

System Innovation in the Transition toward a higher voltage in the overhead wires of the Dutch railway system

An assessment methodology for possible Transitions

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Date: June 22th, 2011

Date:	Version
June 22 th , 2011	Public final report

Title: System Innovation in the Transition toward a higher voltage in the overhead wires of the Dutch railway system
Subtitle: An assessment methodology for possible transitions
Document type: Master thesis
Author: M.W. Bos
Position: Graduate Business Administration:
Innovation & Entrepreneurship
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Date: June 22th, 2011

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Preface

This document concerns a master thesis. This thesis needs to be performed in order to finalize the master Business Administration with master track Innovation and Entrepreneurship of the University of Twente. Thereby, the support from the university was provided by dr. ir. Erwin Hofman (from NIKOS) and prof. dr. Stefan Kuhlmann (from STEPS). While the master thesis on one hand provides the opportunity to show what I have learned till now, on the other hand it provides the opportunity to do research, learn about new theories and get acquainted with new areas of expertise and industries. This opportunity was provided by Lloyd's Register Rail Europe by which I was supported by ir. Richard Koch and many others.

During my stay at Lloyds Register Rail Europe I did not only developed knowledge about the subject of my research (the transition toward an increased voltage in the overhead wires of the Dutch Railway system), but also a about other issues concerned with rail. Thereby I found it very interesting to learn about these issues and the complexity involved. It was a useful experience and a great insight in the railway sector.

At the start of my research I did not know a lot about the railway sector. This knowledge is of course quite important when conducting a research in this area. Therefore I want to thank all the people from Lloyd's Register Rail Europe who put an effort in providing me with the useful required knowledge and insights and/or brought me in contact with their contacts.

The success of this research largely depended on the cooperation of the different respondents. Without their co-operation, researching this possible system innovation would not have been possible, since systems largely depend on the actors within them. The support, time and effort invested by these respondents is therefore highly appreciated. Hopefully I provide you with this research with useful information in return.

Utrecht, 2011

Marc Bos

Management summary

This research involves the system innovation involved in the transition toward a higher voltage in the overhead wires of the Dutch railway system. The involved considered voltage is 3kV DC. A migration to this voltage would provide an increased capacity, less loss of energy and more possibilities for the recuperation of the energy involved with braking. The reason why a migration to 3kV DC is considered is that a system operating under 3kV DC could make use of most of the core concepts and linkages as exist in the current system which is operating under 1,5kV DC. This system has indirect as well as directly involved stakeholders. However, most important seem the directly relevant stakeholders. The focus is therefore on the Ministry of Infrastructure and Environment, ProRail and the NS (which are identified as the directly relevant stakeholders).

In order to research this possible transition and involved system innovation a framework is constructed. This framework is mainly based on the Multi-Level framework, Technological Innovation System and the Hypercube of Innovation. The actors, which are involved in this framework, have a certain role by which they define one or more dimensions. Based on that role they might have the possibility to fulfil functions as described by the Technological Innovation System and thereby contribute to the generation, diffusion and utilization of an innovation. The likeliness of an actor to fulfil such functions depends on how radical the actor perceives the innovation and the value-proposition. The system where these actors are part of is under pressure or supported by factors these actors cannot, or at most in the long term, influence. These factors can affect the likeliness of an actor supporting a possible innovation. Furthermore, the (desired) future developments involving these actors might affect the actors perception, since these developments might hold a (high) future value. The constructed framework therefore holds an assessment methodology for possible transitions and involved system innovations.

Within the current established system the most likely trajectory, in the transition involving the migration to 3kV DC, is the trajectory involved with no transition at all. This since the current (macro)economics put high restrictive pressure on the system and thereby prevent a breakthrough of 3kV DC from occurring. Furthermore, the knowledge development and diffusion seem not to have occurred very well. The developed knowledge is not unanimously accepted by all the actors. This is partly due to lack of knowledge diffusion, but also differs the content of the developed knowledge (this involves financial, technological, exploitation and organizational issues). Therefore it seems

appropriate, in case there is a willingness to reconsider the traction-power supply, to develop uniform, general knowledge.

However, the lack of a long-term strategy prevents a transition from occurring as well since the involved migration holds very large investments which are not supported by the current strategy. Factors to be addressed in such a long term strategy include demography, society, economy and the environment. These factors can at most only be influenced in the long term and largely influence important indicators as for example traffic volumes, sustainability and energy-efficiency. In case a strategy is generated which addresses the mentioned factors, a migration might be possible. The most likely trajectory in that case is unknown, since both involve advantages and disadvantages which are not quantitatively measurable at this moment in time.

Table of content

1. Introduction.....	1
1.1 About Lloyd’s Register Rail Europe B.V.....	1
1.2 Problem definition	1
1.3 Research goal.....	3
1.4 Research question.....	5
1.5 Subquestions.....	6
1.6 Summary of introduction	7
2. Theory.....	8
2.1 System innovation and transition theory	8
2.2 Multi-Level framework.....	9
2.3 Technological Innovation System	14
2.4 The hypercube of innovation	17
2.5 The theoretical framework	19
2.6 Summary of the framework.....	33
3. Methodology	34
3.1 Research design	34
3.2 Research method	34
3.3 Population and sampling	39
3.4 Summarized method.....	40
4. The case.....	42
5. Analysis.....	80
6. Results	95
6.1 Conclusion.....	95
6.2 Recommendations	97
6.4 Managerial Implications.....	100
6.5 Practical limitations.....	101
6.6 Suggestions for further research	102
6.7 Chapter summary.....	103
List of abbreviations	104
References.....	105
Appendix A: Interview protocol for semi-structured interviews	118
Appendix B: Respondents	121
Appendix C: Map of actors.....	122

Appendix D: The researched system 123
Appendix E: [Not mentioned in the public version] 124

1. Introduction

When considering innovations there is a wide variety of different types of innovations. Innovations might for example concern products or processes, but even can involve whole systems. A system innovation is part of a transition toward another, innovated system. Within this research the possible system innovation in the transition toward a higher voltage in the overhead wires of the Dutch railway system is researched. The research is supported by the University of Twente and Lloyd's Register Rail Europe B.V.

1.1 About Lloyd's Register Rail Europe B.V.

Lloyd's Register Rail Europe is part of the Lloyd's Register Group which aim is to provide independent assurance to companies which operate with high-risk and capital-intensive assets in sectors as energy and transportation. Thereby it aims to enhance as well the safety of life, as the safety of property and the environment. The group is one of the world leaders in assessing business processes and products to internationally developed standards, which are set externally or developed by themselves. This makes them typically suitable for clients which are operating with large-scale, high-value assets for whom the cost of mistakes can be very high, financially as well as in terms of impact on the environment or on local communities (Lloyd's Register Group, 2010).

The Lloyd's Register Group's transportation business, which holds Lloyd's Register Rail Europe B.V., provides, next to technical consultancy and assurance services, also strategic and economic consulting. The technical consultancy holds consultancy for engineering, safety and risk management of infrastructure, vehicle fleets and the interaction between them. The assurance services provide the assurance that transport systems are designed, built, operated and decommissioned in safe, efficient and sustainable ways. The mentioned strategic and economic management consulting which is provided to the transport sector involves a broad range of clients. It provides economic and strategic advice on business management, corporate structures and governance. While covering all modes of transport the overall purpose is to optimize the clients transportation system's efficiency, performance and safety (Lloyd's Register Rail Europe B.V., 2010).

1.2 Problem definition

Sustainable transportation became an important issue since the effects of CO₂-emission on climate change became obvious. This involves a quest for sustainable ways of transportation which reduce

pollution or even produce zero-emission. One of the most sustainable ways of transportation these days is transportation by rail. While the automotive sector and the aviation sector have to make huge efforts to meet the agreements concerning CO₂-reduction, the rail sector has to make minor changes or can even continue its current strategy while still easily meeting the demands as set in the agreements. Major advantage in this case is that a large part of trains is powered by electricity, which is a clean power source especially when it considers green energy. Nevertheless the rail sector makes an effort to become more sustainable. Using less energy does not only provide a reduction in CO₂-emissions, but also has financial advantages since it provides lower cost in the long term. Several efforts to make transportation by rail more sustainable include eco-driving, regenerative braking, aerodynamics (fairings) and lightweight train cars.

Another way to reduce the use of energy is by reducing the loss of electricity in the infrastructure. This can be done, for example, by increasing the voltage in the overhead wires. Using a higher voltage implies less loss of energy. Furthermore, with an increased voltage more energy can be recuperated (e.g. Movares, 2010), which implies that less supply of traction-energy is needed. Next to reducing the loss of energy, increasing the voltage in the overhead wires has another advantage; it increases the capacity of the infrastructure (e.g. Movares, 2010). This means that it reduces the need for building additional capacity, which of course causes pollution as well. Transport by rail is, and will be in the near future, the most sustainable way of transportation (e.g. Union Internationale des Chemins de fer, 2011a, 2011b; Railway Mobility, 2011). Therefore, increasing transportation by rail is a sustainable and realistic way to make transport as a whole, more sustainable. The increase of transportation by rail can cause capacity problems which affect the mobility. This mobility is important to economical and societal development (Ministerie van Verkeer en Waterstaat & VROM, 2006). These issues considering capacity problems are already very realistic for example with the “Programma Hoogfrequent Spoorvervoer” (free translation: Programme High-Frequency Rail Transport) in mind, which implies a more intensified use of the railway system in 2020 (e.g. Ministerie van Verkeer en Waterstaat, 2009; ProRail, Nederlandse Spoorwegen & Belangenvereniging rail goederenvervoerders, 2008; Wesdorp, 2010). An increased voltage in the overhead wires can help to solve such capacity problems, because it allows and facilitates a higher capacity of the railway infrastructure.

As mentioned, a higher voltage in the overhead wires clearly provides advantages. Nevertheless, a migration to an increased voltage (25kV DC) has been discussed by several actors, but a decision was postponed since the adaption of a new system was considered very problematic as it comes to

financial, technical, exploitation and organizational issues (e.g. Peijs, 2005; Eurlings, 2007). The current hardware of, for example, substations and trains, does not support an increased voltage. This means that the transition from 1,5kV DC to for example 3,0 kV DC (the increased voltage) holds a large, nationwide innovation of the current system. The innovation of the current system holds a transition. When stimulating a transition toward another system it is imperative to know what the possible system innovations are. The content of such system innovations define the direction of the transition (if, how and where to the system shifts) and if the transition eventually leads to the predetermined innovated system. What the trajectory of the transition should look like and what system innovations should be or will be involved is unknown. The problem can therefore be defined as the lack of knowledge about the trajectory of the proposed transition and the involved system innovations (as shown by Figure 1).

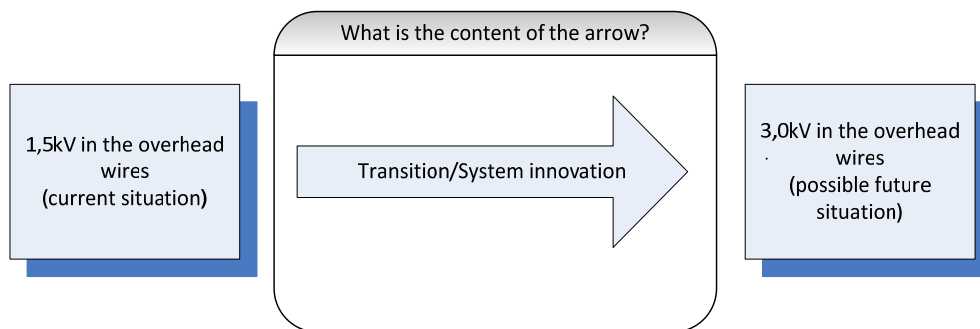


Figure 1: Problem definition

In other words: known is that a higher voltage in the overhead wires provides significant advantages, unknown is the most likely trajectory concerning transition toward this higher voltage. The lack of knowledge of this trajectory can be defined as the problem which is researched in this thesis. This trajectory can be defined as the transition pathway as described by Geels and Schot (2007).

1.3 Research goal

The problem in this research is defined as the lack of knowledge about the possible trajectories of the transition and involved system innovation(s) toward a higher voltage in the overhead wires of the Dutch railway system. In order to be able to stimulate such a transition in a successful matter, it is imperative to pre-establish what the trajectory of the transition might look like and what elements are critical in the trajectory of this transition and involved system innovation(s). As mentioned in Figure 1, the system innovation and thereby the possible trajectories of the transition are unknown. The research goal is to get to know the most likely trajectory (which might include a system

innovation) in the possible transition toward a system which supports a higher voltage in the overhead wires (as shown in Figure 2). The critical elements in such a transition and system innovations (e.g. involved technical changes, actors and institutions) play an important role. These elements might support a transition and system innovations by stimulating them, but these elements could also offer resistance toward the transition and the involved system innovations. Together with the knowledge of possible trajectories and system innovations, the knowledge about the critical elements might provide critical paths within the trajectories. This possibly could eventually provide a trajectory which seems most likely in the transition toward a regime in which there is a higher voltage in the overhead wires.

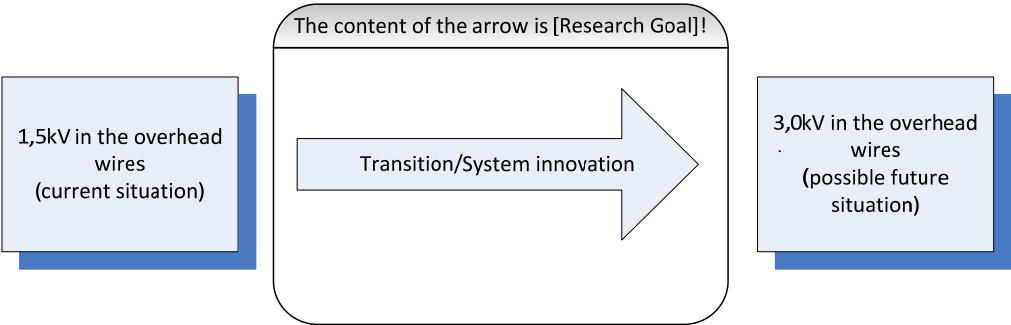


Figure 2: The research goal

In order to reach the established research goal, a research model is constructed (Verschuren & Doorewaard, 2007). This research model is shown in Figure 3 (page 5) and thereby integrated in the different phases of the research.

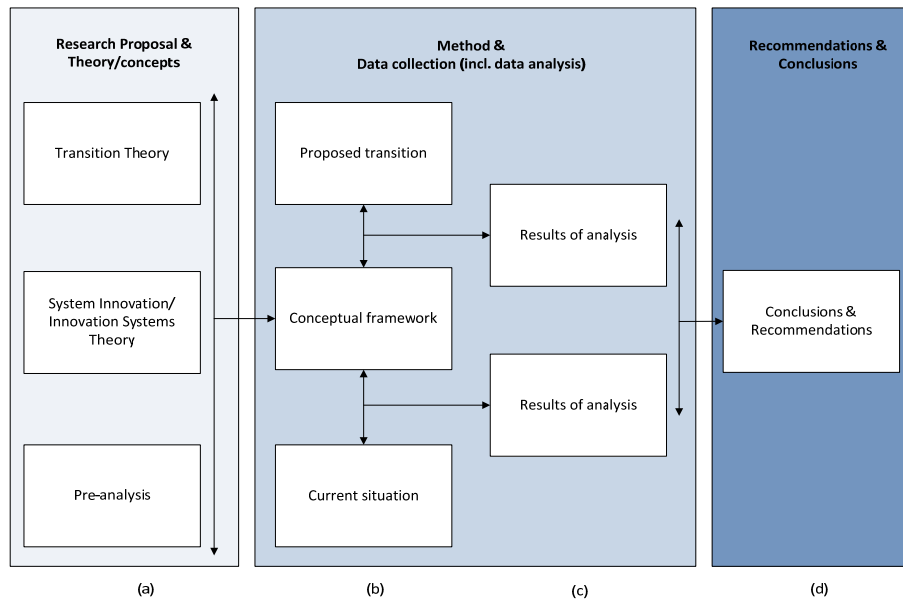


Figure 3: Research model

- (a) A study of the specifics of the innovation, which will be done by a pre-analysis and a study of the theory concerning transitions and system innovations/Innovation Systems.
- (b) Based on the study of the theory and pre-analysis, there will be developed a conceptual framework. This conceptual framework will be used to analyze the current situation and the proposed transition.
- (c) The analysis, of the current situation and the proposed transition, with the use of the conceptual framework, will provide results concerning the possible trajectories of the transition and involved system innovations.
- (d) The results of analysis can be used to draw conclusions and to provide recommendations concerning the trajectories and system innovations within the transition.

1.4 Research question

In order to clarify the research objective, a research question needs to be formulated. The subject of research in this case is the transition toward an increased voltage in the overhead wires. The involved innovation concerns a lot more than just increasing the voltage; a whole system is involved. This system includes elements (e.g. the later on mentioned factors and/or actors) of which some might be critical and others less critical. These critical elements are an important part of the

recommendations which are provided later on in this thesis, since these are probably the reason that the transition has not occurred yet. It is therefore imperative to establish the possible trajectories in which the critical elements are carefully considered. Thereby it is also useful to establish the likelihood of the transition occurring through a certain trajectory, since it has no use to focus on a trajectory which is not likely to occur anyway. Therefore the following research question is phrased:

“What is the most likely trajectory in the transition toward a higher voltage in the overhead wires of the Dutch railway system?”

1.5 Subquestions

Since the research question includes a lot of elements, there are phrased several subquestions:

1. “What could be used for the systemic evaluation and assessment of transitions?”
In order to be able to describe, evaluate and assess transitions in a structured way, a framework is needed. The ability to systemic evaluate and assess transitions provides the opportunity to purposely steer a transition through an Innovation System.
2. “What is the innovation involved in the transition?”
The transition is caused by an innovation. The characteristics of the innovation define the trajectory and the involvement of actors and factors which influence and determine the possible system innovation.
3. “What defines the current system concerning the overhead wires of the Dutch railway system?”
The system (defined as the socio-technical regime by the Multi-Level framework¹) exists of dimensions which are, for example, established products and technologies, stocks of knowledge, user practices, expectations, norms, regulations.
4. “What are the restrictions on this system?”
Several factors put pressure on the system. These factors are not able to influence themselves, but define the dimensions of the system with the pressure they exert. These factors can be changed by the actors from the system. Examples of such factors include landscape² characteristics like available and/or current hardware.

¹ The Multi-Level framework is explained in Chapter 2.

² An explanation of these terms and different levels can be found in Chapter 2.2.

5. “What changes need to be made to the current system and current restrictions in order to make the innovation evolve in a transition?”

The innovation demands possibly for a system innovation and a change of the restrictions in order to facilitate the proposed transition. A map of the needed changes provides one or more trajectories for a transition.

Together the outcomes of the subquestions provide the answer on the overall research question as mentioned in Paragraph 1.4, which addresses the problem definition as stated in Paragraph 1.2.

1.6 Summary of introduction

In this chapter there is established that a proposed transition, to a system which operates under an increased voltage, could possibly address issues considering loss of energy and capacity. However, it is unknown what the trajectories within such a transition might look like. Thereby, there is assumed that multiple trajectories are possible. However, there is looked into the most likely trajectory, since that is the most likely one to occur. In order to establish that knowledge in a proper way, a research question and several subquestions are phrased. These provide direction and clarify the purpose of this research. Thereby there is looked into a method for the systemic evaluation of the considered possible transition; the innovation, the system, restrictions and the possible demanded changes considering a system innovation which is part of a possible transition.

2. Theory

The purpose of this chapter is to provide a theoretical framework which could be used to map and assess the different trajectories in a transition toward another system. Since this involves transitions and system shifts, appropriate theories for this framework concern system innovation (e.g. de Bruin, van der Voort, Dicke, de Jong & Veeneman, 2004), Innovation Systems, innovations and transitions. Since these theories play an important role in the constructed framework, these are explained in Paragraph 2.1 until 2.3. After the explanation of the relevant theory, a theoretical framework is constructed with the use of this theory.

Within Innovation Systems there are several types of specific systems, among which the Technological Innovation Systems, Sectoral Innovation Systems, National Systems of Innovation, Technology Specific Innovation Systems (Hekkert, Suurs, Negro, Kuhlmann & Smits, 2007; Markard & Truffer, 2008a). The Innovation Systems in general concern a composed set of networks of actors and institutions that develop, diffuse and use innovations (e.g. Carlsson & Stankiewicz, 1991; Edquist, 2005; Malerba, 2002). The different Innovation Systems, like the Technological Innovation System and the Sectoral Innovation System, have a focus on a specific issue. A Technological Innovation System focuses on technology, while a Sectoral Innovation System focuses on a specific sector (Hekkert et al., 2007). System innovations are always part of a transition. Useful theory concerning transitions involves the Multi-Level framework. This framework defines multiple levels by which a transition could be explained. Since the mentioned theories do not perfectly fit the scope of the research and initially might be too abstract, there is a need for a to be constructed framework. The main contributors to this framework are the theories concerning the Multi-Level framework (e.g. Ros, Farla, Montfoort, Nagelhout, Reudink, Rood & Zeijts, 2006; Geels, 2002) and the Technological Innovation System (e.g. Carlsson & Stankiewicz, 1991; Markard & Truffer, 2008a, 2008b). Additional theory concerning innovation (e.g. Afuah & Bahram, 1995) is used to clarify or to elaborate on these theories.

2.1 System innovation and transition theory

The mentioned combination of the Technological Innovation System and the Multi-Level framework is extracted from literature (e.g. Hekkert et al., 2007; Markard & Truffer, 2008a). Hekkert et al. (2007) provide a very clear explanation of the combined use of transition theory and Innovation Systems. They claim that in order to make a sustainable change, just the change itself is not sufficient since it is part of a social dimension (e.g. industrial networks, regulation user practices). In other words: an

innovation occurs in a certain system. This should be considered in order to make a sustainable innovation. The acknowledgement of this system level has led to a rapid diffusion of concepts concerning transitions. Hekkert et al. (2007) state that technological change and the resulting innovation are the outcome of Innovation Systems. The knowledge of how these systems function, provides the ability to intentionally shape innovation processes or to initiate and stimulate a system innovation and thereby a transition (Geels, 2002; Hekkert et al., 2007; Tidd, Bessant & Pavitt, 2005). System innovation can occur in a great variety of different ways at different aggregation levels. Nevertheless, de Bruin et al. (2004) state that system innovations always are comprehensive innovations with a long time horizon, which require many stakeholders' efforts and a change of their perspective and a cultural shift (Carlsson & Stankiewicz, 1991). Such changes and shifts are part of transitions toward another system. This shows that system innovations and transitions are very closely related. Hence the combination of those theories is used in this thesis and in many articles considering this subject (e.g. Hekkert et al., 2007; Markard & Truffer, 2008a).

2.2 Multi-Level framework

Transitions can very well be described and understood with the application of the Multi-Level framework (Geels, 2002, 2005). Therefore, the theoretical framework as constructed in this chapter is partly based on the Multi-Level framework. Since it thereby is an important part within this research the Multi-Level framework is explained in this, and the following subparagraphs. While it is normally used for describing transitions it can help to define the trajectories and system innovations as well (de Bruin et al., 2004; Geels, 2002, 2005). The Multi-Level framework is used in this research in order to structure and map the trajectories concerning the proposed transition. A system innovation is always part of such a transition. The Multi-Level framework explains transitions by the interplay of three different levels; a micro-level (the niches), a meso-level (the socio-technical regimes) and a macro-level (the landscape). Thereby, the meso-level (the socio-technical regime) is the key in this framework. It is within this level where the system innovations or regime shifts (as they are called by the Multi-Level framework) occur.

2.2.1 The niches (micro-level)

As mentioned, the Multi-Level framework consists of three levels. The first level (the micro-level) is defined in the Multi-Level framework by the niches. These niches act as 'incubation rooms' for radical innovations, thereby they shield the radical innovations from the mainstream market. This is necessary because the radical innovations have a hard time competing with the established

technologies and thereby would not survive without being in a niche. Niches can occur as market niches or technological niches. In a market niche the selection criteria differ from the criteria of the established market, which provides room for existence of the radical innovation. Technological niches are those niches where the resources are provided by private strategic investments or public subsidiaries. These types of niches have most of the time the function of prototype-markets. In these markets there is not a demand present yet. Thereby technological niches form the basis for experimental, pilot and demonstration projects. These projects make use of real-world users. In the strategic niche management literature there are distinguished three important processes: the first is learning, second is building supportive and social networks and third, the articulation of visions and expectations (Hoogma, Kemp & Schot, 2002; Kemp, Rip & Schot, 2001; Kemp, Schot & Hoogma, 1998; Schot, Hoogma & Elzen, 1994). The learning is necessary to create a working configuration. The building of supportive, social networks is necessary to get more investments and be able to further develop the concerning innovation. Third, was mentioned the process of articulation of visions and expectations. This process provides a future orientation and direction of learning processes (Geels, 2005; Kemp et al., 1998; Schot, 1998; Schot et al., 1994). While these issues are important in successfully managing niches, they already have a focus on the second level; the socio-technical regime. Nevertheless, a break-through of such a radical innovation highly depends on the state of being of the meso-level, which is called the socio-technical regime (as explained in Chapter 2.2.2).

2.2.2 The regimes (meso-level)

The socio-technical regime is the meso-level in the framework (Geels, 2002), which is based on the notion of Nelson and Winter (1982). This regime can also be defined as the system. This system contains among others, several dimensions and actors, and is characterized by for example stocks of knowledge, engineers' practices, user practices, expectations, norms, established products. An example of a socio-technical regime is provided by Geels (2002) in the case study of the transition from sailing ships to steam ships. In this case, the regime initially was based on the wooden sailing ships. This meant that for example the harbours had the depth and sizes suitable for the wooden sailing ships and the job of shipbuilding contained the skills of building these specific ships. In the transition towards the iron steam ships, a swift toward other knowledge, skills, practices, expectations and norms occurred.

As mentioned, the socio-technical regimes are defined by certain characteristics. These result in a somehow predefined trajectory, otherwise referred to as a transition pathway (Geels & Schot, 2007), at sectoral level; the actors behave and act in a certain predefined way as is established in the

regime. This behaviour and these activities are reproduced within these social groups by which they maintain the elements within the regime. These can be defined as stocks of knowledge, engineers' practices, user practices, expectations, norms, established products. The mentioned social groups are interdependent and interacting. This leads to alignment and coordination between and within the social groups. The socio-technical regimes cause a dynamic stability of the socio-technical systems (Geels, 2005). Since this means that a regime is a system which depends on path dependencies and pre-defined trajectories, most innovations are incremental and can only occur on an evolutionary basis. These evolutionary changes (e.g. incremental innovations) will occur without lots of trouble, since this level provides a selection environment for such evolutionary changes. On the other hand, such an environment exerts a significant barrier toward radical innovations. This explains why radical innovations would not be able to survive outside a niche, by which the radical innovation is protected. In case there is a strong socio-technical regime, a radical innovation (inside a niche) might have a hard time to diffuse. A radical innovation might therefore have the opportunity to break through in case the regime is weak and thereby it could change the regime. An example of such a radical innovation which breaks through in the socio-technical regime because of a weakness in the regime, can be found in the transition from wooden sailing ships toward the steam ships (Geels, 2002). In this case the innovation was the technology of the steam engine. This engine was the radical innovation which could break through, since it addressed the weaknesses of the established regime (e.g. the dependence of winds and currents).

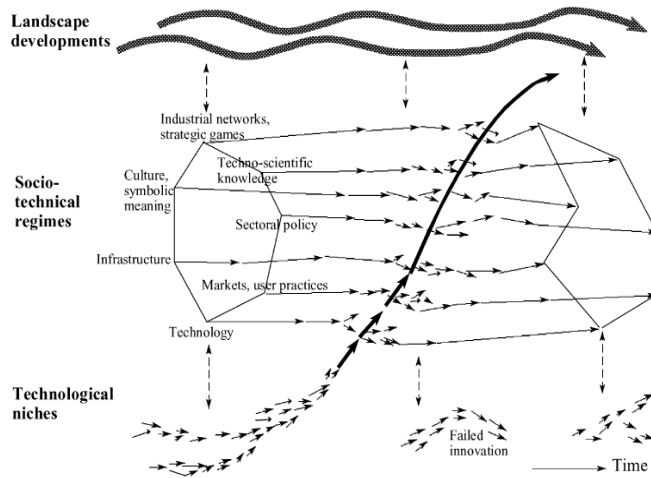


Figure 4: The Multi-Level framework (Geels, 2002)

A break-through of an innovation can occur and can cause a regime shift/system innovation. The factors and dimensions involved with a system innovation/regime shift are explained by Figure 4. Geels (2002) defines seven dimensions within the socio-technical regimes:

1. Technology
2. User practices and application domains (markets)
3. Symbolic meaning of technology
4. Infrastructure (e.g. physical, knowledge)
5. Industry structure
6. Policy
7. Techno-scientific knowledge

As shown by Figure 4, system innovations/regime shifts occur in the socio-technical regime which is at the same level where the mentioned dimensions are part of. These dimensions define the characteristics of the system innovation involved in the transition. Thereby these dimensions can differ per system (Geels, 2002, 2005; Geels & Schot, 2007). This means that not every mentioned dimension is necessarily part of every system, that there could be other dimensions as well and that the content of a dimension can differ. While the theory concerning transitions mainly describes single trajectories (e.g. Geels, 2002, 2005), a transition could occur through different trajectories. Especially since it is possible to steer innovations with the use of innovations systems (Geels, 2002,

Landscape developments (macro-level):

Factors that influence innovation or transitions processes, but are hardly affected by themselves.

Socio-technical regime (meso-level):

A regime which is characterized by e.g. stocks of knowledge, user practices, expectations, norms, established products.

Technological niches (micro-level):

Niches contain radical innovations which would not survive outside a niche.

2005; Hekkert et al., 2007; Kemp & Zundel, 2007). This means that the ability to steer or influence these dimensions provides the power to direct and influence a system innovation.

As mentioned before, the socio-technical regime might resist to radical innovations. Especially in case the regime is very strong, a radical innovation might have a hard time to diffuse. While an obvious conclusion could be that established regimes should be open to new technologies and products in order to provide radical innovations with an opportunity to diffuse, it does not seem likely to occur. Another option is to stimulate the developments in the niches in which the radical innovations occur (Bergek, Jacobsson, Carlsson, Lindmark & Rickne, 2008). This can for example be done by using a Technological Innovation System. On the use of a Technological Innovation System in combination with a Multi-Level framework is elaborated in Chapter 2.5.

2.2.3 The Landscape

The coherence of the regime is supported by the landscape, which represents the macro-level of the Multi-Level framework and refers to aspects of the exogenous environment. The landscape includes a set of factors that can influence innovation or transition processes, but on the other hand hardly or at most in the long, are affected by themselves (Geels, 2002, 2005; Rip & Kemp, 1998; Markard & Truffer, 2008a). Since this might be experienced as an abstract description, it is appropriate to clarify it with the describing the landscape as passive restrictions implied by the exogenous environment of the system (socio-technical regime) which are therefore beyond the direct influence of niche and regime actors (Geels & Schot, 2007). A passive restriction limits/supports by which defines the regime, but it cannot actively change itself or interact with its environment. Examples of such landscape-factors include energy prices and fuel stations. Both of them influence the socio-technical regime, but are not influenced by themselves. Another example might be found in the case study concerning the transition from the wooden sailing ships to the steam ships (Geels, 2002). Thereby, the regime change occurred due to landscape processes of the political and the economical liberalisation in Britain. In this process, Britain became the “world its workshop”, in which it sold coals, manufactured goods, ships, textiles, financial services and imported metallic ores and raw cotton. This landscape processes have influenced the regime, but were or could be hardly affected by themselves.

Through influence of both niches and the landscape, the socio-technical regime can change. While a radical innovation in a niche can break through in a weak regime, landscape-factors can exert a pressure on the regime which makes the regime change. Eventually, a changed socio-technical

regime could also make changes to the landscape (Geels, 2002, 2005; Rip & Kemp, 1998; Markard & Truffer, 2008a). For example, the energy prices and characteristics of fuel stations can be affected by the actors out of the socio-technical regime while those prices and fuel stations are part of the landscape.

2.2.4 Remarks to the Multi-Level framework

Smith, Voß & Grin (2010) consider innovation studies and sustainable transitions in the context of the Multi-Level framework. They remark some useful and important challenges concerning the relations between the levels of niche, regime and landscape which are also of relevance to this thesis. While in the theory is always referred to the regime and niches, they show that there can be interactions between more regimes and niches. Furthermore transitions can depend on the geographic area; while in one area a transition could work, it can fail in other areas. Another issue is the operationalisation of the concepts. The Multi-Level framework is quite abstract. Smith et al. (2010) do not claim that a less abstract framework would be better, because the content of such a framework is very specific. Therefore it is close to impossible to construct a less abstract framework that would perfectly fit all transitions. Nevertheless, this chapter (Paragraph 2.5) contains a framework which is based on the Multi-Level framework and provides a clear and concrete structure for at least this research. Thereby, the challenge is the governing and assessing of the regime shifts (which can also be referred to as system innovations). Innovation systems could be used to influence the regimes. While some regimes might resist to innovations, it is thereby possible to govern and steer a system innovation (and thereby the transition) through for example Innovation Systems (Smith et al., 2010; Kemp & Zundel, 2007).

2.3 Technological Innovation System

As mentioned before in the paragraph concerning niches, strategic niche management distinguishes three important internal processes; learning, building supportive and social networks and third, the articulation of visions and expectations (Schot et al., 1994; Kemp et al., 1998; Kemp et al., 2001; Hoogma et al., 2002). The purpose of these processes is to make the radical innovation in the niche successful. This could also be done with the use of a Technological Innovation System. A Technological Innovation System can be defined as a set of networks which consists of actors and institutions which jointly interact in a specific technological field (Hekkert et al., 2007) and contribute to the generation, diffusion and utilization of variants of a new technology, which might even evolve in a new product (Carlsson & Stankiewicz, 1991; Markard & Truffer, 2008a, 2008b).

The actors and institutions involved in a Technological Innovation System might also be involved in the regimes (as mentioned in the Multi-Level framework) as such. Since they are involved they define the regime with regulatory, normative and cognitive rules. In contrary to what Hekkert et al. (2007) define as the actors within a system, they do not always have to be supportive toward innovations (Bergek et al., 2008). These actors and institutions jointly interact in a specific technological field. Thereby they contribute to the generation, diffusion and utilization of variants of a new technology, which might even evolve in a new product (Carlsson & Stankiewicz, 1991; Markard & Truffer, 2008a, 2008b). A technology and the embodied knowledge is hardly just embedded in a specific region in the world. On the contrary, the relevant knowledge for technologies originates most of the time from various geographical areas from all over the world (Hekkert et al., 2007). An approach which takes technology systems as starting point, cuts through the boundaries of both sectoral and geographical dimensions. A Sectoral Innovation System approach cuts through the boundaries of a National Innovation System as well, but in this type of Innovation System the system is delineated by a specific sector. Hekkert et al. (2007) propose the following set of functions which should be applied in order to map the key activities in Innovation Systems and which can be used to explain the shifts which can occur through Technology Specific Innovation Systems:

- Function 1: Entrepreneurial activities

Entrepreneurs turn the potential for new knowledge networks and markets.

Typical indicators in this function are: Number of new entrants, the number of diversification activities of incumbent actors, and the amount of experiments with a new technology.

- Function 2: Knowledge development

Knowledge is developed by learning and R&D.

Typical indicators to map this function are: R&D projects, Patents and investments in R&D

- Function 3: Knowledge diffusion through networks

It is essential to exchange information by networks. Not only within the R&D setting, but also between R&D, government, competitors and market. Policies can be adjusted to the latest technology and R&D agendas can be adjusted.

Typical indicator is the number of workshops and conferences devoted to the specific topic. Furthermore is the network size and intensity in the network an indicator.

- Function 4: Guidance of the search

Guidance is needed because the resources are almost always limited. Guidance is also needed from a social perspective. The society has to adjust itself, or needs to be adjusted to the new technology/innovation.

Typical indicators are the targets set by governments or industries regarding a specific technology and mapping the number of articles about the technology (this shows the professional interest in the technology).

- Function 5: Market formation

A new technology often has difficulties with competing with established technologies. This issue can be addressed by the formation of temporary niches or create competitive advantage.

Typical indicators are the number of niche markets and specific regulation which purpose is to improve the chances of the new technology

- Function 6: Resources mobilization

Both financial and human capital are needed as an input to activities within the Innovation System.

Typical direct indicators are very hard to establish and therefore are not really there.

- Function 7: Creation of legitimacy/counteract resistance to change

The technology has to become part of the incumbent regime or even overthrow it.

Typical indicator for this function is the growth and rise of interest groups and their lobby actions.

As mentioned, these functions can be used to map and analyse the process concerning the innovation of the system (Hekkert et al., 2007). Thereby an insight is created which can be used to understand the process of system innovation.

2.3.1 Remarks to the Technological Innovation System

The Technological Innovation System focuses on the interplay between the exogenous factors and the internal dynamics within the system (e.g. Bergek et al., 2008; Carlsson & Jacobsson, 1997; Rotmans, Kemp, van Asselt, 2001; Unruh, 2000). Hekkert et al. (2007) define the actors involved in a Technological Innovation System as the actors inside a system and thereby exclude the exogenous actors. Thereby Hekkert et al. (2007) restricts the involved actors to only those whom are supportive toward the innovation. Since there is no general agreement between the different authors about this issue, there is a need for augmented choice. Since the external factors are very important in the

Multi-Level framework, the use of exogenous factors is supported. When only using the internal factors, there would not be any use for the Multi-Level framework.

2.4 The hypercube of innovation

One of the concepts used in the framework is the hypercube of innovation (Afuah & Bahram, 1995). It seems appropriate to explain this theory, since it is used in the constructed framework. Innovation frequently is categorized as either radical, architectural, modular, incremental or niche (Afuah & Bahram, 1995; Tidd et al., 2005), based on effects it has on, for example, products and processes. As shown by Figure 5, the type of innovation depends on the linkages between the core concepts and components versus the degree of change of the core concepts itself. The different actors which come in contact with an innovation might experience one and the same innovation in a different way (Afuah & Bahram, 1995). While, for example, for the manufacturer an innovation is incremental, it can turn out to be radical for a customer. In the hypercube of innovation, the different stages of the value-added chain represent the dimensions. These dimensions exist out of the supplier, innovator, customer and complementary innovator. For each of these dimensions an innovation could be reinforcing or overturning the core concepts and at the same time the linkages between these core concepts could be changed or remain the way they are.

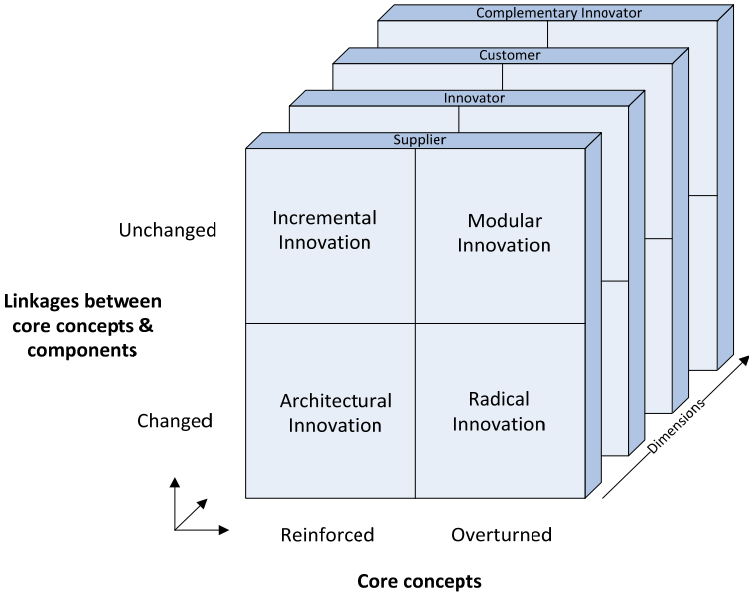


Figure 5: The hypercube of innovation (Afuah & Bahram, 1995)

According to Figure 5 (page 17) the different types of innovation can be defined as:

1. Incremental: The existing core concepts are reinforced while linkages between them are unchanged.
2. Modular: The existing core concepts are overturned while linkages between them are not changed.
3. Architectural: The existing core concepts are reinforced while the linkages between them are changed.
4. Radical: Both the existing core concepts as well as the linkages between them are overturned.

Thereby Afuah and Bahram (1995) measure the intensity of the different types of innovation on an ordinal scale (1 = incremental, 2 = modular, 3 = architectural and 4 = radical). The degree of change is established based on this intensity.

2.4.1 Remarks to the hypercube of innovation

While the model of Afuah and Bahram (1995) is focused on product innovation, it is applicable to system innovation as well. A system innovation, as occurs in a transition, holds the involvement of multi-actor networks (Geels, 2002). These actors are involved in the different dimensions of the system, which means that they might perceive an innovation in a different way. This means that while one actor might perceive an innovation as radical, another might experience it as incremental. This similar issue is discussed by the hypercube of innovation (Afuah & Bahram, 1995). While Afuah and Bahram (1995) consider a value-added chain, it is applicable to a network as well. Nevertheless, the hypercube of innovation considers only the cost and benefits at introduction of the innovation (for example the established skills, which are not useful anymore due to the innovation, are mentioned as cost). The long-term cost or benefits are not taken into account, while these might be the reason to adapt or refuse an innovation. The different cost, as mentioned by Afuah and Bahram (1995), seem more like a barrier for adaption of a new innovation, while the long term cost-benefit ratio provides the value of the innovation. Considering the total value could make the radical change worthwhile, while only considering the type of innovation (the barrier) could show that it is not. Therefore, both should be taken into account and are for that reason integrated in the framework as constructed in this chapter.

2.5 The theoretical framework

The previous paragraphs contain a description of the Multi-Level framework (which could be used to describe transitions), the Technological Innovation System (which is a system that could contribute to the generation, diffusion and utilization of variants of a new technology) and the hypercube of innovation (by which the different ways of perceiving an innovation can be explained). A combination of these theories could address each others' shortcomings (Markard & Truffer, 2008a). This means that it could make the Multi-Level framework less abstract and place the Technological Innovation System in the appropriate context. Together, these theories can provide a clear and structured framework for this research. Nevertheless, there is not an exact fit. This means that the mentioned theories need adjustments and addition. The rest of this chapter contains therefore a description of the constructed theoretical framework, based on the mentioned theory and additional sources.

The construction of the framework is based on the Multi-Level framework. This means that the different levels (niches, socio-technical regime and landscape) form the backbone of the framework. Nevertheless, the content of these levels need some clarification. The functions of the dimensions within the system need definition and the interest of the involved actors, the interaction between those actors and the structure of the network where they are in, needs to be mapped. Furthermore, there probably are restrictions imposed to the system. It is imperative to know what these restrictions are, if they could be influenced and, in case that would be possible, to what expense. In the micro- as well as the meso-level the involved factors are all related to actors. Therefore these factors are structured and mapped in relationship to these actors. The macro-level does not involve actors. This is obvious since one of the main characteristics of the macro-level is that it does not contain any actors (e.g. Geels, 2002, 2005). The fact that the micro- and meso-level specifically depend on the actors and the macro-level definitely not is also clearly displayed by Table 1, Table 2 and Table 3 (page 21, 26 and 29).

2.5.1 The micro-level of the theoretical framework

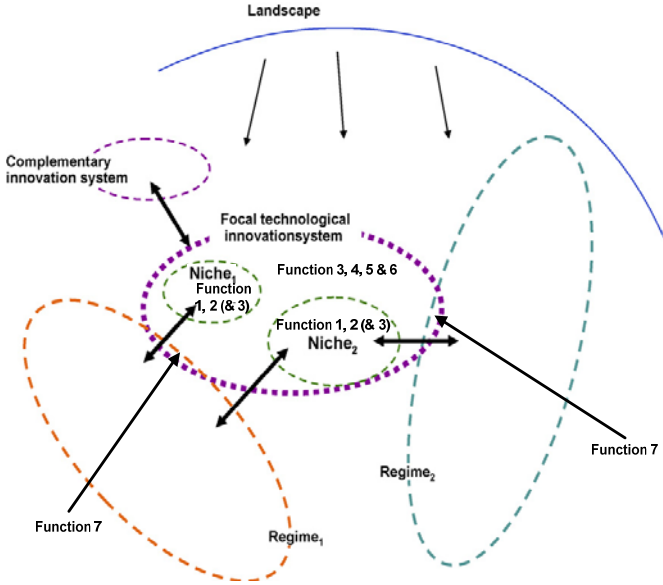
As mentioned, the niches could be defined as the 'incubation rooms' for radical innovations (Schot, 1998). The term 'incubation room' refers to an area which is separated from the environment. The radical innovations are protected by such an 'incubation room' since while they are in it, they could not be affected by the environment. Radical innovations differ very much from what can be considered as for example established practices and knowledge. It is therefore not hard to imagine that a radical innovation would initially not survive in an environment that supports these

established practices and knowledge. Nevertheless, a radical innovation that addresses a weakness in the socio-technical regime could break through. The terms 'niche' and the 'radical innovation' are defined below.

In order to be able to recognize radical innovations and niches, it is necessary to define them. The classification of Henderson and Clark (1990) provides a clear definition of a radical innovation. They classify a type of innovation to whether or not it overturns the existing knowledge of core concepts and components, and the linkages between those concepts and components. In case of a radical innovation, both existing knowledge of the core concepts and components as well as the linkages between them overturn existing ones. The next step is to establish if these radical innovations are in a niche. As mentioned in this chapter, niches can occur as market niches or technological niches (e.g. Geels, 2005; Markard & Truffer, 2008a). In a market niche the selection criteria differ from the criteria of the established market, which provides room for existence for the radical innovation. Technological niches are those niches where the resources are provided by private strategic investments or public subsidiaries. These type of niches have most of the time the function of prototype-markets. In these markets there is not a demand present yet. Thereby, technological niches form the basis for experimental, pilot and demonstration projects. These projects make use of real-world users. These definitions and descriptions of radical innovations provide the ability to identify a radical innovation within a niche.

A radical innovation and a niche are almost always created by for example entrepreneurs and institutions. These entrepreneurs start their entrepreneurial activities because they have discovered or think that they have discovered a potential for a certain innovation. This involves the first function of the of the Technological Innovation System (as mentioned in Paragraph 2.3); entrepreneurial activities (Hekkert et al., 2007). The radical innovation involves knowledge development (function two of the Technological Innovation System). These two functions occur within a niche, since they need the protection provided by the niche. Before making the effort in trying to establish a system innovation, it could be useful to establish the true value and potential of the innovation to the actors within the system. In case the innovation would provide sufficient additional value as opposed to what is established in the current system, it would be worthwhile to initiate a system innovation. Otherwise it would probably not be adapted (Rogers, 2006). Entering the current, established system could be done through the third function of the Technological Innovation System; knowledge diffusion through networks (Hekkert et al., 2007). This is the first function of the Technological Innovation System which has a role in the interface between the niche and the system. Among the

actors involved might be competitors, government(s) and actors from the market. The functions four till seven are part of the mentioned interface as well. These functions are performed, while developing the innovation, by both actors from the niche and actors from the regime. Thereby they interact through the interface. This is explained by Figure 6, based on Markard & Truffer (2008b), as well.



- Function 1:** Entrepreneurial activities
- Function 2:** Knowledge development
- Function 3:** Knowledge diffusion through networks
- Function 4:** Guidance of the search
- Function 5:** Market formation
- Function 6:** Resource mobilization
- Function 7:** Creation of legitimacy/counteract resistance to change

Figure 6: Technological Innovation System and interactions with the Multi-Level framework, based on Markard & Truffer (2008b)

As mentioned, the niche (micro-level) contains different actors which perform different functions within different niches which contain innovations. In this research, these elements should be structured per actor as is shown by Table 1. The table should be perceived as a matrix in which for the relevant actors should be established how they perceive the innovation and what activities out of the Technological Innovation System should be performed. The content of this table is eventually used to map the complete model as shown in Paragraph 2.5.4.

	Type of innovation	Performed functions out of Technological Innovation System (TIS)
Actor(s)	<ul style="list-style-type: none"> - Radical - Architectural - Modular - Incremental 	<ul style="list-style-type: none"> - Entrepreneurial activities - Knowledge development - Knowledge diffusion through networks

Table 1: factors in the niche-level

An innovation might be radical to the system. Therefore, such an innovation is not that easily adapted by the established system. An incremental innovation is more likely to be adapted in the established system through evolutionary processes, while a radical innovation needs revolutionary changes in the system in order to be adapted (Geels, 2002, Hekkert et al., 2007). Since an incremental innovation fits better in the established system than a radical innovation, there is less need for a niche in which such an innovation could be developed. Furthermore, the use of an Innovation System is possibly in that case also unnecessary. In order to get the innovation out of the niche in the system, several functions out of an Innovation System should be performed. Table 1 (page 21) is a matrix which could provide an overview of the involved actors, how they perceive an innovation and the functions out of the Technological Innovation System which they perform. Therefore the matrix should be used to map the different relevant actors and the functions they perform in the niche.

2.5.2 The meso-level of the theoretical framework

The system (referred to as the socio-technical regime by the Multi-Level framework) is defined by several dimensions; technology, user-practices and application domains, symbolic meaning of technology, infrastructure (physical as well as knowledge), industry structure, policy and techno-scientific knowledge (Geels, 2002). These dimensions all involve actors in the way that they are established in a system that exist of actors. These actors are also supposed to perform several functions in the Technological Innovation System. The actors normally perform a certain function by which they define certain dimensions. As shown by Figure 7 (page 23), these actors can be involved in the system by being part of the financial network, research network, producer network, suppliers, user groups, societal groups and public authorities. All these networks and groups fulfil a certain function, by which they influence the system.

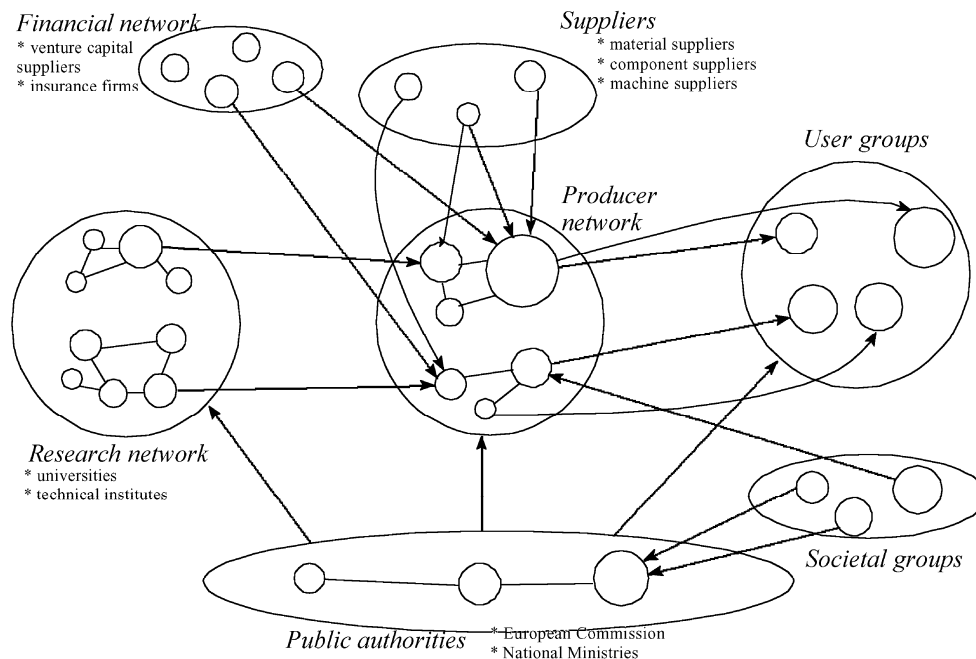


Figure 7: The multi-actor network involved in a system (Geels, 2002).

The way they perform this function and define the involved dimension, depends on the innovation and the way it would affect the actor and its function in the network. While the functions 3 till 7 of the Technological Innovation System are all active in the interface between the niche-level and the system-level, they depend on actors out of both levels. The function an actor has in the multi-actor network as exists in the system, possibly influences the way the actor executes the function in which it is involved according to the Technological Innovation System (TIS).

The functions within the interface between the micro-level and meso-level are:

- Knowledge diffusion through networks (function 3 of TIS³)
- Guidance of the search (function 4 of TIS⁴)
- Market formation (function 5 of TIS⁴)
- Resources mobilization (function 6 of TIS⁴)

The function within the system:

- Creation of legitimacy/counteract resistance to change (function 7 of TIS⁴)

³ TIS: Technological Innovation System.

An innovation which is considered incremental at the manufacturer level might turn out radical at customer level (Afuah & Bahram, 1995). This has consequences for the adoption of an innovation (Afuah & Bahram, 1995; Rogers, 2006). The way an innovation is perceived can be analysed with a measure of how radical an innovation is. The degree of change of the innovation is defined by Afuah & Bahram (1995), whereby radical is considered most changing and incremental less changing.

The explanation of this scale is provided by the clarifications as mentioned below.

1. Radical: Both the existing core concepts as well as the linkages between them are overturned.
2. Architectural: The existing core concepts are reinforced while the linkages between them are changed.
3. Modular: The existing core concepts are overturned while linkages between them are not changed.
4. Incremental: The existing core concepts are reinforced while linkages between them are unchanged.

Incremental innovations occur, as mentioned, on an evolutionary basis. This means that such innovations fit within the current system. A radical innovation overturns the existing knowledge concerning core concepts and components and the linkages between those concepts and components. This means a revolutionary and radical change does not fit in the established system. Important is therefore the value-proposition of the innovation. The cost-benefit ratio means that possible losses incurred as a result of destruction of positive network externalities of competence needs to be compensated by a larger benefit (Afuah & Bahram, 1995; Tidd et al., 2005). While the cost-benefit ratio for a whole network might show more benefit than cost, that not necessarily has to be the case for the individual actors in the network (Afuah & Bahram, 1995). This means that, when for example high cost in combination with low benefit are not compensated, such an individual actor might be against the proposed system innovation and not cooperative for that matter (Dhanaraj & Parkhe, 2006). A 'fair' allocation of cost and benefits ensures a stable network which supports processes which provide benefit to the network as a whole.

As mentioned, an innovation might be perceived in different ways by the several actors. The reasoning of Afuah and Bahram (1995) would imply that a radical innovation would cost more than an incremental innovation. This seems true when considering just the moment of implementation. For example the cost incurred with the destruction of skills and complementary value of existing

products can be enormous when considering a radical innovation compared to a incremental innovation (Afuah & Bahram, 1995). Nevertheless, while a radical innovation initially might destroy the value of existing concepts, over the long term it might provide a larger value than the initial established concepts. It thereby possibly addresses one or more weaknesses of existing, established concepts (Geels, 2002). The radical innovation might initially have overturned the existing concepts and therefore seem radical and costly, while in the long term it was part of a punctuated equilibrium (Gersick, 1988, 1989, 1991), which makes it just part of an evolutionary process at a higher level. When a radical innovation addresses weaknesses of the current concepts it might possibly eventually provide a better outcome in terms of benefit than an incremental innovation. While according to Afuah and Bahram (1995) a radical innovation always costs more than an incremental innovation, those cost might in the long term turn out to be an investment in other concepts which provide a larger benefit than the previous concepts. The hypercube considers the cost of an innovation just at one moment in time (the implementation), but it seems appropriate for a lot of innovations to make use of a larger scope. Since the initial adaption of the innovation (as discussed by the hypercube of innovation) might cause some kind of 'entry-barrier' (a barrier which prevents the innovation from entering the established system), it is an important concept as well. Therefore the framework considers how the innovation is perceived by an actor as well as the cost-benefit ratio over the long term (the complete lifecycle of the innovation).

Several factors come into play when mapping the system. In this mapping, the actor plays a central role. In order to map the system, for every actor should be defined:

1. The role of the actor in the system.
2. The dimension within the system that is defined by the actor.
3. The (possible) role of the actor in the Technological Innovation System.
4. As what type of innovation (how radical) the innovation is perceived by the actor.
5. The value of the innovation to the actor.

Table 2 (page 26) provides a matrix by which the different factors could be measured per actor. An overview of the measures of all the relevant factors for the involved actors provides an insight in the context of the different actors, in what way they are connected and thereby what the system looks like. These connections could be pictured as in Figure 7 (page 23), in which the actors are the central elements in the constructed framework.

Actor specifics in the socio-technical system		Proposed function to stimulate innovation	Likeliness that actor fulfils proposed function		
Role of the actor	Dimension in system	Role in the TIS	Perceived as innovation type	Value of innovation (cost-benefit)	
Actor(s)	<ul style="list-style-type: none"> - Financial network - Research network - Producer network - Suppliers - User groups - Societal groups - Public authorities 	<ul style="list-style-type: none"> - Technology - User practices - Application domains - Symbolic meaning of technology - Infrastructure - Industry structure - Policy - Techno-scientific knowledge 	<ul style="list-style-type: none"> - Knowledge diffusion through networks - Guidance of the search - Market formation - Resource mobilization - Creation of legitimacy/counteract resistance to change 	<ul style="list-style-type: none"> 1. Radical 2. Architectural 3. Modular 4. Incremental 	(qualitative expression of the long-term value-proposition)

Table 2: factors in the socio-technical regime

An actor is part of a certain network in a multi-actor network (Geels, 2002), by which the actor performs a certain role. From out of this role the actor defines a certain dimension of the system where the actor is part of. This role in a system provides the actor the opportunity to perform a certain function in an Innovation System. Whether or not it is likely that the actor performs this function depends on how the actor perceives the innovation and what the value of the innovation is to the specific actor in the long-term (in other words: the incentives). An example of an actor might be a ministry. This actor is a public authority and thereby defines, for example, a certain policy. Since it defines the policy it could fulfil the function of knowledge diffusion through networks and guidance of the search (as defined by the Technological Innovation System). Both of these functions depend on governmental actors (Paragraph 2.3). Whether or not it is likely that a ministry is willing to

perform the concerned functions would depend on how they perceive the innovation and the value the innovation holds for the ministry in the long term.

Table 2 (page 26) provides a matrix which can be used to establish the role of a certain actor in a network and what dimensions an actor defines in a system. Based on that information the role of the actor within a Technological Innovation System could be established. The likeliness of performing that role could be obtained from measuring as what type of innovation an innovation is perceived and what the long term value-proposition to the actor is. Measuring the type of innovation should be done on based on as how radical the innovation is perceived. Measuring the long-term value-proposition could of course be done through a calculation of the cost and benefits, which could result in a NPV (Net Present Value). In that case a positive NPV would mean that an actor is positive toward the innovation while a negative NPV would lead to a negative attitude toward the innovation (Brealey, Myers & Allen, 2006). Nevertheless, it is not likely that an actor would make such a decision just based on the NPV. There probably are considered non-financial cost and benefits as well (which cannot directly be measured financially). Furthermore, it could be the case that initial investments might be considered as too high, since there is not accounted for in the actor's controls. Such controls can for example exist of result controls (Merchant & van der Stede, 2007). In case this controls or even strategy do not or badly support such long-term investments for innovations (Bower & Christensen, 1995), the NPV for long-term projects most probably holds no value to the decision-maker. The exact content of these controls are outside the scope of this research, but they might influence the value-proposition by the actor. Therefore the value-proposition is not measured in NPV, but established based on the knowledge and experience of the involved actor. As a result, it seems appropriate to measure the value-proposition in a qualitative expression of the respondent(s). When the innovation is perceived as radical and the value-proposition is considered low, an innovation is not likely to be supported. In case an innovation is perceived as incremental and holds a high value, it is very likely that an actor supports the innovation and thereby would fulfil a certain function in the Technological Innovation System. In case the innovation is radial and it holds a high value-proposition, the actor could be considered as critical and there should probably be put effort in overcoming the 'entry-barrier'. Only the establishing the type of innovation and value-proposition does not provide sufficient information when trying to establish a trajectory for a transition. The reasoning behind these descriptions is even much more important, because it could provide the critical issues in the trajectory involving multiple actors. A filled matrix could provide a clear overview of these critical issues. Addressing these critical issues could result in a successful trajectory and system innovation which leads to the transition. While the matrix would provide a clear overview of

the different measured factors per actor, it does not provide a clear insight in the network-relations of the different actors. This insight could be obtained by putting the information out of the matrix in the multi-actor network. Within such a network a trajectory could literally be drawn. An example of how such a multi-actor network within the multi-levels might look like is presented by Figure 8.

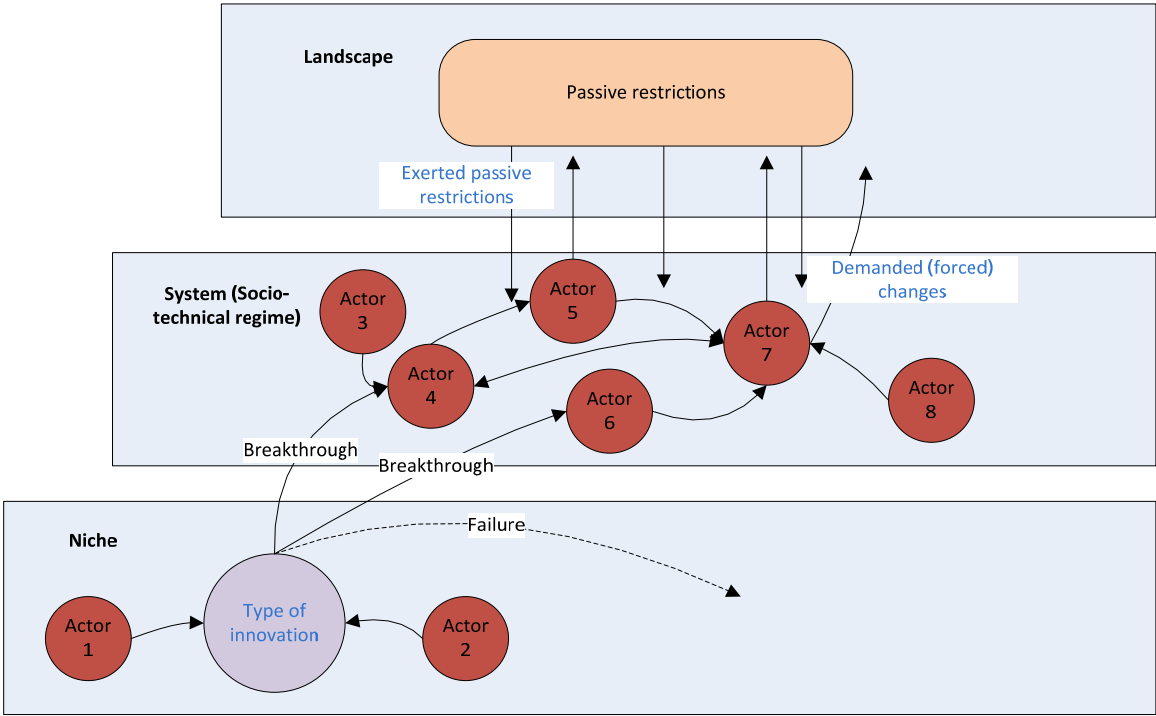


Figure 8: Example of multi-actor network within theoretical framework

2.5.3 The macro-level of the theoretical framework

As mentioned, the macro-level of the Multi-Level framework consists of a landscape which influences the current socio-technical regime (which is defined as the “system” in the constructed framework). Possibly, the system innovation transforms the landscape as well. An exact definition of the landscape-factors is very hard to establish. As mentioned, the landscape can contain tangible factors which might be easy to recognize as landscape-factors, but it can also contain intangible factors like for example processes, which might be very hard to establish.

As mentioned, “Passive restrictions” seem the best description of the landscape. The term ‘passive’ is explicitly mentioned since these factors are not able to actively exert pressure or have the ability to change themselves, thereby they are beyond the direct influence of niche and system actors (Geels & Schot, 2007). The existence of passive restrictions implies that there exist active restrictions as well. These restrictions actively restrict the system and are established by actors from the system. These

active restrictions are not part of the landscape which is mentioned as the macro-level of the Multi-Level framework, but are established by dimensions of the system (e.g. the dimension “policy” could be directly influenced by a public authority). They are not mentioned as active restrictions in this framework. Since the landscape can transform due to pressure from the system, it is necessary to describe the landscape before and after the system innovation. The (transformed) landscape can also exert pressure on the system. Since this influences the behaviour of the actors in the system, it is important to take these transformed landscape-factors into account as well. The exact description of the landscape, as used in the constructed theoretical framework, is: factors which restrict systems without being able to change themselves.

In order to establish the landscape, the passive restrictions need to be mapped. As opposed to the other levels these restrictions explicitly not depend on actors (Geels & Schot, 2007), the structuring could occur according to the matrix provided by Table 3.

Exerted passive restrictions	Demanded changes on passive restrictions

Table 3: factors in the landscape-level

The matrix as shown by Table 3 should be used for mapping the passive restrictions which the landscape puts on the system as well as the demanded changes on the passive restrictions by the innovated system. This because while an established system probably deals well with the established restrictions, this does not have to be the case for the system as exists after the system innovation occurred. The changes to the passive restrictions as demanded by the system innovation, might not be possible or demand too much effort from the system (which is probably reflected in a negative value-proposition to the actors in the system).

2.5.4 The complete framework

The combination of the different levels mentioned in the previous paragraphs results in the framework as pictured in Figure 9 (page 30). In this framework the factors (which are written in the blue colour), define the different levels and thereby indicate what a transition could look like.

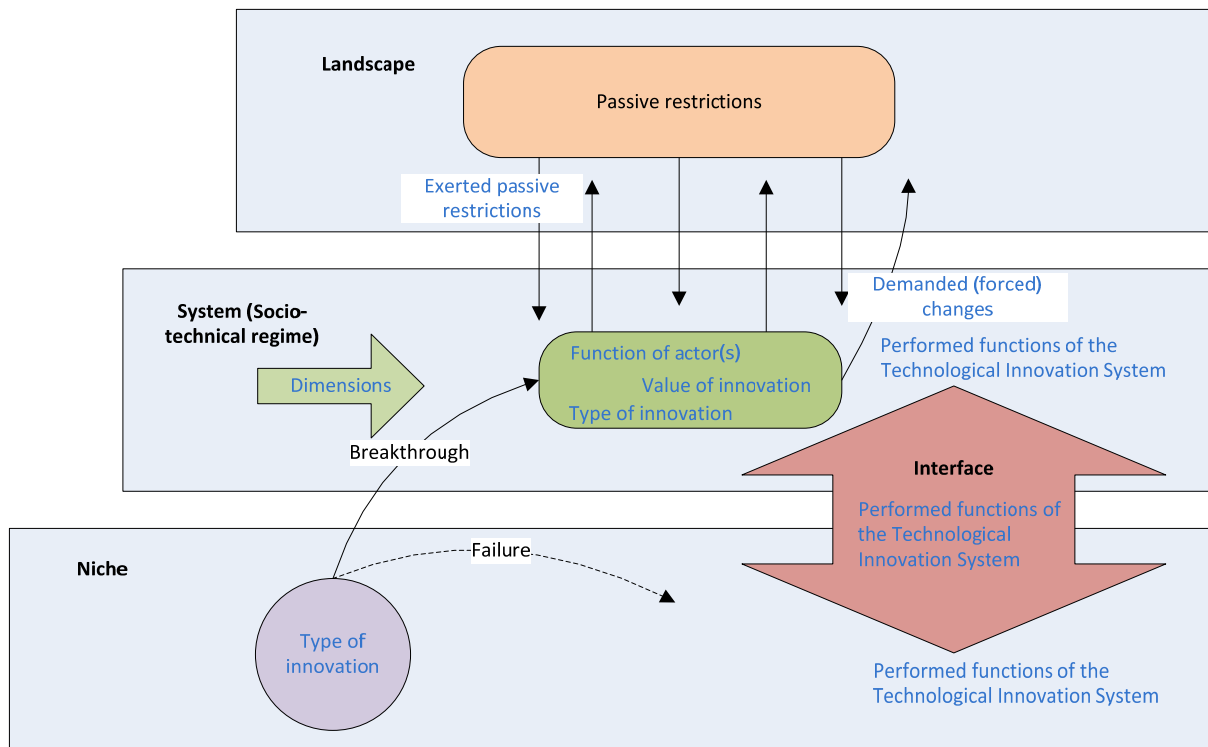


Figure 9: The complete framework

While it might look like a static overview, the framework provides one or more trajectories an innovation could follow in a transition and thereby it shows the system innovation which could occur in case the system adapts the innovation (as shown by the grey arrows in Figure 10 (page 31)). The niche-level holds a description of the type of innovation as perceived by the involved actor(s) and the functions out of the Technological Innovation System which these involved actor(s) might fulfil. Furthermore, it includes a detailed description of the system which is expressed by a network of the different actors with their roles in the system, what dimension(s) of the system they define, what function(s) of the TIS they might fulfil, how they perceive an innovation and what the long-term value-proposition of the innovation to them might be. Between the mentioned levels exists an interface. A chronological description of the factors in this interface provides a clear insight in how an innovation is or could be elevated from the niche-level to the system-level, with the use of an Innovation System. The landscape contains the passive restrictions which exert pressure on the system and at the same time the (proposed) system innovation puts pressure on the restrictions in order to make them support the innovated system. Therefore, next to establishing the current established passive restrictions, there should be established what needs to be changed to the passive restrictions in order to let them support the innovated system.

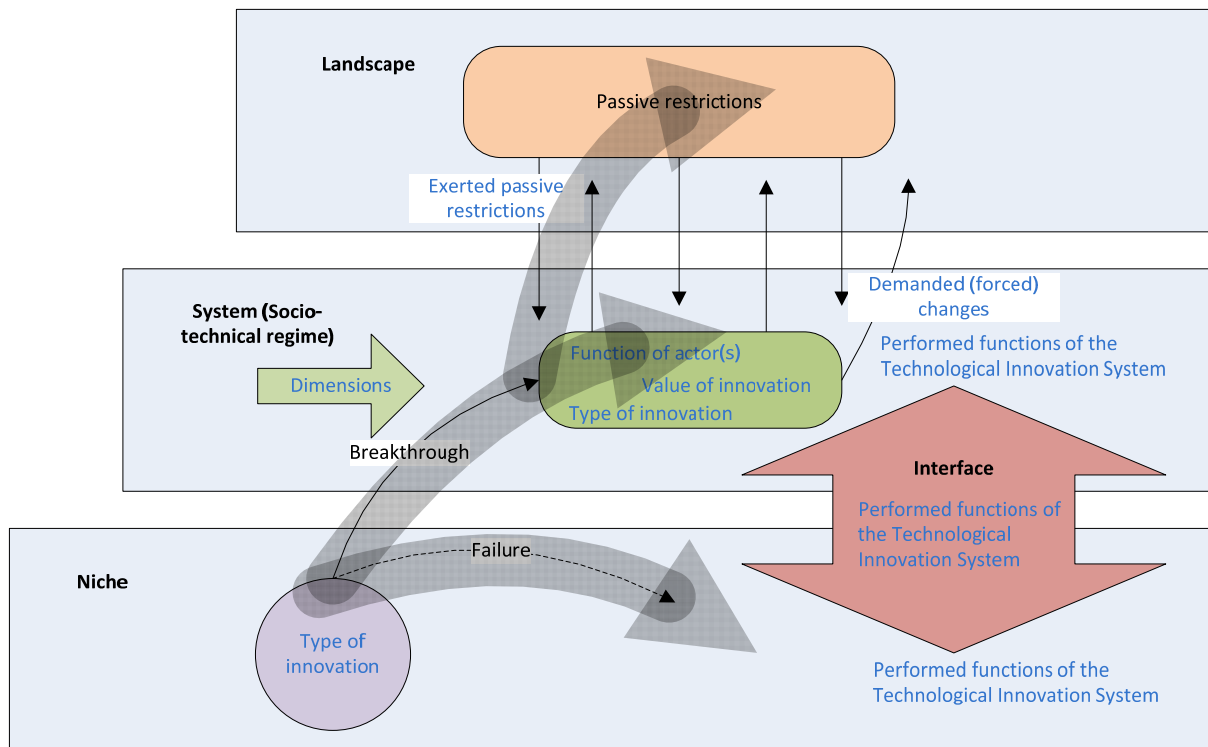


Figure 10: Trajectories within a transition

Possible trajectories in a transition involved with an innovation, are shown by Figure 10. An innovation might not break through in the system due to the strength of the established system, it might be not worth the change according to the actors in the established system or it could be the case that an innovation is not supported properly. In case an innovation breaks through it might be supported by the established passive restrictions out of the landscape, but even more likely would be that the innovation of a system demands a change of the passive restrictions. These different scenarios are pictured by the grey arrows in Figure 10. This does not provide much insight in the relations between the different factors of the framework. These relations can be obtained out of the different matrixes (in Table 1, 2 and 3 as mentioned on pages 21, 26 and 29), which each belong to a certain level of the framework. This is shown by Figure 11 (page 32).

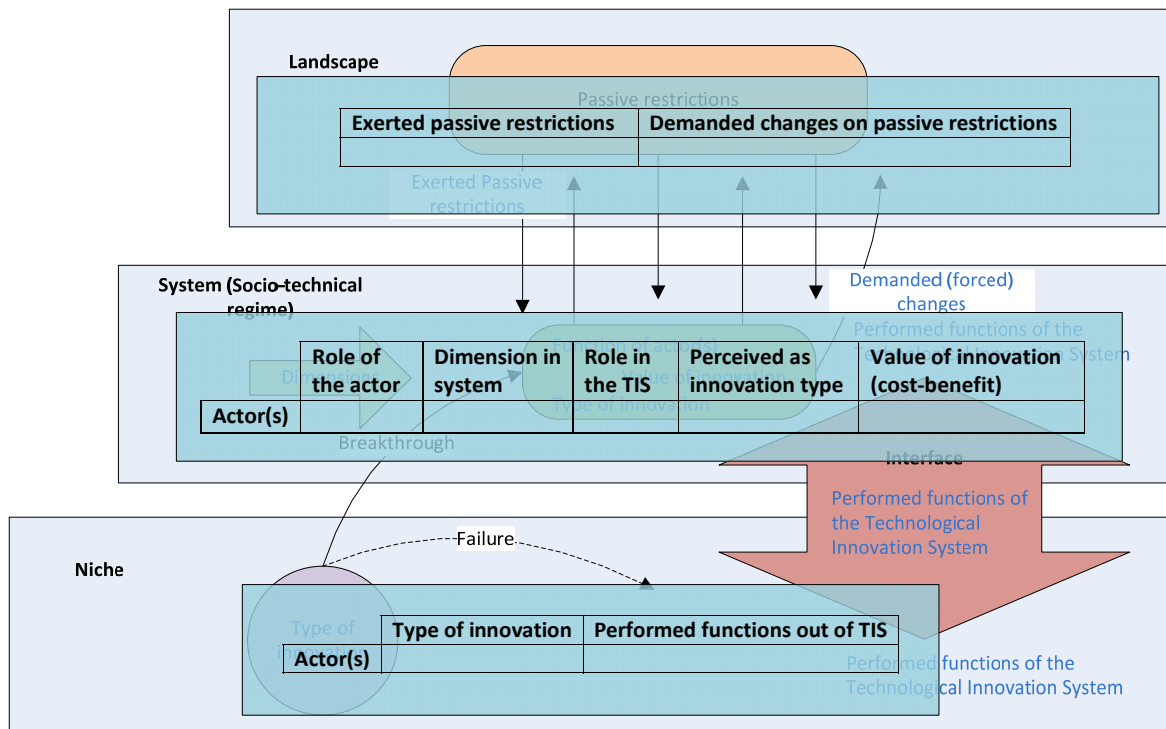


Figure 11: The actor-oriented framework (TIS stands for Technological Innovation System)

From the actor-oriented framework as pictured by Figure 11, the relations of the different factors, their roles, functions and attitude toward an innovation could be obtained. However, Figure 11 lacks a clear overview of the relations between the different actors and thereby lacks the possibility of establishing the trajectories as well. For every actor in the niche and in the system the factors as mentioned in the tables in Figure 11 should be established (which are based on the matrixes out of Table 1 and Table 2). These factors provide the actors' characteristics based on which the trajectories could be drawn. An example of how this could look like is provided by Figure 12 (page 33). From the possible trajectories the most likely trajectory could be established based on how radical the innovation is perceived and the value of the innovation (as explained in Paragraph 2.5.1, 2.5.2 and 2.5.3). Furthermore, the reasoning provides an insight in the critical issues and possibly even how these could be resolved. This information should be used to provide recommendations concerning a successful trajectory and transition.

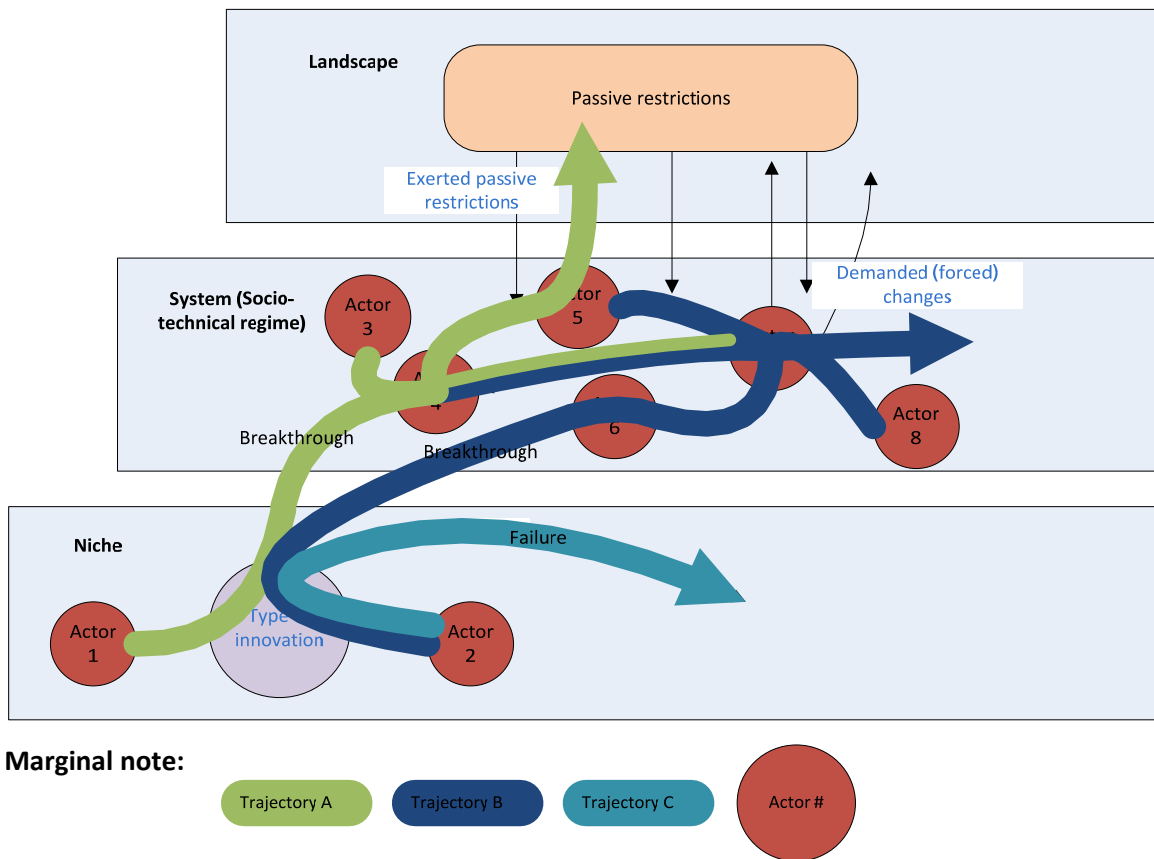


Figure 12: Example of possible trajectories through the network mentioned in Figure 8 (page 28).

2.6 Summary of the framework

There exists or there is developed a certain type of innovation within a niche. Some actors might make an effort to get this innovation breakthrough in the system. Depending on the type of innovation they might make use of an Innovation System. When the innovation breaks through it causes the system, which exist out of actor-based entities, to innovate to another system which supports the innovation. Nevertheless, the established system is limited by passive restrictions. These limitations might not support the innovated system. Therefore the innovated system might possibly put pressure on these restrictions in order to make them change in such a way that these support the innovated system. With this framework an insight could be provided in the possible trajectory or trajectories from the innovation in the niche, through the system and concerned actor-based entities and possible changes to the landscape. Thereby and therefore the most likely trajectory and the critical issues should be established.

3. Methodology

This chapter contains the explanation considering the execution of the research. Next to establishing the research method, the population and sampling, it contains the explanation of the operationalisation of the theoretical framework as mentioned in the previous chapter. The purpose of this chapter is thereby to provide a clarification and an exact description of how the research is performed.

3.1 Research design

A preliminary analysis⁴ is conducted at the start of this research, in order to clarify the relevance and the historical data concerning this issue. Next to that, some experts within Lloyd's Register Rail Europe have been consulted about this issue. This information is used to construct a research proposal. The theories involved concern transitions, system innovations, Innovation Systems and sustainable innovation. The theories concerning these matters are studied and used as a basis for the construction of a theoretical framework, as described in Chapter 2. The suitability of the framework for this research is established by consulting Lloyd's Register Rail and the supervisor from Twente University. Their remarks are included in the theoretical framework as described in Chapter 2. The application of this framework to this specific research is explained in Chapter 3.2.1 till 3.2.4.

3.2 Research method

The method which is used as research strategy is a singular case-study (Babbie, 2007; Eisenhardt, 1989; Shadish et al., 2002; Verschuren & Doorewaard, 2007; Yin, 1994). This is suitable for this research, since it concerns a qualitative and descriptive research. Since most of the data concerning case-studies is qualitative, the research design can be further specified to an intensive qualitative case study (Shadish, Cook & Campbell, 2002). With the use of this method valid causal inferences can be made by using a qualitative process (e.g. interviewing). Another reason for using a case study is that it could probably provide a broader view than other research methods (Shadish et al., 2002). This means that case studies in general contain more types of information than experiments, by which they can inform stakeholders about more diverse matters (Shadish et al., 2002). This provides

⁴ The information considering the preliminary analysis concerning this issue is obtained from literature as is included in the references and conversations/interviews with employees from Lloyd's Register Rail Europe B.V. which are mentioned in **Fout! Verwijzingsbron niet gevonden.** (Appendix B).

eventually a more complete insight in the transition, since it is not limited by a strict delineation as occurs with experiments. The structure of case and sub-cases implies that the method consist of several phases, therefore there are distinguished four stages along which the research is executed. Thereby these stages form the operationalisation of the theoretical framework as mentioned in Chapter 2.5. These stages are explained in the following paragraphs and schematically displayed in Figure 13 (page 41).

3.2.1 Stage one

The initial singular case contains an overview of all the, to the transition related, factors. The related factors and actors are described by the framework as mentioned in Chapter 2.5. Table 1, 2 and 3 (pages 21, 26 and 29) thereby provide the matrixes along which the factors and actors are described. These different factors belong to the different levels as mentioned in Figure 11 (page 32); the niche-, system- and landscape-level. Not all the factors for the involved transition can be described in the initial, singular case (as exist in this stage). This because not all the concerned information is available at that time. Therefore the initial case (in this stage) only includes a description of:

- The landscape (macro-level of framework)
 1. *Exerted passive restrictions*

- The system (meso-level of framework)
 1. *The role of an actor within the system*
 2. *The dimensions of the system which are defined by the actor*

- The niche (micro-level of framework)
 1. *The type of innovation (opposed to the system).*
 2. *The function (in a Technological Innovation System) which an actor should perform to initiate an innovation successful*

The outcome of this description provides an overview which could be graphically pictured as done in Figure 8 (page 28). Several factors as mentioned in the framework in Paragraph 2.5 are not included yet, since they cannot be known in the initial case. The information needed to construct the overview

is obtained through, among others, documents and archival records⁵ (Pare, 2004; Yin, 1994). These documents and archival records are obtained by desk research and interviews within Lloyd's Register Rail Europe B.V., which provide documents as well (the respondents are mentioned in Table 9, Appendix B). The desk research involves the documents and websites of the established actors and subjects involved with the rail sector considering an increased voltage, 3kV, capacity, energy-efficiency and reduction of CO₂-emissions. The documents, websites and interviews provide other documents, websites and possible interviews which are evaluated on their relevance to this subject and researched in case these are directly relevant. These sources not only provide the information concerning the context of the phenomenon which is researched, but also the sub-cases of the case which is researched. Establishing the sub-cases occurs thereby through the so-called snowball sampling (Babbie, 2007; Verschuren & Doorewaard, 2007; Yin, 1994). In other words; these sources provide an insight in which (f)actors are involved and thereby might be useful to be investigated as well. The snowball sampling is explained more elaborate in Chapter 3.3.

3.2.2 Stage two

The sub-cases which are provided by the snowball sampling (in Stage one) consist of actors relevant to the transition. Semi-structured interviews are conducted among this actors with the use of the interview protocol as is included in Appendix A. As a preparation for conducting these semi-structured interviews and constructing a proper interview protocol, several sources are consulted (Babbie, 2007; Pare, 2004; Steehouder, Jansen, Maat, van der Staak, de Vet, Witteveen & Woudstra, 1999; Verschuren & Doorewaard, 2007; Yin, 1994). In consultation with the supervisor from Lloyd's Register Rail Europe there is decided to not record any of the interviews. This since the concept of recording might probably discourage the respondents to make critical remarks. This might have negative effects on the results (Babbie, 2007). The purpose of these interviews is to establish the following:

- The landscape (macro-level of framework)⁶
 2. *The demanded changes on passive restrictions*

⁵ The documents and archival records are included in the references.

⁶ The concerned factor replenishes the landscape as mentioned in Stage one.

- The system (meso-level of framework)⁷
 3. *The function (in a Technological Innovation System) which an actor could perform to make an innovation successful (based on the likeliness which is established by the following two factors)*
 4. *The way an actor perceives the innovation*
 5. *The value of the innovation to the actor*

The way an actor out of the system perceives an innovation, the value an innovation holds for this actor and the effects an innovation has are discussed in the interview. The outcomes provide an insight in the critical issues and possible problems. Furthermore, they indicate how likely an actor is to fulfil a certain function of the Technological Innovation System (TIS).

3.2.3 Stage three

From the information out of the initial case (Stage one; Paragraph 3.2.1) and the sub-cases (Stage two; Paragraph 3.2.2) the complete transition and possible trajectories are drawn in an overview of which examples are provided by Figure 8 (page 28) and Figure 12 (page 33). This overview contains the sum of the previous stages:

- The landscape (macro-level of framework)
 1. *Exerted passive restrictions*
 2. *Demanded changes on passive restrictions*
- The system (meso-level of framework)
 1. *The role of an actor within the system*
 2. *The dimensions of the system which are defined by the actor*
 3. *The function (in a Technological Innovation System) which an actor should perform to make an innovation successful (based on the likeliness which is established by the following two factors)*
 4. *The way an innovation is perceived by the actor*
 5. *The value an innovation holds for an actor*

⁷ The concerned factors replenish the system as mentioned in Stage one.

- The niche (micro-level of framework)
 1. *The type of innovation*
 2. *The function (in a Technological Innovation System) which an actor should perform to initiate an innovation successful*

The result of this stage forms the complete case. The analysis of this case should be structured according to the niche-, system- and landscape-level. However, in addition future developments should be established as well, since these provide an indication whether or not the to be established most likely trajectory eventually also addresses future developments. Therefore there should be looked into how the established landscape-factors develop over time (in this case the future landscape-developments towards 2020 and 2050 are considered for that purpose). Altogether the analysis contains a cross-analysis of the different factors (mentioned in Table 1 and 2; page 21 and 26) which are established for the different direct relevant actors in the niche- and system-level, the factors which are part of the landscape-level (mentioned in Table 3; page 29) and future developments (which concern the established landscape-factors). Based on this analysis there are drawn possible trajectories.

3.2.4 Stage four

The previous stage provides a clear overview of the different levels, involved actors and possible trajectories. In this framework there could be highlighted some critical issues. These issues can contain critical actors and/or factors out of the system. For example, a specific relevant actor which perceives an innovation as radical and considers the value as very negative, could be highlighted as critical. During the interview the reasoning behind the “how an innovation is perceived” and “the value the innovation holds for the actor” is obtained. This reasoning possibly includes suggestions for improving the value to the actor. This reasoning and the suggestions could provide the solutions for solving the possible problems concerning the critical issues.

As mentioned, there could most likely be established several possible trajectories for the transition along with possible concerned critical issues. In addition, there is also looked into factors which are likely to affect the system in the future. These might be useful input for the decision-making involving the system innovation which occurs within the described transition. In order to reflect on these outcomes a group-session was organised on the 17th of May, 2011. During this group-session the respondents could discuss the outcomes and review the possible trajectories and future developments (which are presented during the session). Thereby, the group-session provides input

for conclusions and recommendations which replenish the already established content of the case. Within the case-description (Chapter 4) is therefore explicitly mentioned which content is obtained from the group-session. The respondents which were present during this group-session include respondent 2, 9, 11, 13 and 14 from Table 9 and 10 (Appendix B) and of course the author of this research.

Next to conclusions and recommendations concerning the empirical research, the constructed framework should be reviewed. Therefore the theoretical and managerial implications are discussed and limitations are identified. Furthermore there are provided recommendations.

3.3 Population and sampling

The population exists of the involved actors out of the system (which are part of the multi-actor network), as they are established in the initial case (which contains a description of the innovation, system and landscape). As mentioned, the information concerning this system (including the population) is obtained by analysing documents, archival records and conducting interviews with relevant stakeholders (which are selected through snowball sampling).

There could be established roughly two groups of actors:

- Directly involved actors (influence the innovation or are directly being influenced)
- Indirectly involved actors (cannot influence the innovation and are not directly influenced by the innovation)

The focus group within this research, and therefore the population in this research, is the group of relevant actors which are directly involved (direct stakeholders). The actors from this group highly determine the success of the transition, while the group which consists of indirectly involved actors has no power to influence the innovation whatsoever. Since the last group of stakeholders cannot influence the transition, they are outside the scope of this research. Nevertheless, all the actors are part of a multi-actor network (Geels, 2002). Establishing which actors are part of this network is done by consulting several specialists within Lloyd's Register Rail⁸. Their input is cross-analysed, by which discrepancies become clear. Of course these discrepancies are examined, in order to create a

⁸ The consulted specialist are mentioned in Table 9 (Appendix B).

complete and correct overview of the multi-actor network. The data subtracted from the interviews, documents and archival records is structured in the niche-, system- and landscape-level. Within these levels the structuring occurs according to the matrixes as pictured in Table 1, 2 and 3 (page 21, 26 and 29). The structuring of the critical factors which come forward during the interviews or desk research should be done as by Brown and Eisenhardt (1997). Thereby tables as used on page eight of their article are used to define those factors for the several actors. These tables provide matrixes from which the possible and, most probably, likely trajectories could be drawn.

As mentioned, the sampling occurs through the so-called snowball sampling (Babbie, 2007; Verschuren & Doorewaard, 2007; Yin, 1994). This is a nonprobability sampling method which is often employed in field research, whereby one case provides another case (sub-case) which contributes to the initial case. This means that the initial case provides an overview of the system involved with the overhead wires, the passive restrictions and the innovation. This overview provides other cases, which are involved and therefore are useful to examine as well. These cases could also be referred to as the mentioned 'snowballs'. In examining these 'snowballs', the factors of the system (as mentioned in Chapter 2.5) are used.

3.4 Summarized method

The method is established in four stages. The first stage contains the initial case which provides an insight in the different levels. Within the second stage, the direct relevant actors (which form the subcases) are established and researched through interviews, documents and archival records. The combination of these two stages form a complete case involving these different levels. This case is discussed and reviewed in stage four. A graphical display of the stages is provided by Figure 13 (page 41).

The respondents are obtained through snowball sampling. Thereby the specialist (as mentioned in Table 9, Appendix B) from Lloyd's Register Rail Europe B.V. provide contact information of respondents. These respondents are asked if they know relevant direct actors as well. As mentioned all the information is structured according to Table 1, 2 and 3 (page 21, 26 and 29). The critical factors are processed per actor in matrixes (an example of which can be found in the article of Brown and Eisenhardt, 1997). These factors provide the input and clarification for the different trajectories as mention in Paragraph 5.5.

1	2	3	4
Stage one: Establish the relevant actors and factors mentioned below (initial singular case)	Stage two: Research for the in Stage one established actors and innovation the factors mentioned below (sub-cases)	Stage three: Combine data from Stage one and Stage two (sub-cases integrated in initial singular case)	Stage four: Analyze the outcome of Stage three
<ul style="list-style-type: none"> - The landscape (macro-level of framework) 1. <i>Exerted passive restrictions</i> 2. <i>Demanded changes on passive restrictions</i> 	<ul style="list-style-type: none"> - The landscape (macro-level of framework) 1. <i>Exerted passive restrictions</i> 2. <i>Demanded changes on passive restrictions</i> 	<ul style="list-style-type: none"> - The landscape (macro-level of framework) 1. <i>Exerted passive restrictions</i> 2. <i>Demanded changes on passive restrictions</i> 	<ul style="list-style-type: none"> - Discuss the outcomes in a group-session - Draw conclusions and provide recommendations - Reviewing constructed framework
<ul style="list-style-type: none"> - The system (meso-level of framework) 1. <i>The role of an actor within the system</i> 2. <i>The dimensions of the system which are defined by the actor</i> 3. <i>The function (in a Technological Innovation System) which an actor should perform to make an innovation successful (based on the likeliness which is established by the following two factors)</i> 4. <i>The way an innovation is perceived by the actor</i> 5. <i>The value an innovation holds for an actor</i> 	<ul style="list-style-type: none"> - The system (meso-level of framework) 1. <i>The role of an actor within the system</i> 2. <i>The dimensions of the system which are defined by the actor</i> 3. <i>The function (in a Technological Innovation System) which an actor could perform to make an innovation successful (based on the likeliness which is established by the following two factors)</i> 4. <i>The way an innovation is perceived by the actor</i> 5. <i>The value of the innovation to the actor</i> 	<ul style="list-style-type: none"> - The system (meso-level of framework) 1. <i>The role of an actor within the system</i> 2. <i>The dimensions of the system which are defined by the actor</i> 3. <i>The function (in a Technological Innovation System) which an actor should perform to make an innovation successful (based on the likeliness which is established by the following two factors)</i> 4. <i>The way an innovation is perceived by the actor</i> 5. <i>The value an innovation holds for an actor</i> 	
<ul style="list-style-type: none"> - The niche (micro-level of framework) 1. <i>The type of innovation</i> 2. <i>The function (in a Technological Innovation System) which an actor should perform to initiate an innovation successful</i> 	<ul style="list-style-type: none"> - The niche (micro-level of framework) 1. <i>The type of innovation</i> 2. <i>The function (in a Technological Innovation System) which an actor should perform to initiate an innovation successful</i> 	<ul style="list-style-type: none"> - The niche (micro-level of framework) 1. <i>The type of innovation</i> 2. <i>The function (in a Technological Innovation System) which an actor should perform to initiate an innovation successful</i> 	
	<ul style="list-style-type: none"> - Future developments 	<ul style="list-style-type: none"> - Future developments - Analyze the case and draw different possible trajectories 	

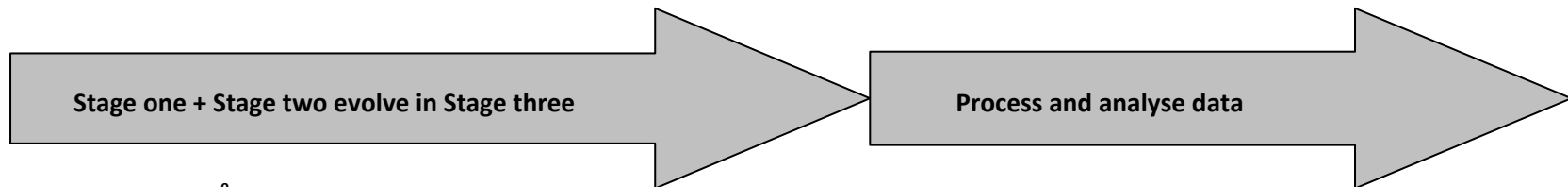


Figure 13: Stages in methodology⁹

⁹ The factors which are written in grey are or cannot be established at the stage they are in.

4. The case

[Due to confidentiality, the content of this chapter (page 42 until page 79) is not part of the public version of the final report]

5. Analysis

[Due to confidentiality, the content of this chapter (page 80 until page 94) is not part of the public version of the final report]

6. Results

Based on the cases and the involved analysis there are drawn conclusions. This analysis and conclusions provide ideas for improvement. These ideas are collected within the recommendations, as can be found in Paragraph 6.2. For this research there is constructed a theoretical framework as mentioned in Chapter 2. It might be the case that the constructed framework provides a useful addition to the established theory, but at the same time it could be that it lacks essential elements. Therefore the implications for the theory are discussed in Paragraph 6.3. Next to theoretical implications there are managerial implications as well. These are discussed in Paragraph 6.4. Since the research is conducted within a certain scope, there are some practical limitations as well. These practical limitations are worth mentioning, since they define under what circumstances the analysis and results are valid. Therefore they are mentioned in Paragraph 6.5. Paragraph 6.6 contains suggestions for further research, since some recommendations or conclusions need further research in order to make valid statements considering these issues.

6.1 Conclusion

[Due to confidentiality, the content of this paragraph (page 95 until page 97) is not part of the public version of the final report]

6.2 Recommendations

[Due to confidentiality, the content of this paragraph (page 97 until page 98) is not part of the public version of the final report]

6.3 Theoretical implications

This framework could be used within another context, but it might need some adjustments since other factors might play a role as well. Due to the oligopolistic (almost monopolistic) character of the researched system the possible trajectories always depend on specific actors, while in a perfect competitive market different actors might possibly be able to fulfil each other its role. Therefore network externalities could be important as well. Since in the researched case the most important actors fulfil an unique function, an adoption curve would be quite digital. For example, an innovation cannot diffuse that much as it comes to an infrastructure manager since there is only one. Furthermore it would be highly unlikely that just one actor would migrate, because the migration would not hold any additional value (even worse, it would destroy current value). Additional value

could only be created when all the actors cooperate. In other transitions this might not be the case. As mentioned by one of the respondents, in the automotive industry there are also developments to less consuming, more sustainable engines. This is motivated by incentives like tax-advantages or described in policies (e.g. the Euro-engines). Since these operate in a larger market with far more independently, privately owned actors, a measurement of positive network externalities could be a very useful addition to the constructed framework. Thereby the constructed framework could not directly be applied to every system.

The TIS turns out to be a useful addition when trying to purposely initiate or assess an innovation involving a transition. While in this research comes forward that only a few functions are fulfilled, it provides useful information about in which stage the transition is and what the reason is that the transition is currently at that stage. However, it does not provide an indication of to what extent a function is fulfilled. For example in this research is mentioned that further knowledge development and diffusion is required since it seems incomplete and is not unanimously shared. Unknown is however at what moment the execution of these different functions can be considered complete. Since this differs per innovation and involved circumstances it is clear that a general valid definition, of when a function is completely fulfilled, cannot be provided. However, it would be useful in the context of the constructed framework to be able to assess to what extent the functions from the TIS are fulfilled.

Normally the Multi-Level framework is used to describe transitions (Geels, 2002, 2007). Within this research it is used as a backbone for the constructed framework. The in Paragraph 2.2.4 mentioned abstractness of the Multi-Level framework, makes it very suitable for this purpose. The integration of additional theories (e.g. TIS, hypercube of innovation, value-proposition) provides the possibility to describe what a transition could or should look like, possibly steer a system innovation or describe what the (missing) critical elements are and thereby assess a possible transition. The broader perspective as provided by the Multiple-Level framework provides a clear insight into the circumstances at all levels and thereby the likeliness of some events to occur (e.g. in this case the landscape-factor involving (macro)economics clearly limits the system while demographics support the system developments). While in the theory involving the Multiple-Level framework is mentioned that transitions involve radical innovations, this research proves that this not necessarily has to be the case. As shown in this research an innovation can consist of small symbiotic innovations which are not very radical, but to the involved system the same innovation could be very radical.

Validating the constructed framework by comparing with other transitions might be hard or close to impossible due to the high number of variables and the involved uncertainty in the niche-, system- and landscape level. These variables might differ quite a lot in the different cases and therefore while in some circumstances with specific characteristics an innovation might have led to a successful transition, another innovation might fail. Comparing different system innovations and transitions in order to determine a possible success might therefore not lead to reliable valid outcomes.

Altogether, this framework could be applied to any innovation/change which involves system innovation and thereby provides a useful framework to anyone who want to research such issues. Nevertheless, describing what a transition should look like and the possible ability to a system innovation, does not guarantee that an innovation will be successful and/or that a transition will occur as is described.

6.4 Managerial Implications

While the constructed framework is applied to the specific case of a migration to 3kV DC, it could also be applied to other innovations (and even changes) which involve system innovations. Thereby the innovation does not even have to be radical since, as shown, a system innovation can be radical while the innovation is not. How radical an innovation really is, depends for that matter on how it is perceived by the actors within a system. Furthermore, the actors within a system all fulfil a certain role by which they define a certain dimension. These dimensions seem related to the functions out of a TIS (e.g. guidance of the search is only possible when an actor has the possibilities to guide a search, for example through policy). Thereby the landscape-factors define and restrict/support these dimensions (e.g. the macroeconomics influence economy and thereby policies and involved reductions on expenditures). However, the likeliness for fulfilling the functions from the TIS seem to depend on how radical the innovation is perceived, what the value-proposition is and additionally, the state of being of the landscape-factors (e.g. a good economic climate might have a positive effect, while a bad economic climate might lead to negative pressure). Actors are more likely to cooperate when it provides value and advantages, and thereby does not cause a lot of interference with the established operations and assets. This could also be used to establish whether or not innovation involves a system innovation, since system innovations are highly unlikely to evolve out of innovations which are perceived as incremental. Furthermore, when allocating the functions of the TIS to the appropriate actors, the system innovation could possibly be purposely initiated and even steered. Mentioned in the previous phrase are the 'appropriate actors'. The appropriateness of an actor is defined by the dimensions an actor defines within a system. The ability to perform a certain

function provides the power to fulfil a certain TIS-function (e.g. defining techno-scientific knowledge provides the ability to develop knowledge). Altogether, this information could be used to map possible trajectories and even possibly to steer to a certain trajectory.

While having established that the framework could be generalized (to any system with an oligopolistic character), it is useful to explain how this could be done. Therefore the method as described by Figure 13 (page 41) could be used. Execution of the first stage leads to the multiple levels as shown by Figure 20 (Appendix D) and an establishment of the different factors and actors. In the following two stages the TIS-functions could be allocated/established and thereby there is also looked into the likeliness of an actor fulfilling a certain function. In a system in which more actors could fulfil a certain function, one could purposively allocate a certain function to an actor which supports the innovation. Another possibility is that during the research might come up that a certain function is not being fulfilled and therefore a suitable actor could be determined. Eventually there is the possibility that, based on the content of these factors, there could be established trajectories of which some might be more likely than others.

6.5 Practical limitations

[Due to confidentiality, the content of this paragraph (page 101 until page 102) is not part of the public version of the final report]

6.6 Suggestions for further research

[Due to confidentiality, the content of this paragraph (page 103 until page 103) is not part of the public version of the final report]

6.7 Chapter summary

[Due to confidentiality, the content of this paragraph (page 103) is not part of the public version of the final report]

List of abbreviations

A	Amperage (kA: kilo Amperage)
AC	Alternating Current
ATB	Automatische Trein Beïnvloeding: Automatic Train Influencing
BREVER	Behoud van Reistijd en Verplaatsing: Constant travel time budgets
DC	Direct Current
EC	European Commission
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
EU	European Union
IS	Innovation System
IVW	Inspectie Verkeer en Waterstaat: Transport and Water Management Inspectorate
LMCA	Landelijke Markt- en Capaciteitsanalyse Analysis: National Market and Capacity Analysis (Ministerie van Verkeer en Waterstaat, 2007)
LRRE	Lloyd's Register Rail Europe
MCDA	Multi-Criteria Decision Analysis
MIRT	Meerjarenprogramma Infrastructuur, Ruimte en Transport: Multi-Year Plan for Infrastructure, Spatial Planning and Transport
MLP	Multi-Level Perspective
NMCA	Nationale Markt- en Capaciteitsanalyse Analysis: National Market and Capacity Analysis (e.g. Ebbink, 2010)
NS	Nederlandse Spoorwegen
NSI	National System of Innovation
NSR	Nederlandse Spoorwegen Reizigers
SCBA	Social Cost-Benefit Analysis
SIS	Sectoral Innovation System
TIS	Technological Innovation System
TSI	Technical Specifications for Interoperability
TSIS	Technology Specific Innovation System
TT	Transition Theory
UIC	Union Internationale des Chemins de fer
V	Voltage (kV: kilo Voltage)

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Appendix A: Interview protocol for semi-structured interviews¹⁰

Introductie

- Voorstellen: Marc Bos, Universiteit Twente,
Master Business Administration: Innovation & Entrepreneurship.
- Achtergrond: Afstudeeronderzoek naar de benodigde systeeminnovatie voor een transitie naar 3kV in de bovenleiding in Nederland.
- Doel: Het bepalen van de mogelijke trajecten van de transitie naar 3kV.

Opbrengsten

- Een kopie van het verslag.

Kosten

- Circa een uur voor het interview.

Algemeen (voorstellen respondent)

- Wie is de respondent (bedrijf/functie)?
- Welke rol vervult de actor (vertegenwoordigd door de respondent) in de railsector?
- Welke dimensie bepaald de actor binnen deze context (bijv. beleid, techniek)?

Uitleg

De verandering wordt bestudeerd als een innovatie die een transitie naar een ander systeem met zich meebrengt. De verschillende niveaus waarmee deze transitie uitgelegd kan worden, zijn het niche-, systeem- en landschapsniveau. Hierbij vormt de niche de beschermde omgeving van waaruit de innovatie ontwikkeld zou moeten kunnen worden, het systeemniveau representeert het systeem waar de innovatie deel vanuit zou gaan moeten maken. Het landschapsniveau vertegenwoordigd de passieve restricties die het systeem op een bepaalde manier limiteren of/en ondersteunen.

¹⁰ In contrary to the rest of this report the interview protocol is in Dutch. This because the interviews are conducted in Dutch among Dutch respondents.

Niche

- 1.) Is uw organisatie al actief met de voorgestelde verandering bezig (geweest)?
 - 1.a) Welke rol vervult/vervulde uw organisatie daarbij?
- 2.) Hoe beoordeelt u de voorgestelde verandering?
 - 2.a) Ervaart de u de voorgestelde verandering als een innovatie wanneer deze binnen de context van het Nederlandse systeem bekeken wordt?
 - 2.b) Welke (directe relevante) actoren zou u benoemen als onderdeel van dit systeem (die ook invloed kunnen hebben op een dergelijke besluitvorming)?
 - 2.c) Welke rol heeft uw organisatie binnen dit systeem en de besluitvorming?

Systeem

- 3.) Hoe beschouwt u de innovatie met betrekking tot het gehele systeem en vanuit uw eigen perspectief?
 - 3.a) Welke voordelen ziet u voor het gehele systeem en voor de eigen organisatie?
 - 3.b) Welke nadelen ziet u voor het gehele systeem en voor de eigen organisatie?
 - 3.c) Hoe radicaal beoordeelt u (de grootte van de barrière voor) de innovatie voor het gehele systeem en voor uw eigen organisatie?
 - 3.d) Hoe beoordeelt u de waardepropositie van de innovatie voor het gehele systeem en voor uw eigen organisatie?
- 4.) Wat zou de reden voor wel of geen overgang kunnen zijn?
 - 4.a) In welke situatie zou een overgang naar 3kV een realistische en succesvolle optie zijn?
 - 4.b) Wat zijn de belangrijkste redenen om het huidige 1,5kV systeem te blijven gebruiken?

Indien de vorige vragen niet van toepassing zijn:

- 4.c) Ziet u wellicht toekomst in een andere (vorm van) TEV?

In geval van een overgang:

- 5.) Verwacht u een algehele verandering of een verandering van enkele corridors?
 - 5.a) Welke optie is volgens u het voordeligst voor het totale systeem?
 - 5.b) Welke optie is volgens de u het voordeligst vanuit uw perspectief?

- 6.) Zou uw organisatie de betreffende systeeminnovatie ondersteunen?
- 6.a) Welke wijzigingen binnen het systeem zijn er volgens u nodig om het systeem geschikt te maken voor de verandering (bijv. techniek, financiering)?

Landscape

- 7.) In hoeverre hebben welke macrofactoren hebben invloed op uw organisatie?
(Bijv.: Sociaal-culturele, Economische, Milieu, Demografische, Geografische factoren)

Afsluiten interview

- Respondent bedanken voor zijn/haar tijd.
 - Mogelijkheid geven aan respondent voor het geven van aanmerkingen/opmerking op hetgeen besproken is.
 - Respondent uitnodigen voor de groepsessie
- De uitkomsten van de verschillende gesprekken worden verwerkt in mogelijke trajecten waarop de transitie plaats zou kunnen vinden. Deze trajecten bevatten hoogstwaarschijnlijk ook een aantal kritische elementen. Het doel is om deze trajecten en kritische elementen in een groepsessie te bediscussiëren. De uitkomsten van deze groepsessie vormt de input voor de conclusies en aanbevelingen. Deze sessie zal hoogstwaarschijnlijk ongeveer een uur duren en plaatsvinden bij Lloyd's Register Rail Europe.*
- Vragen of de respondent andere relevante actoren/respondenten weet voor dit onderwerp.
 - Contactinformatie uitwisselen (indien nodig).

Appendix B: Respondents

[Due to confidentiality, the content of this appendix (page 121) is not part of the public version of the final report]

Appendix D: The researched system

[Due to confidentiality, the content of this appendix (page 123) is not part of the public version of the final report]

Appendix E: [Not mentioned in the public version]

[Due to confidentiality, the content of this appendix (page 123) is not part of the public version of the final report]

