs 2010). Reflexivity is a key element in TM and SNM literature. The monitoring and evaluation of the developments at the different levels is stressed as well as a reflection on the effectiveness of activities that were undertaken, so that these can be adapted if necessary (Loorbach 2010; Schot and Geels 2008). In TM, the concept of 'development rounds' expresses the idea that a critical reflection is necessary after every few years to realign the transition activities with the changing environment (Rotmans, Kemp, and Van Asselt 2001).

The TIS in the model by Markard and Truffer (2008) is interacting with the existing socio-technical regime(s). To stimulate the success of the developing TIS, regime–TIS interactions should be influenced. Weakening the existing regime to create more space for the innovation from the TIS can be a strategy to achieve this. TM literature states that policy measures should increase the pressure on the current regime, using landscape developments and internal regime contradictions (Kemp and Grin 2009). TIS literature states that neoclassical, non-systemic policy measures (e.g. tax measures, consumption quotas) can be useful for this purpose (Hekkert 2010). An example is the European rules for car emissions, which force car producers to make more fuel-efficient cars. Both TIS and TM scholars state that the institutions (laws, rules, routines, etc.) of the current socio-technical regime should be changed to make them more compliant with the

Table 1. Integrated framework for sustainable innovation policy.

Point of intervention	Policy goals	Policy instruments/guidelines
Landscape–TIS interaction	• Goal-oriented modulation (Kemp, Loorbach, and Rotmans 2007) using landscape developments	• Develop long-term visions and long-term policy goals (in transition arena) (Rotmans, Kemp, and Van Asselt 2001)
	• Use regime weaknesses and internal regime contradictions (Kemp and Grin 2009)	• 'Development rounds' to reflect on past and future of the goals and activities
	• Provide guidance of the search	• Set short-term and long-term policy goals, technology targets and express positive expectations (Bergek, Hekkert, and Jacobsson 2008)
	• Reflexivity	• Include entrepreneurs in innovation policy-making (Hekkert 2010)
Regime–TIS interaction	• Weaken existing regime	• Tax policies to put pressure on regime (Kemp and Grin 2009; Hekkert 2010)
	• Prepare regime for new technology	• Minimal consumption quotas (Hekkert et al. 2007)
	• Create broad societal support	• Adapt regulations/institutions: change 'rule of the game' (Van Alphen et al. 2010)
	• Use resources from aligned regimes (Hillman et al. 2011)	• Open and interactive communication with stakeholders (Van Alphen, Hekkert, and Turkenburg 2009)
	• Create legitimacy for new technology	
TIS–TIS interaction	• Use positive externalities between TISs (Bergek, Hekkert, and Jacobsson 2008)	• Identification and support of complementary TISs
TIS internal	• Knowledge development	• Financing and facilitating R&D (Negro, Hekkert, and Smits 2008)
	• Knowledge diffusion	• Stimulate cross-linking platforms (Smits, Kuhlmann, and Teubal 2010)
	• Create networks	• Co-ordinate intellectual property rights (Van Alphen et al. 2010)
	• Create institutions	• Issue best practices (Van Alphen et al. 2010)
	• Development of positive externalities (Bergek et al. 2010)	• Training activities (Hudson, Winskel, and Allen 2011)
Niches	• Enrol actors/entrepreneurs; build a constituency (Kemp, Schot, and Hoogma 1998)	• Mobilise resources for experiments
	• Knowledge development	• Choose technologies and experiments with criteria from SNM (Kemp, Schot, and Hoogma 1998)
	• Higher order learning	• Commercial-scale demonstrations (Van Alphen et al. 2010)
	• Create alignment (technology-user/ technology-institutions/ producer-technology, etc.)	• Public–private partnerships (Van Alphen et al. 2010)
		• Favourable tax regimes (Hekkert et al. 2007)
		• (Temporarily) adapt regulations and institutions in niche: regulatory flexibility (Van Alphen et al. 2010)

technology of the TIS (Bergek, Hekkert, and Jacobsson 2008; Loorbach 2007). Broad societal support for a technology is seen as an important prerequisite for its success in the TM literature. TIS scholars state that for the creation of societal support an open, interactive communication strategy about the technology is useful (Van Alphen, Hekkert, and Turkenburg 2009). Hillman et al. (2011) state that a TIS can also be supported by drawing on resources of aligned regimes. Weakening the regime, opening the regime for a new technology and active support for a new technology can also be seen as creating legitimacy for the TIS in focus.

In the model by Markard and Truffer (2008), the TIS also interacts with other TISs. Bergek, Jacobsson, and Sandén (2008) state that positive externalities can result from TIS–TIS interactions. Therefore it can be useful for actors to identify and support TISs that are complimentary to the TIS in focus. The idea that one TIS can be strengthened by another, related TIS is more-or-less equivalent to the idea from Hillman et al. (2011) that a TIS can be strengthened by an aligned regime.

At the TIS-internal level, knowledge development and diffusion (functions 2 and 3 of the TIS framework) are the main goals that must be supported. TIS scholars mention financing and facilitating R&D or training as a policy instrument for knowledge development (Hudson, Winskel, and Allen 2011; Negro, Hekkert, and Smits 2008). Van Alphen et al. (2010) state that co-ordination of intellectual property rights and the issuing of best practices will support knowledge diffusion. For sharing the knowledge of all the different (niche) experiments, cross-linking platforms are said to be of major importance (Smits, Kuhlmann, and Teubal 2010). Here the TIS becomes rather similar to the 'global niche level' as postulated by Geels and Raven (2006). The TIS level is the level where knowledge and information from the niches can accumulate. The creation of (TIS-internal) networks supports the transmission and retention of knowledge (Musiolik, Markard, and Hekkert 2012). For example, it was found that the German PV TIS functioned well because of large-scale R&D investment policy and growth of knowledge networks. As niche markets grow, positive externalities may arise at the TIS level (Bergek et al. 2010), which strengthen the growing TIS. Over time, the development of institutions within the TIS will be a sign of the maturation of the TIS.

At the niche level, actors contribute to the fulfilment of function five of the TIS framework: the creation of markets. For the proper choice of niche experiments, the policy guidelines of SNM, as described before (Kemp, Schot, and Hoogma 1998) should be taken into account. Niche experiments require that actors/entrepreneurs are enrolled. Several means of financial and institutional (policy) support may stimulate actors to start their activities in a technological or market niche. TM and SNM scholars stress the importance of learning from niche experiments (learning by doing); knowledge development (function 2 in the TIS framework) can be seen as the main goal of technological and market niches. Learning in niches – if successful – will result in the (mutual) alignment of a technology with producer, user and institutional set-up around the technology. SNM scholars also stress the importance of higher order learning in niche experiments (Brown et al. 2003; Hoogma et al. 2002).

The integration of the goals and (policy) instruments from the TIS, SNM and TM literature leads to the conceptual framework shown in Table 1. It should be noted that the policy instruments indicated are not the only possible instruments, but merely examples.

The framework in Table 1 suggests that supporting radical, sustainable innovations and system transformation requires (policy) actions at all points of intervention. Thus stimulating a TIS only makes sense when this action is well aligned with actions and developments at the landscape and regime levels. The same holds for stimulating a specific niche (as could also be learned from the work by Van der Laak, Raven, and Verbong (2007)). What may be missing in Table 1 is the possibility to aim measures at regime–regime interactions, as mentioned by Raven and Verbong (2007).

Conclusions, discussion and suggestions for further research

In this study, we presented a new framework for the analysis of sustainable innovation policy. The framework is based on the TM framework, the SNM approach, and policy recommendations resulting from TIS studies. By integrating these three approaches, optimal use can be made of the complementary strengths of each of the approaches. The framework of this paper is a starting point for policy analysis and maybe, eventually, for policy development. However, whereas the individual components of the framework are backed with (some or much) empirical evidence, this is not the case for the integrated framework as a whole. The current framework gives preliminary ideas for policy development, but it is not a comprehensive policy design framework. Therefore, several steps are proposed for further research. First, the framework should be confronted with several empirical cases of path-breaking innovations that were supported by innovation policy. In such empirical case studies, it can be investigated if policies aimed at overcoming blocking mechanisms can be categorised effectively along the points of interventions of the framework (see Table 1). This may serve as a first test for the categorisation of policies in the framework.

Second, it can be investigated to what extent, in prior cases, policies have been used on the specific points of intervention of the framework, and if so, what policies and with what effects? Third, the policy guidelines in the framework can be further refined by studying more cases where policies promoting sustainable innovations have been applied.

After such testing and refining of the framework, a comprehensive framework may develop that can inform all actors that wish to steer radical innovations in a sustainable direction. Policy-makers can use it to investigate if they are addressing all aspects of a sustainability transition and suggestions for measures related to certain points of intervention can be drawn from it.

Acknowledgements

The helpful remarks and suggestions from Floortje Alkemade, Rob Raven and three anonymous reviewers to earlier versions of this paper are thankfully acknowledged.

Note

1. Van den Bergh, Truffer, and Kallis (2011) argue that transition management can be understood as the policy view related to the complex systems approach. However, since MLP also borrowed from complex systems theory, this distinction is not relevant to our argument.

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