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The dynamic simulation of TIS functions in transitions pathways

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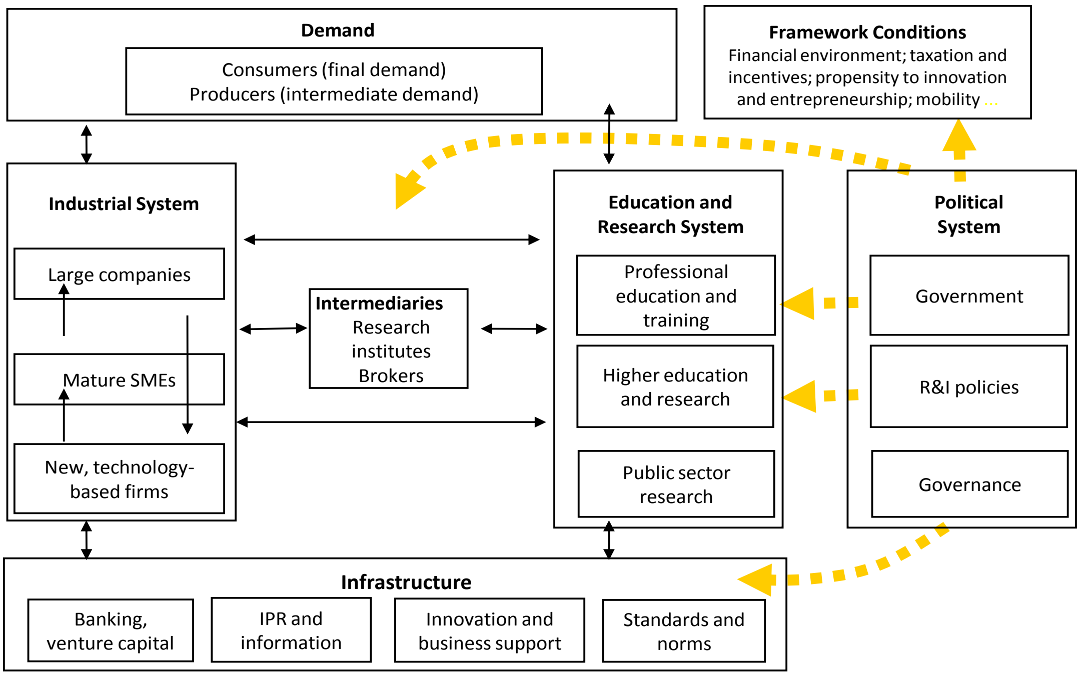
1 Introduction

This paper has the objective of extending the System of Innovation (Kuhlmann and Arnold 2001; figure 1) and Technological Innovation System (TIS) (Bergek et al. 2008) approaches to include pathways of development over time and to include considerations of interactions between niches and the regime from the Multi-Level perspective framework on sustainability transitions (Grin et al. 2010). This should include consideration of consumers and the demand side, which is less comprehensively discussed in the SSI and TIS literature than in the sustainability transitions literature.

The reason for this paper is that the SSI has no explanation of dynamics. It is really a typology of actor types which are assumed to be necessary for innovation. TIS is an application of SSI to individual technologies and a more detailed analysis of how successful the innovation system is, using the concept of functions of the innovation systems. These functions then have to be performed successfully for the technology to be taken up. However, there is still no analysis of the interactions between the functions or how interaction determines the evolution of the innovation system through time and its success or failure.

Also, a critical aspect of the evolution of technologies and the associated social systems is missing: the feedbacks between the dominant design or regime and the new, alternative technology. The current institutional and market setting is taken as exogenous to the innovation system analysis in the TIS. The analysis is limited to identifying those innovation functions which are being successfully undertaken and those which are weak, together with barriers to the uptake of the new technology and proposing measures to overcome these barriers. Here, the MLP on transitions offers an explicit treatment of niche-regime interactions.

Figure 1: The system of innovation structure



Source: Kuhlmann and Arnold (2001)

The research problem addressed by this paper is therefore to move towards a theory of the role of TIS functions in determining the dynamics of innovation. For technologies that represent a radical change in the socio-technical system, the niche-regime structure and dynamic interactions of the MLP is used to provide a theory of the potential dynamic pathways (Geels and Schot 2007). These are used to structure the possible sequences through time of Niche-Regime-Landscape dynamics, which determine different phases in a (potential) transition. The TIS functions have different weights in different phases of a transition, such that the system of TIS functions has different feedback loops in the different phases.

There are a few attempts to combine TIS and the niche-regime-landscape dynamics of the MLP. Weber and Rohracher (2012) compare the two frameworks and argue that they are complementary. Markard and Truffer (2008) develop a scheme to combine the two frameworks, and propose that a TIS usually includes more than one niche, while a niche usually acts around a particular technology. A TIS can be considered to interact with multiple regimes. However, they do not address in detail the internal functioning and dynamics of a TIS or a regime.

2 Dynamics of TIS functions: a model structure

Our argument is that in order to represent the dynamics in a clear way in general publications, the actor structure in the innovation system shown in figure 1 should be extended to show the functions performed by each actor or relationship. Also, the dynamics of a TIS are determined by the feedbacks between the TIS functions and therefore, these should be explicitly represented. To avoid an overcomplicated representation, this should be shown separately. The extension of the SSI to show TIS functions has been undertaken for the low carbon shipping case (figure 2). It is clear that in order to be able to draw the relationships between actors and functions, a precise definition of the activity that embodies the function is required, otherwise the direction of influence is not clear, e.g. guidance of search by environmental policy may be undertaken because the issue of environment performance is raised in society such that policymakers act. Alternatively, or as well, the enactment of policy strengthens legitimation by convincing further actors such as venture capitalists or banks that a market can be developed.

The TIS functions are considered to provide the underlying system structure that determines the evolution of a technology, in a similar way to Suurs' idea of Motors Of Innovation (Suurs 2009). These functions are performed by the actors in the TIS. Therefore, the functions can be assessed by looking at the actions of the relevant actors. There are several versions of the list of functions in a TIS. The following list has been adopted:

Functions

F1 Knowledge generation

F2 Know diffusion

F3 Guidance for the direction of search

F4 Entrepreneurial experimentation

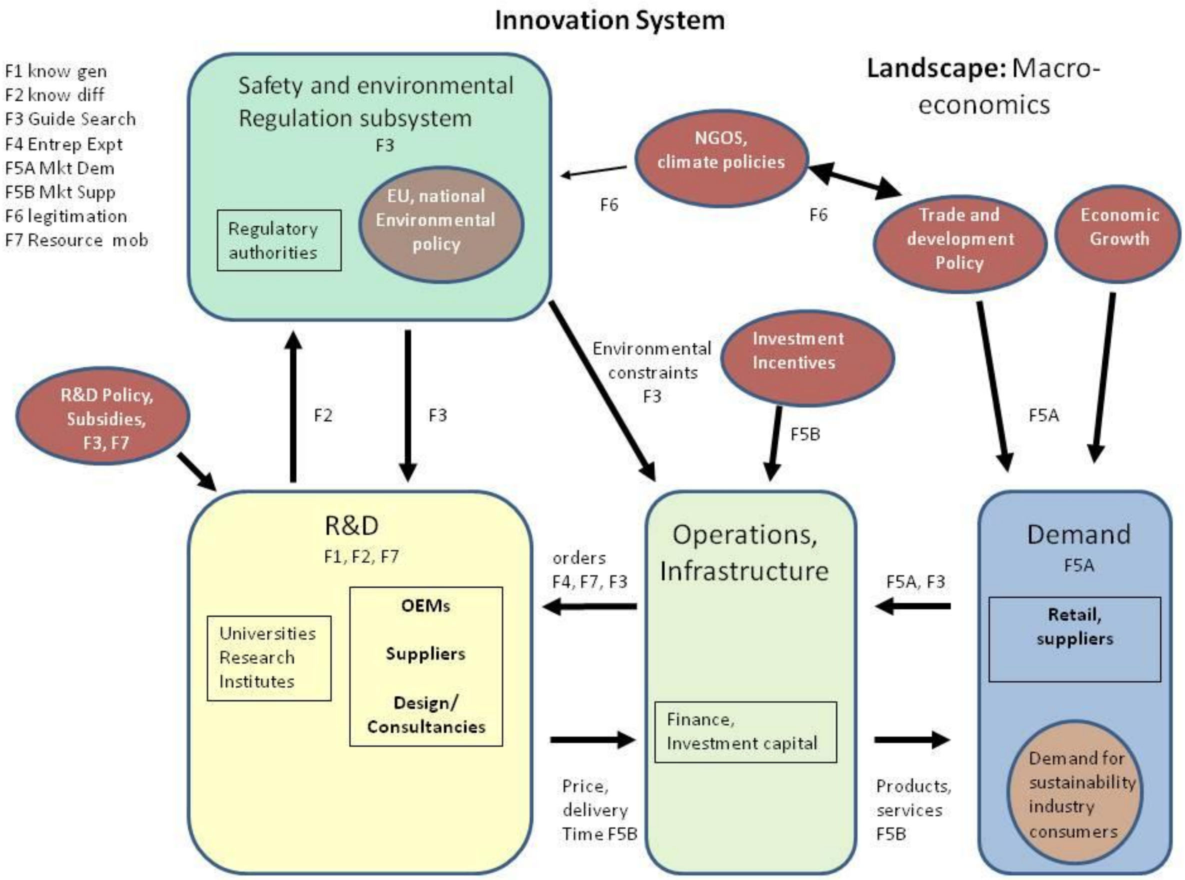
F5 Market formation: demand and supply

F6 Legitimation

F7 Resource mobilisation

The agents in the Sectoral System of Innovation (SSI) are mapped using the structure of Kuhlmann and Arnold (2001). The next step is to use the actor structure of the SSI to assess which actors are undertaking the TIS functions (Bergek et al. 2008), which then can be used for empirical analysis of the functions. Actors may perform more than one function. Market demand has been included in a more central way than in the SSI representation of Kuhlmann and Arnold (2001). This is shown for a typical SSI in figure 2, developed from Köhler and Frencia (2011) and Senger and Köhler (2015).

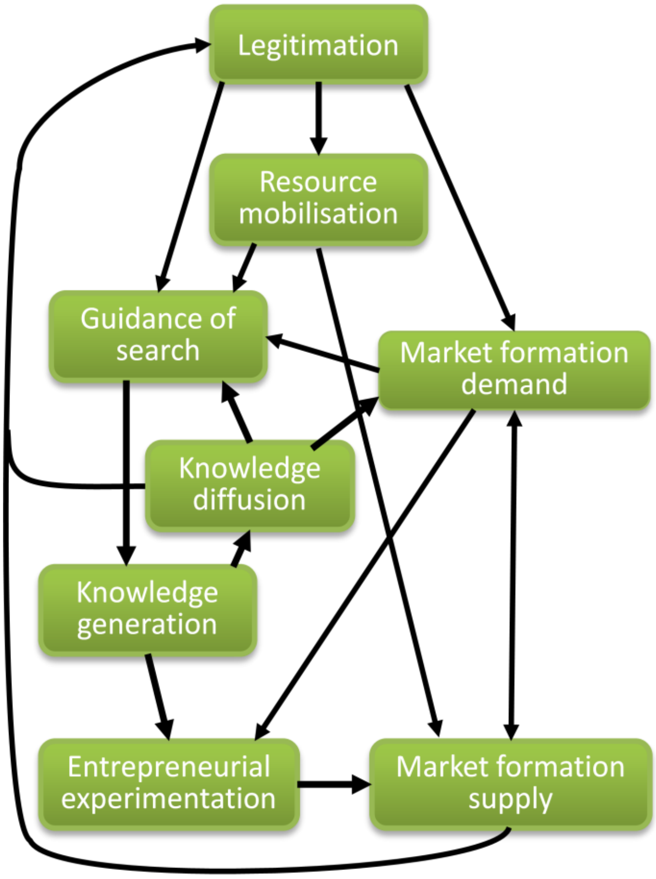
Figure 2: Innovation system diagram with TIS functions mapped to actors



Source: own analysis

Then, the next stage in the analysis is to map out the interactions between the functions; to describe the system of functions. Potential TIS function interlinkages can be determined from the actor analysis and the identification of the functions that they perform. As actors may perform more than one function, actors may influence the system of functions and therefore the evolution of the TIS through multiple effects. A possible system of the TIS functions has been determined from the relationships between the actors expressed in terms of functions as shown in figure 2. These relationships are shown in general in figure 3, but should be re-examined when applied to a particular case study.

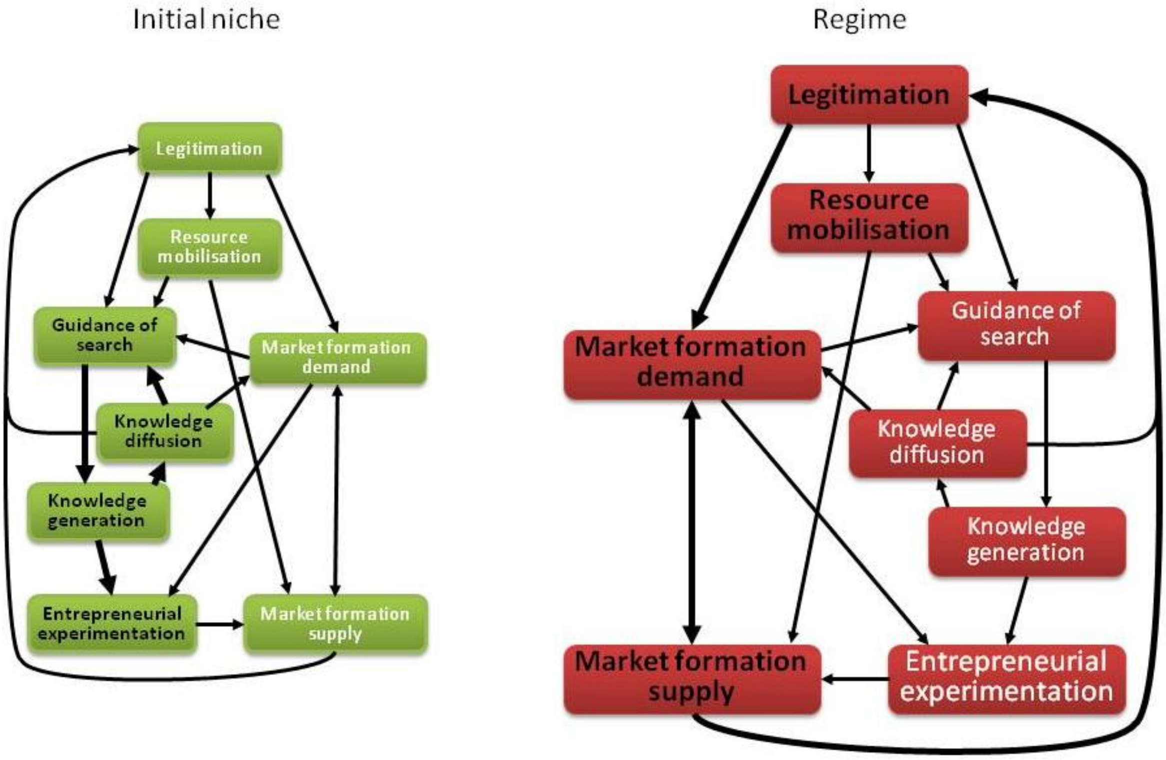
Figure 3: Interactions between TIS functions



Source: own analysis

The TIS functions are then considered in terms of the niche-regime structure of the MLP. Bergek et al. (2008) state that a TIS is associated with a particular technology, but may share actors, institutions and networks with other TISs. In the transitions case study literature, a niche is often associated with a particular technology while there may be several niches that coexist in a particular sector (Köhler et al. 2009). As TIS is applied to a new technology, this can be thought of as a niche in terms of the MLP. Initially, if the niche technology does not yet have a market and there is no product for sale, then knowledge development comes about either as an internal process of the knowledge development function or as a result of the guidance of search function. However, the regime also innovates and performs these innovation functions. While a niche concentrates on new ideas to meet new requirements (e.g. mitigating climate change) in society, the regime is dominated by established economic relationships, which supports its strong market position, and by use of its influence for legitimation. Hence there are two (or more, if there is more than one niche) function systems acting in parallel. This theoretical concept is shown in figure 4. The niche and regime have different states of the relationships between functions. The niche activities emphasise knowledge development and diffusion to meet a new problem, shown by the thicker lines representing more intensive interactions and the functions which are most actively undertaken named in black. The regime innovation functions are dominated by market processes, including continuing legitimation from use in markets.

Figure 4: General system of TIS functions



Source: own analysis

Walz and Köhler (2014) argue that a regime has a common culture and institutional structure with a dominant technological solution, but employing a range of behavioural practices. An examination of the SSI structure shows that a regime has the same types of actors and functions. The MLP argues that while they may be semi-independent initially, if the new technology is to be taken up, it must grow and then the regime will react. Therefore, interactions between the two systems of TIS functions develop. The way in which these interactions develop will determine the evolution of a transition pathway or the suppression of the niche by the regime.

We argue, following Suurs (2009) that the TIS functions have different weights in different phases of a transition and that consequently the system of TIS functions has different main feedback loops in the different phases, indicated as heavier feedback arrows in figure 4. The MLP with its niche-regime structure and attention to dynamic interactions can be used to structure the possible sequences through time of Niche-Regime-Landscape dynamics, which determine the different phases in a (potential) transition.

3 Examples

This scheme of analysis has been applied to examples of new technologies, to see whether this theoretical structure can be used in cases for which empirical observations have already been made. Actor assessments have been undertaken for the following cases:

- small scale/decentralised wastewater treatment (SWTP);
- low carbon propulsion in ships;
- energy efficiency in industry;
- low carbon automobiles;
- the transition from sail to steam power in the 19th Century, as an example of a non-environmental policy driven transition;
- wind electricity generation.

The actor assessments are shown in the Annex. These have been developed into brief illustrations of how this method can be applied for SWTP, low carbon shipping and high efficiency electric motors.

3.1 Small scale/decentralised wastewater treatment (SWTP)

3.1.1 Brief description of the new technology and current state of development

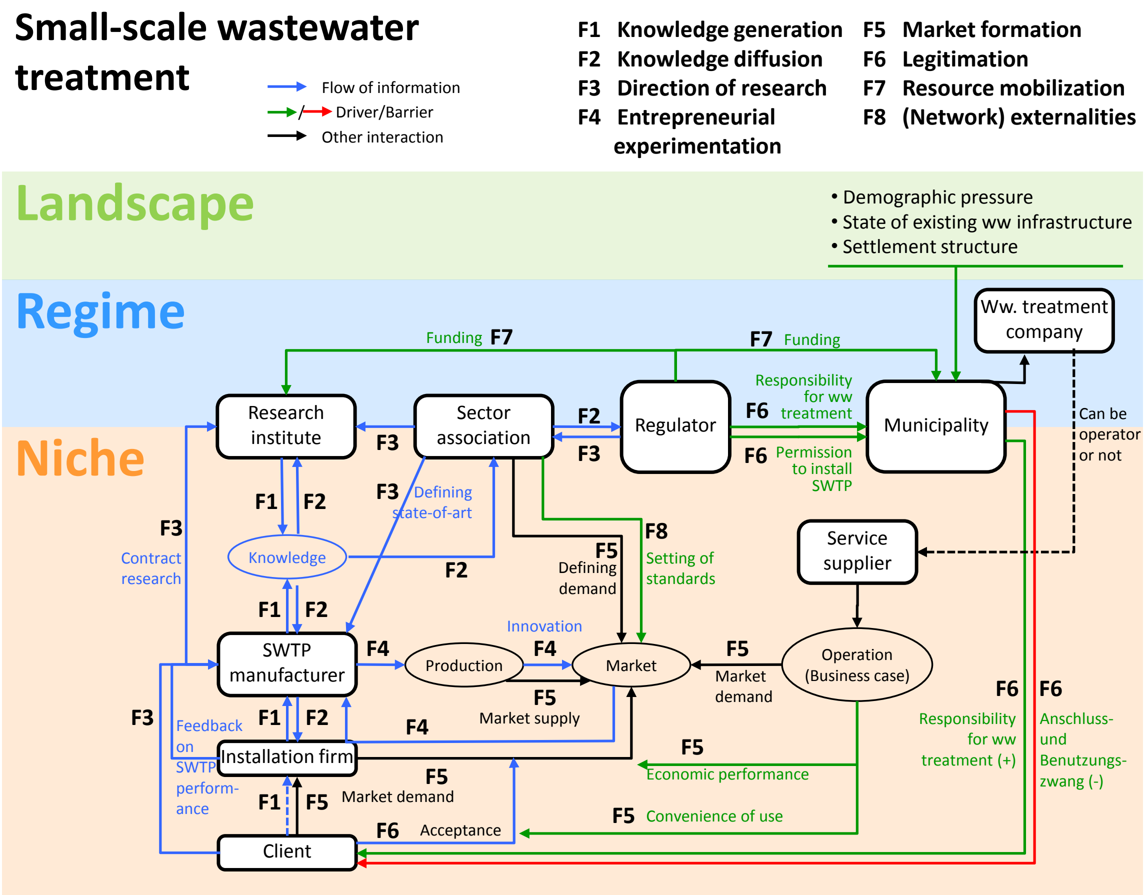
While municipal wastewater infrastructure including a large central treatment plant and a wide collecting sewer network is very effective in more densely populated agglomerations, it loses much of its effectiveness and economic feasibility in remote regions with low or decreasing population density. A long-known alternative is decentralized small-scale wastewater treatment, which, in its original design as cesspool, is little more than a settlement and collection vessel for domestic wastewater. In fact, this type of wastewater treatment is rather limited and its basic effect relies on the separation and subsequent transfer of the sludge to agricultural use or central treatment plants. Owing to the low effectiveness of the basic process and, moreover, the poor state of most of the facilities due to lacking service and maintenance (which were both in stark contrast to the high performance of central treatment plants), the reputation of this technology decreased strongly and, since the 1990s, many public wastewater treatment authorities in Germany decided to phase it out and extend and use the existing centralized wastewater treatment with extended sewerage instead (see Gandenberger and Sartorius 2012).

However, the central approach did not work everywhere. Especially in regions with low or decreasing population density, major infrastructural deficits and weaker economic performance (e.g. left over in some cases from their GDR history), the central approach turned out to be too expensive (Gandenberger and Sartorius 2012). At the same time, the development of decentralized wastewater treatment was successively adopting secondary (biological) and even tertiary wastewater treatment (including nutrient removal), which had in the meantime become state of the art in centralized wastewater treatment. So, from a technical point of view, small-scale wastewater treatment plants (SWTP) succeeded to perform as well as their small centralized counterparts, which was officially acknowledged by including them in Annex 1 of the German Wastewater Ordinance (AbwV) since 2002. But still, there were and are reservations concerning their long-term performance, because operated typically by private home owners they tended to be badly serviced and maintained and their performance could hardly be controlled permanently. But maintenance and reliability do not seem to be the only bottlenecks. By now, most SWTP are purchased and operated by the respective private users, which undermines substantial economic potentials such as buying larger numbers of SWTP at a better price, realizing economies of scale and improve quality by servicing and maintaining a large number of equal devices more efficiently. Eventually, contracting of decentralized wastewater treatment could raise the level of comfort for the users and thus the willingness-to-pay on the demand side. So, evidently, the development of SWTP has proceeded part of its way, but another part still has to be gone.

3.1.2 Actor and functions analysis

The development of SWTP is determined by a variety of actors who perform one or several functions in the respective TIS. Some of the functions have already been performed while others will have to be in the future. How and by whom the functions are fulfilled is described in detail below; the results of this analysis are summarized in figure 5.

Figure 5: Actors constituting the TIS of SWTP and the functions fulfilled by them



Source: own analysis

Knowledge generation (F1) starts with **SWTP manufacturers** who invent and develop the necessary technology and supply the initial niche (wastewater (ww) treatment in remote, hardly accessible locations). Once some SWTP devices have been installed, **installation firms** who install and maintain the devices and **clients** who use and operate them return feedback about the function fulfilment and potentials for improvement of the SWTP devices to the **manufacturers**. Once it turns out that SWTP could be of greater interest giving rise to extended market opportunities, more (potential) suppliers will try to use this opportunity and deploy **research institutes** (by contract research) to contribute to their knowledge formation. Some (sometimes public) research institutes cumulate knowledge about the state of the technology, which can be useful for fulfilling other functions. An instance of such institutes is the *Deutsches Institut für Bautechnik* (DIBt), which helps setting standards for, the construction and authorizes configurations of SWTP devices.

Knowledge diffusion (F2) is based on the knowledge pool created in the course of knowledge formation (F1). A major role for knowledge diffusion is played by **installation firms** (and **clients**), who collect and spread knowledge about the performance of products of various manufacturers. Once the niche increases and SWTP gain wider – even public – interest (i.e. even public wastewater **regulators** think about deploying SWTP), the **sector association** *Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall* (DWA) becomes involved: it collects and reconciles knowledge and opinions of all relevant stakeholders in the field and tries to give a recommendation how to deal with SWTP in Germany. The contribution of **SWTP manufacturers** and **research institutes** (doing contract research for the manufacturers) to knowledge diffusion is limited, because the free exchange of knowledge would affect with the competitive position of manufacturers.

The direction of research (F3) is determined on the basis of diffused knowledge (F2) mainly by the **sector association** (DWA), which comprises all important stakeholders of wastewater treatment (including representatives of the regulator) and serves as common opinion forming institution also for SWTP. Additionally, it defines the technical state-of-the-art, which is the basis for many regulation issues. Although, by setting up the respective regulation and granting financial support, the **regulator** is the ultimate determinator of the direction of research, it often passes over this role to the DWA by referring in its regulation to the state of technology, which is then specified by DWA. The direction of research is also determined by the market, but this function is better reflected by F4.

Entrepreneurial experimentation (F4) going beyond the need for compliance with increasing legislative regulation and standards is carried out mainly on the market by competing **SWTP manufacturers** supplying different, innovative variants of SWTP. With their innovative products they try to meet the demand inherent to the costumers and modified by external (e.g. regulatory) conditions. They then receive feedback about their products and their market potentials from the demand side from **installation firms** and **clients** through communication or the sheer number of sold devices.

Market formation (F5) on the demand side is driven by the **clients** and the **installation firms**, if the SWTPs are operated by the users, or by a **service supplier** who buys the SWTPs and lends them to the users. In the former case, demand is governed by a principal agent relationship, where installation firms are more decisive than the clients. On the supply side the market is formed by a growing number of growing **SWTP manufacturers**. In the sense of specifying certain characteristics the market is also formed the **sector association** who by setting standards (see direction of research, F3) enables the market to develop economies of scale and grow.

The basic legitimation (F6) for installing and using SWTPs comes from the obligation (here: *Fürsorgepflicht*) of the **municipality** to serve the public and, accordingly, dispose of wastewater in a way that does exclude harm to the environment and people's health. This obligation is made explicit and formally established by the **regulator** (esp. Oberste Wasserbehörden) during the legislation process. It is then handed over to **municipalities** and their lower water authority for execution. Implicitly and on an even more basic level legitimation is derived from the acceptance of SWTP technology in practical and economic terms on the social level. The technical measures suitable for complying with the regulation are determined by the **sector association** (see F3). In fact, substantial support for SWTP arose in **municipalities** who expect to derive an economic advantage from the implementation of SWTP. Some regulators (in specific federal states) turned out to be susceptible to this approach after the sector association was able to confirm the technical suitability and reliability of SWTP and the Federal Wastewater Ordinance was supplemented accordingly (in 2002). Other federal states were less supportive because they had already installed a comprehensive central infrastructure. In order to maintain their revenues, they refer to the *Anschluss- und Benutzungszwang* and, accordingly, do not allow their citizens (= **clients**) to use SWTPs.

Resources (mobilization, F7) necessary for SWTP research and development come from the **regulator** and the **manufacturers** who invest in their own R&D. Like other elements of wastewater infrastructure the **regulator** also (partly) subsidizes investments into SWTP installations. The remainder of cost is eventually borne by the users, i.e. the **clients**. If they are short of financial capital, they or a professional contractor can refer to banks as supplier of the necessary financial resources.

Externalities (F8) of SWTP technology and infrastructure in terms of network effects are limited as there is no network involved (in contrast to central ww treatment). Instead, central systems can easily be supplemented by decentral ones wherever it seem appropriate. This may give rise to another type of externality: the complementarity between central and decentralized wastewater treatment. As SWTP can render the central infrastructure more versatile, it exerts positive externalities to the latter. One relevant point in this respect could also be the standards forming the technological basis of SWTP manufacture and operation in Germany and, possibly, in foreign markets.

The preceding description of the actors and the functions they execute in the TIS 'SWTP' implicitly includes a time perspective insofar as, for instance, the formation and diffusion of knowledge naturally precedes innovation and thus the formation of a respective market. Also, it is clear that legitimation of SWTP technology and the mobilization of resources is a precondition for the extension of this market to a larger scale. In order to make the time scale more explicit, we will now focus on the functions, how they interfere with each other and, eventually, how these interactions change with time. At this point, it needs to be pointed out that the development of the innovative SWTP technology is not progressing on its own; SWTP develops in close relation to CWTP, which represents the established technical standard in the field of wastewater treatment in Germany like most other industrial countries. So, on the one hand, CWTP and SWTP compete for users and the respective revenues; on the other hand they can complement each other to their mutual benefit. In order to account for this relationship and, additionally, describe more specifically the time path for the comprehensive integration of SWTP in German wastewater management, we will extend the TIS analysis to both SWTP and CWTP, describe both of them and their interactions in terms of the TIS functions and integrate all that in the niche-regime-landscape logic of the MLP.

3.1.3 Description of a scenario for a transition pathway

The first step in the integration of the TIS and the MLP logic is the assignment of actors and functions to niche and regime. As can easily be derived from the respective states of technical development and market diffusion, well-established, conventional CWTP represents the regime and recently developed, less wide-spread SWTP the niche. Although the above description of the actors and functions refers to SWTP - the niche - only, all functions are carried out in both, the niche and the regime. If they were not, the respective system would not be able to survive in the long run. However, with regard to the functions, niche and regime differ in two respects: different functions can be more or less active depending on the developmental state and at least some of the functions are covered by different actors.

Starting with the latter point, the overlap between niche and regime concerning the actors is rather high. The (mostly risk-averse) regulator(s) basically supports each technology as long as it ensures the protection of nature and health; the municipalities support either niche or regime depending on their specific background (see landscape); the sector association mirrors a large part of the entire TIS and therefore comprises supporters as well as opponents of SWTP; the installation firms sell SWTP if they know the technology and are convinced about them forming a business case; and the **research institutes** can do research in both spheres. Although any specific of these actors may have a stronger assignment to either niche or regime, no specific distinctive feature exists that limits their assignment to niche or regime exclusively and all of them could in principle fulfil their respective functions in both. Actors specific for niche and regime are the manufacturers, as SWTP devices are technically quite different from CWTP and are not designed to be used as a component in the latter. Additionally, operation (including contracting) of SWTP could be done by either the operators of the conventional CWTP operators or by a specialized, independent service provider, who is not part of the regime. However, this leads to the question why SWTP and CWTP, sharing so many of the relevant actors, can be considered as representing different technological regimes or trajectories at all. Only this difference in basic structural characteristics (rather than just gradual differences) and, accordingly, their characterization as different trajectories justifies their assignment to niche and regime, respectively. In the actual case, this difference is much more an institutional than a technical one. Technically, SWTP and CWTP (with sewage networks) of any possible size can be combined and integrated on different levels.[1] In practice, intending to build a centralized wastewater treatment system, municipalities have to decide which size it ought to be. If it then turns out that the planned number of connected households is not (anymore) reached and costs impend to exceed revenues, municipalities can make use of the *Anschluss- und Benutzungszwang* to avoid any users switching to the SWTP alternative and thus maintain as much as possible of their economic basis. Together with the greater familiarity of planners and installers with the conventional system these economic network effects are the main arguments in favour of the distinction between niche and regime (Gandenberger and Sartorius 2012).

Very early stage: natural niche

With regard to the differences in importance of functions in niche and regime and, more generally, in different stages of the technological transition, figure 3 is a good point to start with, as it shows niche and regime in a very early state with hardly any interrelations. It represents a (niche) situation where SWTP is used in a remote place where no other way of wastewater treatment is feasible. Clearly, the most relevant niche functions are about doing research (F1) and spread and use the generated knowledge (F2) to identify a feasible way to solve the technical problems at stake in specific cases (supplier, F4) or, more generally (sector association, F3). Other potential users of SWTP may learn about this rising opportunity, which is the beginning of market formation on the demand side (F5), but as yet the niche is too small to have normative consequences (legitimation, F6) and give rise to the mobilization of major resources (F7). Independent of, and without paying much attention to, the niche, the regime is doing business as usual. As CWTP is well established, radically new products (F4) and the related research (F1) is of low importance. The sector association is trying to maintain or at most slightly improve the routines and their performance by gradually improving and standardizing existing processes (F3). Nevertheless, the regime serves the large majority of water users with its large system of wastewater treatment facilities, which

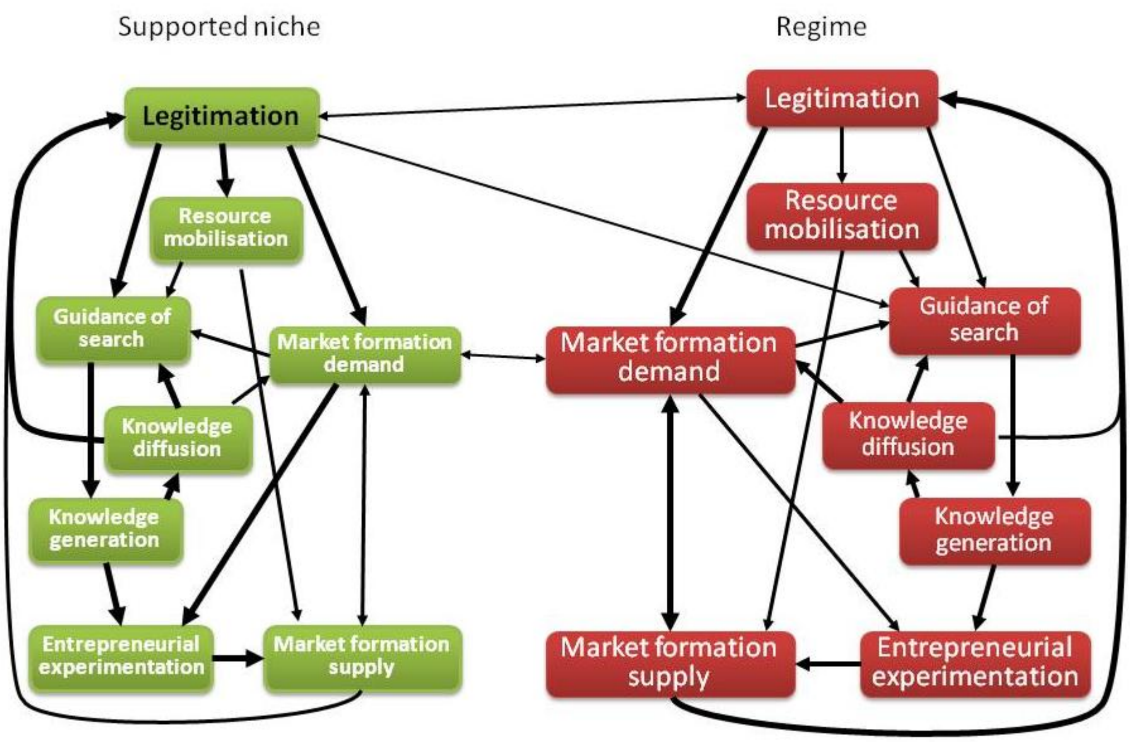
1 This is one argument raised as to why the distinction between SWTP and CWTP makes sense at all.

needs to be maintained, repaired and eventually (re)built. This is the basis for the existence of a substantial market (F5), which provides employment opportunities for a large number of people. And eventually, all this is driven by the economic relevance of the sector and the legitimation of the extended wastewater treatment system in the first place (F6).

Growing niche: early interaction

If the new application opportunities are recognized and the new requirement for SWTP become more widely accepted (e.g. through the new knowledge generated by the niche), the niche is further legitimised and can grow. This is illustrated in figure 6. In the niche, this leads to a much stronger relevance of legitimation (F6), which is done by the regulator through legal authorization and by the sector association DWA, which increases acceptance among installers, operators and eventually users. A precondition for legitimation is the availability of publically available knowledge about SWTP, which is provided by users and installers and collected by DWA. Conversely, legitimation leads to growing market demand and more entrepreneurial experimentation.

Figure 6. Niche growth (green) and regime as innovation function systems; initial stable regime



Source: own analysis

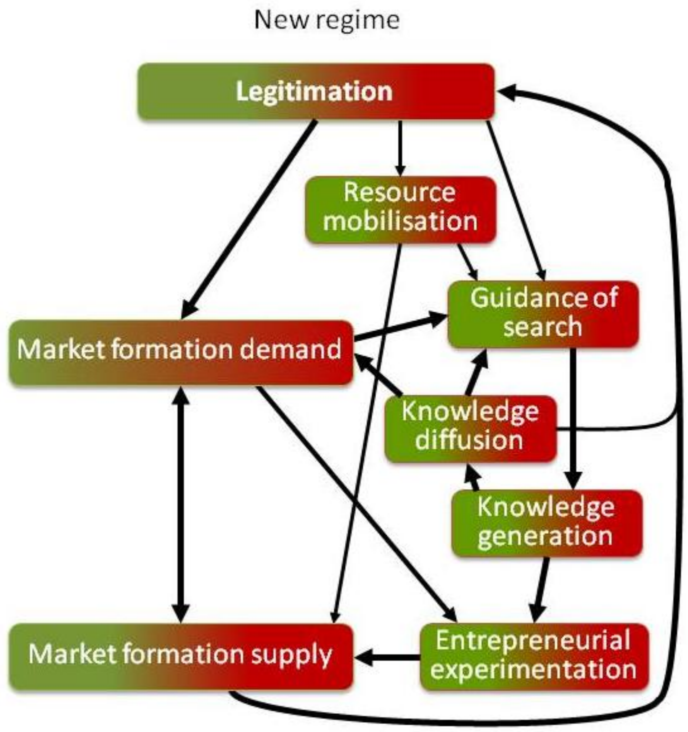
As the niche grows competition between the markets for SWTP and CWTP for a limited number of new installation opportunities starts to increase. Similarly, legitimation affects the allocation of subsidies as one instance of resource mobilization. As their total size is limited, favouring the niche will go at the expense of the regime (and vice versa). Additionally, the legitimation in niche and regime interact, as regulation basically concerns the same issue, wastewater treatment. If, as yet, certain critical issues were always resolved by means of CWTP, this necessarily affects the use of SWTP in the niche, and if, from now on, SWTP are allowed as equivalent alternative in more and more applications (according to Anhang 2 of the *Abwasserverordnung*), this will challenge at least some regulations governing the regime until now (e.g. *Anschluss- und Benutzungszwang*).

The extension of the TIS approach by the MLP also includes the influence of the landscape. One main instance of pressure arising from the landscape in wastewater treatment is demographic change, which includes migration between regions as well as aging of the society. As, owing to its longevity and inflexibility, the regime has difficulties in dealing with this challenge and SWTP can even contribute to a way out, this may again lead to a substantial shift of legitimacy in favour of the niche. In both cases, such legitimation may have a strong effect on the market demand – in favour of SWTP and in disfavour of CWTP. Eventually, the combination of legitimation directly of via a growing market will enhance entrepreneurial experimentation, because the market demand is seen to move into a take-off phase.

Grown niche – integration into the regime

The larger the niche grows, the more the functional activities in it will move from knowledge generation and diffusion (F1 and F2) and direction of research (F3) towards more market-related activities (F5). Also, resource mobilization (F6) will shift from research funding towards (partial) financial subsidies or even private funding. So, not only the size but also the conditions in the niche regarding main activities and driving forces resemble increasingly those in the regime. As pointed out earlier, the niche and its actors are not expected to displace the regime. Rather they are thought to complement each other with both components contributing a substantial share in the future. In this case, the decision between SWTP and CWTP is not anymore a matter of (specific) perspective or opinion, but specific circumstances. All components are available on the market and the installers/users can choose freely. As a consequence, the markets in niche and regime merge and with them the actors differing mostly in niche and regime: the technology developers and manufacturers. If the markets merge and knowledge in niche and regime become part of a generally accepted knowledge pool (and since most actors could not be assigned to either niche or regime anyway), it makes no longer sense to distinguish all other respective functions in niche and regime. Then the old regime and the grown up niche are becoming the new adapted regime (see figure 7). This is similar to the reconfiguration pathway of Geels and Schot (2007).

Figure 7: Regime reconfiguration, niche absorbed and the niche knowledge, market and legitimation functions adopted by the regime



Source: own analysis

3.2 Low carbon propulsion in ships

3.2.1 Brief description of the new technology and current state of development

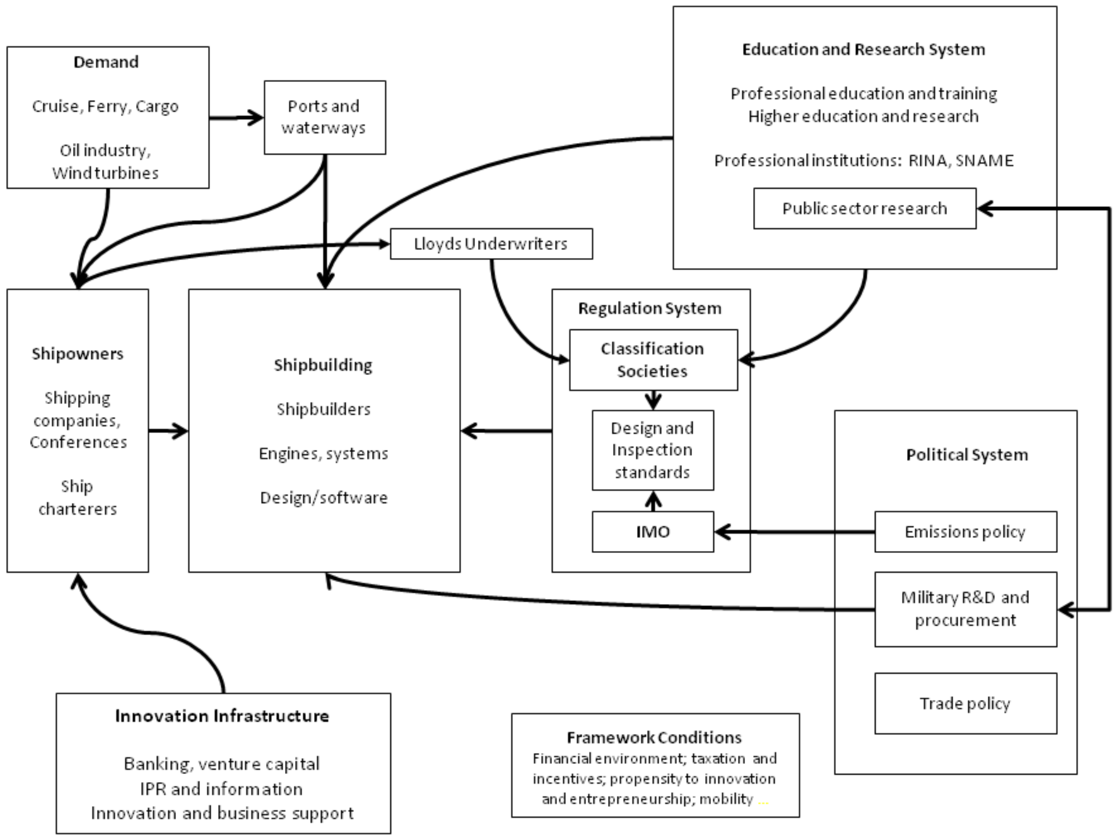
Renewable power for ships is a case where multiple niches are already available (Köhler 2014). These include: biofuels in conventional diesel engines for, LNG/CNG with which ships are already in commercial operation, various wind technologies and potentially hydrogen fuel cells. Dual fuel engines for diesel and LNG are already commercially available. It is also possible to dramatically reduce the energy requirements of shipping by reducing operational speeds. Shipping is a large and rapidly growing source of GHGs (Köhler 2014; IMO 2015). There is also a strong economic argument as well for adopting non fossil fuel propulsion: fuel costs up to 50% of operating costs in recent years (Senger and Köhler 2015). However, ships require high power outputs – more than sail can provide alone. Traditional sailing ships has displacements up to 10000 tonnes, while modern cargo ships up to 300000 tonnes and therefore combination of e.g. low operational speed, fuel cells and wind would be necessary (High Seas 2013). Sail propulsion could be a significant contributor if the industry adopts smaller ships with slower speeds, but this contradicts current mainstream/regime thinking about logistics, where larger ships are seen as necessary to obtain economies of scale – but on a clear path of diminishing returns to scale, as can be seen in the newest orders 20000TEU+ container ships. These require heavier structure and deeper hulls for an optimal hull with the necessary strength, can use fewer and fewer ports (e.g. the Elbe to Hamburg has to be dredged and otherwise only Rotterdam, Bremerhaven and Wilhelmshaven can accept ship ships in the EU) and hence few berths are available. There are difficulties in loading and unloading such large volumes of containers rapidly, i.e. longer turn-round times in port, which adds to costs. This suggests that smaller slower ships might be accepted if they can be demonstrated to be reliable and cheap. However, smaller and slower ships would require change in logistics chains and to maximise benefits of slower, wind assisted ships it is necessary to change ship design and adopt more complex routing schemes. These technologies – real time routing using continuously updated weather reports and forecasts are now available (e.g. the VINDSKIP project, LadeAs 2015).

Despite economic argument of higher oil prices, sail is still not being adopted – partly because there is no market demand for zero GHG ships, partly because of development costs in a globally competitive industry with overcapacity, where shipbuilders are trying to reduce costs. The response to high oil prices has been slow steaming, when oil prices drop, the optimal combination of number of ships and speed changes to higher speed and fewer ships (for lower capital costs of ships and goods in transit). For container/bulk market, require a trade which is not time critical and has favourable winds. A potential example is round the world container services, where the shipping service circumnavigates the globe.

3.2.2 Actor and functions analysis

The innovation system for low carbon shipping is shown in figure 8. This is extended to include the TIS functions in figure 9.

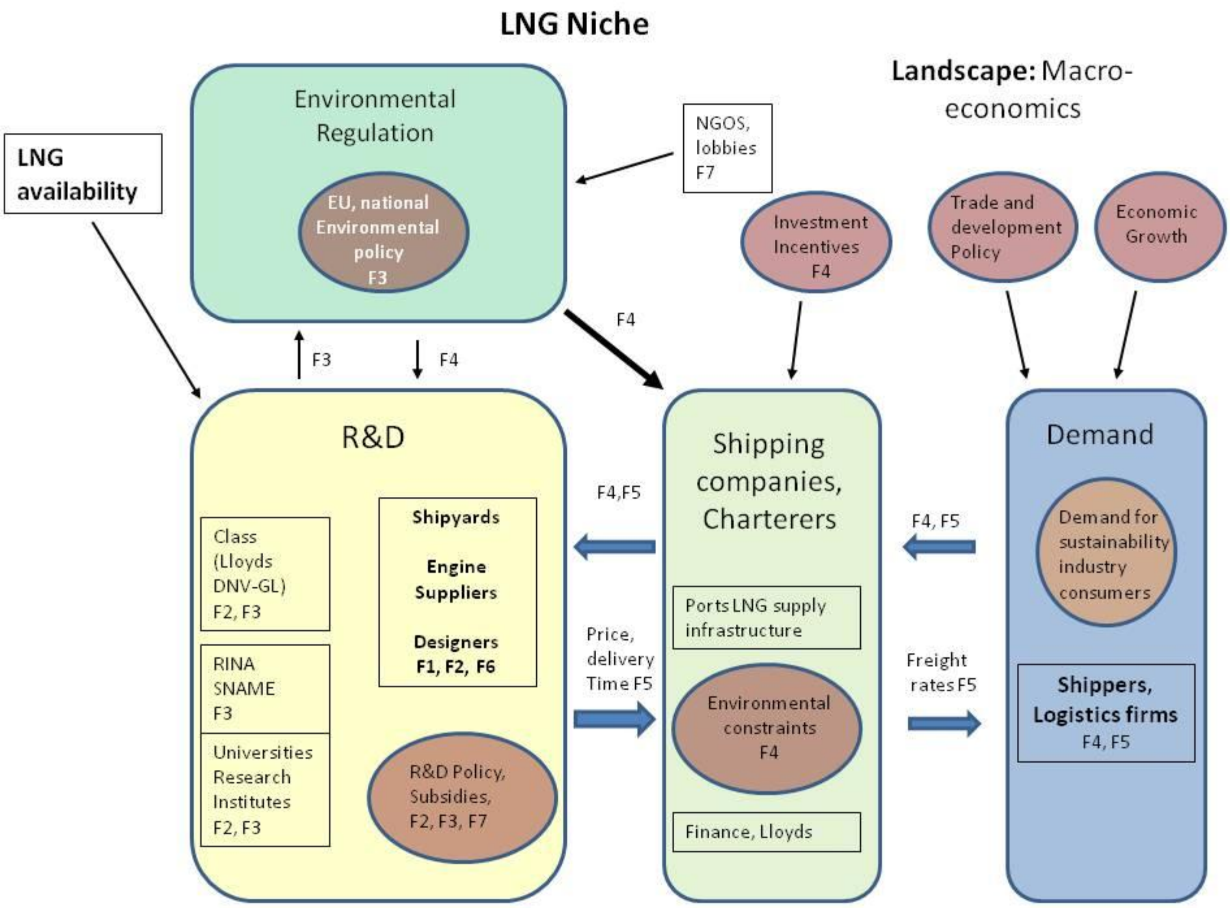
Figure 8: Innovation system in shipping



Source: Köhler and Frencia (2011)

An important characteristic of the shipping innovation system is the division between logistics companies who organise/demand shipping transport services and shipping companies who may be operators, charterers or ship management companies. R&D is heavily influenced by the classification societies as well as shipyards and propulsion system suppliers.

Figure 9: Low carbon shipping for LNG with TIS functions



Source: own analysis

3.2.3 Description of a scenario for a transition pathway

Current status of functions in the niche

Entrepreneurial activity is currently weak, with limited guidance of search through environmental policy. While the IMO has introduced a set of energy efficiency design indexes for ships, with requirements to improve over time, niche growth requires identification of a market where there is relatively high potential for wind power as auxiliary power and also support for entrepreneurial activity.

Regime problems

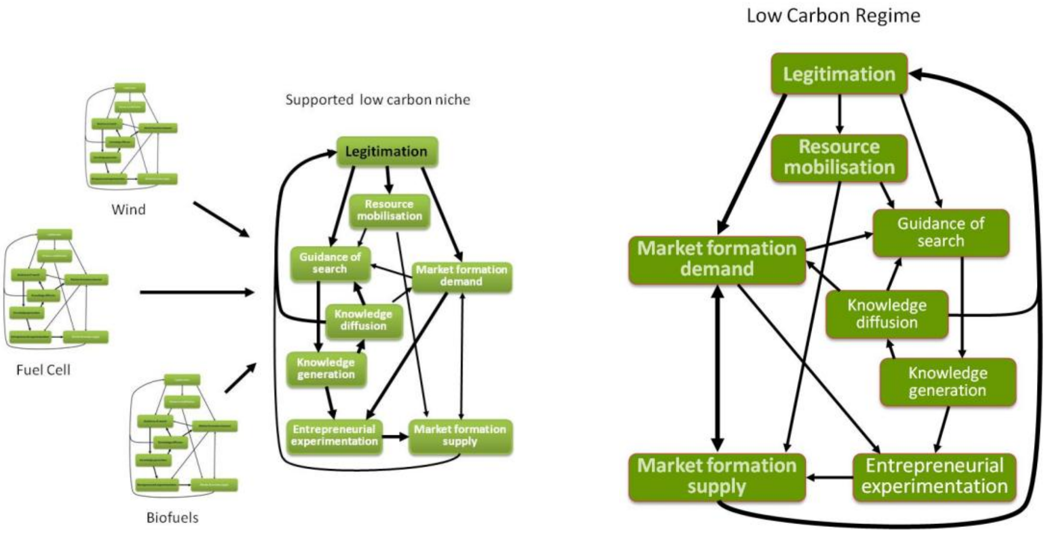
There are signs of regime destabilisation: shipping regulated mainly by IMO, which is tied to the IPCCC Kyoto process and moving very slowly towards market based mechanisms for climate change mitigation. But, regional environmental legislation in the US and in the EU (North Sea and Baltic) already forcing adoption of new fuels and technologies : low sulphur requirements require either low sulphur diesel fuel or LNG.

Scenario for a transition pathway

If support comes from the EU for new technologies e.g. wind technologies to develop niche markets for the EU maritime industry in e.g. fairtrade cosmetics, which are high value goods where transport costs are a small component of price and where the goods are not time critical. LNG ferries are also being demonstrated, as they do not require large scale changes to ship design and the fuel is available in large quantities, although it does require an extension of the fuel supply system. This would generate some limited legitimation through the promise of zero carbon emissions ships and perception of ships as the most energy efficient and cheapest form of freight transport. Shipping companies could also be subsidised to demonstrate the technology and its cost savings. With successful demonstration of the technologies and increasing landscape pressure due to increasing understanding of climate impacts, the technology niche could grow to other markets and combinations with other low carbon fuels e.g. biofuels. Logistics systems might then shift to take advantage of the reduced costs. These factors could enable the development of a supported niche as shown for the SWTP case in figure 6.

The niche might then demonstrate environmental and cost advantages. In response, the regime could seek to partly respond to the pressures to which the niche is providing a solution (emissions reduction). A further pressure on conventional ships from shortage/increasing cost of bunker fuels would weaken the demand for conventional technology. These pressures could also lead to the development of the other alternative technologies – biofuels and fuel cells. These niches combine to offer a practicable alternative to the regime, as shown in figure 10.

Figure 10: Supported niche as a combination of niches in low carbon shipping



Source: own analysis

This 'supported' niche comprises not only the low carbon power sources, but also the logistics system changes required to allow for changed routing and speeds. It also requires new institutions, safety standards for design and operation. However, it can fulfil the same need of society – mass transport of goods – as the regime and once this supported/empowered niche is developed it is therefore able to relatively easily replace the fossil fuel regime to form a new *low carbon shipping regime*. This would then be a case of a transition pathway in which the old regime is replaced by a new regime.

3.3 Energy efficient electric motors in industry

3.3.1 Brief description of the new technology and current state of development

This case study applies our conceptual approach to the development and diffusion of energy efficient technologies in the industrial sector, where we focus on the particular example of energy efficient electric motors (in the following mentioned as: *electric motors*). Electric motors and the systems they drive are estimated to account for between 43% and 46% of all global electricity consumption (Waide and Brunner 2011). In electric motor driven systems, the energy losses that occur in the system are typically larger than the losses in the motor itself.

In contrast to the examples described in the previous sections, the producers, sales structures and end-users of the new technologies (i.e. energy efficient technologies) and the old technologies (i.e. non-efficient technologies) are largely the same. The niche and the regime are therefore strongly connected, and efficient motors being in a "niche" refers more to the market structure especially on the demand side than to technological and economic feasibility. With regard to the market and sales structure it is important to note that motors and pumps are often provided to the end-user via an intermediary, e.g. a large distributor or OEM (Original Equipment Manufacturer). However, as will be discussed below in sections 3.3.2 and 3.3.3, new structures in the innovation system possibly influence the diffusion of energy efficient technologies.

Like many energy efficient technologies, electric motors are subject to the energy efficiency gap (Jaffe and Stavins 1994; Allcott and Greenstone 2012). The energy efficiency gap refers to the gap between the uptake of energy efficient technologies and the cost-optimal level. That means that technologies are available at cost-effective levels (in the case of electric motors, but are only adopted by a small user group. Companies that purchase electric motors tend to underinvest in higher-efficiency options and choose electric motor systems or components with a low first cost (Waide and Brunner 2011). Reasons for such an underinvestment include a lack of awareness of energy cost savings, organizational structures that manage equipment procurement budget separately from operations and maintenance budgets, or the fact that motors are often integrated into equipment produced by OEMs before sale to the final user (Waide and Brunner 2011; Fleiter and Eichhammer 2012). The OEM dilemma leads also to the fact that the end user often has no information about the energy consumption of the motor itself and is not able to base his investment decision on energy efficiency criteria (Fleiter and Eichhammer 2012). Another important reason is that motors are provided by large distributers which can deliver a standard motor, when it breaks down, in a short time period while it may be more time consuming for the end-user to wait for an energy efficient motor which must be produced to order.

To overcome these barriers European and national energy efficiency policy is an important driver for supporting the uptake of energy efficiency innovations (for an overview about complementary policy instruments addressing motor systems cf. EMSA and IEA 2014). Due to the fact that no single instrument is able to deal with all barriers entirely, different policy measures address different aspects of the innovation system (Brunner et al. 2014). Beside measures that address the supply side (e.g. Eco-Design Directive, R&D funding, minimum energy performance standards (MEPS)) and the demand side (e.g. financial incentives or energy labelling), policy measures increasingly address the structure of the entire innovation system and the interdependencies between the different actors. However, intermediaries which are a relevant factor regarding barriers are rarely addressed with policy instruments today. In Germany, the recently adopted National Action Plan on Energy Efficiency (NAPE) uses a variety of policy measures, some of which are new, that promote structural changes to the innovation system, e.g. by supporting energy efficiency networks, by introducing energy audits (inspired by the EU Directive on Energy Efficiency EED) and by promoting energy contracting (BMWi 2014). These organizational innovations involve new actors and new constellations of actors that address particular barriers and help to strengthen the adoption of energy efficiency technologies.

The following sections describe the TIS for electric motors in industry, focusing on how policy-driven structural changes to the innovation system may influence market formation and support the diffusion of efficient technologies.

3.3.2 Actor and functions analysis of the current state

As stated above (see chapter 2), the TIS concept is very suitable for the analysis of the current status of a particular innovation system. Whereas the "overall function" can be characterized as the generation and diffusion of innovations, various sub-functions have been proposed by a series of conceptual and empirical articles (among others Bergek et al. 2008, Hekkert et al. 2007). As already mentioned, the importance of particular TIS functions is different in the various phases of the innovation process. Thus, this example first assesses the current characteristics of the TIS functions for electric motors in industry before we analyze in section 3.3.3 the current Niche-Regime-Landscape dynamics from the MLP perspective which may influence a (potential) transition pathway.

The innovation system for electric motors is at a detailed level of analysis very heterogeneous in terms of both actors functions. Whereas innovation studies in the energy field have focused so far on the technological aspects, the analysis of innovations has to widening the horizon to non-technological innovations, such as organizational, financial and service innovations (in combination with technological innovations). The diffusion of technological innovations is often related to organizational and service innovations, such as e.g. in the case of energy consultancy, contracting or energy efficiency networks (e.g. Schleich et al. 2015; Rohde et al. 2015).

Current status of TIS functions

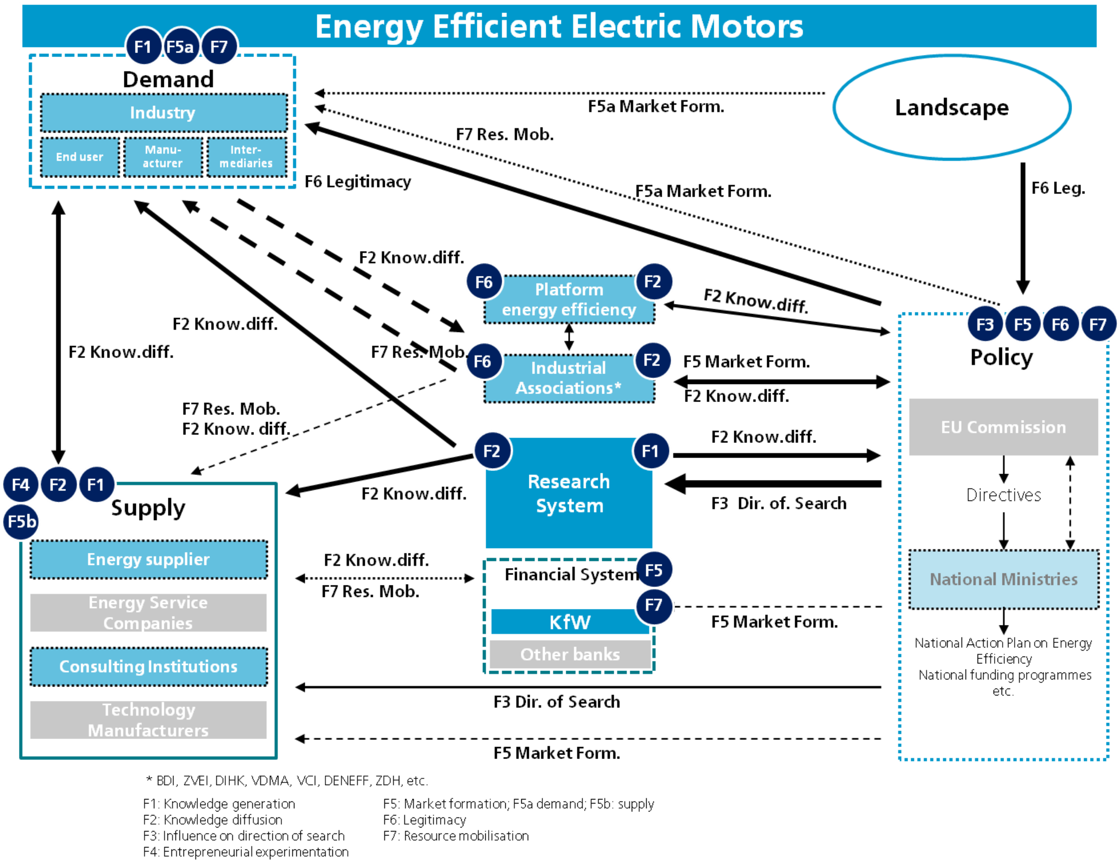
Figure 11 gives a schematic overview about the innovation system for electric motors in industry which consists inter alia of demand and supply-side actors, policy, financial system, research system, associations and platforms. The arrows shown in this figure aim to illustrate the interrelation between the different actors and TIS functions. Additionally, the functions shown in blue circles related to the different actors represent the most important functions fulfilled by these actors. If a TIS function is not fulfilled adequately by an actor the arrows and lines are dotted. One function could be influenced or fulfilled by various actors, i.e. one function could not be related to one actor. It must be noted that figure 11 illustrates the most important functions fulfilled by the actors for more clarity. Thus, there may be other functions relevant for the corresponding actors. How, by whom and in which manner the functions are fulfilled is described in detail below.

Most likely all relevant actors in the innovation system covering electric motors fulfill the two functions *knowledge generation (F1) and knowledge diffusion (F2)* adequately. Knowledge generation (F1) starts with the development of an energy efficient electric motor by technology manufacturers (see figure 11: supply side). As stated above, the emergence of innovations is not the crucial event, but rather the diffusion in the market. Apart from that the TIS approach in the literature with these two functions mostly focuses on the factor "Knowledge", but for the case of electric motors the analysis has to place an increased focus on the functions *Market Formation (F5)*, *Legitimation (F6)* and *Resource Mobilization (F7)* as these are likely more relevant. However, regarding *Knowledge Diffusion (F2)* energy service companies and consulting institutions also play an important role because these strengthen the knowledge and awareness for energy efficient technologies on the demand side. Furthermore, research institutes contribute to this function designing and evaluating policy instruments, such as e.g. with Eco-design preparatory studies, studies focusing on the design of innovative financing schemes or market incentive schemes or evaluation studies on policy impacts. The function *Influence on Direction of Search* (F3) is driven by policy actors at national and European level e.g. in the form of research funding programmes. *Entrepreneurial Experimentation* (F4) in the case of electric motors is also driven by policy instruments, such as the Eco-design Directive at EU level which will force the technology into the market. The slowness of the diffusion in the market is not the problem of the technological availability, but of the long transition times accepted for Ecodesign purposes and the long lifetime of electric motors.

As stated above, this example suggests splitting up the function *Market Formation (F5)* in "demand side" (F5a) and "supply side" (F5b) as the assessment turns out to be very different. Whereas on the supply side the availability of electric motors is – also due to the Eco-design process – not crucial, the diffusion on the demand side (F5a) as already mentioned is slowed. Nevertheless, this function may be influenced by policy actors establishing a policy mix promoting the diffusion of energy efficient technologies. This policy mix in Germany currently consists of a bundle of instruments such as e.g. promotional programs for energy consultancy or the implementation of cross-cutting technologies (BAFA 2015b), tax reductions (e.g. eco tax cap for manufacturing industry (Spitzenausgleich) or special equalization scheme (Besondere Ausgleichsregelung)), mandatory energy audits for large companies according to Article 8 of the Energy Efficiency Directive (EED) (BAFA 2015a), energy efficiency networks and also new activities resulting from the National Action Plan on Energy Efficiency (BMWi 2014) which directly and indirectly influence the diffusion of electric motors. To assess the effectiveness of the current policy mix in the TIS one has to distinguish individual motors, components containing motors (such as pumps or compressed air systems) and whole systems including electric motors. For the first two matters adequate policy instruments exist (e.g. standards or financial incentives). However, one has to note that standards for electric motors do not fully consider systems aspects which are quite complicated. One example for financial incentives is the promotional program for cross-cutting technologies from the German Federal Office for Economic Affairs and Export Control (BAFA) where funding – among other technologies – is also eligible for electric motors which directly pushes the adoption of this technology on the demand side (BAFA, 2015b). Currently approximately 30,000 applications across all cross-cutting-technologies in this program have been submitted. Furthermore, energy efficiency networks can help to overcome the lack of knowledge and fear of unknown technology. However, gaps in the policy mix are still present with respect to intermediaries.

Summarizing the above, the function *Market Formation (F5a)*, meaning the adoption of this technology, is not fulfilled adequately from the demand side perspective as among others policy instruments addressing intermediaries such as OEMs are still missing. As explained in section 3.1.1 there are various reasons for this which are broadly discussed in the literature analyzing barriers on energy efficiency (Jaffe and Stavins 1994; see also section 3.1.1). The basic *Legitimation (F6)* for electric motors is driven by the Eco-Design Directive. At institutional level the *Legitimation* has been strengthened by different business associations and other institutions in the recent years. However, the diffusion is slowed due to the existence of several barriers resulting from both intermediaries and end users which hinder the adoption of electric motors on the demand side. With regard to *Resource Mobilization (F7)* companies often have other investment priorities than to focus on energy efficient technologies or face a lack of capital availability for the implementation of these measures (Fleiter 2012). Furthermore, it may be the case that more efficient motors are not rapidly available (intermediaries) or the motor does not fit in the existing installation or could not be changed in a machine easily. However, policy instruments may strengthen the function *Resource Mobilization (F7)* (see section below). As a first hypothesis it could be stated that the functions *"Market Formation" (F5b)*, *"Legitimacy" (F6)* and *"Resource Mobilization" (F7)* are likely more important for the diffusion of electric motors than the other functions.

Figure 11: Schematic illustration of the TIS for energy efficient electric motors



Source: Authors' compilation

To summarize it can be noted that the actors and innovations in the electric motors innovation system are diverse and partly less easily tangible. As stated above, the diffusion of energy efficiency innovations is more dependent on the demand side than on the supply side. In the case of electric motors the innovation itself is not crucial but rather the broad diffusion on the user side. Thus, manufacturers and research institutes fulfil their functions (especially F1, F2 & F4) adequately (see figure 11: "Research System" and "Supply"). However, there is currently less corresponding demand from the industrial sector. Additionally, Energy Service Companies (ESCOs) as well as energy suppliers are partly currently lacking innovative business models on energy efficiency. However, the upcoming pilot tenders on energy efficiency in Germany could serve as a possibility to bundle activities to provide large volumes to producers and contractors.

3.3.3 Description of a scenario for a transition pathway

In order to shed light on transition pathways in the energy efficiency innovation system, it is crucial to capture the heterogeneity of actors and relate them to driving forces and blocking mechanisms. Compared to the current status of the other pillar of the 'Energiewende' which is the uptake of renewable energies, energy efficiency as the second pillar suffers from a relatively weak lobby in policy processes. However, some institutions, such as e.g. the German Business Initiative on Energy Efficiency (DENEFF) with its members, are becoming significant actors in the innovation system. When analyzing a transition pathway for electric motors, it has to be noted that the regime-niche interaction is slightly different in the case of energy efficiency compared to other examples of renewable energies, such as Wind or PV. Niche and regime actors and their fulfilment of functions are mostly the same. However, as described above, the regime which is among others dominated by technology adaptors currently slows an extensive diffusion of this technology on the demand side even though energy efficiency potentials in industrial motor systems are considerable and the related payback times for companies when adopting the technology are a few years at the most (Fleiter and Eichhammer 2012). The currently existing lock-in or stabilizing factors of the regime are among others a lack of sufficient policy instruments which address the intermediaries of efficient electric motors and as stated above the existence of several non-economic barriers which prevent the diffusion at company level (e.g. Rohdin and Thollander 2006). In addition, exemptions from several taxes and surcharges on the electricity price for (large) industrial electricity consumers lower their incentive to invest in energy efficiency. However, one has to note that in the recent year policy instruments have been adjusted in connecting these exemptions to the implementation of energy audits and energy management systems. Since 2013 this is the case for the eco tax cap for manufacturing industry and since 2015 also for the special equalization scheme. Regardless these developments there still remain barriers, such as e.g. the fact that retailers and wholesalers primarily focus on the price of the electric motor rather than on the energy efficiency of their products (Fleiter and Eichhammer 2012). In some cases delivery bottlenecks of the highest energy efficient motor may cause the decision for another one.

Nonetheless, there are also signs of a subsequent destabilization in the regime. Recently, new policy initiatives (such as for example the energy efficiency platform or the initiative for energy efficiency networks), different stakeholder processes, etc. have contributed to an agenda-setting process for this purpose (BMWi and BMUB 2014) and thereby contribute to the function *Legitimation* (F6) which is highly relevant to diffusion. To strengthen the function *Resource Mobilization (F7)* and thereby to push the diffusion of electric motors (*Market Formation*, F5a) on the demand side policy incentives are very important. As stated above, different funding programmes including energy consultancy as well as funding for the adoption of cross-cutting technologies may help to overcome barriers. However, policy instruments should as well address intermediaries directly. Furthermore, the advantages of multiple benefits of energy efficiency may serve as a strong argument to influence the diffusion of energy efficient technologies

(IEA, 2014) and contribute to both functions *Market Formation* (F5a) and *Legitimation* (F6).

The extension of the TIS approach by the MLP also includes the influence of the landscape. Equally relevant for the diffusion of energy efficiency innovations as compared to renewable energies is the catastrophe of Fukushima which caused both a changing process in policy and also an institutional change. Currently some actors are initiating changing processes and new constellations of actors such as the initiative on energy efficiency networks (BMWi and BMUB 2014) or the platform on energy efficiency arise. In the German energy efficiency innovation system business associations besides play a crucial role for the diffusion of energy efficient innovations. These institutions are at the same time a relevant link to the demand side as they represent the different industrial sectors. In the long-run the old regime and the grown-up niche will hopeful be become the new adapted regime. But to achieve this goal the promotion of the diffusion of organizational innovation such as an energy review or also energy management systems as a more comprehensive approach (which at most entails the adaption of recommended technological innovations) by a bundle of policy instruments is crucial.

4 Conclusions

The research problem addressed by this paper is to move towards a theory of the role of TIS functions in determining the dynamics of innovation. For technologies that represent a radical change in the socio-technical system, the niche-regime structure and dynamic interactions of the MLP is used to provide a theory of the potential dynamic pathways (Geels and Schot 2007). These are used to structure the possible sequences through time of Niche-Regime-Landscape dynamics, which determine different phases in a (potential) transition. The TIS functions have different weights in different phases of a transition, such that the system of TIS functions has different feedback loops in the different phases.

This approach addresses the problem that the main innovation theory, the SSI has no explanation of dynamics. It is really a typology of actor types which are assumed to be necessary for innovation. TIS is an application of SSI to individual technologies and a more detailed analysis of how successful the innovation system is, using the concept of functions of the innovation systems. These functions then have to be performed successfully for the technology to be taken up. However, there is still no analysis of the interactions between the functions or how interaction determines the evolution of the innovation system through time and its success or failure. Also, a critical aspect of the evolution of technologies and the associated social systems is missing: the feedbacks between the dominant design or regime and the new, alternative technology. The current institutional and market setting is taken as exogenous to the innovation system analysis in the TIS. The analysis is limited to identifying those innovation functions which are being successfully undertaken and those which are weak, together with barriers to the uptake of the new technology and proposing measures to overcome these barriers. Here, the MLP on transitions offers an explicit treatment of niche-regime interactions.

The agents in the Sectoral system of Innovation (SSI) are mapped using the structure of Kuhlmann and Arnold (2001). The next step is to use the actor structure of the SSI to assess which actors are undertaking the TIS functions (Bergek et al. 2008), which then can be used for empirical analysis of the functions. Actors may perform more than one function. Market demand has been included in a more central way than in the SSI representation of Kuhlmann and Arnold (2001).

Then, the next stage in the analysis is to map out the interactions between the functions; to describe the system of functions. Potential TIS function interlinkages can be determined from the actor analysis and the identification of the functions that they perform. As actors may perform more than one function, actors may influence the system of functions and therefore the evolution of the TIS through multiple effects. A possible system of the TIS functions has been determined from the relationships between the actors expressed in terms of functions.

The TIS functions are then considered in terms of the niche-regime structure of the MLP. Bergek et al. (2008) state that a TIS is associated with a particular technology, but may share actors, institutions and networks with other TISs. In the transitions case study literature, a niche is often associated with a particular technology while there may be several niches that coexist in a particular sector (Köhler et al. 2009). As TIS is applied to a new technology, this can be thought of as a niche in terms of the MLP. Hence there are two (or more, if there is more than one niche) function systems acting in parallel.

Walz and Köhler (2014) argue that a regime has a common culture and institutional structure with a dominant technological solution, but employing a range of behavioural practices. An examination of the SSI structure shows that a regime has the same types of actors and functions. The MLP argues that while they may be semi-independent initially, if the new technology is to be taken up, it must grow and then the regime will react. Therefore, interactions between the two systems of TIS functions develop. The way in which these interactions develop will determine the evolution of a transition pathway or the suppression of the niche by the regime.

We argue, following Suurs (2009) that the TIS functions have different weights in different phases of a transition and that consequently the system of TIS functions has different main feedback loops in the different phases, indicated as heavier feedback arrows in figure 4. The MLP with its niche-regime structure and attention to dynamic interactions can be used to structure the possible sequences through time of Niche-Regime-Landscape dynamics, which determine the different phases in a (potential) transition.

This approach has been illustrated for the cases of small scale/decentralised wastewater treatment (SWTP), low carbon propulsion in ships and energy efficiency in industry. Actor analyses and assessment of the positions of actors as niche or regime and the functions that they undertake have also been performed for low carbon automobiles, the transition from sail to steam power in the 19^{th} Century, as an example of a non-environmental policy driven transition and wind electricity generation.

The main conclusion from this conceptual approach is that the system representation of the TIS functions can be usefully extended to consider niche-regime interactions in an MLP framework. The examples of decentralised water and low carbon ships indicate how such an analysis can be undertaken. The new consideration here is how two or more TIS function systems interact. In the case of decentralised water, how the niche TIS combines with the regime TIS and in the case of low carbon shipping, how several low carbon niche TISs can combine to form a new regime.

A further important conclusion is that the Sectoral System of Innovation actor analysis, in the form developed by Kuhlmann and Arnold (2001) can be extended by showing the TIS functions that the various categories of actors undertake. This has been shown in all the examples, including the efficient electric motors. This is a very useful extension of the actor analysis, as it clarifies for any particular example where the TIS functions in the innovation system are being performed and this makes the assessment of the functions clearer. Also, it provides a basis for determining the interrelationships between the TIS functions and the description of the system of functions for the TIS.

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6 Annex: Actor analyses

Examples: water, energy efficiency, low carbon shipping, sail to steam in shipping, wind, low carbon automobiles

A.1 Small scale Wastewater treatment

Direct Agents	Indirect Agents	Regime	Landscape	Functions
Small scale plant manufacturers (niche) Research Institutes (later, when they get funding from government)	Customers Equipment manufacturers (later/using established technology)	Centralized system/components manufacturers, operators Research institutes (to a lesser extent)	Good research infrastructure prevailing in several parts of Germany	F1 Know GEN
Small scale plant manufacturers (niche) Installation firms Research institutes – with plant manufacturers through joint projects Verbände – sector associations through standardisation, regulations		Centralized system/components manufacturers, operators See direct agents	Sector association (DWA) as powerful knowledge collector and disseminator	F2 Know Diff
Customers Government authorities standards, requirements		Government authorities standards, requirements	Variety of small suppliers	F3 influence DIR SEARCH
Small scale plant manufacturers (niche) Operators – of small scale plant -		Centralized system/components manufacturers, operators	Many small companies: variety of ideas, but limited resources	F4 Entrepreneurial Expt
Customers Installation firms Government Authorities (later, when market is growing)		Market (for centralized system components and their integration) exists already; basically the same as direct agents		F5 Market Formation
User/customer – acceptance Sector associations – advocacy Government authorities: central + municipalities		See direct agents (different proponents/members)	Water Framework Directive + bad condition of WWT infrastructure in some states + bad economic situation in some of these states + favourable settlement structure	F6 Legitimation
Small scale plant manufacturers (niche) Operators (later stages)	User/customer Government Authorities (Funding of research)	Government Authorities (Funding of implementing innovation)		F7 Resource Mobilisation
Sector associations: standards, regulations, permissions to install small scale plants		See direct agents		F8 Network externalities

A.2 Low Carbon Shipping

Direct Agents	Indirect Agents	Regime/Landscape	Functions
Shipyards, engine manufacturers, equipment suppliers Research Institutes (later, when they get funding from government) Classification Societies: also act as consultancies Engineering design consultancies	Cruise lines Shipping companies demanding advanced technologies Military shipbuilders, Navies Offshore charterers: oil, gas, wind Aviation: new aerofoil concepts through intelligent materials	R Established, consolidated shipyards: China, S. Korea, Japan, Cruise ship yards: Meyer Werft, Fincantieri, Wärtsilä, STX (?), Kvaerna, Military shipbuilders	F1 Know GEN
Classification Societies Professional Institutions: RINA Royal Institution of Naval Architects (UK), SNAME Society of Maval Architects and Marine engineers (US), NYK (Japan), DNV/GL (Norway/Germany) etc. IMO	Funding agencies for research and knowledge sharing networks: EU, national		F2 Know Diff
Environmental policy SOx, NOx, climate change IMO: ballast water, SOLAS, climate change measures Demand in the different trades, new trades: energy companies & offshore industry, Logistics companies (ICT in logistics, (sustainable) Supply chain management) Classification societies: design requirements for structural strength, and damaged stability, other safety requirements	Ports, intermodal terminals, Waterway management: operational constraints, automation of cargo handling, container and loading systems with built in weight monitoring, also for ships for loading and ballast safety Energy policy Biofuels policy Trade policy UNFCCC, EU ETS International shipyards: Cost pressure through decreasing subsidies and increased competition from Asia NGOs	R Global production networks L regions of economic growth L automation L pervasive computing and the Internet	F3 influence/ guidance DIR SEARCH
Specialist shipyards Small firms which grew: e.g. SkySail, Ballast water Management Systems			F4 Entrepreneurial Expt

Direct Agents	Indirect Agents	Regime/Landscape	Functions
suppliers, control systems suppliers Established shipping companies e.g. Maersk, BP, Stena New operators Venture capital			
Logistics companies and cruise operators	Global trade and logistics networks Biofuels sector	R Global production networks L regions of economic growth L Fairtrade, biofuels, organic products L mobile office, virtual reality	F5 Market Formation
Classification Societies Professional Institutions: RINA Royal Institution of Naval Architects (UK), SNAME Society of Maval Architects and Marine engineers (US) IMO Lloyd's insurance markets		L perception of climate change L culture of social sustainability	F6 Legitimation
Shipyards, equipment suppliers Research Institutes (later, when they get funding from government) Classification Societies Engineering design consultancies Charterers/Ship operators	Universities, shipping training high schools		F7 Resource Mobilisation
New entrants, equipment suppliers, shipyards.	From the other functions		F8 Network externalities

Regime

Established shipyards, engine and propulsion manufacturers, equipment suppliers

Shipping lines

Charterers

Banks

Lloyd's insurance market

Investment funds: Lloyd's names, German Banks

Classification societies

Professional engineering institutions

International logistics service providers: ICT systems, continuous monitoring

Vertically integrated energy companies

Cruise lines/operators: expanding the range of cruise holiday services – climbing walls, low cost cruises, liner cruises (Cunard), sailing cruises

Yachts

Cruise ferry operators

Holiday companies

Offshore service providers

A.3 Sail to Steam in the C19th

Direct Agents	Indirect Agents	Regime/Landscape	Functions
Shipyards, Steam engine manufacturers, General engineers I K Brunel Boiler development Steam engine development Propellor invention and development Iron hulls Classification Societies: also act as consultancies	Canals Growth of regions in the 2nd Kondratiev Wave: Clyde, North East England, Liverpool and north west England	R Established wooden shipyards 2nd Kondratiev wave in the UK: railways, Iron, steam locomotives	F1 Know GEN
Classification Societies Professional Institutions: Institution of Civil engineers, RINA Royal Institution of Naval Architects (UK), SNAME Society of Maval Architects and Marine engineers (US),	Funding agencies for research and knowledge sharing networks: EU, national		F2 Know Diff
Government subsidies for packet lines Navies Global shipping lines Specialist market intermediaries in the shipping sector Classification societies: design requirements for structural strength, and damaged stability, other safety requirements	Development of Fe materials – steel Development of steam engines for industry and railways	Liner packet services Growth in shipping demand leading to requirements for larger ships – above the maximum practical size of wooden ships	F3 influence/ guidance DIR SEARCH
Iron shipyards Mail steamers Lloyds underwriters Baltic Exchange for shipbroking	Professional ship owners, New shipping line management practices	Lloyds exchanges, Ship brokers Insurance companies	F4 Entrepreneurial Expt

Direct Agents	Indirect Agents	Regime/Landscape	Functions
Ports (tugs, coaling infrastructure) River operations Packet lines Subsidised liner companies (Cunard etc.) Suez canal Panama canal	Canals, inland waterways, Navies New, deeper and longer harbours	LWaves of emigration to the US from Europe L Global industrial trade networks e.g.cotton and trade liberalisation to 1850 L international industrialisation outside the British empire L Development of empire L development of long distance cables for global communication	F5 Market Formation
Classification Societies Professional Institutions: RINA Royal Institution of Naval Architects (UK), SNAME Society of Maval Architects and Marine engineers (US) Shipping lines and intermediaries Lloyd's Register of Shipping			F6 Legitimation
Shipyards Charterers/Shipping lines Engineering companies Research Institutes (later, when they get funding from government) Classification Societies	Universities, shipping training high schools		F7 Resource Mobilisation
New entrants, equipment suppliers, shipyards.	From the other functions		F8 Network externalities

Landscape (selection environment)

Internet

Mobile devices and pervasive computing; e-markets, virtual reality, automation (autopilots, automated systems condition monitoring, and AI, intelligent materials

nanotechnology materials

New perceptions of prosperity and wealth: Climate change, sustainability,

Fair trade, anti-G20

Regions of economic growth: NIS, Arctic, Antarctic,

Aging, wealthy populations

Changing values of the next generation

Migration leading to closer cultural links between the EU and Muslim countries

A.4 Energy efficiency (in industry)

Influences (Landscape)

- Fukushima → change in policy ("institutional change")
- Energy policy targets
- Climate change

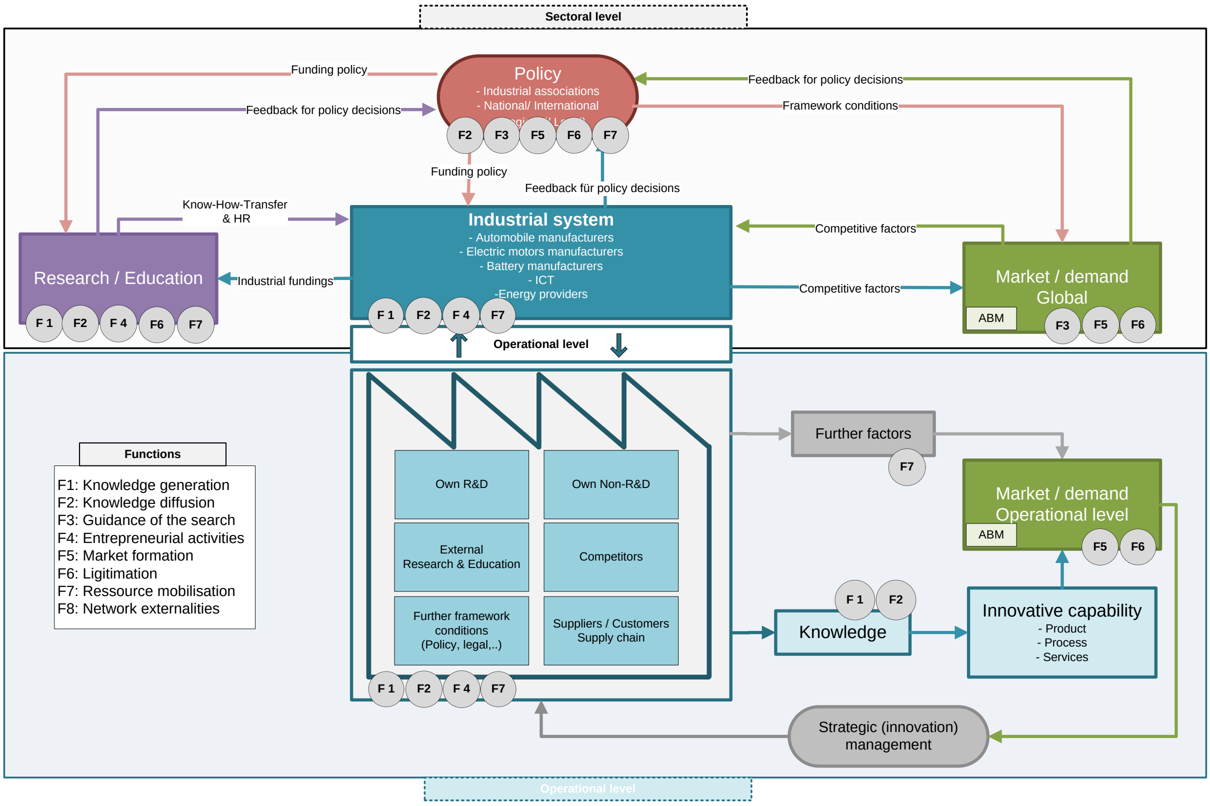
Direct Agents	Indirect Agents	Functions	Blocking mechanisms	Driving forces/ inducement mechanisms
Manufacturers (R&D) Research Institutes (later, when they get funding from government); research networks		F1 Know GEN	Lack of capital, lack of market	Federal funding
Manufacturers Sector associations through standardisation, regulations Energy Service Companies (ESCOs) Crowdfunding platforms (for financing) Consulting engineers	Government (standards)	F2 Know Diff	Split incentives (decoupling of costs and benefits among actors; Original Equipment Manufacturer Dilemma)	Federal funding (e.g. consultancy programs)
Research institutes Government authorities standards, requirements		F3 influence DIR SEARCH	Lack of policy commitment	Federal funding Energy policy targets
Manufacturers Energy Service Companies (ESCOs) Energy supplier		F4 Entrepreneurial Experimentation	Split incentives (decoupling of costs and benefits among actors)	Federal funding (e.g. consultancy programs)
Sector associations through standardisation, regulations Platform energy efficiency Energy Service Companies (ESCOs) Crowdfunding platforms (for financing) Consulting engineers Energy supplier Customers	Stakeholder (e.g. NGOs)	F5 Market Formation	Lack of time and/or information Lack of capital/financing Split incentives, discounting, risk (perception) Original Equipment Manufacturer Dilemma	Energy policy targets Policy support schemes (BesAR, EnergieSt, StromSt, etc.)

Direct Agents	**Indirect Agents**	**Functions**	**Blocking mechanisms**	**Driving forces/ inducement mechanisms**
User/customer – acceptance Sector associations – advocacy Government authorities: central+ municipalities Different platforms ("e.g. Plattform Energieeffizienz"		F6 Legitimacy	Lack of ambitious energy efficiency targets	New policy initiatives (such as energy efficiency platform), stakeholder processes, etc.
Manufacturers Operators/Customers Financial institutions (?), Crowdfunding platforms Sector associations through standardisation, regulations Platform energy efficiency Energy Service Companies (ESCOs) Consulting engineers Energy supplier		F7 Resource Mobilisation	Lack of time, capital and information	Energy cost savings CO2 reduction (→ climate policy) Political debate in parliament and media Lobbying activities
Research networks LEEN networks (?) Operators (industrial networks, e.g. for waste-heat recovery)		F8 Network externalities	Lack of time and/or information	Positive external economies in the form of knowledge gen/diff (F1+2) Less uncertainty

A.5 Wind power

Direct Agents	**Indirect Agents**	**Regime/ Landscape**	**Functions**
Turbine manufacturers Operators Research Institutes (later, when they get funding from government)	R&D policy		F1Know gen
Turbine manufacturers Operators Research Institutes (later, when they get funding from government) All through research projects	Funding agency		F2 Know Diff
Larger turbines – cost and difficulty of siting Cost pressure through decreasing subsidies Government subsidies for wind – or low carbon Energy policy – decreasing subsidies, environmental policy– limited possibilities for siting climate policy	NIMBY .not in my back yard		F3 influence/ guidance DIR SEARCH
Small firms which grew Larger firms coming into the technology New operators (not established power companies) and financiers			F4 Entrepreneurial Expt
Policy – subsidies for energy from renewables, feed-in tariffs/quotas	Negative – limited transmission infrastructure, network development plans Requirements for selling into the centralised power system		F5 Market Formation
Environmental groups (Greenpeace, WWF etc.) Renewables technology associations			F6 Legitimation
Operators turbine manufacturers	User/customer Government policy through Feed-in tariffs for finance		F7 Resource Mobilisation
As part of knowledge diffusion – from individuals to firms			F8 Network externalities

A.6 Low carbon automobiles



Direct Agents	Indirect Agents	Regime/ Landscape	Functions
Spin-Offs (former A123) Former consumer cell manufacturers (e.g. LG Chem) Research Institutes			F1 Know GEN
Spin-Offs Former consumer cell manufacturers Research Institutes Sector associations (later)	Automobile manu-facturers (unique selling point)		F2 Know Diff
Environmental policy (Co2 regimen-tations) Automobile manufacturers Government authorities and Sector associations (maintaining competi-tiveness/reducing the dependence on raw materials)	Final customer (ris-ing fuel costs) Energy companies		F3 influence DIR SEARCH

Direct Agents	**Indirect Agents**	**Regime/ Landscape**	**Functions**
Spin-Offs Big companies coming in Former consumer cell manufacturers			F4 Entrepreneurial Expt
Automobile manufactures (mostly company cars) Government authorities			F5 Market Formation
(Inter)national testing facilities Final customer (by acceptance) Sector associations (by promoting advantages) Government authorities (open commitment)			F6 Legitimation
Automobile manufacturers and suppliers (via Joint Ventures) Regional and local authorities Government authorities via Subsidies and incentives Research facilities			F7 Resource Mobilisation
Spin-Offs Former consumer cell manufacturers Research Institutes Sector associations (later)			F8 Network externalities