Stimulating technological innovation:

Problem identification and intervention formulation with the technological innovation systems framework

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Het stimuleren van technologische innovatie:
Problemen identificeren en interventies formuleren met het technologisch innovatiesysteem raamwerk

(met een samenvatting in het Nederlands)

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CONTENT

Chapter 1

Introduction – Stimulating technological innovation

1.1 BACKGROUND OF THE TECHNOLOGICAL INNOVATION SYSTEMS FRAMEWORK

Technological innovation is in high demand. It not only embodies the potential for efficiency increase, new products, and higher profits, but also for higher economic growth, improved employment, and solving societal challenges (e.g. climate change). Whatever the reason to strive for technological innovation, insight into how successful innovation processes generally unfold is of value.

Creating this insight is not an easy task as the innovation process is non-linear, systemic, and involves a multitude of factors other than the innovation itself. For instance, innovation is a collective act performed by many actors who are both enabled and constrained by the prevailing institutional infrastructure (e.g. Edquist & Johnson, 1997; Chaminade & Edquist, 2010). What is more, technologies and actor behavior are intertwined to such an extent that they can hardly be analyzed independently (e.g. Hafkamp, 2006). Despite the magnitude of the challenge, the innovation systems framework provides a theory to understand under what conditions innovations are successfully developed and implemented.

The national innovation systems framework, which became the first of many innovation system strands, was developed to provide insight into what determines national competitiveness. It emerged at the end of the 1980s/beginning of the 1990s, at a time when especially western countries were confronted with increased competition on the global market, for instance from China and from new countries formed after the dissolution of the Soviet Union. The national innovation systems framework emerged in Europe, and was built on the idea that, as its name already gives away, national competitiveness depends on the extent to which nations create the right conditions for innovation (Freeman, 1987; Lundvall, 1992). The framework has many similarities with the theory of Porter on national competitive advantage (Porter, 1990a, 1990b) that emerged in the United States at around the same time. Porter's theory builds on the idea that the competitive advantage of nations depends on the extent to which the right conditions are created for companies to be internationally competitive, for which innovation is imperative. Since both frameworks shed light on a pressing issue of the time, there was much contact between academia and policy makers already in the early phases of theory development (Porter 1998; Sharif, 2006).

After the national innovation systems framework became more widespread, the initially national and economic development oriented framework was adapted so that it could also provide insights in other domains and for other purposes. For instance, Cooke et al. (1997) explained that there were sometimes good reasons to analyze innovation processes at the level of the region, and Malerba (2002) proposed the same for the sector. This led to the emergence of two additional innovation system strands, namely regional and sectoral innovation systems, both of which still focus mainly on questions related to economic development. The last main strand that emerged[1] focused on specific technologies or technological domains (Carlsson & Stankiewiecz, 1991; Carlsson et al., 2002) and is nowadays called the Technological Innovation System (TIS) framework (e.g. Markard & Truffer 2008; Jacobsson & Jacobsson, 2014). Contrasting the earlier innovation system strands, the TIS-framework focused more on the merits of technological innovation for solving societal challenges (e.g. climate change).

There is a broad consensus that the structure of any innovation system comprises actors, interactions between these actors (networks), and institutions in the form of both formal and informal rules. Some authors also distinguish additional elements, such as technology or infrastructure (Chaminade & Edquist, 2010; Jacobbson & Bergek, 2011; Jacobsson & Jacobbson, 2014; Klein Woolthuis et al., 2005; Markard & Truffer, 2008; Wieczorek & Hekkert, 2012). These structural elements show many interactions and feedback loops, reflecting the nonlinear, systemic and complex nature of the innovation process.

Literature on innovation systems prescribes that innovation policy requires a tailor-made approach that fits the specifics of the innovation process, leading all innovation system strands to break with the neoclassical policy rationale of market failures. Instead, as the success of innovations is deemed to depend on how well the system that forms around it performs, any intervention that improves system performance is seen as desirable.

Initially, the innovation systems framework mainly tried to identify problems[2] (reasons for weak system performance) directly in the system structure. However, this proved to be difficult for multiple reasons. Firstly, it is difficult to judge or measure whether an element of the structure is 'good' or not. For example, if ten entrepreneurs are active in a system, is that sufficient? Secondly, a 'good' structure in one country, region or sector may not be 'good' in another. For instance, in some countries R&D is mainly performed by companies, while in other countries it occurs more in research institutes (Edquist, 2006). As long as R&D is performed, one is not preferred over the other. Thirdly, the system is dynamic, which means that if a 'good' structure has been found, it is already outdated. To tackle these conceptual issues, the focus shifted from the structure

1 New strands are still emerging, for instance Agricultural Innovation Systems (e.g. Klerkx et al., 2012). The Entrepreneurial Ecosystems framework (e.g. Stam, 2015) also has much in common with the Innovation Systems framework.

2 Different terms have been used to indicate such weaknesses in innovation systems, including systemic problems (Chaminade & Edquist, 2010; Wieczorek, 2014), system failures (Klein Woolthuis et al., 2005; Weber & Rohracher 2012) and blocking mechanisms (Bergek et al., 2008). Each term has nuances of meaning which I describe in detail in chapter 2.

only to the contribution of the structure to the fulfillment of certain key processes. The concept of key processes became especially prominent, and was further developed, within the TIS framework in which these key processes are often called 'functions' (Bergek et al., 2008; Hekkert et al., 2007).

Under this new reasoning, the structure can be considered 'good' if the functions are satisfactorily fulfilled. If function fulfillment is unsatisfactory, the structure must be considered 'not good', resulting in a system that does not develop at all or that develops in a 'stunted fashion' (Bergek et al., 2008). Structure and functions are thus two sides of the same coin, or as Markard and Truffer have put it: "two intertwined sides of the same object, the system" (2008, p. 601). An important advantage of thinking in terms of functions next to structures is that functions are more universal among countries, regions, sectors or technological domains, as different structures may lead to similar function fulfillment. To exemplify the relationship between structure and functions, Textbox 1.1 explains it using the simile of a four-stroke engine.

Textbox 1.1: The simile of the engine.

It must be noted that there are many limitations of comparing innovation systems with engines. Among other things: an engine is mechanistic, whereas an innovation system is social; the parts of an engine do not change and evolve, whereas the elements of an innovation system do; failure in one part of a motorcycle engine often leads to complete failure, whereas failure in one part of an innovation system will only slow it down; and finally, there is no agency in a motorcycle engine, whereas this is an important aspect of innovation systems (see e.g. Farla et al., 2012; Markard et al., 2012. Despite these limitations, the comparison works well for clarifying the relationship between functions and structure. The following simile is based on the book Zen and the Art of Motorcycle Maintenance (Pirsig, 1974) in which a motorcycle engine is also described in terms of structure and functions.

A motorcycle engine consists of parts, e.g. the cylinder, piston and rings, carburetor, connection rod, crankshaft, valves and sparkplug. These can be called the structural elements of the engine. A large variety of four-stroke engine designs is available, for instance, they can have one or multiple cylinders and can have different cylinder configurations (V-shaped, opposed etcetera). This diversity in structures makes it difficult to identify when the structure is 'good'.

The four strokes can be considered the functions of an engine: the air-fuel mixture is (1) drawn in the combustion chamber, (2) compressed, (3) made to explode and (4) pushed out as burned gas. Pumping around oil is another function of the engine. These functions are fulfilled well if the parts (structural elements) of the engine interact in the way they are supposed to, but are not fulfilled well if there is a problem with one of its parts. Note that these functions must be fulfilled in any four-stroke engine, independent of the number of cylinders or cylinder configuration. Now, the structure of an engine can be considered 'good' if all functions are satisfactorily fulfilled.

If you want to identify what is causing an engine to run in a stunted fashion, it is first necessary to have a basic understanding of its parts (structural elements). Then, you run the engine and look for signs of weak functions (e.g. black smoke). Subsequently, you diagnose which function is not fulfilled properly. For example, you may find that there is insufficient pressure buildup in the cylinder chamber by using a pressure gauge (determine function fulfillment). Then, you locate the cause, e.g. worn piston rings or valves that do not close completely (problems in structure). Finally, you fix it by replacing the piston ring or cleaning the valve (intervening in structure) after which the engine should run smooth again. If not, the diagnosis process must be repeated.

To identify the key processes or functions of a TIS, authors analyzed system buildup around historically successfully developed and implemented technologies. The identified patterns materialized into lists of TIS-functions (Bergek et al., 2008; Hekkert et al., 2007; Hekkert & Negro, 2009; Jacobsson et al., 2004; Johnson, 2001). For instance, Hekkert et al. (2007) distinguishes between seven functions, namely (F1) entrepreneurial activities, (F2) knowledge development, (F3) knowledge diffusion through networks, (F4) guidance of the search, (F5) market formation, (F6) resources mobilization, and (F7) creation of legitimacy/counteract resistance to change. What is more, the framework distinguishes between multiple phases of development that a TIS general moves through, and for each of these phases of development, patterns of desirable feedback loops between functions have been identified (Hillman et al., 2009; Suurs, 2009; Suurs & Hekkert, 2009). Nowadays, TIS-analyses have been performed on a multitude of – often renewable energy related – technologies, for instance solar energy (e.g. Jacobsson et al., 2004; Dewald & Truffer, 2011), wind energy (e.g. Jacobbson & Karltrop, 2013; Wieczorek et al., 2013), and biomass (e.g. Negro et al., 2007, 2008).

The addition of functions to the TIS theoretical framework strongly improved its ability to identify problems and formulate interventions. Knowing what functions are not fulfilled well provides a clear rationale for intervention: if function fulfillment is improved, system performance will improve, which will in turn increase the chance that the technology in focus will be further development and implemented. This can be achieved by alleviating problems in the system structure that inhibit function fulfillment. In this way, functions act as a focusing device as they point the attention in the direction of the problems that matter. In this dissertation, the focus is placed not on the TIS theoretical framework a whole. It for instance does not discuss the usefulness of the TIS theoretical framework for understanding why some technologies have become a success and others not. Instead, this dissertation focusses on the part of the TIS theoretical framework that facilitates the formulation of interventions, which will further be called the TIS *intervention* framework.

1.2 FOUR LIMITATIONS OF THE TIS INTERVENTION FRAMEWORK

This section will place the current TIS intervention framework under a magnifying glass and works toward identifying four theoretical limitations that limit its potential. For this, it is discussed to what extent the TIS intervention framework facilitates an analyst from the start of the research project to the formulation of interventions. The four identified theoretical limitations form the starting point for this dissertation's subsequent chapters.

Both Bergek et al. (2008) and Wieczorek and Hekkert (2012) have proposed a stage-wise approach for TIS-analyses that have the purpose of identifying problems and formulating interventions. Table 1.1 provides an overview of the distinguished stages by these authors, and shows that both approaches are quite similar.

Table 1.1: structural/functional analysis steps.

Analysis stages	**Equivalent stages in Wieczorek and Hekkert (2012)**	**Equivalent stages in Bergek et al. (2008)**
1. System boundaries	-	Defining the TIS in focus
2. Describe structure	Mapping structural dimensions and their capabilities	Structural components
3. Determine and assess functioning	Coupled structural –functional analysis	Functions and functional pattern
		Assessing functionality & setting process goals
4. Identify systemic problems	Identification of systemic problems	Inducement & blocking mechanisms
5. Formulate interventions	Goals of systemic instruments	Key policy issues
	Design of systemic instruments	-

The system boundaries are set in the first analysis stage. This stage is given explicit attention to in Bergek et al. (2008) and only implicitly in Wieczorek and Hekkert (2012). The second stage concerns describing the structure of the delineated TIS, which is done by mapping structural elements. Both Wieczorek and Hekkert (2012) and Bergek et al. (2008) use a synonymous term for 'structural element', namely structural dimension and structural component respectively. Third, the functioning of the system is determined and assessed. Wieczorek and Hekkert (2012) call this a structural/functional analysis, because indicators for the functioning can be found in the system structure (e.g. number of entrepreneurs as indicator for the function entrepreneurial activities). In relation to the assessment of the determined functional pattern, only Bergek et al. (2008) emphasizes taking into account the TIS' phase of development, because the desirable functional pattern differs for each phase. Then, the fourth stage entails the identification of problems that underlie the weakly fulfilled functions. Where Wieczorek and Hekkert (2012) use the term systemic problem, Bergek et al. (2008) uses the largely synonymous term blocking mechanism. In addition, Bergek et al. (2008) explain that it is useful to not only identify what is inhibiting TIS development (blocking mechanisms), but also what is stimulating it (inducement mechanisms). Finally, in the fifth stage, interventions are formulated. Bergek et al. (2008) stop after the identification of policy issues, whereas Wieczorek and Hekkert (2012) continue with 'designing systemic instruments', which is synonymous for intervention formulation. The above process is highly iterative, meaning that the analyst may, or even should, go back and forth between different stages.

The TIS intervention framework already facilitates the first three analysis stages to a large extent. How boundaries can be set and what considerations may play a role while setting them has been extensively discussed in literature (e.g. Carlsson et al., 2002; Bergek et al. 2008; Hekkert et al., 2007; Markard & Truffer, 2008). In addition, although there is still some discussion about what structural elements can be distinguished, describing the system structure is a rather straightforward process. What is more, as also explained above, the framework already provides much insight into what processes (functions) are desirable, specified for different phases of TIS development. The subsequent sections discuss four theoretical limitations of the current TIS intervention framework, one of which has consequences mainly for problem identification, two for both problem identification and intervention formulation, and one for only intervention formulation.

To start with, the identification of problems in an innovation system is a process of following causality. Ultimately, the interest lies in understanding weak system performance, which the TIS framework prescribes can be traced back to weak function fulfillment. Subsequently, weak function fulfillment can in turn be traced back to problems in the system structure. The term blocking mechanism currently reflects this form of causality as it represents the 'mechanism' between problems in system structure, through functions, to ultimately system performance.

However, when focusing on the problems in system structure themselves, there is little to no attention for causality. A blocking mechanism is used to indicate a single problematic 'factor' pertaining to the system structure. This has as consequence that a TIS-analysis generally leads to the identification of independent problems (see e.g. Faber & Hoppe, 2013; Patana et al., 2013; Wieczorek et al., 2013), after which interventions are formulated for each problem separately. Furthermore, available overviews and categorizations of potential problems are presented as lists and thereby suggest conceptual independence (see e.g. Chaminade & Edquist, 2010; Klein Woolthuis et al., 2005; Negro, et al., 2012; Weber & Rohracher, 2012). All of this is striking, since innovation systems literature has, in places, mentioned that problems in innovation systems reinforce each other (Johnson & Jacobsson, 2001; Klein Woolthuis et al., 2005). This is also what is to be expected from a framework that emphasizes the highly dynamic nature of the innovation process. In other words, the interactions between problems in innovation systems have so far largely been neglected, which brings us to the first limitation of the TIS intervention framework in relation to problem identification: *limited attention for how problems interact, influence each other, and may form chains of causes*.

What is more, analysts may be confronted with varying, if not inconsistent, opinions in data when identifying problems or formulating solutions in the form of interventions. For instance, one actor may argue that limited government regulation is a problem, while another argues that this is desirable. Sometimes the role that an actor has in the innovation system may provide part of the explanation, for example, government versus companies. However, different opinions also often exist within otherwise relatively homogenous actor groups (e.g. between companies that produce similar products, or between government officials that pursue the same goals). This puts the analyst in a difficult position and may – even though this does not do justice to the data – entice the analyst to favor one opinion over the other or to ignore that the data is inconsistent. However, there are reasons to believe that there are ways for coping with such data inconsistencies, namely, values play an important role in what problems and potential solutions actors perceive or as Hafkamp (2006) puts it: "[…] their dialogue on problems and solutions is value-based from the start […]" (p. 377). In other words, problems and potential solutions are highly subjective. What is more, Verschuren (2010), while describing how research can go about diagnosing problems (not specifically innovation systems research), mentions that: "Sometimes it is less important to indicate the exact causes of a problem than to learn more about the opinions shared by the different stakeholders with regard to the background and the causes of the problem. In these cases, insights into the opinions and perceptions are more important than objective knowledge of a problem." (p. 34). This leads us to the second limitation of the TIS intervention framework: *it does not provide the theoretical means for coping with inconsistent data on problems and potential solutions.*

The third theoretical limitation relates to the context of a TIS. Since reasons for weak performance may be found in a systems' context, taking sufficient context into account during problem identification and intervention formulation is important. Textbox 1.2 explains how the simile of the engine introduced earlier already implied the importance of system context for innovation systems. Recent literature on technological innovation systems has specifically emphasized context (Bergek et al., 2015), and has proposed how it can be conceptualized. In multiple occasions this work emphasizes that context structures are not static: "They tend to change over time, both as a matter of autonomous developments in context structures and as a consequence of the focal TIS growing and becoming more mature." (p. 56). However, when focusing on sectoral context structures, the nature of the relation with a TIS is explained differently: "A sector […] provides a quite stable context, which individual TISs either have to adapt to or try to change to their own benefit." (p. 56). This raises the question whether it can be assumed (as the latter quote suggests) that the sectoral context is 'quite stable', or whether an open mind about the influence of sectoral context structures on TISs is necessary (as the former quote suggests). This brings us to a third limitation of the TIS intervention framework: *questions remain about what influence sectoral context structures have on TISs.*

Textbox 1.2: The simile of the engine (continued).

> Problem diagnosis of an engine can also result in the conclusion that its 'stunted fashion' has nothing to do with the engine itself, but with its context. For example, black smoke can also be caused by lean mountain air. In this case, there are two interventions possible of which the first is to reduce the amount of fuel added by the carburetor (intervention in system structure). The second intervention possible is to drive the motorcycle down to a valley (adapt the context). For innovation systems, changing the context is often more difficult, for instance because the actors have little influence over them (e.g. macro-economic decisions, fluctuating energy prices etc.). However, although changing the contextual setting may be impossible for actors in an innovation system, it is sometimes possible to negate negative influence from 'outside'. An example is linking renewable energy subsidies (internal structure for a renewable energy related TIS) to the oil price (exogenous factor). If subsidies go up when oil prices go down, the relative advantage of renewable versus fossil-fuel technologies remains the same, thereby limiting the influence of contextual structures. In this way, this simile thus implies that, when diagnosing why a TIS is running in a 'stunted fashion', giving attention to context of a TIS is important.

In relation to the next analysis stage – intervention formulation – literature on innovation systems provides guidance up to the point of formulating options for interventions, but does not go beyond. For instance, categorizations of possible interventions are available that may act as inspiration (e.g. Weber & Rohracher, 2012; Wieczorek & Hekkert, 2012). A consequence of this is that the output of a TIS analysis is often, if not always, a list of intervention options that may alleviate the identified problems. Although this is where a TIS-analysis usually stops, the subsequent activity will be to make a selection from the available intervention options, thereby possibly combining multiple interventions. Unfortunately, the TIS intervention framework currently does not provide insight into what considerations underlie this choice process. Although it is clear that interventions with the largest potential impact will be preferred – in the case of innovation systems the impact on improving system performance - little is known about what factors influence the impact of interventions, or a set of interventions, on improving system performance. This brings us to the fourth limitation of the TIS intervention framework: It provides little insight into what type of intervention, or set of interventions, is likely to have a large impact on improving the performance of an innovation system.

The above four limitations show that the already strong TIS intervention framework can still be strengthened, especially in relation to the problem identification and intervention formulation stages. For each of the four identified limitations of the current framework, either adaptations or extensions will be proposed. These adaptations or extensions are subsequently applied to case study material, after which their merit is reflected upon. Since, as consequence of the highly iterative nature of a TIS-analysis, the proposed theoretical adaptations or extensions sometimes have consequences for the preceding analysis stages of boundary setting, structure description and determining function fulfillment, these are thus reflected upon when relevant. In this way, the research objective of this dissertation is to further strengthen the TIS intervention framework.

1.3 CASE SELECTION

For this dissertation, cases were selected from the empirical domain of energy-efficient houses in the Netherlands. There were four main reasons for this. First, this empirical domain is a good candidate for TIS-analyses because making the housing stock energy-efficient is strongly dependent on further development and implementation of technologies. Second, analyzing the construction sector has already proven a good empirical domain for gaining insights into how innovation can be stimulated, both in the Netherlands (e.g. Bossink, 2002; 2004; 2007;

2011) and in other countries (e.g. Rohracher, 2011). Third, the Dutch construction sector is still associated with many problems (Faber & Hoppe, 2013) and possibilities for improvement thus seem manifold, making further insight into how innovation may be accelerated desirable. Fourth, since a multitude of technologies must come together to either built or renovate a house energy-efficiently, a wide variety of innovation systems can be distinguished. For instance, independent technologies can be delineated as a technological innovation systems by itself, or the sector as a sectoral innovation system that is making use of technologies from different technological innovation systems. Most importantly, however, is that this domain is highly dynamic and thus complex: insights gained from exploring complex cases are usually also applicable to less complex ones, but not vice versa.

Although not all innovation systems analyzed in this dissertation are delineated as technological innovation systems, all insights gained are applicable to the TIS intervention framework. This is a consequence of all innovation system strands sharing central theoretical concepts, which makes alternative conceptualizations explored for innovation systems in general also applicable to TISs.

1.4 RESEARCH QUESTIONS AND OUTLINE

The four limitations of the current TIS intervention framework as identified in Section 1.2 provided the starting point for the research projects performed as part of this dissertation. This section explains what research question was posed, and what approach was taken in each of these research projects. Since these research projects will subsequently be presented, this section also forms the outline for the rest of this dissertation.

Chapter 2 explores the limited attention for how problems interact, influence each other, and may form chains of causes. The objective of this chapter is to explore whether an innovation system analysis that gives explicit attention to problem interactions yields contrasting or additional insights compared to an analysis of independent problems. This chapter presents an innovation system analysis of Dutch energy-efficient housing during which explicit attention was given to how problems interact. As part of the analysis, an alternative meaning of the term blocking mechanism was used, namely as a 'mechanism' consisting of interacting systemic problems. This chapter answers the following research question: <u>What problems inhibit the Dutch energy-efficient housing innovation system, how do these problems interact, does analyzing problem interactions provide additional insights compared to analyzing independent problems, and if so, what are these additional insights?</u>

Chapter 3 makes a contribution to overcome the second limitation of the TIS framework, namely that it does not provide the theoretical means for coping with inconsistent data on problems and potential solutions (interventions). The starting point of this chapter is that this is the result of an implicit assumption in literature, namely that an analyst can reveal the objective truth of what the problems are. Instead, this chapter takes a subjectivist view, thereby giving attention to the value-based nature of problems and solutions (Hafkamp, 2006). Our approach is based on the notion that actors focus their attention only on problems, and solutions, that are consistent with the institutional logics that guide them (Thornton et al. 2012). Institutional logics are "the socially constructed, historical patterns of material practices, assumptions, values, beliefs, and rules by which individuals produce and reproduce their material subsistence, organize time and space, and provide meaning to their social reality." (Thornton & Ocasio, 1999, p. 804). Institutional logics theory explains that actors are guided by institutional logics to act, and in this way, logics determine what problems and solutions are perceived (Thornton & Ocasio, 1999). In relation to innovation systems, this leads to the premise that inconsistent data on problems and potential solutions can, at least sometimes, be traced back to institutional logics that conflict. The objective of this chapter is thus to explore the usefulness of institutional logics theory for coping with inconsistent data regarding problems and potential solutions during an innovation system analysis, and if found useful, how this can be approached. This is explored by analyzing what institutional logics guide actor behavior in the Dutch innovation system of renovating houses energy efficiently, for which the following research question is posed: What institutional logics guide actor behavior in the Dutch innovation system of renovating houses energy-efficiently, and what insights do these logics provide into the origin of conflicting opinions about problems and potential solutions as collected for this innovation system?

Chapter 4 subsequently targets the third limitation of the TIS framework, namely that questions remain about what kind of influence sectoral context structures have on TISs. The objective of this chapter is to increase our understanding on the nature of TIS/sector interactions. For this, a TIS-analysis is presented of the heat pump for renovation purposes in the Netherlands, during which context, especially sectoral context, was given explicit attention. The conceptualization of TIS-context from Bergek et al. (2015) formed the conceptual foundation for the analysis. This chapter aims to answer the following research question: How does sectoral context influence function fulfillment in the heat pump technological innovation system in the Netherlands?

Chapter 5 aims to shed give first insights into what type of intervention, or set of interventions, is likely to have a large impact on improving the performance of an innovation system. As this is a challenging question that can surely not be answered in this dissertation alone, the objective of this chapter is restricted to lay a preliminary foundation for a conceptual framework that should increase our understanding on this matter. For this, inspiration was found in the intervention framework of systems thinking[3] (Forrester, 1995; Meadows, 2008; Senge, 1990; de Vries, 2013), more specifically in the idea that the transformational power of interventions relates to the characteristics of the points in a system where the intervention acts upon. This idea comes from the concept of leverage points (Meadows, 1999; 2008) and has materialized into a ranking of points in a system on the chance that they embody for creating transformational change. In this chapter, the reasoning behind this ranking is, in a preliminary way, adapted to fit the TIS framework. Through an illustrative case study of highly energy-efficient houses it is illustrated how the ranking can be used as addition to an innovation systems analysis. This chapter concerns the following research question: What influences the impact of interventions on improving the performance of a technological innovation system, and can interventions be ranked based on these insights?

Chapter 6 discusses the findings from each chapter in relation to the theoretical limitations as set forth in section 1.2. In addition, chapter 6 reflects on main implications, limitations and possibilities for future research. Finally, it is concluded to what extent this dissertation has contributed to strengthening the TIS intervention framework.

3 Systems thinking has already proven useful for gaining insights in relation to TISs (e.g. Walrave & Raven, 2016).

Chapter 2

Interactions between systemic problems in innovation systems: The case of energy-efficient houses in the Netherlands*

* This chapter is based on the forthcoming paper Kieft, A., Harmsen, R., Hekkert, M.P. (in press). Interactions between systemic problems in innovation systems: The case of energy-efficient houses in the Netherlands. *Environmental Innovation and Societal Transitions*. doi:10.1016/j.eist.2016.10.001. A previous version of this paper was presented at the 2015 annual conference of the EU-SPRI forum: *Innovation policies for economic and social transitions: Developing strategies for knowledge, practice and institutions*, organized by VTT in Helsinki, Finland on June 10-12, 2015.

2.1 INTRODUCTION

Different terms have been used to indicate problems in innovation systems, including systemic problems (Chaminade & Edquist, 2010; Wieczorek, 2014), system failures (Klein Woolthuis et al., 2005; Weber & Rohracher, 2012) and blocking mechanisms (Bergek et al., 2008).[1] Although especially the term blocking 'mechanism' suggests that feedback plays an important role to understand problems in innovation systems, problems are, to the best knowledge of the authors, not conceptualized as such. Even though some literature mentions that problems in innovation systems reinforce each other (Johnson & Jacobsson, 2001; Klein Woolthuis et al., 2005), the overviews and categorizations of potential problems are presented as lists and thereby suggest conceptual independence (see e.g. Chaminade & Edquist, 2010; Klein Woolthuis et al., 2005; Negro et al., 2012; Weber & Rohracher, 2012). Case studies also reflect this conceptual independence of problems since they generally discuss problems one by one (see e.g. Faber & Hoppe, 2013; Patana et al., 2013; Wieczorek et al., 2013).

The main premise of this chapter is that problems in innovation systems often interact, and may form 'mechanisms', that in turn prevent the innovation system to develop. In order to further explore this, we carried out a case study of the Dutch energy-efficient housing innovation system. Our aim is to answer the following question: What problems inhibit the Dutch energy-efficient housing innovation system, how do these problems interact, does analyzing problem interactions provide additional insights compared to analyzing independent problems, and if so, what are these additional insights? Based on the insights from this case study, we reflect on the merits of giving explicit attention to problem interactions during a TIS-analysis.

2.2 THEORY

Literature on innovation systems mentions in some places that problems interact. For instance, "[…] there is a range of obstacles […], which may act independently but are likely to reinforce one another" (Johnson & Jacobsson, 2001, p. 95), or "Most problems in the innovation system will not be uni-dimensional but will consist of a complex mixture of causes and effects […]" (Klein Woolthuis et al., 2005, p. 614). Despite this, problem interaction has not yet received much conceptual attention, which is reflected in how literature discusses problems. For instance, literature that discusses potential problems in innovation systems relates most problem categories to single structural elements (a.o. Chaminade

1 The nuances of meaning of these terms are discussed in the Theory section (2.2).

& Edquist, 2010; Klein Woolthuis et al., 2005; Negro et al., 2012; Weber & Rohracher, 2012). Chaminade et al. (2012) puts it this way: “almost each author has his or her own list of potential systemic problems” (p. 1477), to subsequently add that the types of problems discussed in literature “can be pinned down to infrastructure problems, [actor] capability problems, network problems, institutional problems and transition and lock-in problems” (p. 1477).[2] Others hint at a direct conceptual relation between problems and structural elements (Jacobsson & Bergek, 2011),[3] which implies that interactions between problems do not matter, or explain that analysts should determine whether “the weakness of the function has something to do with actors, institutions, interactions, *or* infrastructure [emphasis added]” (Wieczorek & Hekkert, 2012). Evidently, there is room for exploring the conceptual value of problem interactions in innovation systems.

The limited theoretical attention for problem interactions also reflects on case studies, as these – not infrequently – present a single independent problem to underlie a weak function. For instance, Patana et al. (2013) mention in their discussion of the Finish life science innovation system that actors in the field are too scattered, leading to difficulties in deciding on a concerted direction. In this example, there is probably another problem that underlies this scattered nature of the field, among other possibilities, a wide spatial distribution of actors, a lack of trust, or possibly a lack of financial means to organize regular meetings. A second example – related to the function mobilization of resources – comes from the analysis of the European Wind TIS by Wieczorek et al. (2013). They find that “in the future, if the offshore wind system develops, the scarcity of specialized, deep water vessels may […] become a serious constraint” (p. 304). Yet, it is not explained why this situation may arise, even though this can be a result of problems related to, for instance, difficulties for vessel suppliers to get loans (financial infrastructure) or a lack of skilled personnel (human infrastructure). These examples show that the identification of independent problems often leaves questions open about what made them arise, thus posing challenges for formulating interventions. This does not imply that any innovation system analysis contains loose ends; analysts often implicitly give attention to what causes what in their text. Yet, especially for more complex innovation systems it is very challenging for an analyst to oversee all problems and all interactions without an explicit analysis of how problems interact.

2 The problem category of ‘transition and lock-in problems’ does at first sight involve feedback. However, as Klein Woolthuis et al. (2005) persuasively argued, ‘lock-in’ is the result, rather than the cause of unsatisfactory system performance and can thus not be classified as a problem category.

3 They mention: “Indeed, all the four types of system failures identified by Klein Woolthuis et al. (2005) in their synthesis and re-categorisation of previous literature on system failures are related to structural components […]” (p. 46).

Authors have used a variety of terms to indicate ‘problems’ in innovation systems; each with its own nuance of meaning. First, the term ‘systemic problem’ is generally used to indicate weaknesses that pertain to the internal system structure (endogenous problems). Second, the term blocking mechanism – prominent in especially TIS literature – points at any factor[4] that causes weak function fulfillment. These factors can reside either inside (endogenous) or outside (exogenous) the system (Johnson & Jacobsson, 2001; Bergek et al., 2008). Finally, although the term system ‘failure’ has been used as synonym for systemic problem by some authors (Klein Woolthuis et al., 2005), it is also increasingly employed to indicate broader issues with an innovation system (Weber & Rohracher, 2012). As it is now, the conceptual link between the terms systemic problems, blocking mechanism and system failure is not clear.

In this chapter, we focus on the conceptual link between the terms systemic problem and blocking mechanism and – based on the insights from our case study – propose a reconceptualization in such a way that interactions between problems become conceptually part of them.[5] Instead of using the term blocking mechanism to indicate a problematic ‘factor’, we use it to indicate a ‘mechanism’ consisting of interacting systemic problems. Such a blocking mechanism will usually include systemic problems that pertain to the internal system structure (endogenous systemic problem), but can also contain problems from its context (exogenous systemic problem). Note that, by including exogenous problems in the term systemic problems, we give it a broader meaning than what is currently prominent in literature. This reflects the increased attention for the system context in recent literature on innovation systems (e.g. Bergek et al., 2015). Under this new conceptualization, weak function fulfillment and weak system performance may thus be caused by a blocking mechanism that consists of interacting systemic problems. To illustrate how this may work during an innovation systems analysis, our case study makes use of these adapted meanings of the terms systemic problem and blocking mechanism.

We based the selection of our case study on the expectation that an explicit analysis of how systemic problems interact has added value especially for innovation systems that share one or more of the following related characteristics: mature, locked-in (Unruh, 2000), making a transition, and strongly structurally coupled with contextual systems. First, mature systems are often relatively large which leads to many feedback loops between elements of the system. Second, such systems are of-

4 For instance, Bergek et al. (2010) mention that blocking mechanisms are “factors that provide obstacles to the development of functions” (p. 131), and Jacobsson and Karltorp (2013) use the terms factors and blocking mechanisms interchangeably.

5 In the Discussion section (2.5) we reflect further on the conceptual link with the term ‘system failure’.

ten locked into certain technological combinations. For example, the Dutch energy-efficient housing innovation system can be considered a mature sectoral innovation system that is locked into the combination of using little insulation with gas-based technologies for heating. Lock-in is not necessarily problematic; such a system may have developed effective routines to deal with problems. However, when a transition is desired, this locked-in nature of the system will inhibit change and may become the source of problems itself. In our case study, the system is making the transition toward building highly energy-efficient houses,[6] and the advent of new technologies (e.g. better insulation materials, renewable energy technologies etcetera) is increasingly putting pressure on current routines. What is more, mature systems often have strong structural couplings with their context (Bergek et al., 2015). Problems that express themselves in such systems often have their origin outside of the immediate system boundaries, making it fruitful to analyze how the problems inside and outside the system interact. In our case study for instance, strong structural couplings with TISs of non-renewable technologies must be broken down, whereas structural couplings with TISs of renewable technologies must be created or strengthened. Additionally, since buildings are inherently tied to a certain location, this innovation system is strongly affected by the Dutch geographical and political context structures, e.g. in the form of the strong Dutch political belief in decentralization as we will see in the case study (Section 2.4). The combination of these characteristics makes the innovation system of energy-efficient houses in the Netherlands a good candidate for exploring the merits of an explicit analysis of problem interactions.

2.3 METHOD

The data necessary to map systemic problems, their interactions, and possible blocking mechanisms that these form, came from the combination of interviews with practitioners and supplementary literature. The interviews were held with multiple stakeholders involved with highly energy-efficient houses. We used snowball sampling to identify potential interviewees. In total, 23 semi-structured interviews were conducted – lasting on average two hours – with government officials, project managers of housing associations, private project developers, construction companies and advisors/consultants. We collected supplementary literature to clarify statements given by the interviewees, e.g. the exact contents of

6 This is in line with the European goal of building only 'nearly-zero energy' houses by 2020 as introduced in Council Directive 2010/31/EU on the energy performance of buildings (recast) [2010] OJ L153/13 [EPBD recast]. To define highly energy-efficient, the definition of a nearly-zero energy building from the EPBD recast is used: "a building that has a very high energy performance […]. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby" (p. 18).

mentioned laws and regulations. Adding interviews and literature to the analysis stopped when this no longer led to new insights (theoretical saturation).

To determine how the systemic problems in this innovation system interact, it is important to know in which phase of the building process they arise. Our definition of these phases was based on the Dutch NEN 2574 norm (NEN, 1993),[7] to which a Land preparation phase was added. This led to the following phases (1) the Land preparation phase which includes the construction of basic infrastructures (roads, utility networks etcetera), (2) the Program phase which includes the formalization of goals and ambitions by project initiators, (3) the building Design phase and finally (4) the Construction phase. After the interviewees had mentioned a specific problem, they allocated it to a certain phase of the building process. Then, they were asked to explain what had caused this problem to arise and how this problem affected later phases of the building process. This led to elaborate descriptions of how problems interact.

Cards that resemble flashcards or playing cards were used to structure the interviews (see Figure 2.1). There were three types of cards available: (1) cards for problem categories, (2) blank cards and (3) cards for phases of the house building process. There were problem category cards for each of the structural elements and functions of an innovation system, for instance, the card 'rules and regulations' related to the structural element Institutions, and the card 'financial resources' related to the function Mobilization of resources. These problem category cards were meant to provide the interviewees with ideas for problem categories, although the possibility of adding additional problem categories was constantly stressed. The interviews started by asking what problems inhibit building highly energy-efficient houses in the Netherlands and in which building phase these problems manifest themselves. For each problem mentioned, a problem category card was placed on the table underneath the building phase card to which it corresponds. Interviewees could then specify the problem by writing on a blank card and placing it on top of the problem category card. If interviewees mentioned a problem that did not directly relate to the building process, the card was placed on the left side of the unfolding overview. This led to overviews of cards (for an example see Figure 2.1) that were not only accompanied with elaborate explanations for each problem separately, but also with explanations about how they interact. The interviews were recorded and transcribed into text.

7 The Use/Exploitation phase was dropped because it falls outside the research scope. Additionally, the Elaboration phase – of which tender activities and price setting are part – was not explicitly used during the interviews because these activities are increasingly made part of earlier phases (see section 2.4.1).

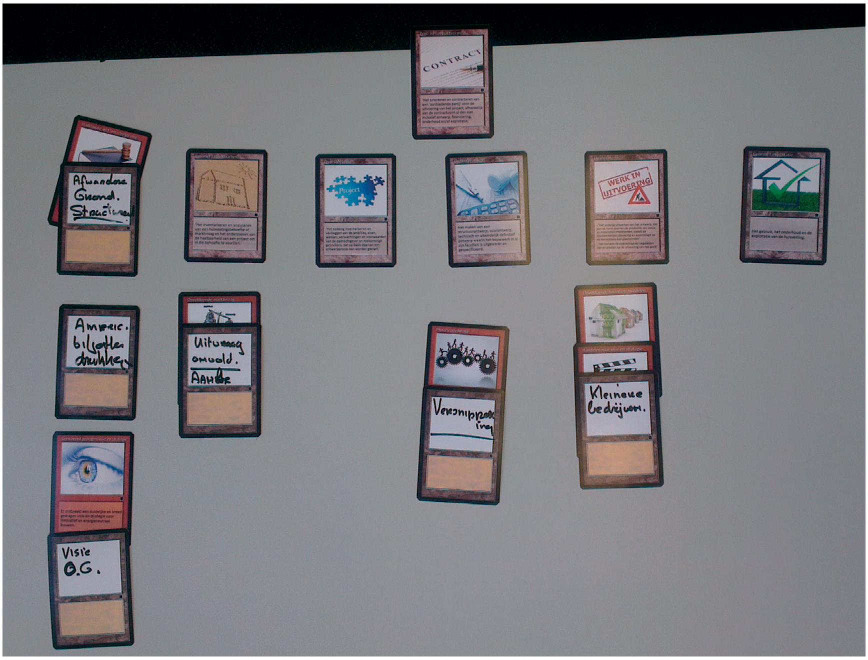


Figure 2.1: Photo portraying how cards were placed by one of the interviewees. Most interviewees placed more cards. This example was chosen for visual clarity.

Data analysis consisted of coding and grouping relevant textual fragments from both the interviews and the supplementary literature.[8] During this process, guidelines were used for initial coding (Charmaz, 2006), open coding (Strauss & Corbin, 1998) and focused coding (Charmaz, 2006). Next, a diagram was created to show how the identified problems interact (Figure 2.2 in Section 2.4.1). The process of creating the diagram resembled the process of axial coding (Charmaz, 2006). The elaborate explanations that interviewees had given of 'what caused what' formed the basis for the interactions in the diagram. Subsequently, a storyline was written to accompany the diagram, which was structured according to seven main umbrella themes that grouped problems with a certain common ground. A preliminary version of the diagram and the storyline were discussed and validated in a meeting with five experts on energy-efficient houses.

The final step consisted of linking the identified systemic problems to the structural elements, the system functions, and to categorize them as national, sectoral or technological. Categorizing problems as national, sectoral, or technological was straightforward for some problems, but in many cases the allocation

8 For this purpose, the Computer Aided Qualitative Analysis Data Software (CAQDAS) NVivo was used. NVivo qualitative data analysis software; QSR International Pty Ltd. Version 10, 2012.

process was fuzzy. For instance, some problems may have both national and sectoral characteristics (e.g. national regulations about how the land market is organized), while others have both sectoral and technological characteristics (e.g. construction companies causing technical problems because of a knowledge insufficiency regarding energy-efficient technologies). If allocation was difficult, sectoral was chosen over technological and national over sectoral. For linking the systemic problems to structural elements and system functions we used the definitions from Wieczorek and Hekkert (2012). The results of this final step can be found in Table 2.1 at the end of Section 2.4.1. To explore the question whether explicit attention for problem interactions during an innovation system analysis yields contrasting or additional insights compared to an analysis of independent problems, the data was analyzed in three steps. To begin with, two sets of systemic problems that both form a blocking 'mechanism' were selected from Figure 2.2 and placed in Figure 2.3. These two blocking mechanisms were subsequently analyzed and the gained insights compared to the output of an analysis that only identifies independent problems (for which the results would have resembled Table 2.1). Finally, the outcomes of our analysis were compared to an earlier innovation system study of this empirical domain (Faber & Hoppe, 2013).

2.4 RESULTS

The current situation in the Dutch innovation system of energy-efficient housing can only be understood against the backdrop of its history. From the end of World War II to the beginning of the 1990s, the Dutch house building sector was characterized by a high degree of central planning. The national government took the lead in reconstruction activities after World War II and decided on the areas where new houses were allowed to be built. To achieve high efficiency, house construction was organized in large projects in which whole neighborhoods were erected and this led to the dominance of larger construction companies, as only these could deliver the required capacity for constructing whole neighborhoods. Additionally, row houses became the norm because these could be built efficiently in series. Then, in the beginning of the 1990s, the national government decentralized responsibilities for constructing houses to municipalities and other local stakeholders, for instance, housing associations and private project developers. To incentivize these local stakeholders to take up this responsibility it was decided to restructure the land market, which provides the starting point for discussing the identified problems and their interactions.

2.4.1 Problem interactions in the innovation system of Dutch energy-efficient houses

This section provides a storyline to accompany all problems and their interactions as shown in Figure 2.2. These problems fall within three problem themes, namely Land market, Project-based approach (the standard house building process followed in the sector) and Resources.[9] Each box represents one problem and the connecting lines signify which problems interact. The different box outlines show whether a problem was allocated as sectoral, national, or technological (see Method, Section 2.3). Problems are placed underneath the building phase in which they arise and next to the problem theme they belong to. Problems that only indirectly influence the house building process are shown in the most left column. In the storyline below, the terms in italics correspond to the boxes in Figure 2.2.

The first theme – <u>*Land market*</u> – starts with the *decentralization of house-building activities* that took place in the beginning of the 1990s. Decentralization was facilitated by setting strict restrictions on the space allotted for development, and additionally by creating an *open land market* in which private actors could compete for this allotted space. This created *landscarcity,* which made land-prices skyrocket whenever a municipality decided to designate an area for constructing houses (this changed temporarily when the financial crisis hit in 2009). The national government hoped that high potential gains on land would persuade stakeholders to enter the land market and start housebuilding activities, thereby removing the need for national subsidies (Tijdelijke Commissie Huizenprijzen, 2013). Indeed, *speculation on land-prices and land development* became a profitable business which led to the involvement of private project developers and later also to the involvement of large construction companies and housing associations. As a result, most of the land in the Netherlands that has development potential came into the hands of speculating stakeholders.

Public organizations started to *behave like private enterprises*. Housing associations moved away from their core public task of providing cheap social housing and became active in the private segment. Municipalities – tempted by potentially high profits – also started to develop new housing areas more aggressively. The historic divide between public and private stakeholders faded.

Close interactions between public and private stakeholders at the beginning of the house building process became the norm. The designated land for a

9 Presenting and discussing all problem themes proved infeasible because of space limitations. A complete description of all identified problem themes can be found in Kieft et al. (2013). The other main themes were Conservatism, Building Concepts, EPC (Dutch calculation methodology for energy-efficiency of buildings) and insufficient Room for Experimentation.

new house building project is usually owned by multiple stakeholders (mostly private project developers, housing associations and municipalities). Since 'the one who owns the land has the right to build', these landowners are forced to collaborate. Therefore, these *landowners create consortia* in which decisions are made in consensus.

Land preparation activities, such as building the road and utility networks, are usually supervised by the municipality. To organize this efficiently, most municipalities first buy all the land from the other landowners, and grant them a so-called *construction claim* that gives them the right to buy the land back after land preparation activities are finished. These construction claims create a *monopoly position for landowners* as they are the ones that hold the development rights, even though they no longer own the land. In this way, construction claims form an almost *impenetrable entry-barrier for new companies*.

During the consensus processes that are typical within the consortia of landowners *innovative ambitions water down under pressure of commercial interests*. Although municipalities are often ambitious in terms of reaching high energy-efficiency, other landowners are often profit driven and thus disfavor any increase in construction costs. Their *monopoly position* provides them with strong bargaining power, resulting in f*ew energy-efficient technologies in building design*. As response, *municipalities create detailed development plans* with strict demands regarding building design and set *strict permit requirements*.

To distribute land profits among consortium members, the *residual land value calculation* methodology became widespread. This methodology subtracts all costs, for instance construction costs and land preparation costs, from the combined selling-price of the houses. What remains is called the residual land value, which is then distributed among consortium members. In this way, rising house prices increase the already *high profits for landowners (before the financial crisis)*.

As most houses in the Netherlands are developed and designed by companies that own the land (which allows them to make profit out of land development), the Netherlands counts *very few self-built houses*. Potential buyers have to accept the design choices made by the consortia that construct the houses. In other words, there is a very *limited role for potential buyers* (future home owners) in the first phases of the house building process, making this innovation system characterized by an extreme form of supply push.

The second problem theme – *project-based approach* – collects all problems related to the traditional way of organizing building projects in the Netherlands. In this approach, a specific development plan that satisfies the *strict permit requirements* from the municipality is created for each project.

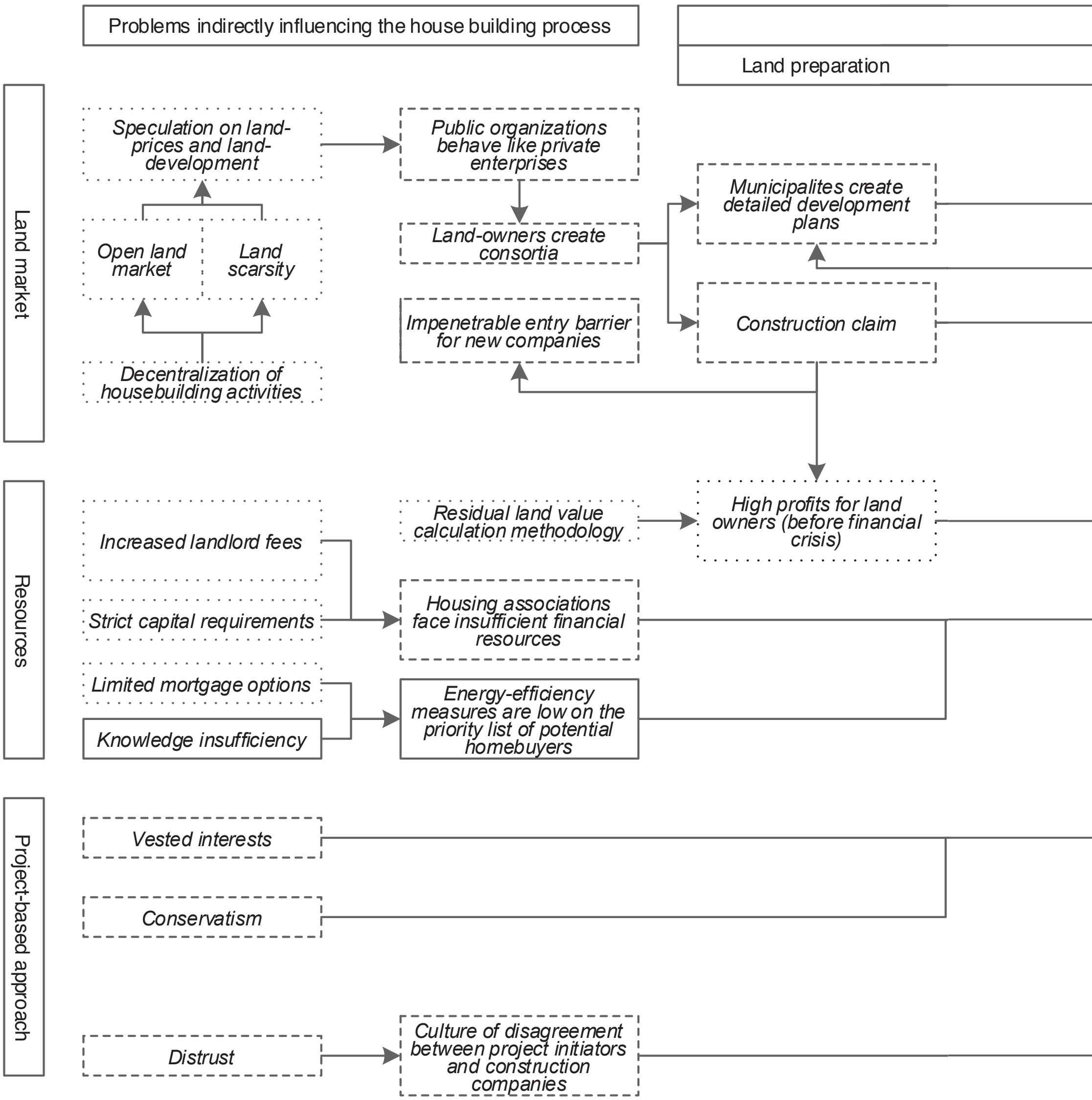
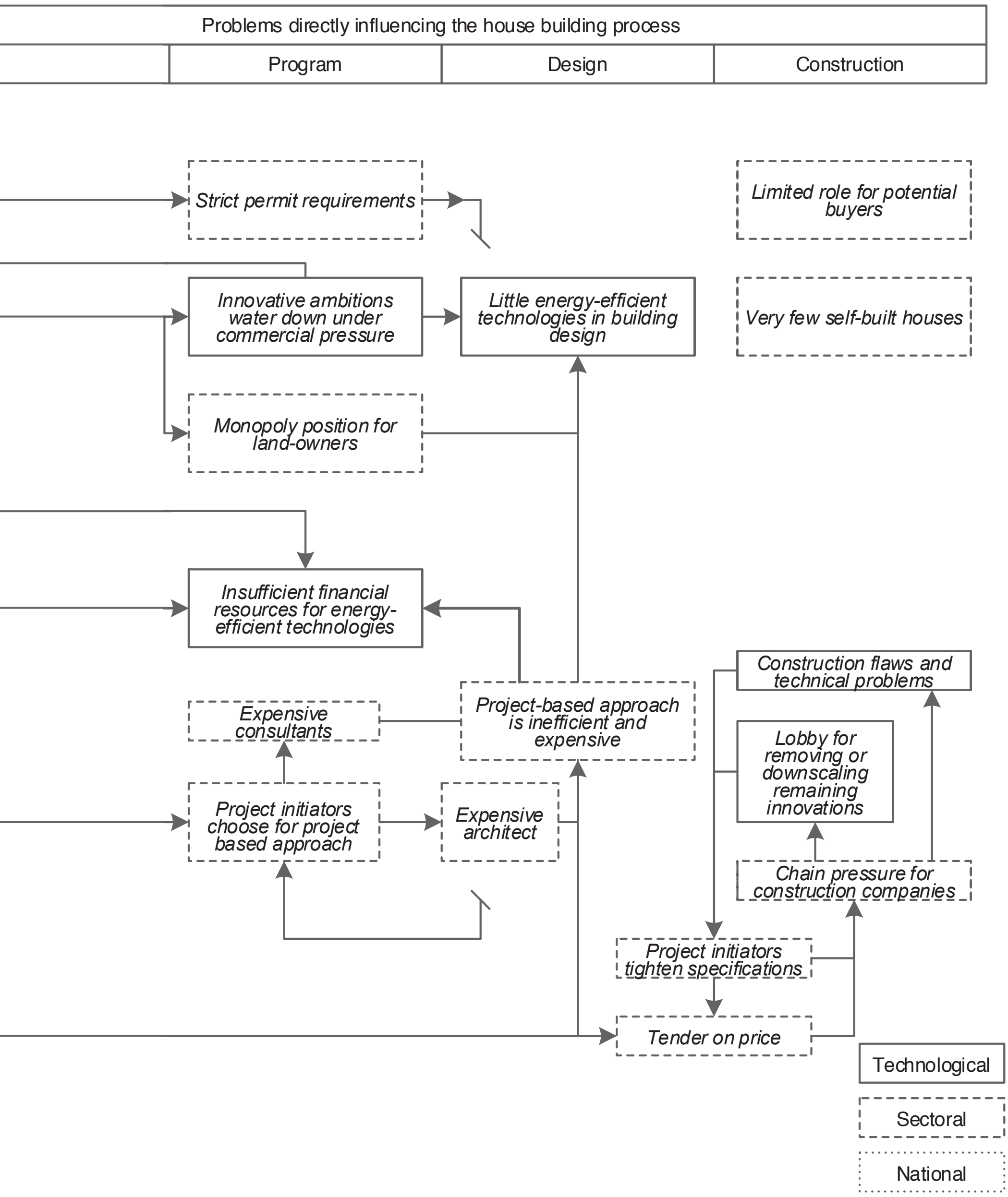


Figure 2.2: Problems and their interactions in the Dutch innovation system of highly energy-efficient houses.


Problems directly influencing the house building process
Program
Design
Construction
Strict permit requirements
Limited role for potential buyers
Innovative ambitions water down under commercial pressure
Little energy-efficient technologies in building design
Very few self-built houses
Monopoly position for land-owners
Insufficient financial resources for energy-efficient technologies
Construction flaws and technical problems
Expensive consultants
Project-based approach is inefficient and expensive
Lobby for removing or downscaling remaining innovations
Project initiators choose for project based approach
Expensive architect
Chain pressure for construction companies
Project initiators tighten specifications
Tender on price
Technological
Sectoral
National

Subsequently, an architect is asked to create a design which is then built by a construction company. In relation to the project-based approach, interviewees mentioned a deeply rooted *distrust between project initiators and construction companies*, or a *culture of disagreement*. To understand why, we have to take a closer look at what happens within the *project-based approach*.

The *project-based approach is inefficient and expensive* in both the program phase and in the design phase. Project initiators spend large amounts of resources on creating the initial development plans, usually assisted by *expensive consultants* and *expensive architects*. Although initial designs often include innovative sustainable technologies, these are often removed to offset the high costs of the program and design phases and ultimately lead to *little energy-efficient technologies in building design*. What is more, project initiators (which can be either a private project developer or a housing association) organize a tender on price and thus grant the project to the construction company that accepts the lowest profit margin. This creates so-called *chain-pressure for construction companies*, who subsequently *lobby for removing or downscaling remaining innovations* to reduce the cost of training their employees. Additionally, costs are reduced by working fast, which leads to *construction flaws and technical problems*. Unsatisfied with the final build quality, *project initiators tighten specifications* for the next project, and, by doing so, increase the *chain pressure for construction companies*. To defend their profit margin, construction companies subsequently try to claim additional costs and file suit if this is not accepted by the project initiator. Some interviewees blame the 'conservative' construction companies for this situation, while others blame the 'unprofessional' housing associations.

The use of so-called building concepts provides – in theory – an alternative for the inefficient project-based approach. A building concept is a standardized design method that combines standard building components in different ways to create varieties in building design. Using a building concept has the potential to reduce the high costs of both the program and the design phase since the creation of a specific development plan for each new-to-build area can be simplified. This not only reduces the activities of the project initiator, but also reduces the need for consultants and architects. However, persuading project initiators to choose for a building concept is difficult. There are strong vested interests in 'keeping things as they are', because many organizations benefit from the project-based approach. In general, *conservatism* is high among established parties (project initiators, consultants and architects) leading to a strong *lobby for the project-based approach*. *Project initiators keep choosing for the project-based approach*, even though more efficient approaches are available.

Table 2.1: Identified systemic problems related to structural elements and functions.

System function	Systemic problems	Structural element
Entrepreneurial activities	– Impenetrable entry barrier for new companies	Actor/Interactions
	– Open land market	Institutions
	– Land Scarcity	Infrastructure
	– Landowners create consortia	Interactions
	– Construction claim	Institutions
	– Monopoly position for land-owners	Institutions
Knowledge development	*Interviewees mentioned no problems related to this function.*	–
Knowledge diffusion	– Knowledge insufficiency (of potential homebuyers)	Actors
	– Distrust (between housing associations and construction companies)	Actors/Institutions
Guidance of the search	– Decentralization of housebuilding activities	Institutions
	– Conservatism	Institutions
	– Public organizations behave like private enterprises	Actors
	– Municipalities create detailed development plans	Actors/Institutions
	– Project initiators tighten specifications	Actors
	– Innovative ambitions water down under commercial pressure	Actors/Interactions
	– Project initiators choose for project-based approach	Actors
	– Strict permit requirements	Actors/Institutions
Market formation	– Decentralization of housebuilding activities	Institutions
	– Open land market	Institutions
	– Limited role for potential buyers	Actors
	– Very few self-built houses	Infrastructure
	– Energy-efficiency measures are low on the priority list of homebuyers	Actors
	– Few energy-efficient technologies in building design	Infrastructure
	– Lobby for removing or downscaling remaining innovations	Actors/Infrastructure
Mobilization of resources	– Strict capital requirements (for housing associations)	Infrastructure
	– Increased landlord fees (for housing associations)	Infrastructure
	– Housing associations face insufficient financial resources	Actors/Infrastructure
	– Limited mortgage options (for potential homebuyers)	Institutions
	– Expensive consultants and architects	Actors
	– Residual land value calculation methodology	Institutions
	– Land Scarcity	Infrastructure
	– Speculation on land-prices and land-development	Actors
	– High profits for land-owners (before financial crisis)	Infrastructure
	– Tender on price	Institutions
	– Chain pressure for construction companies	Interactions
	– Project-based approach is inefficient and expensive	Interactions/Institutions
	– Insufficient financial resources for energy-efficient technologies	Infrastructure
Creation of legitimacy	– Vested interests	Actors/Institutions
	– Conservatism	Institutions
	– Construction flaws and technical problems	Infrastructure
	– Project initiators choose for project-based approach	Actors/Institutions
	– Lobby for removing or downscaling remaining innovations	Actors/Infrastructure

The third and final problem theme – Resources – combines all problems related to finances. The first two themes already mentioned the *inefficient and expensive project-based approach* and the *high profits for landowners (especially before the financial crisis)*. These profits are rarely used to fund energy-efficiency measures[10]; instead, most municipalities use the land profits to increase the general municipal budget and private project developers just increase their profits. For the limited take up of energy-efficiency, private project developers point at the fact that en*ergy-efficiency measures are low on the priority list of potential homebuyers*. They attribute this firstly to *limited mortgage options* to finance energy-efficiency measures, and secondly to a *knowledge insufficiency* about the benefits of living in a highly energy-efficient house. In addition, housing associations face insufficient financial resources, because of *strict capital requirements* that inhibit investments and *increased landlord fees*.

Table 2.1 provides an overview of how all problems identified in this research relate to the main concepts of the innovation systems framework. This table represents the results we would have had if we had stopped the analysis after identifying only independent problems.

2.4.2 Independent problems versus interacting problems

In this section, we explore the question whether attention for problem interactions yields contrasting or additional insights compared to an analysis of independent problems. First, we select from Figure 2.2 two sets of problems that together form a blocking 'mechanism', under the new meaning of the term as a mechanism that consists of interacting systemic problems, and placed these in Figure 2.3. Then, we analyze these two mechanisms and reflect on whether the same insights would have emerged if the analysis was stopped after independent problems were identified (Table 2.1). Third, we compare our results to an earlier innovation system study of the same empirical domain (Faber & Hoppe, 2013).

The first blocking mechanism (left side of Figure 2.3) consists of a set of systemic problems that together lead to an *uneven distribution of financial resources* in the system. Together, these problems thus negatively influence the function Mobilization of resources (Table 2.1). Collectively analyzing them shows that, while there are multiple problems that directly relate to housing associations and potential homebuyers which makes them experience *insufficient financial resources for energy-efficient technologies* (strict capital requirements, increased landlord fees and limited mortgage options), concurrently the *project-based approach is inefficient and expensive*, and there are *high-profits for landowners*.

10 Some housing associations did use land profits from one project to develop ambitious highly energy-efficient houses in another.

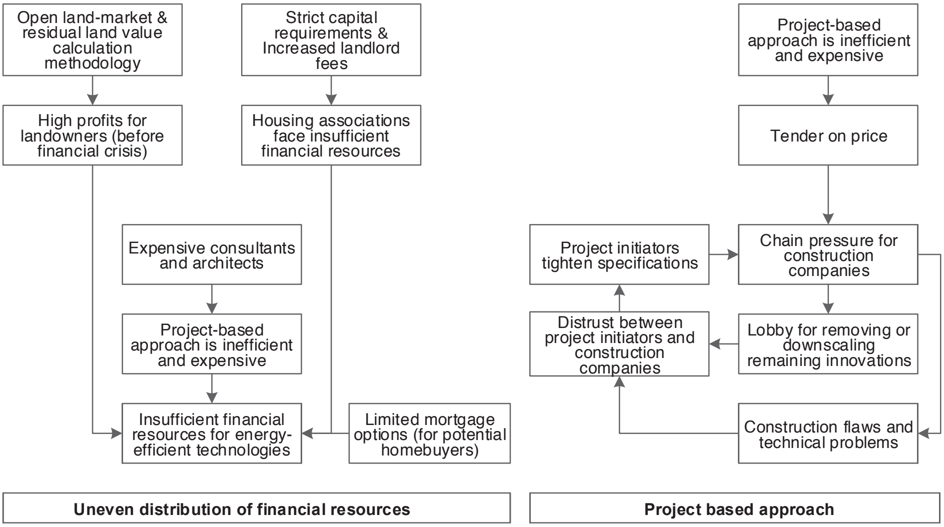


Figure 2.3: Blocking mechanisms in the Dutch innovation system of highly energy-efficient houses.

In other words, solving the problem of *insufficient financial resources for energy-efficient technologies* as experienced by housing associations and potential homebuyers, can also be achieved indirectly, namely by reducing the profits for landowners (through restructuring the land market), and by making the building process more efficient (through changing the project-based approach). Analyzing these problems collectively provides the insight that the real problem seems to be an uneven distribution of financial resources among actor groups, making direct intervention on all problems not necessary or desirable.

If our problem analysis would have stopped after independent problems were identified, and the results would thus have resembled Table 2.1, recommendations would have been different. They probably would have included interventions for all identified problems, for example increasing the maximum mortgage options for potential homebuyers, and easing the strict capital requirements and lowering the landlord fees for housing associations. However, taking into account that these problems interact, reveals that increasing financial resources of homebuyers and housing associations will likely only lead to higher profits for landowners as a result of the residual land value calculation methodology (Section 2.4.1). Such interventions would clearly not achieve the goal of increasing investments in energy-efficient technologies. To put it in other words: the 'additionality' of such interventions is questionable (Chaminade & Edquist, 2010).

The earlier innovation system analysis of the same empirical domain (Faber & Hoppe, 2013) did not reveal all systemic problems that form this first blocking mechanism. They mention that low income homebuyers experience difficulties in getting a mortgage and that the project-based approach is a source of sectoral fragmentation, but do not mention the high costs of the project-based approach, or the problems related to the land-market, such as the residual land value calculation methodology. Continually searching for an underlying problem – which was a fundamental part of our analysis – led to more problems being revealed and thus increased insights compared to this earlier innovation system analysis of the same empirical domain.

The second blocking mechanism (right side of Figure 2.3) relates to how project initiators and construction companies react to each other during the building process. Analyzing these problems collectively provides the following insight: project initiators and construction companies both blame the other and take protective measures against each other. Project initiators blame the construction companies for their lobby to remove or downscale innovations from the project, and for construction flaws and technical problems. However, construction companies see this as a logical reaction to the chain pressure created by the tender on price together with tight project specifications. If we look at this more closely, all of these 'problems' only arise when the *inefficient and expensive project-based approach* is followed. This raises the question: is the project-based approach itself not to blame? Changing to an alternative house building process has the potential to alleviate all these problems in one go, for example by using Building Concepts.

If this innovation systems analysis was stopped after independent problems were identified; in other words, if the results would have resembled Table 2.1, interventions would have probably been formulated for all identified problems. For instance, that project initiators should tender on more criteria than only price, that construction companies should be involved earlier in the house building process, and that employees of construction companies need additional training to install new technologies. Although such interventions may have some effect, they focus on symptoms and keep the underlying problem intact, namely the expensive first phases of the project-based approach.

The earlier innovation systems analysis of the same empirical domain by Faber and Hoppe (2013) does identify multiple of the systemic problems that are part of this second blocking mechanism, but largely overlooks that they interact. They mention that there is a "myopic competition on prices" (p. 636), a 'circle of blame' in which actors "have no difficulty in recognizing shortcomings of other agents" (p. 634), and a sectoral fragmentation that is caused by the project-based approach. Our analysis not only revealed additional problems (for example the *chain pressure for construction companies* and their *lobby for removing or* *downscaling innovation*), but also how these systemic problems collectively form a mechanism that is blocking the system from further developing.

Due to the differences between the innovation systems analysis of Faber and Hoppe (2013) and our analysis, it is not surprising that also the interventions put forward vary. Faber and Hoppe (2013) focus on encouraging sectoral integration, and on "setting project tendering conditions that favor cooperation on a wider set of sustainability criteria" (p. 636). In other words, they focus on interventions that try to improve the current project-based approach. This contrasts with our analysis that showed why the project-based approach may itself be part of the problem, and how the inefficiency of the project-based approach is preceded by an inefficient land-market. Restructuring the land-market, in combination with rethinking the project-based approach may provide better results.

2.5 DISCUSSION

The explicit attention that we gave to how problems interact – both during data collection and analysis – added explanatory power to our innovation system analysis. The use of the building phases during the interviews stimulated the interviewees to mention how problems interact: if they mentioned a problem and allocated it to a certain phase of the building process, they would often start mentioning additional problems from an earlier or later phase in the building process. This led to rich data: more problems were identified compared to an earlier analysis of the Dutch sectoral innovation system (Faber & Hoppe, 2013). In addition, the followed approach made it possible to identify two blocking 'mechanisms' that consist of interacting systemic problems. Analyzing these mechanisms showed that direct intervention on all identified problems is in this case not necessary and that targeting only the symptoms may even counterproductive effects. Our findings have three main implications for the policy formulation process.

First, analyzing systemic problems as mechanisms may reveal that some 'problems' are actually symptoms of other problems. When this happens, it should signal a policy maker that a single targeted intervention on the underlying problem may be more fruitful than formulating interventions for all problems separately. Unfortunately, it is often more difficult to intervene on an underlying problem compared to intervening on a symptom. An example from the first mechanism discussed in this chapter is that intervening on how the land-market is organized will probably create more resistance from vested actors compared to reducing the landlord fees for housing associations. If a policy maker cannot target the underlying problem because of such practical reasons, she/he should be careful with targeting the symptoms only, as our analysis showed that such interventions may be negated by reactions elsewhere in the system and have counterproductive effects. To conclude, the act of problem diagnosis is just as important as the act of intervention formulation itself, and should get the attention it deserves.

Second, this study sheds some additional light on the question whether policy makers should strive for gradual or radical institutional change. Some authors have emphasized that substantial institutional change can be achieved through a gradual process (Mahoney & Thelen, 2010). However, in relation to our case study, it is highly questionable if the project-based approach and the land-market can be changed through such a gradual process. For example, although incremental changes have made building projects today vastly different from fifty years ago, the general idea of how houses ought to be built has remained the same (the project-based approach). Although further gradual institutional change may lead to efficiency improvements in the project-based approach, it will not lead to its demise. If policy makers have the ambition to alleviate the whole blocking mechanism, for instance by replacing the project-based approach with an approach that revolves around building concepts, it is necessary to strive for more radical policy change, or punctuation (Kern, 2011, 2014).

The third implication for policy formulation is that the best place to intervene is often not in the system itself, but in its context. A blocking mechanism under its new meaning will often consist of a combination of internal systemic problems and contextual systemic problems. Since the problems that form the mechanism interact, an intervention on a contextual problem may indirectly lead to the alleviation of internal systemic problems. To reveal blocking mechanisms that go beyond the immediate system boundary, an analyst needs to trace the origin of internal systemic problems, which will lead him/her to contextual problems. In practice, this means that additional interviews are held when problems are identified for which cause or consequence remains unclear. Such a process will reveal structural couplings between the innovation system and its context. The variety of used shape outlines in Figure 2.2 signifies that there are many structural couplings between the technological, sectoral and national parts of this innovation system. Additionally, tracing the origin of internal systemic problems in the system context also reduces the risk of loose ends in an innovation systems analysis. For example, at first it was not clear to us what was causing the lack of financial resources for potential homebuyers and housing associations. This 'loose end' signaled us to perform additional interviews and ultimately led to the identification of contextual problems that were underlying this lack of financial resources, namely issues related to how the land market is organized.

The alternative conceptualization of the terms blocking mechanism and systemic problem used during the case study contributed to its explanatory power. Seeing a blocking mechanism as a 'mechanism' that consists of interacting systemic problems stimulates an analyst to reveal how problems interact. An analyst can do so by adding an additional analysis step after independent problems have been identified. What is more, a broader meaning of the term systemic problem that incorporates not only internal systemic problems (endogenous), but also contextual systemic problems (exogenous) stimulates an analyst to give attention to the system context. In this way, the proposed conceptual adaptation does justice to the recent discussion about the importance of system context (Bergek et al., 2015). One key issue for further consideration is the conceptual clarity of the term system 'failure'. As already mentioned in the Theory section, this term is sometimes used as synonym for systemic problem and sometimes to indicate broader issues with an innovation system.[11] More work is necessary to get the conceptual link clear between system failures and the conceptualization of blocking mechanisms and systemic problems as proposed here.

Although the innovative approach presented in this chapter proved useful during our case study there are still areas that need further consideration. This approach makes performing an innovation systems analysis more complex, requiring high analytical skills and more time. It also raises additional questions, for example, when are sufficient problems from the context taken into account and when can the analysis stop? In addition, questions remain open about the applicability of the approach for different types of innovation systems. For instance, is this approach only useful for more mature and locked-in innovation systems that are going through a transition, or also for other types of innovation systems? To make the approach more practical for analysts, performing additional case studies may prove favorable.

2.6 CONCLUSION

The innovation systems approach is already a powerful framework to find ways for stimulating innovation. It strives to improve the performance of the innovation system by identifying systemic problems and by formulating interventions that may alleviate these problems. However, a discussion of literature on problems in innovation systems revealed that the complexity focus of the framework is not so

11 For instance, in Klein Woolthuis et al. (2005) the terms systemic failure and system failure are used interchangeably and mean the same as the term systemic problem in Wieczorek and Hekkert (2012), whereas in Weber and Rohracher (2012) the term structural system failure is a synonym for systemic problems, while the term transformational system failures indicates broader system issues.

apparent in how the framework identifies problems. This led to the premise that the innovation systems framework may benefit from more attention to how problems interact and can form mechanisms. The merits of giving explicit attention to problem interactions was explored in a case study of the Dutch energy-efficient housing innovation system for which the following research questions was answered: What problems inhibit the Dutch energy-efficient housing innovation system, how do these problems interact, does analyzing problem interactions provide additional insights compared to analyzing independent problems, and if so, what are these additional insights?

During the case study an alternative meaning of the term blocking mechanism was used, namely as a 'mechanism' that consists of interacting systemic problems. This led to the identification of more problems compared to an earlier study of the same empirical domain, and to the identification of 'mechanisms' of interacting problems, instead of to the identification of independent problems. In the case of energy-efficient houses in the Netherlands, many problems can be traced back to how profits from land are distributed among stakeholders, and to the project-based approach as the dominant organizing principle of the building process. Earlier studies have focused on interventions that increase the efficiency of the project-based approach, and in this way overlook the possibility of moving toward an alternative organization of the building process, for instance based on building concepts. The findings indicate that understanding how systemic problems interact and form mechanisms is of key importance for designing policy measures and intervention strategies. Neglecting problem interactions in innovation systems may not only lead to inaccurate problem diagnosis, but also to ineffective or even counterproductive interventions.

This chapter showed that the innovation systems framework more broadly, and thus also the TIS intervention framework, may benefit from more explicit attention to how systemic problems interact, influence each other, and form mechanisms. This may be achieved by conceptually recognizing that links between systemic problems provide important explanatory power and contribute to accurate problem diagnosis. Areas for further consideration are the type of innovation systems for which an analysis of interacting problems as 'mechanisms' is most fruitful, at which point to stop such an analysis and how to turn the approach into a more practical analysis tool. In addition, the link between the concepts of blocking mechanisms and systemic problems as used in this chapter, and the concept of system failures needs to be further explored. To conclude, increasing attention for interactions between systemic problems contributes to a TIS intervention framework that is well positioned to diagnose problems, and to formulate interventions to alleviate these problems.

Chapter 3

Perceptions of problems and solutions in innovation systems: Institutional logics in the Dutch case of renovating houses energy efficiently*

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3.1 INTRODUCTION

When analysts set out to identify problems and potential solutions in relation to a specific technology – and for this purpose use the TIS intervention framework - they may be confronted with varying, if not inconsistent, opinions. In relation to problems, one actor may perceive a situation as problematic while another sees it as desirable; for instance, one may argue that limited government regulations is a problem, while another argues that this is desirable. Or in relation to solutions – when two actors share the opinion that there is a lack of resources – one actor may propose a subsidy, while another may opt for a tax-reduction. Sometimes the role that an actor has in the innovation system may provide part of the explanation, for instance, government versus companies. However, different opinions also often exist within otherwise relatively homogenous actor groups (e.g. between companies that produce similar products, or between government officials that pursue the same goal). The innovation systems framework currently does not provide the theoretical means to cope with such data inconsistencies. This puts the analyst in a difficult position and may – even though this does not do justice to the data – entice the analyst to favor one opinion over the other or to ignore that the data is inconsistent. The usefulness of the TIS intervention framework would increase if it can be used to understand why data in relation to problems and potential solutions is inconsistent.

The starting point of this chapter is that the TIS intervention framework is not able to provide such insights because of an implicit assumption, namely that problems and potential solutions in innovation systems are 'out there', and that an analyst can thus determine the objective truth about them. However, values play an important role in what problems and potential solutions actors perceive or as Hafkamp (2006) puts it: "[…] their dialogue on problems and solutions is value-based from the start […]" (p. 377). In other words, the value-based nature of problems and potential solutions makes them inherently subjective. Therefore, this chapter explores the merits of taking a subjectivist view on problems and solutions during an innovation systems analysis, for which we draw on the concept of institutional logics (Thornton et al. 2012). Institutional logics are "the socially constructed, historical patterns of material practices, assumptions, values, beliefs, and rules by which individuals produce and reproduce their material subsistence, organize time and space, and provide meaning to their social reality." (Thornton & Ocasio, 1999, p. 804). Institutional logics theory explains that actors are guided by institutional logics to act, and thus determine what problems and solutions are salient (Thornton, 2002). In relation to innovation systems, this leads to the premise that data inconsistencies regarding problems and solutions may be understood better when it is seen as a consequence of institutional logics that conflict.

In this chapter we set the objective to explore the usefulness of institutional logics theory for coping with inconsistent data regarding problems and potential solutions during an innovation system analysis, and if so, how this can be approached. For this, we analyzed the Dutch innovation system of renovating houses energy-efficiently, which suited our purpose because in the Netherlands a discussion is unfolding about what is the best renovation approach, leading to inconsistent perceptions on problems and solutions in the field. We asked the question what institutional logics guide actor behavior in this innovation system, and what insights do these provide into the origin of the conflicting opinions about problems and potential solutions that were collected for this innovation system.

The following sections proceed as follows. The theory section shortly recaps the central theoretical concepts of the innovation systems framework and introduces the institutional logics concept in further detail. Subsequently, the method section discusses our research design. The results section then presents two institutional logics that guide action in our case study, shows how these logics shed light on why actors perceive different problems and solutions, and thereby help to explain why the collected data was inconsistent. Then, the discussion section goes into both the merits and challenges of identifying institutional logics as part of an innovation system analysis, to finally reflect on the added value of a subjectivist view on problems and potential solutions for the TIS intervention framework.

3.2 THEORY

In innovation systems literature, it is generally recognized that Actors, Institutions and Interactions (sometimes called networks) are central building blocks or structural elements of the system. Some strands of literature recognize additional structural elements, e.g. Technology (Jacobbson & Bergek, 2011; Jacobsson & Jacobbson, 2014; Markard & Truffer, 2008) or Infrastructure (Chamanide & Edquist, 2010; Klein Woolthuis et al., 2005; Wieczorek & Hekkert, 2012). Conceptually, the term systemic problem points at weaknesses in these structural elements (Jacobsson & Bergek, 2011; Wieczorek & Hekkert, 2012). When the performance of an innovation system is unsatisfactory, this is thus likely caused by weaknesses that pertain to its structure.

To identify systemic problems, it is common practice to combine an analysis of the system structure with an analysis of key processes, often called functions. Analyzing the fulfillment of functions provides an indication of the innovation systems' performance, while the systemic problems are the reasons for why functions are not fulfilled well. In the search for systemic problems, the functions are thus used as focusing device. As concept, functions are most prominent in literature on technological innovation systems (Bergek et al., 2008; Hekkert et al. 2007), although sets of functions have also been proposed for other innovation system strands.[1] The general process for performing an innovation systems analysis consists of several stages that include demarcating the system, describing the system structure, determining function fulfillment, identifying systemic problems, and formulating interventions to alleviate those problems (Bergek et al., 2008; Wieczorek & Hekkert, 2012). Together, these steps form a so-called structural-functional analysis of an innovation system.

For most steps of a structural-functional analysis, additional literature is available that provides analysts with the necessary guidelines, help and tools. For example, Bergek et al. (2015) provide a detailed description of TIS demarcation; Hekkert et al. (2007) describe in detail how the performance of a TIS can be determined; and lists of potential systemic problems in innovation systems are available for analysts to draw upon (Chaminade & Edquist, 2010; Klein Woolthuis et al., 2005; Negro et al., 2012). In this way, literature facilitates an analyst to a large extent. However, as we already explained earlier, it does not provide the theoretical means for coping with inconsistent data on problems and solutions, which we argued to be the result of innovation systems literature taking an objectivist view on problems and solutions.

There are reasons to believe that taking a subjectivist view on problems and solutions may, at least sometimes, prove favorable. In a subjectivist view, instead of trying to *reveal* objective reality, the goal is to *understand* subjective reality. Truth is considered to exist in the eye of the beholder and such research thus 'tends to rely upon the "participants" views of the situation being studied' (Creswell, 2003, p. 8). This implies that – during an innovation systems analysis - multiple 'truths' about problems and solutions may exist concurrently, which may reduce the enticement for an analyst to favor one opinion over the other or to neglect the inconsistency of the collected data. The subjectivist view is firmly embedded in institutional theory, and in this chapter, we draw upon the concept of institutional logics.

The institutional logics concept offers an explanation for why actors may perceive different problems and potential solutions, even though they are in a

1 In e.g. national innovation systems literature the concept of activities is close to the concept of functions (see e.g. Edquist, 2006). Some authors also use the term functions in relation to national innovation systems (e.g. in Galli and Teubal, 1997).

similar situation. Institutional logics comprise the cultural knowledge that is available to social actors, and actors are both enabled and constrained by them (Thornton & Ocasio, 2008). Fuenfschilling and Truffer (2014) put it this way: "How actors make sense of and act upon reality is contingent on prevailing institutional logics" (p. 774). Thus, actors will - often unconsciously - draw on these logics during the process of 'sensemaking, problem solving, decision making, and coordination' (Thornton et al., 2012).[2] Such logics determine how actors behave, and thus also what situations are judged as problematic and what solutions are proposed. What is more, logics are "realized in actors' material practices: what people do and how they do it." (Reay & Jones, 2016, p. 446). In this chapter, we for instance discuss how two substantially different renovation methods in the Netherlands are reflections of two conflicting institutional logics. To conclude, why actors perceive different problems and solutions in an innovation system may be the result of multiple logics guiding actor behavior.

Although much research on institutional logics has focused on institutionalization at societal level (e.g. Bhappu, 2000; Friedland & Alford, 1991), the meta-theory is broad enough to facilitate research at other levels of analysis (Thornton & Ocasio, 2008). In their words, "institutional logics may develop at a variety of different levels, for example organizations, markets, industries, inter-organizational networks, geographic communities, and organizational fields" (Thornton & Ocasio, 2008, p. 106). When a researcher focusses on such so-called field level logics, it is important that the level at which institutionalization occurs is made clear (Thornton & Ocasio, 2008). Our study is a case in point of field level logics that institutionalize at the sectoral level.

It is important to understand that institutional logics as concept is a meta-theory but also a method of analysis (Thornton & Ocasio, 2008). Interestingly, this means that the theory slightly depends on the chosen method of analysis. Reay and Jones (2016) discuss three ways to identify logics, namely pattern deducing, pattern inducing and pattern matching. The technique of pattern deducing captures logics through quantifying qualitative data, for instance, by counting the co-occurrence of words. The pattern inducing technique stays closer to the qualitative data and relies upon a bottom-up inductive approach based on coding (labelling) texts. Contrasting these first two techniques, pattern matching does not start with the empirical data, but first formulates so-called 'ideal-type' logics. Each ideal-type logic is associated with a different pattern of expected behavior. They are a deliberate simplification of reality and can be considered

2 Although this means that action is restricted by the institutional logics that are prominent in a certain field, actors also influence the institutional logics through the process of institutional entrepreneurship (Greenwood & Suddaby, 2006).

stereotypes: "ideal types are not for describing an organizational field, but instead are theoretical models for comparing the effects of various meanings" (Thornton & Ocasio, 2008, p. 110). Methodologically, analysts first distill ideal-type logics - and the associated expected pattern of behavior - from theories and/or an otherwise created understanding of the field under study. These expected patterns of behavior as expressed by the ideal-type logics are subsequently compared to empirical data to see how well they match, thereby providing insight into the institutionalization of the ideal-types. In this chapter we make use of this pattern matching technique.

3.3 THE CASE OF RENOVATING HOUSES ENERGY EFFICIENTLY

The empirical domain of renovation houses energy efficiently was chosen because it satisfies three criteria. First, it is a good candidate for an innovation systems analysis because reaching the goal of an energy efficient housing stock depends on further development and implementation of new technologies. Second, based on previous experience with the empirical domain, we knew that actors have substantially different perceptions of both problems and of potential solutions. Third, the field is characterized by two distinctive renovation methods of which we hypothesized that these reflect the prevalence of two conflicting institutional logics in this field.

In the analysis, we focus on houses built before 1992, owned by either private homeowners or housing associations. In 1992 the regulatory requirements for heat-insulation were significantly increased,[3] giving older houses generally weak insulation and thus high improvement potential. Additionally, targeting such houses is often cost-effective, because taking energy-efficiency measures can be combined with general maintenance activities. In the Netherlands, there are 5.7 million of such houses, of which 56% are owned by homeowners, 9% by private landlords and 35% by housing associations (Rijksdienst voor Ondernemend Nederland [RVO], 2011). The percentage of houses owned by housing associations in the Netherlands is high compared to other European countries (Economidou et al., 2011). Since homeowners and housing associations together own 91% of the housing stock, most initiatives striving to stimulate energy-efficient renovation focus on these target groups.

To renovate a house energy-efficiently, a set of technologies must be combined, for instance insulation, a heat pump, and solar panels. Discourse on how these technologies are to be combined happens at the sectoral level. We thus

3 From 1992, the Building Code prescribes a minimum heat-insulation for all construction components of Rc 2.5 m2K/W.

consider the innovation system of energy-efficient renovation in the Netherlands to be a sectoral system that makes use of the technologies provided by different technological innovation systems. Since the field level logics discussed in this chapter guide actors in how to combine technologies, their institutionalization occurs at sectoral level.

3.4 METHOD

The first step in our research design was formulating ideal-type logics. To complement the knowledge that we already had about this domain as a result of earlier research projects, we interviewed people with a good overview of the field, for example consultants that had completed projects for multiple stakeholders. Since logics are realized in actors' material practices, we initially focused on understanding how actors in the Netherlands approach renovation projects. This exploration made clear that - in the Netherlands - two substantially different renovation approaches can be distinguished: a more traditional one based on stacking energy-efficiency measures, and a more holistic one that makes use of so-called renovation concepts. Subsequently, to further deepen our understanding of these two renovation approaches, additional sources were consulted, for instance, documents that explain the advantages of each approach, professional magazine articles that compare them, and websites of initiatives that advocate them. Finally, in depth interviews with experts on both renovation approaches were performed. Based on the created insights, two conflicting 'ideal-type' institutional logics were formulated. For each logic, we described the expected actor behavior if it were guided by the ideal-type logic, and how these different actor behaviors materialize into two distinct renovation approaches.

The second step in our research design consisted of identifying the perceptions on problems and potential solutions present within this innovation system, for which we used a combination of interviews, websites and professional magazines. The depth of the interviews was considered more important than the quantity of interviews, which led to interviews that lasted two hours on average. We started with interviewing people that had been recommended by the earlier interviewees and worked from there (snowball sampling). In total, twenty interviews were conducted with government officials, project managers of housing associations, product suppliers, energy cooperatives, construction companies and advisors/consultants. Additionally, websites of initiatives related to renovating houses energy efficiently were consulted, because they usually explain what problem the initiative is trying to tackle and how the initiative provides the solution. Finally, professional magazine articles often contain interviews or workshop reports in which perceived problems and possible solutions are mentioned. We had access to articles from two professional magazines.[4] Data collection continued until new data stopped providing additional problems and possible solutions (theoretical saturation).

The interviews were transcribed into text, after which the textual fragments from interviews, websites and professional magazines were concurrently analyzed. The analysis started with open coding[5] (Strauss & Corbin, 1998) of both problems and solutions.[6] Subsequently, all coded fragments were reexamined and grouped into categories according to the guidelines on focused coding (Charmaz, 2006). For example, if fragments mentioned similar problems or proposed similar solution, these were combined into one category. The identified problems and solutions were subsequently linked to the innovation systems framework for which the classification of structural elements by Wieczorek and Hekkert (2012) - Actors, Interactions, Institutions, Infrastructure and Technology - formed the coding scheme.

The third step consisted of relating the identified problems to the characteristics of the ideal-type logics formulated earlier. Although professional magazine articles and websites had proven useful earlier, they were less useful for this step since the arguments for why a situation was considered problematic was often not given. Therefore, the interviews provided the main evidence for this step. They had allowed asking successive 'why' questions after an interviewee had mentioned a problem, which had stimulated them to articulate their reasons. These reasons provided the information to link a problem or a solution to a certain logic characteristic. For example, an interviewee that mentioned the problem of a high tax on electricity would explain that this inhibited the unavoidable and necessary transition from fossil fuels to sustainable electric technologies. Additionally, many identified problems could also logically be related to a characteristic of an ideal-type logic. For example, a lack of production capacity for prefab construction parts is only a problem when choosing for centralized prefab fits the expected pattern of behavior associated with a particular logic. In this way, the characteristics of the ideal-type logics provided the coding scheme to which the problem perceptions were linked. In the fourth step, this exercise was repeated for the collected data on potential solutions.

4 Energy & ICT and Klimaat & Sanitair as published by the sector organization for installation companies UNETO-VNI.

5 A synonym for this term is initial coding (Charmaz, 2006).

6 For this purpose, the Computer Aided Qualitative Analysis Data Software (CAQDAS) NVivo was used. NVivo qualitative data analysis software; QSR International Pty Ltd. Version 10, 2012.

3.5 RESULTS

The results are presented in five consecutive sections, of which the first four represent the four steps of our research design. The first section presents two ideal-type logics – the *steps* and the *leaps* logic – that both reflect substantially different approaches to renovating houses energy-efficiently. The second section first addresses the origin and emergence of both logics and subsequently explains what a renovation looks like and how the renovation process is organized when actors are guided by either one. Then, the third section shows how actors that act within these logics judge the same situation differently, leading to different perceptions of problems in the Dutch renovation innovation system. Subsequently, the fourth section illustrates how – even if a situation is considered problematic within both logics – the sensible solution often varies. Finally, section five discusses the extent of institutionalization of both ideal-type logics at the sectoral level.

3.5.1 Ideal-type logics influencing in the Dutch renovation innovation system

An overview of the characteristics of both ideal-type logics can be found in Table 3.1. The rest of this section will explain the associated pattern of behavior in more detail, whereby the terms used in the table are shown in *italics* in the text.

Before we begin, it is important to note that when the leaps logic was initially introduced, renovation projects were organized in accordance with *either* the steps logic *or* the leaps logic. However, as the prevalence of the leaps logic increased, renovation projects gradually started to reflect a combination of both logics. Nowadays, renovation projects are approached in a multitude of ways, always somewhere on the spectrum between the two extremes as set by the two ideal-types. Despite that they have started to blend, it can still be observed whether a renovation project leans more toward the steps logic or to the leaps logic. We will come back to this 'blending' of both logics in Section 3.5.5, but for now focus on the extremes in the form of the ideal-types.

Table 3.1: Ideal-type institutional logics in the Dutch renovation innovation system.

	Steps logic	**Leaps logic**
Stance	*Pragmatic*	*Idealistic*
Motivation for housing associations	*Compliance*	*Commitment*
Motivation for homeowners	*Quick wins (financial / comfort)*	*Significant change (sustainability / comfort)*
Approach	*Adaptation*	*Transformation*
Focus	*Individualistic*	*Holistic*
Values	*Flexibility*	*Efficiency*

The Steps logic reflects a *pragmatic stance* toward renovation. Although reducing energy-use and increasing renewable energy production is considered a worthy goal, it is even more important that measures are easy to implement and cheap. The motivation for housing associations is characterized by *compliance* to reaching sectoral goals, whereas the main motivation for homeowners is characterized by achieving *quick wins* in terms of financial gains or comfort increase. The preferred approach revolves around *adaptation* of the house and focusses on implementing *individualistic* measures that fit the criteria of low investment cost, high financial gains and little hassle. Furthermore, *flexibility* is an important value for actors that act within this logic, which builds on the argument that every house, homeowner, and renter is unique. Persuading homeowners to renovate is considered easier when the proposition is tailored to their needs and preferences, and fits the current structure of the house. For example, solar panels are placed around an already existing dormer, the number of installed solar panels depends on household energy-use, and aesthetic preferences of the homeowner determine the choice for a certain type of solar panel (mono, poly or thin-film). Persuading renters to accept a renovation as proposed by a housing association is also considered easier if the proposition is tailored to specific renter needs.[7] Additionally, housing associations and homeowners that act within this logic value the *flexibility* of choosing for a few measures now, while keeping the option open to take additional measures later. Actors guided by this logic are supporters of renovating houses in consecutive steps.

The Leaps logic reflects a more *idealistic stance* toward renovation. Combatting climate change is an important driver and making the housing stock energy-neutral is a means to this end. The main motivation for housing associations is characterized by *commitment* to creating an energy-neutral housing stock, whereas the motivation for homeowners is characterized by achieving

7 In the Netherlands, a housing association is only allowed to renovate after the consent of 70% of renters.

significant change, both in terms of sustainability and in comfort increase. To make leaps toward energy-neutrality possible, a *transformation* of the house is considered necessary. This requires a *holistic* focus, in which measures are not judged independently, but collectively. Finally, *efficiency* is an important value for actors that act within this logic. Cost-efficiency is considered crucial to persuade housing associations and homeowners to go beyond the quick wins, and process efficiency is the designated path toward reducing the inconveniences of renovation activities. Since the idealistic stance of this logic requires immediate and substantial action, the lack of flexibility in terms of choosing and timing measures is accepted. Actors guided by this logic are supporters of renovating houses in leaps.

3.5.2 Renovations in accordance with the Steps logic and the Leaps logic

The rest of this section shortly describes the origin of both logics and portrays the distinct renovation approaches that they induce. In this way, the renovation approaches discussed below are realizations of the ideal-type logics in material practice. Table 3.2 provides an overview of how the organization of a renovation project differs, depending on which ideal-type logic guides actor behavior. In the subsequent text, the terms used in the table are again shown in *italics* in the text.

Table 3.2: Two renovation approaches depending on the guiding ideal-type logics.

	Steps logic	**Leaps logic**
Goal	*Steps in Energy Label / Energy Index*	*Leaps to Zero-on-the-meter*
Cost criterion	*Investment costs and payback time*	*Cost-neutral*
Measures combining	*Stacked (often only the quick wins)*	*Integrated*
Nature of solutions	*Customization*	*Standardization*
Production location	*Decentralized*	*Centralized*
Energy carrier	*Hybrid (electricity and gas)*	*All-electric*
Company size	*Small and medium sized companies*	*Larger companies and consortia of medium sized companies*
Upfront investment	*Low*	*High*
Deep renovation	*Exception*	*Norm*

The origin of the steps logic lies in the traditional renovation sector. Originally, there were roughly four reasons to renovate a house, namely periodic maintenance, necessary repairs, house upgrades (e.g. new bathroom, dormer), and comfort increase (e.g. double glazing). The sector had for long been dominated by relatively small companies that specialized in a certain type of renovation activities (painting, placing dormers, replacing installations, making constructional modifications etcetera). It was already then common practice that multiple companies are involved in a single renovation project. A fifth reason to renovate a house emerged when attention for energy-efficiency and renewable energy production increased. Companies added energy-efficiency measures and renewable technologies to their existing portfolio (e.g. insulation and solar panels) and new specialized companies entered the market. In line with the working methods of the traditional renovation sector, actors guided by this logic are supporters of a step-wise approach for implementing energy-efficiency measures and renewable energy technologies, where each company involved only takes responsibility for its own work.

Renovation projects organized in accordance with the steps logic usually set the goal of improving the house's *Energy Label* or *Energy-Index*. The Energy Label runs from G to A and indicates energy performance. Each type of energy-efficiency or energy-production measure represents a certain improvement in the Energy label of the house. For example, for a house that has an F label, insulating the walls may mean an increase to C, additionally placing solar panels can bring the Label to B, and finally installing a heat pump may lead to Label A. The contribution of a measure to the improvement of the energy performance (the number of made Label steps) is calculated using the Energy-index methodology. For example, Label B corresponds with an Energy-Index of 1.25.[8] The main cost criteria for selecting measures are the *investment costs and payback time of individual measures* and they are combined by *stacking* them (*often only the quick wins*). Since every renovation project is considered unique, the quick wins may be different for each renovation project and actors thus strive for *customization*. The pragmatic stance and adaptation approach that belong to this logic has as consequence that houses – after renovation - generally keep using a *hybrid* of gas and electricity. Full substitution of gas for electricity requires making substantial simultaneous changes to a house (e.g. thorough insulation, heat pump + radiant floor heating), which does not fit the step-wise approach that is associated with this logic. Since adaptation of the house is strived for, most renovation activities are performed on location (*decentralized*). What is more, this approach is especially prominent with *small- and medium sized companies*. Upfront investments for companies are *low*, and a step-wise approach fits well their specialization on one or a couple of measures. For example, an insulation company can contribute

8 Housing associations recently switched from using both the Energy Label and the Energy Index to using the Energy Index only.

to making a couple of Label steps, but cannot on its own perform a deep renovation. When actors are guided by this logic, deep renovation is the exception.

The roots of the leaps logic lie in the market for constructing new houses. In the Netherlands, the process of constructing new houses is largely standardized, which is achieved by using standard house designs that are easy to build in series. The sheer size of these housing projects led larger construction companies to dominate the market. These larger construction companies had earlier not shown much interest for renovation. However, this changed after the demand for new houses plummeted during the 2008 financial crisis. As might be expected, their renovation propositions resembled their working methods in the market for new houses. This led to the introduction of a new logic to the market for house renovation that revolved around taking leaps.

Renovations organized in accordance with the leaps logic generally set the goal of reaching *Zero-on-the-meter* (in Dutch Nul-op-de-Meter). Zero-on-the-meter is reached when, annually, the amount of energy produced is equal to the energy-use of an average family. Actors choose to transform the house, for instance, replacing the whole house façade with a well-insulated one, replacing the gas-boiler with a heat-pump, and replacing the radiators with floor- or wall heating. The main cost criterion for investment is that the renovation is *cost-neutral*, which means that the payback time of the investment must at least coincide with, or must be lower than, the economic lifetime of the renovation. To achieve this, actors take a holistic focus, which leads measures to be *integrated* as much as possible. For instance, both solar panels and a heat pump are integrated in the roof. Furthermore, actors strive for *standardization* of the renovation process. This is done by creating standardized packages of measures, for which Renovation Concept is a common term. What is more, actors choose to pre-fabricate construction parts in a *centralized* factory and then transport them to the house. At the house, these prefab construction parts are subsequently installed in a matter of days. The idealistic stance associated with the leaps logic makes natural gas intrinsically unsustainable and undesirable. This generates a strong preference for an *all-electric* solution for hot tap water and heating. Other reasons brought forward to go all-electric are that it makes calculating Zero-on-the-meter easier, and that it reduces network costs. Since the upfront investments to create a renovation concept and establish the prefabrication location are *high*, a company needs to have substantial financial resources available. This explains why developers of renovation concepts are generally *larger companies or consortia of medium sized companies*. When actors are guided by this logic, deep renovation is the norm.

3.5.3 Influence of institutional logics on the perception of problems

In this section, we discuss how a different guiding logic translates into another perception of the same situation. We give three examples from our data. Each example is a situation that is perceived as problematic when sensemaking is shaped by one logic, but not when it is shaped by the other. The three examples relate to 1) the goal of housing associations to reach Energy Label B on average in 2020, 2) a lack of financial resources for pilot project, and 3) the higher tax for electricity than for gas. At the end of this section, Table 3.3 provides an overview of how these situations relate to the structural elements of the innovation systems framework and - depending on the guiding logic for interpreting these situations - whether they are considered problematic or not.

The goal of housing associations to reach Label B on average in 2020 is part of a national-wide energy covenant called the Energie-akkoord (Sociaal-Economische Raad [SER], 2013). This covenant is a binding agreement and thus a formal institution in innovation systems terminology. To reach this goal, many housing associations choose to renovate all their houses to Label B, even though – since the goal is label B *on average* - they can also choose to renovate some houses to energy-neutral and others not at all. When sensemaking is shaped by the steps logic, there is nothing wrong with this situation as each label step contributes to a more energy-efficient housing stock. Taking additional steps is considered something for later concern. Contrasting this, when sensemaking is shaped by the leaps logic, every taken step-wise measure is seen to create sunk costs, and in this way, to reduce the feasibility of taking a single leap to Zero-on-the-meter by using a renovation concept. Thus, depending on the logic, this goal by housing associations is either considered a driver for change or an obstacle.

The second example relates to a lack of financial resources for pilot projects, and thus to the structural element financial infrastructure. When the leaps logic guides sensemaking, additional financial resources are still considered necessary to further develop and test the integration of technologies as renovation concepts are still in the development phase. However, when the steps logic guides sensemaking, further pilot projects are considered unnecessary because all individual technologies are already thoroughly tested. Thus, depending on the logic, money that goes toward pilot projects is either well spend or a waste.

The final example also relates to the structural element financial infrastructure and is the relatively high electricity tax compared to the gas tax.[9] An organization or person whose actions are shaped by the leaps logic will consider this problematic as it makes the business case for going all-electric less attractive.

9 Even after the recent increase of the gas tax, and the decrease of the electricity tax in 2016 (Dutch Ministry of Finance, 2016), the gas tax is still a factor 4 higher per GJ.

Contrasting this, since in the steps logic all-electric technologies are not idealistically preferred over gas-based technology, this same situation is not considered problematic. There are sufficient technologies available that decrease gas-usage (e.g. a hybrid heat pump or a more efficient gas-boiler) and these are all considered viable steps toward an energy-neutral housing stock in the longer term. Thus, depending on the logic, the current energy tax laws are either unfair or fine.

Table 3.3: Varying problem perceptions for two conflicting ideal-type logics.[1] (I)nstitutions, (In)frastructure.

Situation	Problem under Steps logic	Problem under Leaps logic	Structural element[1]
Goal by housing associations of Label B on average in 2020	No *Every small step contributes to a more energy efficient housing stock and additional steps are always possible later*	Yes *Every small step reduces the feasibility of using a Renovation Concept*	I
Lack of financial resources for pilot projects	No *Technologies have already been thoroughly tested and are ready for implementation*	Yes *The integration of technologies needs more testing*	In
Electricity tax relatively high compared to gas tax	No *All-electric is not preferred over gas-based technologies*	Yes *Electrification of the housing stock is necessary and unavoidable. The high electricity tax inhibits this transition*	In

3.5.4 Influence of institutional logics on the perception of solutions

In this section, we discuss how the perception of potential solutions in relation to this innovation system depends on the logic followed by actors during problem solving. We discuss three situations that were considered problematic by all actors, namely the incompetence of specialized companies, uncertainties in relation to the energy performance of measures, and the inconvenience of renovation activities for homeowners and renters. For each of these problems, we discuss how the perceived solution depends on the guiding logic. At the end of the section, Table 3.4 provides an overview of how these problematic situations relate to the structural elements of the innovation systems framework and – depending on the guiding logic for interpreting these situations - what solutions are proposed.

The first example relates to the incompetence of specialized companies. They are said to be knowledgeable about only a few types of measures, to give selective advice, and to make mistakes during installation. When actors draw on the steps logic, the most sensible solution for this problem lies in educating them, for instance, through nationally organized educational programs. Contrasting this, actors that draw on the leaps logic propose to circumvent specialized companies all together and move the end-responsibility to better organized concept developers. Thus, depending on the guiding logic, specialized companies should either be empowered or forsaken.

The second example relates to uncertainties around the energy performance of taken measures. Uncertainty in relation to how much energy (and thus costs) can be reduced, creates reluctance to invest. Providing energy performance guarantees is in theory a solution to this. However, when problem solving is guided by the steps logic, implementing such a guarantee is considered hardly feasible because the energy performance of individual measures is dependent on measures installed by other companies. Companies are very reluctant to take responsibility for someone else's work. In contrast, when problem solving is guided by the leaps logic, providing performance guarantees as solution is considered feasible because the whole renovation is performed under supervision of one concept developer (which can also be a consortium of companies). Thus, depending on the guiding logic, providing energy performance guarantees as solution is thus either feasible or infeasible.

In the final example, different solutions are proposed for the inconvenience of renovation activities for homeowners and renters. Since the steps logic materializes into a decentralized approach with renovation activities taking place on-site, solutions are found in adequate manners and friendly communication by workmen. For instance, always taking off shoes before entering the house, explaining what the activities for that day entail, and making sure that no delays take place. Contrasting this, the leaps logic materializes into a centralized approach where construction parts are prefabricated in a factory. This reduces on-site activities significantly and in this way reduces the inconvenience for homeowners and renters. Depending on the guiding logic, the perceived solution for a problem can be quite different.

Table 3.4: Varying solutions for two conflicting ideal-type logics.[1] (A)ctors, (I)Institutions

Problems	**Solution following Steps logic**	**Solution following Leaps logic**	**Structural element**[1]
Incompetent specialized companies	*Educate them*	*Circumvent them*	A
Uncertainties around energy performance of measures	*Providing a performance guarantee for individual measures is not feasible*	*Providing a performance guarantee for the whole renovation is feasible*	I
Inconvenience of renovation activities	*Adequate manners and friendly communication of workmen*	*Use of prefab construction parts. On-site activities are limited*	I

3

3.5.5 Institutionalization of the ideal-type logics

Before the leaps logic was introduced, the steps logic was the dominant logic guiding actors in the Dutch renovation innovation system. This changed in 2011 when the Energiesprong program, initiated by the Dutch government, started to advocate the use of concepts for renovation, which were first developed in the market for new houses. Of course, this sparked the interest of construction companies that already had experience with such concepts. In terms of clients, this development mainly sparked interest of housing associations and this ultimately led to the formation of the covenant *Stroomversnelling Huurwoningen* (rough translation: *acceleration rental homes*). The covenant was signed by a consortium of housing associations and large construction companies and the goal was set to renovate 111.000 houses using renovation concepts toward Zero-on-the-meter in 2020. The renovation concepts developed within this covenant are suitable for row houses constructed in the 1960s and 70s, and flat buildings build between 1940 and 1970, which amounts to approximately 700.000 houses or about 35% of the houses owned by housing associations in the Netherlands (RVO, 2011). Since all houses suitable for using renovation concepts can also be renovated by a step-wise approach, both renovation approaches currently battle for dominance in this market segment. Thus, a handful of housing associations follow the leaps logic in a relatively 'pure' form, but only for a part of their housing stock.

For the market of homeowners, a similar covenant was initiated in 2014 (*Stroomversnelling Koopwoningen* [rough translation: *acceleration owner-occupied houses*]). This covenant focusses on developing concepts for row houses built between 1950 and 1980, which are approximately 600.000 houses, or about 19% of the total houses in this market segment (RVO, 2011). Developing renovation concepts for homeowners is more challenging than for the rental market for two main reasons. First, since ownership is much more dispersed, even row houses that were alike when they were built may currently be very diverse (e.g. newly placed dormers or extensions). Second, instead of a handful of housing associations, concept developers now have many homeowners as client, each with their own preferences. Thus, renovation concepts for the homeowner segment must be more flexible. What is more, concept developers that focus on homeowners are generally smaller companies that were formerly guided by the steps logic, and this can still be seen in how they organize the renovation process. Together, this leads the leaps logic for the market segment of homeowners to be watered down in the direction of the steps logic.

The introduction of the leaps logic also led to changes in the institutionalization of the ideal-type steps logic. Although actors guided by the steps logic initially considered customization absolutely necessary, some actors now advocate using standardized packages of stacked measures. Interestingly, some have started to use the term 'concept' for such packages, even though these packages have little in common with the renovation concepts associated with the leaps logic. Thus, also the steps logic is watering down as reaction to the increasing prevalence of the leaps logic. These results show that - although the steps and label logics are still clearly visible in the current innovation system of renovating houses energy-efficiently – they are slowly moving away from some of their 'ideal-type' characteristics and have started to blend.

3.6 DISCUSSION

In this section we will first reflect on the formulated ideal-type logics from the perspective of the institutional logics meta-theory. Then, we discuss implications of our study for innovation system analysts. Finally, we deliberate on the implications for the policy formulation process which usually follows an innovation systems analysis.

3.6.1 Reflections on the identified ideal-type logics

The institutional logics meta-theory describes that all field level logics, thus also the steps- and leaps logics, are anchored in and are shaped by higher institutional orders of society, namely state, market, profession, corporation, family, and community (Thornton et al., 2012). We argue that the Label step logic is – because of the prominent role for smaller specialized companies – anchored in the order of the profession, and – because of its focus on decentralization – to the order of the community. Contrasting this, the leaps logic is anchored in the order of the corporation: it has its roots in the market segment of newly-built houses which is dominated by larger corporations. The role of the state and the position of the market are uniform for the whole renovation sector, and thus also for the two ideal-type logics. Finally, the order of the family is not applicable, considering the low number of family run companies in the market for renovating houses.

The steps- and leaps logics explained the pattern of inconsistency within our identified problems and solutions well. However, we are the first to acknowledge that – although we discussed the institutionalization of both logics shortly – the results presented in this chapter do not provide hard evidence for their institutionalization. This was also not the intention of this chapter as we only set out to explore whether formulating ideal-type logics as part of an innovation systems analysis can increase insights, which it did. If empirical evidence for actual institutionalization of logics is desired, there are multiple methods through which this can be achieved (Reay & Jones, 2016). In our view, this is not always necessary since - depending on the goal of the analysis - the insights gained from an analysis of ideal-types only may already prove sufficient.

3.6.2 Implications for innovation system analysts

Analyzing institutional logics as part of an innovation systems analysis turns it into a more powerful problem analysis tool. If an analyst is confronted with inconsistent data on problems and potential solutions, this should signal to consider the possibility of conflicting logics guiding actor behavior. Analyzing logics reduces the analysts' enticement to favor one opinion over the other or to neglect the data inconsistency. Since this gives insight into the origin of the inconsistent data, it does better justice to the collected data.

The results do not imply that multiple institutional logics are guiding actor behavior in every innovation system. For instance, chances are high that only one institutional logic is prominent in an emergent innovation system around a single new technology. In such a situation, the analyst will find that data collected about problems and solutions is largely consistent, making an analysis of institutional logics unnecessary. This is different for more complex innovation systems, for instance a system created through a merger of two earlier distinct systems. If an analyst identifies multiple logics in relation to a single innovation system this may signal a directionality failure (Weber & Rohracher, 2012). Especially for such systems, we expect analysts to be confronted with inconsistent data, making an analysis of institutional logics fruitful. That many innovation systems studies have focused on the emergent phases of development may thus explain why literature has given so little attention to how analysts can deal with data inconsistencies in relation to problems and solutions during an innovation systems analysis.

3.6.3 Implications for intervention formulation

As we have seen, if multiple logics are identified in relation to an innovation system, the identified solutions (intervention options) may be inconsistent with each other. For instance, a particular intervention may stimulate the uptake of innovations in line with one logic, but also block the uptake of innovations in line with another logic. One way to assure consistency among interventions[10] is by favoring one logic over the other, and only selecting the interventions that are in line with this logic. For instance, a policy maker could only select the solutions that are in line with the steps logic and except that this possibly hinders innovation in line with the leaps logic. Another option would be to design two intervention strategies – one for each logic – but this may be difficult without

10 Ensuring consistency between interventions is crucial when designing policy mixes for technological innovation systems (Reichardt et al., 2016).

creating inconsistencies between both intervention strategies. Finally, a policy maker could select only the interventions that are beneficial to all actors, independent of the logic that guides them, but this does limits the options for intervention considerably.

Analytically, the ideal-type institutional logics concept is based on first setting extremes and then nuancing these. Setting extremes makes it easier for the analyst to see patterns, and our experience is also that such deliberate simplification resonates with practitioners because it structures thinking processes. However, although the formulation and analysis of ideal-type logics can substantially increase insights, it must be stressed that it always remains necessary to consider the actual institutionalization of the ideal-type logics in practice. If this is forgotten, the empirical situation may be oversimplified, leading to the wrong conclusions and thus to interventions that will not have the desired effect.

3.7 CONCLUSION

Innovation system analyses are often performed with the purpose to identify problems that inhibit innovation and to subsequently formulate interventions. A discussion of literature on innovation systems revealed that the current framework does not provide the theoretical means for coping with inconsistent data in relation to problems and possible solutions. We argued that this is the consequence of an implicit assumption in innovation systems literature that problems are 'out there', and that an analysts should strive to reveal the objective truth about them. However, analysts that take such an objectivist view may be enticed to favor one opinion over the other or to neglect the inconsistent data. This does not do justice to the collected data and may lead to wrong conclusions. It was thus argued that the innovation systems framework may benefit from the ability of taking a subjectivist view on problems and potential solutions.

To explore the merits of taking a subjectivist view, we drew on the institutional logics concept. In this chapter we set the objective to explore the usefulness of institutional logics theory for coping with inconsistent data regarding problems and potential solutions during an innovation system analysis, and if so, how this can be approached. An analysis of the Dutch energy-efficient renovation innovation system was carried out during which two ideal-type institutional logics were identified, namely the steps logic and the leaps logic. These logics proved useful to understand why the collected data in relation to problems and solutions for this innovation system was inconsistent, and in this way demonstrated to form a useful additional analysis step. These findings indicate that an innovation system analyst can – if confronted with inconsistent data – indeed avoid difficulties during the analysis process by taking a subjectivist view. What is more, such an approach contributes to creating coherent intervention strategies. In this way, the possibility of taking a subjectivist view on problems and potential solutions strengthens the TIS intervention framework.

Chapter 4

The influence of sectoral context on Technological Innovation Systems: the case of heat pumps for Dutch residential houses

4.1 INTRODUCTION

Although literature has always recognized that TISs are usually embedded in – and show overlap with – other systems (e.g. Markard & Truffer, 2008), initial work mainly focused on understanding internal TIS dynamics (Bergek et al., 2008; Hekkert et al., 2007). The necessity of a more elaborate conceptualization of the context of TISs has recently been specifically stressed (Bergek et al., 2015). Bergek et al. (2015) describes not only in general what kind of influence contextual structures may have on TISs, but also what kind of influence specific types of contextual structures, including sectoral context structures, have on TISs. For contextual structures in general, it is emphasized that they are not static: "They tend to change over time, both as a matter of autonomous developments in context structures and as a consequence of the focal TIS growing and becoming more mature." (p. 56). Yet, in relation to sectoral context structures specifically, it is mentioned that "A sector […] provides a quite stable context, which individual TISs either have to adapt to or try to change to their own benefit." (p. 56). In other words, literature currently implies that autonomous development in sectoral context structures is rare if not nonexistent.

The purpose of this chapter is to take a detailed look at the influence of sectoral context on the functioning of a TIS. For this purpose, this chapter presents a case study in which TIS-context was brought to the forefront of attention. The case focusses on heat pumps for use in residential houses in the Netherlands for which the following research question was concerned: How does sectoral context influence function fulfillment in the heat pump technological innovation system in the Netherlands? Our findings suggest that the sectoral context of a TIS is not always as static as what literature expects.

This chapter proceeds as follows. As addition to what was already explained in this dissertation's introduction, the theory section provides a more detailed description of the phases of development, and recaps the stages of a standard TIS-analysis. In addition, it discusses how TIS context has been conceptualized. Then, in the method section, we adapt the general TIS-analysis stages to explicitly incorporate TIS-context, after which in the results section, we present the outcome of applying this method to the technological innovation system of heat pumps for use in Dutch residential houses. At the end, we reflect on what kind of influence TIS context, and then specifically sectoral context, may have on TIS functioning.

4.2 THEORY

A developing TIS moves through a number of phases of development (Suurs & Hekkert, 2009; Hekkert et al., 2011). Roughly speaking, in the first phase (*pre-development*), actors collectively develop knowledge and work toward a first prototype to provide evidence that the technology works. In this phase, the focus thus lies on the function knowledge development (F2) and knowledge diffusion through networks (F3). The other functions provide support, for instance, a high potential for the technology should be emphasized (F4), so that resources are made available (F6) for knowledge development (F2). In the subsequent *development* phase, the technology is tested in pilot projects. The focus thus lies on the function entrepreneurial activities (F1) and, because these pilot projects are usually collective activities, on knowledge diffusion (F3). The main subject for knowledge development in this phase is making the theoretical knowledge gained in the first phase practically useful (F2). It is important that the technology is considered legitimate by sufficient actors (F7) so that sufficient resources can be mobilized to support the other functions (F6). Possibly, the technology is successfully introduced in a niche market (F5) which, together with a hopefully successful pilot project (F1), further stimulates actors to emphasize the necessity of the technology (F4). Then, in the *take-off* phase, the first pilot projects end (F1) and the effort to bring the technology to the market further increases (F5). This phase may be accompanied with strong resistance from outside the system, therefore requiring strong legitimacy creation (F7), which the hopefully successful pilot projects (F1) provide. The growing market (F5) stimulates actors to increase the expectations for the technology (F4) what may lead to additional and larger scale pilot projects (F1). Obviously, resources are required to support the other functions (F6), whereas knowledge development (F2) becomes less prominent during this phase. Subsequently, in the *acceleration* phase, the pilot projects move to the background (F1) as further stimulation of the market (F5) becomes the highest priority. Because the technology has proven its worth in the pilot projects, more actors begin to support the technology (F4) and, as a result of cost reductions (F6), diffusion accelerates. Finally, saturation is reached in the *stabilization* phase where the diffusion stabilizes. Since each phase of development requires the fulfillment of different functions, it is important to take the phase of development into account when judging whether function fulfillment in a particular system is 'good' or not.

As also explained in more detail in the introduction of this dissertation, Bergek et al. (2008) and Wieczorek & Hekkert (2012) have described the stages that should be taken during a TIS analysis. Although both descriptions have their differences, they share the central idea of combining an analysis of the system structure with an analysis of functions. The following stages reflect the stages as introduced by Bergek et al. (2008) while using the terminology from Wieczorek and Hekkert (2012). First, the boundaries of the TIS in focus are set. Second, the structure is described (structural elements). Third, a functional analysis is performed during which all seven functions are judged on the extent in which they are fulfilled. Fourth, the pattern of function fulfillment is compared to what is expected in a certain phase of development, thus coming to a judgement of whether the function fulfillment is 'good' or not. Fifth, systemic problems are identified that are underlying the weak functions, and sixth, these systemic problems are targeted with interventions, thus strengthening the functional pattern and improving the system performance. As this shows, analyzing the context of a TIS is not considered a separate stage of a TIS-analysis.

Although the importance of the context of a TIS was always recognized, also before the renewed attention to context, it was always somewhat implicit. In a way, the activity of boundary setting already implicitly involves a consideration of the context as setting the boundaries more broadly comes close to setting the boundary lean and taking context into account. In addition, efforts to integrate the TIS perspective with the Multi-Level-Perspective (MLP), in which the TIS is conceptualized as a niche that is influenced by (outside) regime and landscape forces, can also be seen as attempts to bring the TIS context to the forefront (Meelen & Farla, 2013, Markard & Truffer, 2008). However, a more elaborate conceptualization of TIS-context was proposed only recently (Bergek et al., 2015).

Bergek et al. (2015) first explains that interactions between a TIS and contextual structures can be of two kinds, namely external links and structural couplings. External links refer to dependencies of the TIS on its context. For example, the electricity law restricts the possibilities for connecting radically new energy generation technologies (e.g. blue energy) to the grid. Companies that develop these radically new technologies – and are thus part of the TIS – usually do not have the capacity to influence the electricity law. External links are thus one-directional from the context to the TIS. Structural couplings refer to 'shared elements between a TIS and specific context structures" (Bergek et al. 2015, p. 53). A case in point are fossil fuel companies that become active in wind energy and thus span multiple TISs. Because such companies often have better access to government, they may be able to successfully lobby for changes to laws and regulations. Structural couplings are thus two-directional between the TIS and its context. In earlier development phases, TISs are mostly dependent on their environment (only external links), whereas in later development phases, the TIS will have more structural couplings.

According to Bergek et al. (2015) a TIS can have external links and structural couplings with at least four contextual structures: other TISs, sectors, geographical context structures and political context structures. To begin with, some technologies may complement each other whereas others compete, signaling different types of TIS/TIS interactions. Next to TIS/TIS interactions, TISs often interact with sectors as these generally rely on multiple technologies to provide users with a product or service. TISs may also interact with different geographical context structures, for instance when a TIS spans multiple regions. The political context provides the final contextual structure. Political context "cuts across geography, sectors and technologies" (Bergek et al., 2015, p. 60) and is thus not restricted to the national level alone. In relation to contextual structures in general, Bergek et al. (2015) mentions that they tend to change over time, either because TIS actors influence it, or because of autonomous changes.

The distinction between four contextual structures does not mean that necessarily all context structures must be taken into account in a TIS-analysis. Bergek et al. (2015) explains that, depending on the purpose of the case study "we can focus on a particular context structure to investigate its dynamics and links to the focal TIS" (Bergek et al., 2015, p. 61). In the case of the heat pump for use in Dutch residential houses, the most relevant contextual structures are other TISs as well as the sector. When a house is renovated, activities are rarely restricted to installing a heat pump only. Instead, there are usually multiple technologies installed (insulation, solar panels, heat pump etcetera), implying the importance of TIS/TIS interactions. Furthermore, the choice for installing a heat pump or not, and if so what type, is made at sectoral level as it depends much on how the renovation process is organized, and what other technologies are chosen for during the renovation process. TIS/sector interactions are thus also deemed important. The focus on one nation (the Netherlands) makes the geographical dimension less relevant. The Netherlands is also unique in the sense that policies (and thus politics) in relation to the build environment (and thus heat pumps) are mainly set at national level. For the case study as presented in this chapter, the Netherlands thus provides a shorthand denomination for the geographical and political dimensions.[1] During the analysis, the focus is put on the relevant TIS/TIS and TIS/sector interactions.

The conceptual means to structure an analysis of TIS/TIS interactions are provided by the categorization of modes of technology/technology interactions by Sandén and Hillman (2011). To begin with, technologies may be in *competi-*

1 Bergek et al. 2015 goes even further: '[…] dealing with geographical context gets rather unproblematic for an analyst if the relevant technological, sectoral and political context structures overlap in a territory (e.g. a specific country). Then this country may be treated as a shorthand denomination for all different contexts." (p. 58).

tion with each other because they make use of a common resource or accommodate the same market. Technologies may also be in *symbiosis*, meaning that one technology benefits from the implementation of the other, and vice versa. Next, a situation of *neutralism* refers to two technologies that do not affect each other. *Parasitism* (and predation) materializes when technology 1 is benefiting technology 2, whereas technology 2 is inhibiting technology 1. Subsequently, *commensalism* describes a situation where one technology is benefited, while the other is not affected, and finally, *amensalism* happens when one technology is inhibited, while the other is not affected. It is assumed that the modes of interaction between two TISs will be largely in line with the modes of interaction of their respective technologies. For instance, if two technologies compete, the actors within the two respective technological innovation systems are also expected to compete, or if two technologies interact through a commensalism relationship, actors within one TIS will try to collaborate with the other, whereas actors within the other TIS will not be bothered. The case study of the heat pump will thus not only make use of the Sandén and Hillman' categorization to describe the interaction between the heat pump and other technologies, but also to describe the interactions between actors from the respective TISs.

Also the interaction between a TIS and a sector has been described by Bergek et al. (2015). It is explained that TISs often depend on the infrastructure, norms and values or regulations at sectoral level. An example that is put forward are building codes. Building codes may determine to a large extent whether it is feasible to install renewable energy technologies, especially technologies that can be seen from the outside (for instance solar panels in historic cities). Often, such sectoral regulations will affect a TIS one-directionally. Building codes for instance mainly restrict the possibilities for implementing a certain technology (an external link). When actors in a TIS are able to influence the building codes, there is a structural coupling between the TIS and the sector. In relation to the influence of sectors on TIS development, Bergek et al. (2015) mentions that they tend to be institutionalized to a large extent, meaning that regulations, the interactions between actors, preferences etcetera, are deeply embedded in the system and do not change much. In their words: "A sector […] provides a quite stable context, which individual TISs either have to adapt to or try to change to their own benefit." (Bergek et al. 2015, p. 56). In this chapter, we will explore whether the case study of the heat pump in the Netherlands is in line with this description of TIS/sector interaction.

4.3 METHOD

In this section, the standard TIS-analysis stages are adapted to incorporate more explicit attention for TIS-context. The method followed consists of six stages, each of which is explained below in more detail.

The first stage of the analysis consists of analyzing the technology itself. The purpose of this stage is to make sure that setting a boundary around the focal technology (in this case the heat pump) makes sense considering its specific characteristics. To already give away the outcome, based on the analysis of heat pump technology, it is concluded that it is necessary to distinguish between two general types of heat pumps instead of analyzing the heat pump as a single technology (the standalone heat pump and the hybrid heat pump).

The second stage of the analysis consists of analyzing the modes of interaction between the focal technology (in this case two types of heat pumps), and other relevant technologies. For describing the modes of technology/technology interactions the categorization as brought forward by Sandén and Hillman (2011) will be used. The purpose of this stage is to get insight into whether the focal technology is sufficiently independent from other technologies to justify a separate analysis. Based on this stage, it is concluded that the hybrid heat pump is difficult to analyze independent from the high-efficient gas boiler, and that furthermore insulation technology, low-temperature heating systems, and solar panels have important technology/technology interactions with the heat pump that should be considered.

The third analysis stage involves gaining insight into the systems that have formed around the respective technologies (TISs) and into the structural couplings between them. This stage is necessary for deciding whether to analyze all TISs separate from each other or to combine them. For instance, if two TISs are highly structurally coupled it may be better to analyze them as a single system. Based on this stage, it is decided to distinguished between two TISs: (1) the standalone heat pump TIS and (2) a combined hybrid heat pump/high-efficient gas boiler TIS.

In the fourth stage, relevant aspects of the sectoral context are discussed that influence the two distinguished TISs as discerned in the previous stage. The purpose of this stage is to make sure that sufficient attention is given to the sectoral context. In the case of the heat pump, for instance, the choice between one type of heat pump or the other is found to highly depend on the renovation goal that sector-level actors strive for.

The fifth stage subsequently consists of describing function fulfillment and inhibiting systemic problems. Because of space restrictions, the influence of the sectoral context on function fulfillment is specifically stressed. The consequence of this choice is that problems pertaining to the internal structure of the heat pump TISs, or that express themselves especially in the interactions between the standalone heat pump TIS and the hybrid/gas boiler TIS are given less attention. Readers interested in the more complete version of the analysis are referred to the report on which this chapter is based (Kieft et al., 2015). The functions as distinguished by Hekkert et al. (2007) are used to structure the description. Since the first four stages led to distinguishing two TISs (standalone and heat pump/gas boiler TIS), this is done twice. Finally, as sixth and final stage, the phase of development of both TISs is reflected upon.

Data for the analysis came from multiple sources. For the first four stages, data was used from preliminary interviews with experts on heat pumps and experts of the renovation sector. This data was combined with documents, for instance government documents and research reports. Finally, internet websites were used to get background information about specific initiatives in relation to heat pumps or to renovation more generally. Data for the fifth stage (function fulfillment and problem identification) was based on interviews with a wide variety of actors. These included government officials, housing associations, house renovation consultants, energy cooperatives, installers, heat pump manufacturers, and industry associations. In total, sixteen of such interviews were conducted, which lasted two hours on average. Data analysis consisted of coding relevant textual fragments, and subsequently ordering them according to the concepts from the TIS-framework.

4.4 RESULTS

This section is structured according to the six analysis stages as discerned in the previous section.

4.4.1 Heat pump technology

A heat pump literally 'pumps heat' into a house as it transfers heat from an external heat source to the inside of the house. Multiple external heat sources can be used, for instance outside air, ventilation air, surface water or soil. A fluid with a very low boiling temperature is pumped to the external heat source where it absorbs heat and is turned into a gas. A pump subsequently transfers the gas to the inside of the house where it is put under pressure, thereby releasing the earlier absorbed heat. This makes the gas turn into a fluid again after which the cycle is repeated. Simplified, it is the reverse process of a refrigerator. The created heat can be transferred to different so called 'heat sinks', for instance, it can be used to create warm water (for central heating or tap water), or directly for heating the air in a certain room. Counterintuitively, the heat source may have a lower temperature than the heat sink: cold air still contains heat. For instance, just like an already low temperature in a refrigerator can be reduced by removing heat from the inside, a heat pump can remove heat from a relatively cold heat source and transfer it to a warmer heat sink. Although there is a wide variety of heat pumps available, only a few types are fit for large scale implementation in Dutch houses.

In the Netherlands, by far most houses are heated using a high-efficient gas boiler. These boilers create warm water that is not only used for central heating, but also for warm tap water. Almost every house in the Netherlands thus has a connection to the gas grid, which can be explained by the large natural gas reserves in the Netherlands. The use of oil for central heating in combination with electricity for hot water – which is a common combination in other European countries – has never been prominent in the Netherlands. Heat pumps are seen as an improvement compared to the high-efficient gas boiler because they generally run on electricity instead of on gas.[2] If the electricity for running the heat pump is produced sustainably, for instance with solar or wind energy, the heat pump produces sustainably produced heat. What is more, heat pumps are also very efficient. The energy (in the form of heat) that is transferred to the house can be up to four times higher than the energy (in the form of electricity) necessary to run the pump.[3] What is more, because in the Netherlands houses are generally heated using warm water as medium (water as heat sink), only heat pumps that transfer heat to water are considered a viable option. This thus leaves out heat pumps that heat air. To conclude, conditions in the Netherlands are most favorable for the implementation of heat pumps that run on electricity and use water as heat sink.

Within the category of heat pumps that run on electricity, a distinction can be made between two main types. The first type – which will be called the *standalone heat pump* – has sufficient capacity for heating a house and providing warm water throughout the year. Only on very cold days and with high peaks in the use of warm water, is additional back-up electric heating necessary (simple electric coil). Users that do not want to make use of this back-up heating can simply turn it off. The second type – the *hybrid heat pump* – has a much lower capacity, making it on itself unable to heat a house and provide warm water throughout the year. It is called a hybrid, because this smaller capacity heat pump is generally used in combination with a gas-fired boiler. Most hybrid heat

2 Heat pumps can also use gas for running the pump, but these heat pumps are generally much larger, making them unfit for use in residential homes.

3 For heat pumps this efficiency is generally denoted with the so-called COP value. For instance, a heat pump with a COP of 3 can transfer three times more energy to the house than what is necessary to run the pump. A COP of 3 thus reflects an energetic efficiency of 300%.

pumps only support heating the house, whereas providing warm water remains the responsibility of the gas-fired boiler. They are usually installed next to a gas-fired boiler, although hybrid heat pumps that are integrated with a gas-fired boiler in a single machine are also available. In theory, a hybrid heat pump can also be used in combination with an electric boiler. However, this is not a viable combination for the Netherlands, first because of the prominence of the gas-fired boiler, and second because of much resistance from the companies that own the electricity grid (because this combination leads to high peak demand on the electricity grid). The rest of the chapter thus makes the distinction between the standalone heat pump as replacement for a high-efficient gas boiler, and the hybrid heat pump as addition to the high-efficient gas boiler.

Heat pumps can in theory make use of a wide variety of external heat sources (air, water, soil), but not all of these are viable options for larger scale implementation of heat pumps in residential houses. First, since the availability of surface water near houses is rare, the use of water as heat source is not considered viable for large scale implementation. Second, although using soil as heat source has multiple advantages, for instance that the soil can also be used in the summer to transfer heat to (air-conditioning), it is generally more difficult to install and thus more expensive. For instance, a pit must be dug in the garden, which homeowners often do not like. There is also a minimum distance between pits, which complicates installing multiple soil heat pumps in densely populated areas. This type of heat pump thus falls outside of the system boundaries. Instead, air as heat source provides the most convenient solution: any house has access to air. Some houses (especially newer houses) have an active ventilation system and thus have access to relatively warm ventilation air, which is a good heat source for the heat pump. However, as ventilation air is rest heat from heating the house it thus, by definition, does not by itself contain enough heat for heating a house. Using ventilation air as heat source is thus only viable for hybrid heat pumps, whereas both standalone and hybrid heat pumps can make use of outside air. As only a part of the housing stock has an active ventilation system, for many houses using outside air as heat source is the most viable option.

4.4.2 Interactions of heat pumps with other technologies

Ideal conditions for the heat pump arise when the temperature difference between the heat source and the heat sink is only small. On the heat source side, a low heat source temperature reduces the efficiency of the heat pump since it is more difficult to remove heat from a low temperature heat source compared to a higher temperature heat source. A hybrid heat pump that uses relatively warm ventilation air as heat source thus generally has a higher efficiency than a standalone heat pump. On the heat sink side, there are more possibilities for improving the conditions for the heat pump. First, the user sets requirements on the concurrent amount of heat required, for instance whether showering and doing the dishes should be possible at the same time, or at what speed a room can be heated up. In theory, the conditions for using the heat pump thus improve if a user reduces its requirements (for instance by showering using lukewarm water). However, it is assumed that the user requirements do not change when a heat pump is installed and we thus do not further take this into account. Second, when a house is insulated well, the demand for heat is not only much lower, but also more constant. Insulation thus improves the conditions for installing a heat pump. Third, the required temperature of the heat sink matters. Floor heating or wall heating systems generally require lower temperature water, which is why they are often called low-temperature heating systems. Such low-temperature heating systems thus also improve the conditions for using a heat pump. Fourth and finally, the availability of energy carrier matters. For instance, if a house already has solar panels on the roof, this availability of electricity may benefit the use of a heat pump. To conclude, the ideal conditions for a heat pump arise when a house is insulated well, utilizes a low-temperature heating system, and can make use of electricity from solar panels. Thus, three additional technologies should be taken into account: (1) insulation technology, (2) low-temperature heating systems, (3) and solar panels.

To gain a better view on the technology/technology interactions between the above-mentioned technologies, their respective interactions are described using the categorization from Sandén and Hillman (2011). To begin with, since adding insulation, installing low-temperature heating, or solar panels does not benefit the high-efficient gas boiler in any way, nor does it inhibit it, the high-efficient gas boiler has only neutralism relationships with insulation, low-temperature heating, and solar panel technologies.

For discussing the modes of interactions of heat pumps with insulation, low-temperature heating, and solar panel technologies, no distinction has to be made between standalone and hybrid heat pumps since they have the same modes of interaction with these technologies. The relation between heat pumps and insulation technologies can be described as *commensalism*, because the conditions for the heat pump improve with more insulation, whereas the case for insulation is not affected by the standalone heat pump. Similarly, heat pumps can make use of the electricity generated from solar panels, but solar panels are not benefited by a heat pump, signaling another *commensalism* relationship. Finally, also for low-temperature heating systems, the heat pump benefits (because the heat sink temperature is lower) while low-temperature heating technology does not necessarily benefit from using a heat pump: the hot water can just as well be created using a high-efficient gas boiler. To conclude, the relationship between heat pumps on the one hand, and insulation, low-temperature heating systems, and solar panels on the other, can all be described as *commensalism*.

Technology/technology interactions are less straightforward between the standalone heat pump, the hybrid heat pump, and the high-efficient gas boiler. To begin with, the standalone heat pump is in *competition* with the high-efficient gas boiler, since either one or the other is used. The standalone heat pump is also partly in *competition* with the hybrid heat pump, although concerning legitimacy creation, it can be said that the hybrid heat pump and the standalone heat pump have a *symbiotic* relationship. Contrasting this, the hybrid heat pump mainly has a *commensalism* relationship with the high-efficient gas boiler: a hybrid heat pump is always installed in combination with a high-efficient gas boiler, whereas the latter does not depend on the former. This provides the insight that the high-efficient gas boiler and the hybrid heat pump – as technologies – are tightly linked, whereas the standalone heat pump stands apart. Table 4.1 provides an overview of the modes of interaction between the technologies mentioned in this section.

Table 4.1: Modes of interaction between relevant technologies.

Technology 1	**vs**	**Technology 2**	**Mode of interaction**
High-efficient gas boiler	vs	low-temperature heating	Neutralism: both are unaffected
High-efficient gas boiler	vs	insulation	Neutralism: both are unaffected
High-efficient gas boiler	vs	solar panels	Neutralism: both are unaffected
Heat pump	vs	low-temperature heating	Commensalism: former is benefited, latter is not affected
Heat pump	vs	insulation	Commensalism: former is benefited, latter is not affected
Heat pump	vs	solar panels	Commensalism: former is benefited, latter is not affected
Hybrid heat pump	vs	high-efficient gas boiler	Commensalism: former is benefited, latter is not affected
Standalone heat pump	vs	high-efficient gas boiler	Competition: both compete for the same market
Standalone heat pump	vs	hybrid heat pump	Competition: both compete for the same market Symbiosis: shared legitimacy creation

4.4.3 Structural couplings

This section makes the move from the technologies themselves to the innovation systems that have formed around them. It is not only discussed to what extent a separate TIS has formed around respectively the standalone heat pump and the hybrid heat pump, but also to what extent these systems are structurally coupled, not only with each other, but also with the TIS of the high-efficient gas boiler. We do not strive for completeness in the description of these systems because the intention is limited to deciding whether to distinguish between two or three TISs in the rest of the analysis. For describing the system structure, three types of organizations with an especially prominent role are focused on, namely (1) manufacturers that develop and produce the technologies, (2) industry associations that represent the interests of actors in these systems, and (3) installers that install the technologies.

The standalone heat pump TIS is discussed first. Manufacturers of standalone heat pumps are mostly foreign companies that sell their products in the Netherlands. By far most of these manufacturers do not produce either hybrid heat pumps or high-efficient gas boilers. The standalone heat pump is installed by specialized installers that also generally do not also install either hybrid heat pumps or high-efficient gas boilers. In this way, the manufacturers and installers of standalone heat pumps are unique to the standalone heat pump TIS. This does not mean that the standalone heat pump TIS and the hybrid heat pump TIS do not show any structural overlap. For instance, there is a Dutch industry association for heat pump manufacturers (Dutch Heat Pump Association) that represents both standalone and hybrid heat pump manufacturers. This organization has set the goal of installing 300.000 additional heat pumps, independent of type, in the Netherlands before 2020 (Wagener & Mosterd, 2013). In addition, there currently is a sustainable heat subsidy program active in which both standalone heat pumps and hybrid heat pumps are eligible for support (also other technologies like pellet stoves). The trade association for heat pumps, the set goals, and the available subsidies all represent structural couplings between the standalone heat pump TIS and the hybrid heat pumps TIS.

Actors in relation to the hybrid heat pump and the high-efficient gas boiler can hardly be discussed separate from each other. Manufacturers of hybrid heat pumps are mostly Dutch manufacturers who originally produced, and still produce, high-efficient gas boilers. There are also manufacturers that only produce high-efficient gas boilers. What is more, few, if any, installers only install hybrid heat pumps. Instead, hybrid heat pumps are mostly installed by more advanced installers of high-efficient gas boilers that offer the hybrid heat pump as additional product. The average installer can only install a high-efficient gas boiler, although more installers have started to send their staff to training programs for also installing hybrid heat pumps. Clearly, these actors (manufacturers and installers) represent strong structural couplings between the hybrid heat pump TIS and the high-efficient gas boiler TIS.

The TISs of insulation, low temperature heating, and solar panels stand largely apart from the heat pump and high-efficient gas boiler TISs. Manufacturers of the former technologies do not generally also produce other technologies. Insulation and solar panels are also generally installed by specialized companies. Installers that can install not only gas boilers, but also hybrid heat pumps and low temperature heating systems do exist and provide, together with industry associations for installers in general, the only structural couplings between the heat pump TISs and the TISs of the other technologies. The structural couplings between the heat pump TISs and the TISs of insulation, low temperature heating and solar panels are thus not further analyzed.

Figure 4.1 provides an overview of the three TISs and shows what actors and institutions form structural couplings between them. Three things can be noted. First, the hybrid heat pump TIS does not have any unique actors or institutions: they are all shared with the other TISs. Second, the standalone heat pump TIS does have unique actors. Third, there are strong structural couplings between – on the one hand – the hybrid heat pump TIS and the high-efficient gas boiler TIS (shared manufacturers and installers), and – on the other hand – between the standalone heat pump TIS and the hybrid heat pump TIS (industry association, goals and subsidies). Clearly, the TIS of the standalone heat pump is much more independent compared to the TIS of the hybrid heat pump.

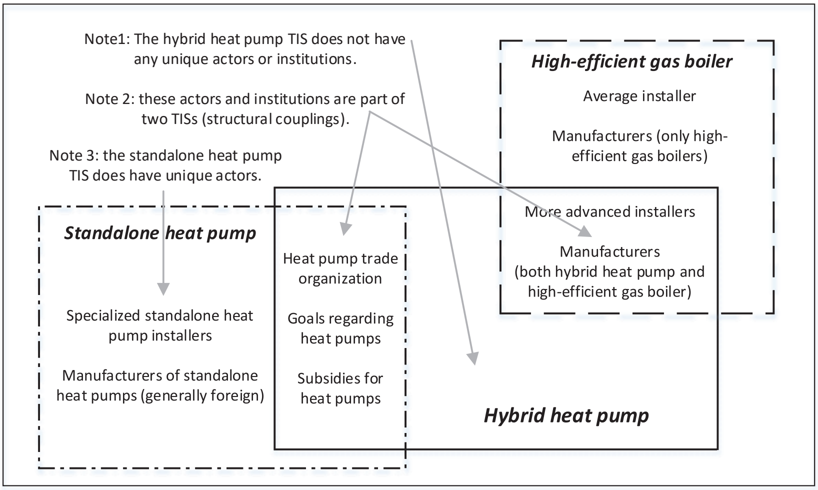

Figure 4.1: Structural couplings: TISs of standalone heat pump, hybrid heat pump and high-efficient gas boiler.

We note here that, as expected, the interactions between actors from the respective TISs are largely in line with the modes of technology/technology interactions as described in section 4.4.2. For instance, the hybrid heat pump has a partly symbiotic and partly competitive relationship with the standalone heat pump, which expresses itself in their partly structurally coupled TISs. Another example is the commensalism relationship between the high-efficient gas boiler and the hybrid heat pump, which expresses itself in the fact that the hybrid heat pump TIS is dependent on actors that are also part of the high-efficient gas boiler TIS (for installers and manufacturers), while the high-efficient gas boiler TIS is not dependent on the hybrid heat pump TIS. Finally, the competitiveness between the standalone heat pump and high-efficient gas boiler technologies is also visible in their respective TISs as these show no overlap (no structural couplings). Although the above clearly implies that analyzing the standalone heat pump TIS as separate entity makes sense, it also again raises the question whether the hybrid heat pump TIS should be analyzed on itself or in combination with the high-efficient gas boiler TIS. Before being decisive on this matter, it is necessary to discuss relevant dynamics at sectoral level to which we turn next.

4.4.4 Relevant sectoral context structures

It is important to understand that for most sectoral actors, the heat pump is not an end in itself, but rather a means to an end. For instance, housing associations, the national government and municipalities may be interested in reducing energy-use and increasing energy-production in residential houses, but for them it generally does not matter what technologies are utilized to achieve this goal. However, the ambition level of the goals does strongly influence what technologies make most sense to implement, and in this way goals thus influence whether the heat pump is chosen for or not. For instance, when renovating a house toward energy neutral, more and different technologies will be necessary than when the goal is to slightly improve the house' energy-efficiency. This section discusses different renovation goals that Dutch sectoral actors commonly strive for, and illustrates why, depending on the set goal, either a standalone heat pump, a hybrid heat pump or a high-efficient gas boiler will be preferred.

In the Netherlands, it is quite common to set the renovation goal in relation to the energy label of the house. An energy label runs from label G (very inefficient) to label A++ (energy neutral). Each measure taken, which can be either an energy efficiency measure (e.g. insulation) or an energy production measure (e.g. solar panels), represents a certain increase of the energy label and, depending on the ambition level of the renovation, different technologies will be 'stacked'. Housing associations have set the collective goal of reaching an average of label B in 2020, which is also made part of the Dutch energy covenant (in Dutch: Energieakkoord). As a result of this sector wide goal, many housing associations choose to renovate all of their houses to label B. However, there are also many housing associations that strive for reaching label A or higher. This may be because of intrinsic motivation, but is often because the sectoral goal is to reach label B *on average*: by renovating part of their houses to label A or higher, housing associations can be less ambitious for the rest of their housing stock. In other words, both renovating toward label B and renovating to label A or higher are common renovation goals.

Next to setting the goal in terms of energy label improvement, it is increasingly common to renovate toward the goal of zero-on-the-meter. A zero-on-the-meter house annually produces enough energy to offset the energy-use of an average family. This goal was introduced by the Dutch government as part of the so-called Energiesprong program. In addition to the zero-on-the-meter goal, this program also advocated the use of so called renovation concepts, which is a standardized methodology for renovating a particular type of house (e.g. a particular type of row house or flat building). By far most renovation concepts are geared to reaching zero-on-the-meter. Instead of performing renovation activities on site (which is common for label renovations), construction components are prefabricated in a factory after which the house is stripped and the prefab components are installed in a matter of days. What is more, most renovation concepts are all-electric, which means that the house is no longer connected to the gas grid after renovation. When the goal of zero-on-the-meter is thus set, measures are not 'stacked' as with energy label renovations, but form a coherent set of measures. In this way, renovations toward zero-on-the-meter differ substantially from energy label renovations.

What technologies can be used (and make sense using) strongly depends on the renovation goal pursued, and this is where it gets interesting for the heat pump. Label B can be achieved relatively easily with a bit of additional insulation, a high-efficient gas boiler and a couple of solar panels. A heat pump or low-temperature heating system are not necessary, but if used, they reduce the requirements for insulation and solar panels. For reaching higher energy labels it becomes increasingly harder: it requires not only better insulation and more solar panels, but usually also low-temperature heating and either a hybrid or a standalone heat pump. However, since the standalone heat pump is the more expensive of the two, the hybrid heat pump remains the obvious choice even for more ambitious energy label renovations. In other words, renovation goals of label A or higher are very difficult, if not impossible, to reach with a high-efficient gas boiler. For renovations toward zero-on-the-meter, especially when all-electric is strived for, the options are even more limited. Next to insulating the house really well, installing as many solar panels as possible, and using low-temperature heating, a hybrid heat pump is an absolute necessity. If all-electric is part of the goal, the only remaining option is a standalone heat pump. Table 4.2 provides an overview of the relation between renovations goals and technologies.

Table 4.2: Possibilities of using technologies for different renovation goals.

	Up to label B	**label A or higher**	**Zero-on-the-meter**
Necessary insulation	+	++	+++
Heat sink temperature	*High temperature*	*Medium temperature*	*Low-temperature*
Solar panels	*A couple*	*Many*	*As many as possible*
High-efficient gas boiler	*Possible*	*Sometimes possible, but usually not*	*Impossible*
Hybrid heat pump	*Possible but not always necessary*	*Possible and usually necessary*	*Very difficult or impossible (in case of all-electric)*
Standalone heat pump	*Possible, but expensive*	*Possible, but expensive*	*Usually necessary*

From the above we can also deduct that the conditions for using a heat pump improve with more ambitious renovation goals. This is a result of the technology/technology interactions as earlier explained in section 4.4.2. Since insulation, low-temperature heating, and solar panels all have *commensalism* interactions with the heat pump, the more insulation, low-temperature heating and solar panels are used, the better the conditions for the heat pump become. Instead, since the high-efficient gas boiler has *neutralism* interactions with these technologies, the case for the high-efficient boiler does not improve with higher ambition levels. If ambitious goals are set (either label A or higher or zero-on-the-meter), it is even necessary to install a heat pump since such goals cannot be reached with a high-efficient gas boiler.

In relation to the standalone heat pump, the discussion of structural couplings between TISs (section 4.4.3) already implied that this TIS is rather isolated from other TISs. This is also suggested by the above discussion of renovation goals that relates to the sectoral context. The standalone heat pump is not only necessary for reaching zero-on-the-meter, but also not an obvious choice for energy label improvements. What is more, the part of the sectoral system that is trying to facilitate zero-on-the-meter is strongly dependent on further development of the standalone heat pump, and in turn, the TIS is strongly dependent on the success of this part of the sectoral system, making them strongly structurally coupled. Thus, when analyzing the standalone heat pump TIS, it is crucial to take the part of the sectoral context into account that facilitates zero-on-the-meter renovations.

In relation to the hybrid heat pump, the discussion of structural couplings between TISs (section 4.4.3) already implied that the TISs of the hybrid heat pump and the high-efficient gas boiler are closely connected. Also this insight is confirmed by the discussion on renovation goals. To reach higher energy labels, a combination of a high-efficient gas boiler and a hybrid heat pump becomes a necessity. In other words, not only from a technology perspective but also from a sectoral context perspective, it is difficult to separate between the hybrid heat pump and the high-efficient gas boiler. For this reason, the hybrid heat pump and high-efficient gas boiler will be considered a single TIS. What is more, this hybrid heat pump/high-efficient gas boiler TIS is very dependent on the part of the sectoral context that is striving for energy label renovations. At the same time, this part of the sectoral context is very dependent on this TIS, again reflecting strong structural couplings. Thus, when analyzing the hybrid heat pump/high-efficient gas boiler TIS, it is crucial to take the part of the sectoral context into account that facilitates energy label renovations. For linguistic purposes, this TIS will be called the hybrid/gas boiler TIS from here on.

Figure 4.2 gives an overview of how the TISs of the standalone heat pump and the TIS of the hybrid heat pump/ gas boiler overlap with the sectoral context. Four things are noted: (1) the standalone heat pump and the hybrid/gas boiler TISs show structural overlap. More detail about this overlap can be found in Figure 4.1, (2) the standalone and hybrid heat pump TIS not only show structural overlap, but system actors from both respective systems are also in competition with each other for renovations of label A of higher. More detail about this can be found in Table 4.2, (3) actors in the hybrid/gas boiler TIS try to gain ground within the zero-on-the-meter goal by openly discussing the necessity for all-electric solutions, which has so far been prominent in zero-on-the-meter renovations, especially within the housing associations market segment. However, resistance against letting this focus on all-electric go has been fierce, and (4) as long as the focus on all-electric solutions within zero-on-the-meter renovations remains in place, the standalone heat pump has free reign within zero-on-the-meter renovations. Clearly, how the competition between energy label renovations against zero-on-the-meter renovations plays out at sectoral level is of significant influence on the relative success of both TISs.

The function fulfillment for both TISs is presented in the upcoming section, during which the influence of sectoral context on function fulfillment is specifically stressed. In line with Figure 4.2, for the standalone heat pump TIS, the influence of the sectoral context that is pursuing zero-on-the-meter renovations is emphasized, whereas for the hybrid/gas boiler TIS, the influence of the sectoral context that is pursuing energy label renovations is emphasized. After discussing the function fulfillment, the phase of development and momentum of both TISs is reflected upon.

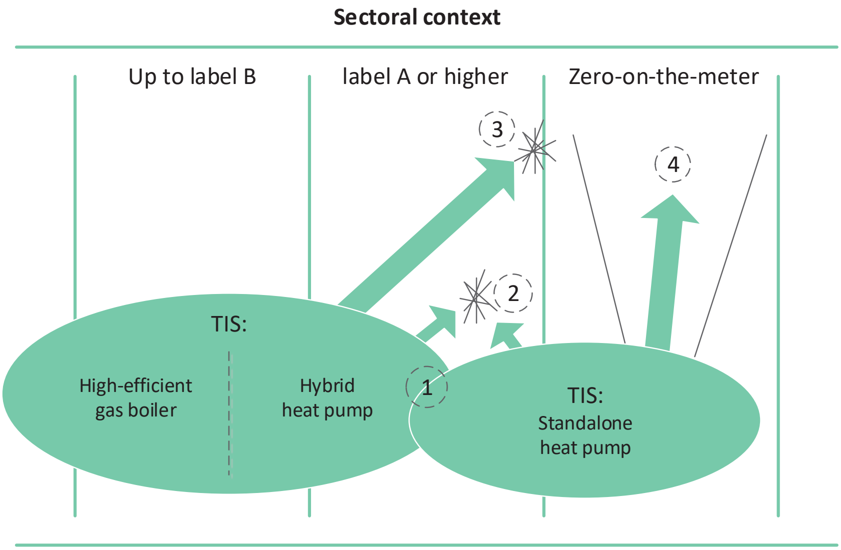

Figure 4.2: Overlap between sectoral context and respectively, the standalone heat pump TIS and the hybrid/gas boiler TIS.

4.4.5 Function fulfillment and main systemic problems for the hybrid/gas boiler TIS

To start with, the numerous hybrid heat pumps available on the market are an indication that most *entrepreneurial activities* have finished. Some hybrid heat pump manufacturers are reaching the end of the pilot stage and are planning for large scale implementation of their technologies. There are thus no main problems in this TIS that pertain to entrepreneurial activities.

In relation to *knowledge development*, even though the market for house renovations is a relatively new market for heat pumps (especially air-source heat pumps), heat pump technology has for long been used in other application fields. Therefore, further knowledge development in relation to heat pump technology in general, and thus also for the hybrid heat pump, is expected to revolve around minor performance increases. However, more knowledge is needed in relation to integrating heat pump technology with other technologies prominently used for renovation, for instance on how to use the available electricity from solar panels as efficient as possible. However, a main problem inhibiting this type of knowledge development is the segmented nature of the installation sector: since most installers are highly specialized, it is difficult for them to view the technology they are specialized in as part of a larger whole. In this way, it is a problem at sectoral level that is mainly inhibiting further knowledge development within the hybrid/gas boiler TIS.

Knowledge regarding hybrid heat pump technology is not reaching all relevant stakeholders, signaling weak *knowledge diffusion*. Although educating installers on heat pump technology is a high priority for both industry associations and the government, this has only seen slow progress. The problem does not lie in the availability of specialized trainings for heat pump technology, but rather, it is not easy to persuade installers to take these trainings. Main reasons for this are lack of financial means or lack of time because of often busy schedules. In addition, the highly-specialized nature of installers means that there is little interest in learning about new technologies, and on how to integrate different technologies into a holistic approach. Again, actor distribution and characteristics at sectoral level are negatively influencing this function. Another problem relating to the sectoral context is that, although the energy label provides homeowners with a list of possible measures to take based on the characteristics of their house, it does not offer the option of a hybrid heat pump. A problem that does pertain to the TIS-itself relates to the multitude of terms that are in circulation for describing the same type of heat pumps. This has the consequence that a rather high knowledge level is required to understand the information that is provided. For housing associations, this lack of clear information is mainly annoying since, as professional organizations, they often have the capacity to understand the available material. However, for homeowners that do not have such a knowledge base, the use of confusing terminology is highly problematic.

Guidance of the search in relation to the hybrid heat pump is also highly influenced by the sectoral context, both in a negative and positive manner. For instance, the Dutch energy covenant contains concrete renovation goals for housing associations and the private rented sector. Unfortunately, although this has given a boost to taking energy-efficiency measures in general, the set ambition level is too low to be highly beneficial for the hybrid heat pump. Namely, the goals are specified as reaching label B on average, which can also be attained with only a high-efficient gas boiler (see Table 4.2). What has been highly beneficial for the hybrid heat pump, are discussions about sustainable heat that are taking place in the context of the TIS, of which the current sustainable heat subsidy program that includes heat pumps is a result. In this way, the sectoral context plays an important role in the extent to which actors are guided toward the use of the heat pump.

As *market formation* in relation to especially housing associations is stimulated by the goals as set in the Dutch energy covenant, especially the market for homeowners remains small. The recently introduced indicative energy label[4] has potential for stimulating the homeowner market as drafting them was made obligatory when selling a house.[5] However, that the hybrid heat pump is not mentioned on the energy label as possible measure certainly does not stimulate its uptake. Another problem is that installers are hesitant to provide performance guarantees for the hybrid heat pump since it depends so much on technologies installed by other companies. This is unfortunate, since it makes especially homeowners hesitant to invest.

As already mentioned, especially smaller installers struggle with *mobilizing sufficient resources*, both in terms of finances and time. In addition, the height of initial investment costs is a leading criterion for homeowners, which does not benefit the hybrid heat pump as it comes in addition to a high-efficient gas boiler. What is more, as result of the relatively high electricity tax compared to the gas tax, the payback time of a heat pump is often long, if the investment pays back at all. Although the heat pump is energetically quite efficient, this is not always the case in financial terms.

Finally, in relation to the function *creation of legitimacy*, proponents of the standalone heat pump and the hybrid heat pump are bringing each other' technology in discredit to such an extent, that it negatively affects the legitimacy of heat pump technology in general. To end with, since many installers are highly-specialized in installing high-efficient gas boilers, they will refrain from advising the use of a hybrid heat pump.

Figure 4.3 provides an overview of what main problems are inhibiting function fulfillment in the hybrid/gas boiler TIS. Although some problems are endogenous to the TIS, most problems relate to its sectoral context and relate to one of three types. First, there are problems that relate to the energy label, namely that the hybrid heat pump is not mentioned on it and that many actors renovate not higher than label B. Second, there are problems that relate to installers. They are highly-specialized, often in installing gas boilers only, and they are usually smaller companies with a lack of financial means and time to follow trainings about the hybrid heat pump. In addition, they are hesitant to provide performance guarantees, because of the interdependencies between the heat pump and other technologies utilized. Finally, the high electricity tax can be considered

4 An indicative energy label is a preliminary indication of the energy label based on a paper-based analysis. For instance, instead of visiting a house, an energy label issuer calculates the energy label based on bills for taken energy-efficiency (e.g. insulation) and/or energy-production measures (e.g. solar panels).

5 The effects of this intervention are still uncertain as compliance has been low so far.

a problem at the level of the electricity sector. In all, it can be concluded that the sectoral context has a major influence on the functioning of this TIS.

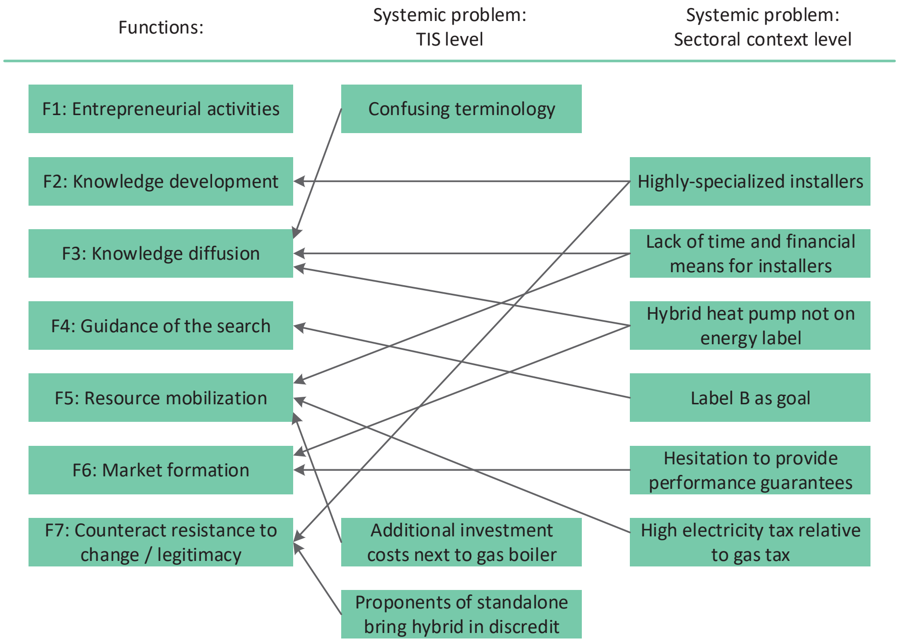

Figure 4.3: main problems inhibiting function fulfillment in the hybrid/gas boiler TIS.

4.4.6 Function fulfillment and main systemic problems for the standalone heat pump TIS

There already is a multitude of standalone heat pumps on the market, again signaling that *entrepreneurial activities* at technology level have largely finished. However, pilot projects that integrate standalone heat pumps in zero-on-the-meter renovations are still under way. In the rental houses covenant (Stroomversnelling Huur), initial pilot projects on individual houses have been completed and the next phase of upscaling toward complete blocks of houses has started. In the covenant for homeowners (Stroomversnelling Koop), first pilot projects are underway. Much depends on these pilot projects for the standalone heat pump. Not only does the standalone heat pump have to prove its worth, if these pilot projects became a success, many more houses may be renovated using renovation concepts that strive for the zero-on-the-meter goal. If that happens, that will surely stimulate the uptake of the standalone heat pump, as it is the designated choice in zero-on-the-meter renovations (see Table 4.2).

As the use of concepts was already prominent in the market for new houses, *knowledge development* in relation to renovation concepts that strive for the zero-on-the-meter goal has a sound knowledge base to work from. Still necessary knowledge development relates to measuring the actual performance of the heat pump within a renovation concept. The focus of knowledge development has thus shifted from the drawing board to pilot projects (see also previous function).

Knowledge diffusion between participants is an important pillar in both renovation concept covenants (Stroomversnelling huur and koop). In addition, it is made sure that knowledge already developed in the covenant for rental houses, which started earlier, is diffused to the more recent covenant for homeowners. However, for heat pump manufacturers it is still 'everyone for himself'. Although multiple heat pump manufacturers do participate in zero-on-the-meter pilot projects, they are hesitant to share the gained knowledge among each other. A main systemic problem thus relates to whether the renovation concept covenants are able to stimulate heat pump manufacturers to share knowledge.

The zero-on-the-meter goal provides concept developers with a clear target to work toward, and in this way contributes to *guidance of the search*. In addition, both covenants are strictly organized with the purpose of not creating unnecessary delays. For instance, participants officially have to commit to actively participate, and new actors are not allowed after the start-date if there is any reason to believe that this will create delays. What is more, despite that all-electric has become the norm for achieving the zero-on-the-meter goal in the covenant for rental houses (thus requiring the use of a standalone heat pump), the necessity of all-electric is heavily debated in the covenant for homeowners. Here it is argued that the zero-on-the-meter goal can also be achieved with gas-based technologies, which in practice means the application of a hybrid heat pump. In this way, the debate around gas-based or all-electric undermines the application of standalone heat pumps. Thus, the debate about electricity versus gas is the main systemic problem that is hindering this function.

Both renovation concept covenants already try to create a market for renovation concepts, even though they are not yet available (*market formation*). For instance, to participate in the covenant for rental houses housing associations had to commit to implement the still to be developed renovation concepts, which created a strong the incentive for concept developers. In addition, even though renovation concepts for homeowners are not yet available, the Energiesprong program has initiated a television show in which homeowners are already introduced to the idea, and a website on which homeowners can already express their interest. What is more, to participate in the covenant for homeowners, actors (e.g. provinces, municipalities, energy cooperatives) must commit to actively promote renovation concepts under their residents/members when they become available. The main systemic problem relates to the fact that, so far, only a small portion of such actors in the Netherlands have signed the covenants.

In relation to *resource mobilization*, especially for financial resources, activities have been initiated to facilitate both covenant participants and clients for the renovation concepts (homeowners and housing associations). To start with, the energiesprong program assists the participants in both the rental and homeowner covenants with knowledge and limited financial means (small subsidies). Furthermore, since the concept developers in especially the covenant for rental houses are relatively large, financial resources can be freed up relatively easy. Although concept developers for the homeowner market are generally smaller companies, they often work together to share the development costs. To facilitate clients to mobilize funds for a renovation to zero-on-the-meter, activities are underway to let the appraisal value of the house increase significantly after the renovation. In addition, the national government has allowed for a higher mortgage loan if homeowners choose to renovate toward zero-on-the-meter, and landlord fees for housing associations are lower if they choose for a zero-on-the-meter renovation. Since a renovation to zero-on-the-meter is currently still more expensive than the set goal of 45.000 euro, subsidies are still necessary for the pilot projects, signaling the still high costs of a zero-on-the-meter renovation as main systemic problem in relation to this function. Although there are subsidies for homeowners that participate in zero-on-the-meter pilot projects available, their height is too low to make participation cost-effective. Covenant participants hope that the pilot projects will make the costs decrease substantially.

For the function *creation of legitimacy*, it is relevant that there is no alternative to the use of a heat pump when zero-on-the-meter is chosen for as renovation goal. For this reason, there is hardly any discussion about whether to use a heat pump for achieving the zero-on-the-meter goal. The only discussion there is, is what type of heat pump to install (either standalone or hybrid), which relates to the debate around all-electric versus the use of gas (see *guidance of the search*). The main systemic problem is thus not so much the resistance toward the standalone heat pump, but rather the resistance against the zero-on-the-meter goal, and the focus on all-electric. Finally, that proponents of the standalone and the hybrid heat pump bring each others' technology in discredit also plays a role here.

Figure 4.4 provides an overview of main problems inhibiting function fulfillment of the standalone heat pump TIS. Again, by far the most problems relate to the sectoral context. The standalone heat pump TIS is not only highly dependent on the success of the zero-on-the-meter goal at sectoral level, preferably with a strong focus on all-electric, but also on the success of the two renovation concept covenants (Stroomversnelling). Together with the findings for the hybrid/gas boiler TIS, it can be concluded that the sectoral context has much influence on the functioning of these TISs.

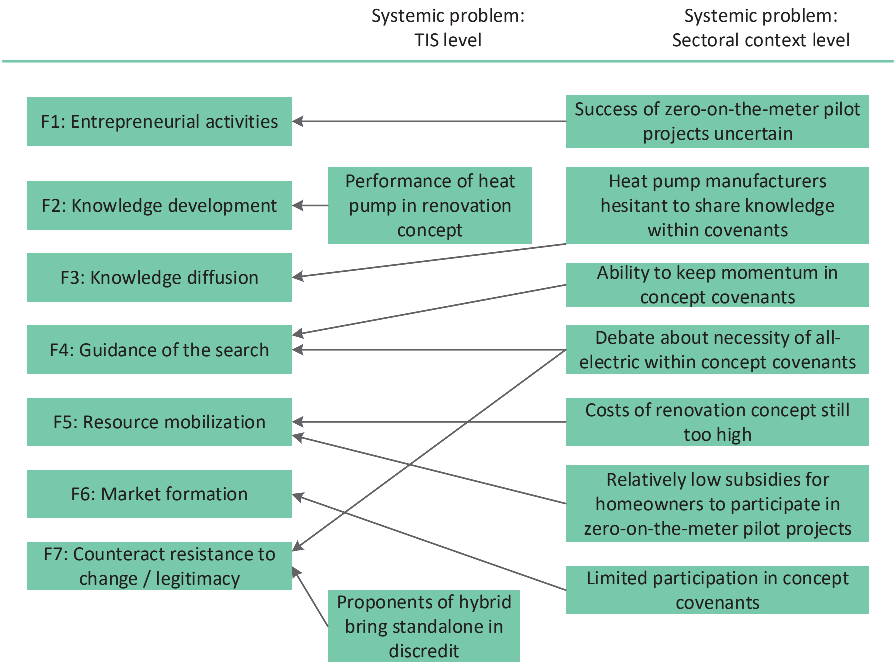

Figure 4.4: main problems inhibiting function fulfillment in the standalone heat pump TIS.

4.4.7 Reflection on the phase of development and momentum of both innovation systems

The quite different function fulfillment for the innovation systems of the hybrid/gas boiler TIS, and of the standalone heat pump TIS, implies that they are in a different phase of development. The phase of development can be determined by comparing the function fulfillment for both systems from the previous section to what functioning theory expects in a certain phase of development as described in the theory section.

The hybrid/gas boiler TIS has reached the end of the *take-off* phase, but is having difficulties moving to the *acceleration* phase. Although the hybrid heat pump has proven itself in pilot projects (F1), it is confronted with much resistance (F7) from installers that are used to installing high-efficient gas boilers. This lack of legitimacy makes installers reluctant to provide performance guarantees, which inhibits the creation of a market (F5) which is the most important function for moving to the acceleration phase. Finally, the incomplete information on the indicative energy label also does not help for creating a market. In all, the hybrid/gas boiler TIS is having difficulties moving to the acceleration phase (see Figure 4.5).

Although the standalone heat pump TIS has only reached the beginning of the *take-off* phase (and is partly still in the *development* phase), major activities are already underway for bringing this innovation system to the *acceleration* phase. In relation to zero-on-the-meter renovations for housing associations – and thus standalone heat pumps in this market segment – the beginning of the take-off phases has been reached. For this market segment, initial pilot projects on individual houses have ended, and pilot projects have now started to focus on renovating complete housing blocks (F1). This contrasts to the homeowner market, for which first pilot projects are still underway. It is proving difficult to create sufficient legitimacy (F7) with homeowners as it is difficult to persuade them to participate in pilot projects, which is slowing down the implementation of the standalone heat pump in this market segment. It is striking that – even though pilot projects have not yet finished – much effort is already put in forming a market (F5). In other words, even though a finished product is not yet available, activities are already underway that aim to support the system in reaching the *acceleration* phase. Although actors in this innovation system do everything in their power to keep its momentum going, it is too early to tell whether the momentum can be sustained (see also Figure 4.5).

When reflecting on the above, it is clear that both TISs are highly influenced by their sectoral context. Progress in the hybrid/gas boiler TIS is slow, for a large extent because of rigidities in relation to the more traditional renovation approach based on energy label steps. However, next to this part of the sectoral context being quite conservative and thus quite stable, other parts are highly dynamic. Zero-on-the-meter renovations, as these were introduced relatively recently into the renovation sector, is a case in point. It is striking to see that the success of the standalone heat pump TIS depends so much on such an autonomous development in its sectoral context. How the competition between energy label and zero-on-the-meter renovations plays out at sectoral level will, to a large extent, determine the relative success of the hybrid/gas boiler TIS versus the standalone heat pump TIS.

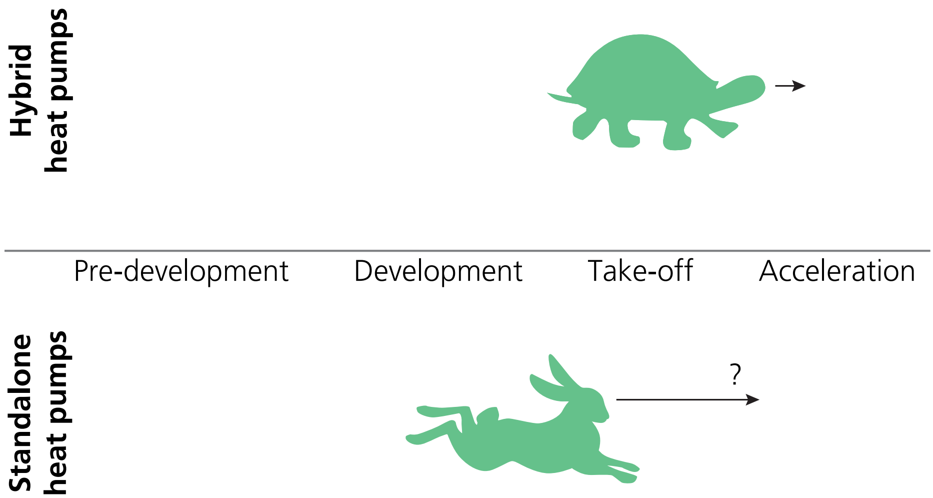

Figure 4.5: Phase of development and momentum of the hybrid/gas boiler and standalone heat pump TISs.

4.5 DISCUSSION

This discussion reflects on some theoretical and methodological lessons that can be drawn from the presented case study. The following subjects are considered: (1) the importance of understanding the technology in focus and its modes of interaction with other TISs, (2) the importance of taking sufficient context into account and (3) the analysis stages that can be followed when desiring to take TIS-context explicitly into account during a TIS-analysis.

Firstly, giving attention to heat pump technology itself and to its modes of interaction with other technologies proved to be an imperative first analysis stage. Without it, the distinction between the hybrid and standalone heat pump would not have been made, and the hybrid heat pump would not have been analyzed together with the high-efficient gas boiler. This would not only have complicated data collection (since actors commonly mean one type or the other when talking about the 'heat pump'), but also have obscured the quite significant differences between the two in terms of system structure, function fulfillment, systemic problems, and phase of development. Bergek et al. (2015) was indeed right when stating that analysts should strive for "a more than superficial grasp of technologies involved" (p. 61). Conceptually, this also affirms the importance of seeing 'technology' as a structural element by itself (e.g. Markard & Truffer, 2008).

Secondly, just like the case of highly energy-efficient building in chapter 2, the case presented in this chapter also confirms the importance of taking sufficient contextual structures into account. Figures 4.3 and 4.4 made evident that most systemic problems[6] inhibiting the respective TISs of the hybrid/gas boiler TIS and the standalone heat pump are not endogenous to the TIS, but rather relate to the sectoral context. An analysis of 'only' the heat pump TIS would have clearly come to quite different conclusions.

Thirdly, taking the context explicitly into account during a TIS-analysis requires a somewhat different order of activities compared to an analysis of a single TIS. The first stage should always be to thoroughly understand the technology in focus, after which in the second stage technology-technology interactions must be explored to decide if, and if so what other technologies, and related TISs, to consider during the analysis. Third, it should be decided what contextual structures are important to consider. Although for the heat pump case study the structural context was found to be most important, other TISs may require emphasizing other contextual structures. Fourth, instead of only mapping the system structure of the TIS itself, it is necessary to also map its external links, but even more importantly, its structural couplings with related TISs and other relevant contextual structures. The rest of the analysis may largely follow the standard analysis stages as described in literature (function fulfillment, phase of development, systemic problems, interventions), thereby taking the considerations into account brought forward in the other chapters of this dissertation. To conclude, taking context explicitly into account during a TIS-analysis requires additional activities, especially in the earlier analysis stages.

4.6 CONCLUDING REMARKS

We can now reflect on the purpose of this chapter, namely to get insight in the kind of influence that sectoral context may have on the functioning of a TIS. It can be concluded that the nature of the TIS/sectoral context interaction in this case study is different from what literature on TIS context has described. As mentioned earlier in the theory section, the sector is often seen as a relatively stable environment that TIS actors should either adapt to or try to change (Bergek et al., 2015). Although this is certainly true for part of the sectoral context of the heat pump TISs, some parts are also highly dynamic. The more traditional renovation approach based on energy labels provides a quite stable context for the hybrid/gas boiler TIS, whereas the advent of the zero-on-the-meter goal is a case in point of a not only autonomous, but also highly significant change in the sectoral context, affecting both heat pump TISs. Actors in the standalone heat pump TIS

6 Here, a broad meaning of the term systemic problems that includes not only problems internal to the TIS, but also external to the TIS is used. Broadening the meaning of this term was proposed earlier in chapter 2 (section 2.2).

clearly benefit from zero-on-the-meter renovations, even though in initiating it they had no role. Thus, the success of the standalone heat pump TIS strongly depends on the success of an autonomous development in its highly-dynamic sectoral context.

Chapter 5

Toward ranking interventions for Technological Innovation Systems via the Leverage Points concept*

* This chapter is based on Kieft, A., Harmsen, R., Hekkert, M.P. Toward ranking interventions for Technological Innovation Systems via the Leverage Points concept, as submitted to the Journal *Technological Forecasting and Social Change*. A previous version of this paper was discussed during the dialogue session *Dynamics in Innovation Systems: new directions for the Technological Innovation Systems framework* at the 7th International Sustainability Transitions Conference: *Exploring New Avenues for Innovation and Research Policies*, organized by the Wuppertal Institute and the Centre for Transformation Research and Sustainability (TransZent) in Wuppertal, Germany on September 6-9, 2016.

5.1 INTRODUCTION

So far, the TIS intervention framework facilitates analysts up to the point of formulating intervention options (Bergek et al, 2008; Wieczorek & Hekkert, 2012). For instance, analysts can employ lists of common types of problems (Chaminade & Edquist, 2010; Klein Woolthuis et al., 2005; Negro, et al., 2012; Weber & Rohracher, 2012), and lists of intervention options (e.g. Weber & Rohracher, 2012; Wieczorek & Hekkert, 2012). As it is now, the output of an innovation system analysis is thus also usually a list of systemic problems that need to be alleviated, and a list of intervention options through which this may be achieved. To date, little attempts have been made to shed light on the follow–up activity of choosing between the formulated intervention options.

To facilitate the choice between intervention options, insight is needed into the factors and considerations that may play a role in this choice process. However, TIS-literature has so far not provided the theoretical means for this. Although it is a given that intervenors employing the innovation systems framework strive for improving system performance, little is known about what factors influence the impact of interventions on improving the performance of an innovation system. In addition, although an innovation systems analysis usually leads to the formulation of multiple interventions, little is known about how interventions can best be combined. Ultimately, it comes down to the question what type of intervention, or set of interventions, is likely to have a large impact on improving the performance of an innovation system. As this is a challenging question that can surely not be answered in this chapter alone, we reservedly set the objective to lay a preliminary foundation for a conceptual framework that has the potential to increase our understanding on this matter. For this, we find inspiration in the intervention framework of systems thinking[1] (Forrester, 1995; Meadows, 2008; Senge, 1990; de Vries, 2013), more specifically in the idea that the transformational power of interventions relates to the characteristics of the points in a system where the intervention acts upon.

5

An obvious similarity between the systems thinking and innovation systems frameworks is that both analyze complex systems consisting of elements that interact.[2] More important however is that they follow a similar intervention rationale, namely that interventions should focus on alleviating problems that inhibit system performance. In addition, they share that - since problems can relate to any element of the system - every element of the system provides a

1 Systems thinking has already proven useful for gaining insights in relation to TISs (e.g. Walrave & Raven, 2016).

2 In Systems Thinking the terms variables, concepts (Forrester, 2009; Senge, 1994) and elements (Meadows, 2008) are commonly used. In Innovation Systems, the terms elements (Klein Woolthuis et al., 2005; Markard et al., 2012; Wieczorek & Hekkert, 2012) and components (Bergek et al., 2008; Weber & Rohracher, 2012) are prevalent.

potential point for intervention.[3] From systems thinking, we will mainly draw on the concept of leverage points (Meadows, 1999; 2008).

Part of the leverage points concept is the idea that some points in a system are more likely to incite transformational change when acted upon than others. This has materialized into a ranking of points in a system on the chance that they embody for creating transformational change. We disentangle the underlying reasoning of this ranking and, in a preliminary way, adapt it to fit the innovation systems framework. We focus on Technological Innovation Systems (TIS), because the process of intervention formulation is most established for this strand (Bergek et al., 2008; Markard & Truffer 2008; Wieczorek & Hekkert, 2012). In this way, we strive to answer the following research question: What influences the impact of interventions on improving the performance of a technological innovation system, and can interventions be ranked based on these insights?

The chapter continues with explaining the leverage point concept and the associated ranking in further detail. Subsequently, we discuss conceptual differences between the innovation system and systems thinking frameworks that are necessary to consider when adapting the ranking to fit the TIS intervention framework. After this, we discuss how the proposed TIS-ranking sheds light on what considerations play a role while choosing where in a TIS to intervene, which we exemplify through an illustrative case study of highly energy-efficient houses. Finally, we discuss two intervention sets that are currently being implemented in the Netherlands in this empirical domain, illustrate how these relate to the proposed TIS-ranking, and reflect on what their composition implies for creating a coherent intervention set.

5.2 THE RANKING OF INTERVENTION POINTS FROM SYSTEMS THINKING

Before judging whether the reasoning, or which parts of the reasoning, behind the ranking from systems thinking is useful for the innovation systems framework, the leverage points concept and the reasoning behind the ranking must be well understood. Therefore, this section discusses the leverage points concept and the associated ranking from systems thinking in more detail, thereby using systems thinking terminology. Conceptual differences between both frameworks (and limitations of the systems thinking framework) that influence how the reasoning behind the ranking can be transferred to the TIS-framework are discussed in the successive section.

3 Systems Thinking calls these “places to intervene”.

The leverage points concept holds the key to understand the order in which the intervention points are placed on the ranking. A leverage point is a point in a system where a shift "can produce big changes in everything" (Meadows, 1999, p. 1). In other words, it is a point in a system that has great transformational power because of its capacity to create a snowball effect of change throughout the system.[4] As each complex system is unique, the leverage point in each system can be different. However, systems thinking also holds that, because different types of intervention points vary in their characteristics, some points in a system are more often a leverage point than others. The ranking thus expresses the chance that intervening on a certain point will lead to system transformation, or in conceptual terms, the chance that an intervention point in a particular system is a leverage point (Meadows 1997, 1999, 2008).

The nine intervention points that together form the ranking all relate (some more direct than others) to the conceptual 'building blocks' that systems thinking uses to describe a complex system. For this reason, to form a foundation for the subsequent explanation of each intervention point, we first discuss these conceptual 'building blocks'. To begin with, systems thinking describes the structure of a complex system in terms of four elements, namely *stocks*, *flows*, *feedback loops* and *delays* (Forrester, 2009; de Vries, 2013). Stocks are 'accumulated stuff' that can take many forms (people, money, water, cars, trust etc.). Flows increase or decrease these stocks, and feedback loops link stocks with flows. For example, if there is a shortage of skilled labor (stock), this may trigger additional training programs (feedback loop to flow) leading to more skilled people entering the labor force (increased inflow). Most feedback loops have inherent delays, for instance, the time it takes to design the training programs and give the trainings. In addition, how stocks, flows, feedback loops and delays are connected depends on the *paradigms* that underlie the system, the *system goals*, and the *rules* in place. Some intervention points on the ranking relate one-on-one to a building block, although most target a sub-type of a building block or connections between building blocks.

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Table 5.1 gives an overview of the ranking. The highest-ranking intervention point is considered to have the highest chance of being a Leverage Point.[5] For each intervention point, we will give an example from a system of unsustainable electricity production based on fossil fuels that is desired to change into a system of sustainable electricity production based on renewables (see also Table 5.1).

4 This reasoning reflects the frameworks' emphasis on the dynamic nature of complex systems: interactions between system elements are even considered more important than the elements themselves (Forrester, 1995).

5 This ranking is a combination of the rankings from Meadows 1997, 1999 and 2008. It shows the nine leverage points as presented in Meadows 1997, but uses the terminology from Meadows (1999) and (2008).

This is a complex case for which we do not strive for completeness: our goal is limited to providing illustrative examples.

Table 5.1: A ranking of intervention points in complex systems according to Systems Thinking.

Ranking	Intervention point	Illustrative examples of changes at the intervention point
1	Paradigms	From optimizing electricity production on efficiency only, to also optimizing electricity production on environmental aspects[39]
2	Goals	From stable and efficient electricity supply through economies of scale, to stable and low carbon electricity supply
3	Self-organization	From centrally balancing electricity supply with electrical load, to decentral demand-side-management
4	Rules	Prioritizing renewable production technologies on the electricity grid over fossil-fuel based technologies
5	Information flows	Providing real-time information on renewable electricity production
6	Reinforcing feedback loops	Deflecting financial resources from the development of fossil-fuel based technologies, to the development of renewable energy technologies
7	Balancing feedback loops	Decoupling of economic growth and energy-use through energy efficiency improvement
8	Material stock-and-flow structure	From a one-directional electricity grid, to a two-directional electricity grid
9	Numbers	Reducing value-added tax for solar panels

The first item on the ranking are paradigms. Paradigms are "the shared idea in the minds of society, the great big unstated assumptions […] or deepest set of beliefs about how the world works." (Meadows, 2008, p. 162). Systems thinking assumes that, if a paradigm changes, everything changes, or as Meadows puts it "People who have managed to intervene […] at the level of paradigm have hit a […] point that totally transforms systems." (Meadows, 2008, p. 163). For example, for decades, the energy production system has been optimized mainly on efficiency, especially on cost-efficiency. The shift toward a renewable electricity production system is made possible by a paradigm change, namely that the electricity system must not only be optimized on efficiency, but also

6 To note: we chose to exemplify this item with a relatively small paradigm change. A more extreme paradigm change would be toward energy production being solely optimized on environmental aspects while efficiency altogether loses its relevance.

on environmental aspects. If a paradigm shift happens, this can fundamentally change a system.

Goals form the second item on the ranking. According to systems thinking, the system itself can have goals. These goals not so much depend on what actors in the system *say*, but more on what the system *does*. For an unsustainable energy production system, main system goals are energetic and economic efficiency. This can be achieved through economies of scale in the application of energy production, which leads to a centralized production system. Instead, for a sustainable energy production system, the main goal becomes producing only low carbon electricity. Since economy of scale is no longer part of the goal, this may induce a more decentralized production system, or a combination of centralized and decentralized energy production. A system goal that both energy systems share is retaining a stable electricity grid through balancing supply and demand. Systems thinking considers the potential system change that can be achieved with intervening on goals substantial: when goals change, many lower ranking items of the system are also deemed to change. Although there is nothing physically difficult about changing a goal, they are generally so deeply entrenched - in procedures, routines etcetera - that trying to change them often leads to major resistance.

The ability of self-organization relates to the rules in the system, and then specifically to the extent in which these allow the system to adapt and evolve. A system with a high level of self-organization has "marvelously clever rules" that "govern how, where, and what the system can add onto or subtract from itself under what conditions" (Meadows, 2008, p. 159). An example from the illustrative case is not balancing the electricity grid by adapting production, but by balancing through adapting demand (local demand-side-management using smart grid technologies). Although changing self-organizing principles can fundamentally change a system, it generally affects many actors simultaneously and may thus coincide with substantial resistance to change.

All other types of rules are next, and then especially the rules that determine what acceptable behavior is and what is not. Meadows mentions that "Power over the rules is real power." (2008, p. 158). For instance, most rules for the electricity system are laid down in the electricity law. A change in the electricity law could for instance entail prioritizing renewable energy technologies on the electricity grid. Systems thinking holds that, although an intervention on this type of rules generally affects less actors compared to an intervention on a self-organizing principle, resistance to change is often still substantial.

Information flows determine who in the system does - and who does not - have access to information. For instance, providing real-time information about locally produced solar electricity to households may stimulate the use of solar electricity when it is available (thus contributing to the goal of grid stability). Another example is the smart meter that adds an information flow from homeowners to the net owner. This latter example also shows that intervention on information flows sometimes coincides with physical constraints (because a communication infrastructure for the smart meter must be facilitated), but more importantly with resistance to change (because homeowners must be persuaded to have the smart meter installed). Although adding an information flow can contribute much to changing a system, and can sometimes be achieved relatively easily, there are sometimes physical constraints and/or resistance to change that must be overcome.

The next two items on the ranking both relate to feedback loops. Reinforcing feedback loops exist if an increase in a stock leads to an increase in a flow, which in turn increases the stock. Such reinforcing feedback loops often lead to exponential growth, but can - in reverse – also cause exponential decline. For instance, fossil-fuel based technologies have long gained large investments, which stimulated their use, led to profits, which led to more investments. Deflecting financial resources from the development of fossil-fuel based technologies, to the development of renewable energy technologies may in this way strengthen the latter' position (strengthen a reinforcing feedback loop) at the expense of the former (weakening a reinforcing feedback loop). A balancing feedback loop counteracts the negative effects of a reinforcing feedback loop, for instance, improvement of energy efficiency may counteract the additional CO_2-emissions that result from economic growth (decoupling). What is more, by far most feedback loops have inherent delays. They may be too long or too short and lead to unwanted system fluctuations. For instance, the long lead times of energy production projects in combination with cycles of economic growth and decline create periods of overproduction and underproduction. However, it is often physically difficult to change the length of delays, for instance, the construction of new energy production capacity during a period of underproduction is difficult, if not impossible, to speed up. Although feedback loops – and their delays – may contribute to achieving system change, affecting them is often challenging, either because of physical constraints (especially for delays) or because of resistance to change (especially for reinforcing feedback loops).

The next item on the ranking – material stock-and-flow structure – represents the physical parts of the system. The electricity grid forms an important part of the material stock-and-flow structure in the energy system. Since shifting to renewables means that an increasing part of energy production happens locally (e.g. solar panels on houses), and because energy demand and supply at the house level are not constant, the electricity grid needs to facilitate bi-directional power flows. This requires strengthening the electricity grid, which is not insurmountable with a bit of human ingenuity and perseverance. However, if only the electricity grid is strengthened, this will not magically incite actors to implement renewable technologies. For this, changes in relation to higher ranked items are also necessary (e.g. in the paradigm or the rules). To conclude, even though targeting the material stock-and-flow structure may be a requisite for changing a system, it – by itself – is rarely able to incite a system transformation.

Finally, numbers are parameters that determine the size of flows through the system. If a number changes, the basic structure of elements and how they link up stays the same. For example, reducing the value-added tax on solar panels changes little in what actors are involved, what their responsibilities are, what kind of information they receive etcetera. Although this makes intervening on augmentations often relatively easy, the effects on inducing system change is also usually low. For instance, although reducing the value-added tax on solar panels may slightly improve the payback time of the investment and thus stimulate some homeowners to invest, it will not persuade homeowners that do not like their aesthetics (paradigm), or help homeowners that are not allowed to install solar panels because their house is located in a historic district (rules). Because of this, systems thinking explains that intervening on numbers is "Diddling with the details, arranging the deck chairs on the Titanic.' (Meadows, 2008, p. 148): "Mostly, the numbers are not worth the sweat put into them." (Meadows, 1999, p. 8).

Since the ranking was created based on practical experience with modelling complex systems, the available descriptions of the ranking (Meadows 1997, 1999, 2008) do not explicitly mention what underlies the positioning of each item on the ranking. Based on careful reading the arguments in the available texts, we identified three factors that together seem to determine the chance that an intervention point has transformational power in a certain system, and thus the position of the intervention points on the ranking. (1) the inherent system change potential of that type of intervention point, (2) physical constraints that may complicate intervening there and (3) resistance to change from vested actors. Figure 5.1 provides a graphical depiction that we will use to further explain the reasoning behind the ranking.

The first factor (system change potential) entails that some intervention points inherently possess more potential to change a system than others. As the earlier description already implied, this is because of the 'layered' nature of the ranking in the sense that (1) intervening on higher ranked items is expected to create a snowball effect of change in lower ranked items, thus increasing their potential for creating system change and (2) the degree of freedom for intervening at lower ranked items is restricted by higher ranked items, which reduces their system change potential. For instance, trying to get a law change mandated that does not fit the system goal will be difficult at best. The second and third factor follow from the reasoning that the *potential* for system change that an intervention point embodies often cannot be reached, either due to *Physical constraints* or because of *Resistance to change* from vested actors. *Overcoming resistance to change* and *Overcoming physical constraints* thus form the other two axes in Figure 5.1. To conclude, an intervention point with system change potential only has transformational power in a specific system (only is a leverage point) when both physical constraints and resistance to change can be overcome.

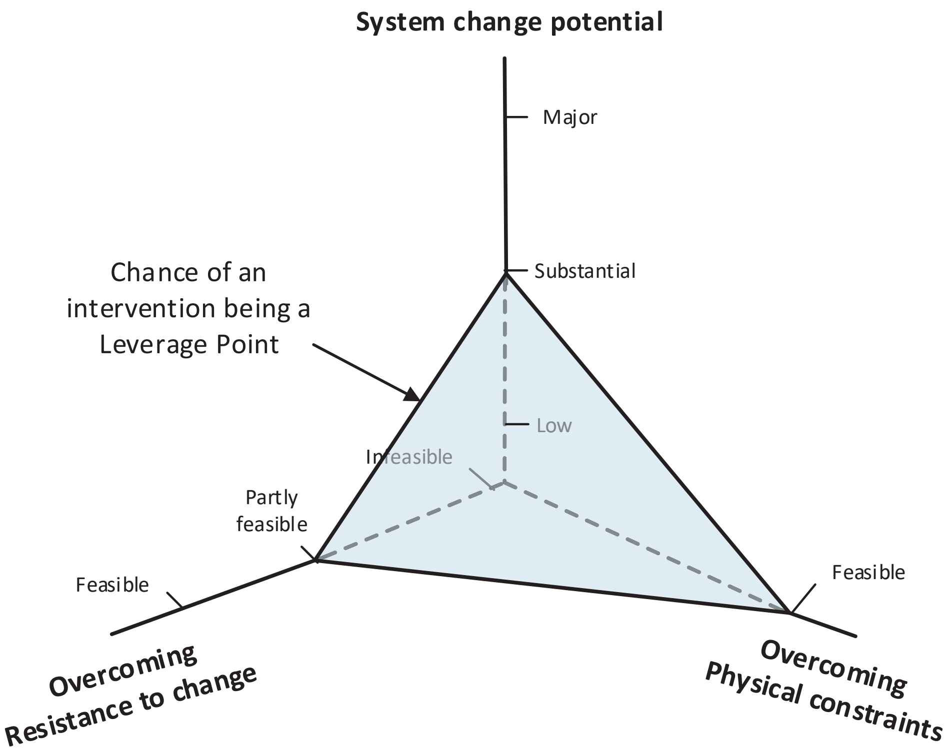

Figure 5.1: Graphical depiction of the chance that an intervention on a certain point in a system has transformational power (chance of an intervention point being a leverage point).

5.3 CONCEPTUAL DIFFERENCES BETWEEN TECHNOLOGICAL INNOVATION SYSTEMS AND SYSTEMS THINKING

Although the systems thinking framework has sufficient overlap with the TIS intervention framework to use the former for inspiration, conceptual differences make re-interpretation and adaption of most items on the Systems Thinking ranking necessary. In this section, we will consider the following: (1) how the three factors determine the positioning of items on the ranking from systems thinking and how to position items on the TIS-ranking, (2) differences in what 'building blocks' both frameworks use to describe a system, (3) the focus on single interventions by systems thinking in contrast to the focus on intervention sets by TIS-literature, (4) differences in how to set system boundaries, and (5) subtle differences in used terminology.

First, reflecting on the ranking from systems thinking, we note that for each intervention point there is a trade-off between – on the one hand – the inherent potential for system change that it embodies and – on the other hand – implementation difficulties that can be expected, either because of physical constraints or because of resistance to change. This trade-off is most evident in the comparison between the highest-ranking item (paradigms) and the lowest ranking item (numbers) as it is the complete opposite. Intervening on paradigms embodies the highest system change potential but is also usually very difficult to implement, whereas intervening on numbers can be easy to implement but then often embodies very low system change potential. However, we also note that how this trade-off plays out does not consistently determine the position of all items on the ranking. For instance, information flows are located higher on the ranking than feedback loops, even though the implementation difficulties of the latter are on average considered to be higher. Since we have no reason to believe that positioning items based on the complex interplay between three factors (see section 5.2) is wrong, we will position the items on the TIS-ranking in a similar way. We do note that it is tempting to believe that there are additional factors that play a role to which we come back in the discussion section.

Second, the TIS framework generally considers actors, interactions between these actors and institutions the main building blocks of a system (often called the structural elements). For institutions, it is common to distinguish between formal institutions laid down in legislation and regulation, and informal institutions in the form of culture, norms and values. In addition, infrastructure is often seen as a structural element that can be divided into knowledge, financial and physical infrastructure (Wieczorek & Hekkert, 2012). Finally, also the technology itself is sometimes argued to be a structural element (e.g. in Jacobbson & Bergek, 2011; Jacobsson & Jacobbson, 2014; Markard & Truffer, 2008). These structural elements show many interactions and feedback loops, making a TIS highly dynamic and complex. Two striking differences between the TIS-framework and systems thinking are that the latter does not recognize actors as an element of the system structure and that paradigms gain a more implicit attention in the TIS-framework. Systems thinking describes the amount, growth and decline of actors in a system in terms of stocks and flows. Although resistance from actors is an important factor determining the feasibility of interventions, other characteristics or actions of actors are given less attention. Thus, although systems thinking gives attention to actors, they are mainly considered a hindrance for change and not drivers for change. Paradigms are important in relation to multiple parts of a TIS and are therefore difficult to consider as separate item. To begin with – from the perspective of the TIS-framework – paradigms can be considered a specific type of informal institution. What is more, past paradigms may still be 'fixed' in older physical infrastructure of the system.[7] Finally, as will become more clear later, the directionality of a TIS relates to the goals that actors pursue, which will be in line with the paradigms that they adhere to. Since paradigms are difficult to consider separately from other elements of a TIS we do not give them a separate position on the TIS-ranking.

Third, while systems thinking is interested in finding a single intervention that may change the whole system (an intervention at the leverage point), TIS instead strives to design sets of mutually supportive interventions. Systems thinking puts great confidence in the ability of interventions to create a snowball of change throughout the system. In other words, systems thinking reasons that a single intervention can incite a complete system transformation. Instead, the TIS-framework is built on the premise that the automatic nature of this process cannot be assumed. How TIS-literature conceptualizes problems also reflects this stance, as weak system performance is considered to arise from a multitude of largely independent insufficiencies in system elements.[8] In other words, intervening successfully in a TIS requires forming sets of mutually supportive interventions. For the ranking this means that, although systems thinking assumes that an intervention in the higher ranges of the ranking will usually automatically lead to changes in lower ranges of the ranking, for technological innovation systems this cannot be assumed.

Fourth, while a systems thinking analyst includes everything that is relevant within the system boundaries (Meadows, 2008), a TIS-analyst makes the distinc-

7 For instance what size a house should be (older houses are in the Netherlands on average much smaller compared to newer houses).

8 For a more detailed discussion of the lack of attention for how problems interact in the innovation systems framework see Chapter 2.

tion between the system itself and the systems' context (Bergek et al., 2015). This has as consequence that, according to systems thinking, problems always relate to the internal structure of the system, and that interventions thus always act upon a point in the system itself. In contrast, problems that inhibit a TIS may exist both inside and outside the system boundaries (Meelen and Farla, 2013; Bergek et al. 2008), which implies that not only the TIS itself, but also its context may provide options for intervention. In relation to the ranking, this means that, for broad TIS delineations more of the items on the ranking will fall within the TIS. To assure that sufficient examples are available, we will exemplify the items on the TIS-ranking with an illustrative case study of a TIS with a rather broad system delineation.

Fifth, and finally, the terminology of both frameworks has subtle differences. To begin with – as the earlier description of the ranking from systems thinking reflects – systems thinking focusses on the points in a system where intervention is possible, whereas TIS-literature focusses on the interventions itself. Furthermore, where systems thinking emphasizes system transformation, TIS-literature emphasizes system performance. Since we now move to discussing TISs, we will continue with the TIS-terminology.

5.4 A RANKING OF INTERVENTIONS FOR TECHNOLOGICAL INNOVATION SYSTEMS

In this section, we will propose a ranking of interventions for technological innovation systems. To create the TIS-ranking, we linked the items from the systems thinking ranking to related concepts from the TIS theoretical framework. If there was no directly equivalent concept available, we reinterpreted the meaning of the systems thinking concept from the perspective of the TIS intervention framework. As already mentioned, because paradigms relate to multiple other items on the TIS-ranking, they do not come back as separate item on the TIS-ranking. For the positioning of items on the TIS-ranking we followed the reasoning behind the systems thinking ranking as described in the previous sections. Table 5.2 gives an overview of the items on the formed TIS-ranking (column 1 and 2) and shows how these relate to the items from the Systems Thinking ranking (column 3).

Table 5.2: A ranking of interventions in TISs, and related terms from the systems thinking ranking.

Ranking of interventions for TISs	**Description**	**Related concepts from systems thinking ranking**
1. Directionality	Collective direction of actor goals	Goals
2. Institutions	Formal and informal institutions (structural element Institutions)	Self-organization
		Rules
3. Information flows	Any intervention that increases information flows (i.e. structural elements actors, knowledge infrastructure, physical infrastructure)	Information flows
4. Feedback loops	Feedback loops in system structure or between functions, and their delays	Reinforcing feedback loops Balancing feedback loop
5. Physical infrastructure	Physical infrastructure	Material Stock-and-Flow structure
6. Augmentations	Slightly strengthen, improve or increase already existing structural elements and links	Numbers

The rest of this section will discuss each item on the TIS-ranking, thereby using examples from the empirical domain of renovating houses energy-efficiently, or in short, the renovation TIS. Although most examples apply to any country, some are specific to the Netherlands. We interpret this system to be a TIS around the competence bloc (Carlsson et al., 1997) of technologies necessary to renovate houses energy-efficiently, which is embedded in the traditional construction sector and in turn in a national system. The main reason for focusing on this TIS is its highly dynamic nature because of fast technological developments in renewable energy production and energy-efficiency technologies. Consequently, because of the constantly changing situation, new interventions are regularly proposed and this empirical domain thus provides examples of interventions for each of the items on the ranking.

The TIS-ranking starts with interventions that affect its directionality (Weber and Rohracher, 2012), which is related to the *goals* concept from Systems Thinking. Directionality is an emergent system property, which means that – although not all actor goals are necessarily aligned - they do collectively point into a certain direction.[9] Intervening on the directionality may involve a collective reflection process, which causes actors to redirect their goals to a collective – often societal – goal. An example of an intervention from the renovation TIS is the extent to

9 A Technological Innovation System has no goal in itself. In earlier TIS-literature TISs were seen as having goals (see e.g. Bergek et al. 2008), but this view has become less prominent after the attention for agency increased (Farla et al., 2012, Markard et al., 2012).

which the pursuit of energy-efficiency (e.g. insulation) and energy-production technologies (e.g. solar energy) is part of actors' goals. Although attention for such technologies is increasing with homeowners, housing associations and construction companies alike, for most it is still considered a secondary factor. In other words, the emergent direction is not yet toward energy-efficiency and renewable energy production. Although there are no physical constraints that stand in the way of directionality shifts, it is unlikely that actors (in this example homeowners, but also government, construction companies etcetera) will collectively change their goals overnight. Intervening on directionality may dramatically improve system performance, but implementation is often very difficult or something for the long haul.

Second on the TIS ranking are institutions, which relates to the *rules, and self-organization* concepts from systems thinking. To facilitate further development and implementation of the technology, new institutions (rules) may have to be designed or outdated ones that have turned into bottlenecks may have to be adapted. In addition, because of technological change, it is not only the content of the institutions in a TIS that matters, but also their ability to adapt to changing circumstances (their self-organization). This may be achieved by periodically monitoring policies and adapting them if needed, or by using portfolio approaches instead of focusing on single technological options.[10] An institutions-related intervention from the renovation TIS concerns the Dutch electricity law. The electricity law was created when centralized electricity production was the standard and to date does not facilitate small scale energy production on houses.[11] Although an intervention on institutions may have a major impact on creating a market for renewable electricity production technologies (and thus improve the performance of this TIS), the degree of freedom for intervening on the electricity law is limited by the system directionality. For instance, proposing far reaching adaptations to the electricity law (e.g. proposing to only allow renewable energy technologies to be connected to the grid) are not in line with the current system directionality and are thus unlikely to be accepted. What is more, even though there are no physical constraints that inhibit a law change, vested actors may resist intervening here. For instance, in the Netherlands it has proven difficult to

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10 These examples come from (Weber & Rohracher, 2012), in which these are mentioned as examples for increasing system Reflexivity, which is a quite similar concept to Self-Organization from Systems Thinking.

11 A specific example is people that annually produce net surplus electricity with their solar panels who cannot supply this to their neighbors, because they then become a 'supplier' by law and need to adhere to unrealistically high financial and organizational requirements. In practice, this means that they have to sell their excess electricity to their energy supplier for a low price.

make even small changes to the electricity law.[12] Intervening on institutions may be powerful, but is also often difficult to implement.

Information flows are vital in any innovation system because through them new knowledge is diffused. There are multiple ways to add information flows in an innovation system. For example, by making partnerships between research institutes and companies a requirement for gaining government grants (intervention on interactions) or by initiating an online platform where information about product performance is shared between users (intervention on knowledge infrastructure). An example specific to the renovation TIS can be found in the type of guarantees given by installation companies. For decades, guarantees were only provided on installed products and the installation work, and not on the actual energy savings. Providing guarantees on energy savings requires an additional information flow between energy-use data and installation companies. Although there are little physical constraints that inhibit adding this information flow, installation companies would have to incorporate energy performance guarantees into their routines which will lead to delays at best. As a single intervention, targeting information flows is often easier than targeting higher items on the ranking but unfortunately, the impact of adding information flows is often limited by the higher ranked items. For instance, even if performance guarantees are successfully implemented, it would not drastically improve the performance of this TIS as long as the electricity law does not allow local energy production (institutions) or the directionality of the TIS is not geared toward sustainability. However, providing installation companies with information on the energy-use of their clients may stimulate their awareness of sustainability issues and in this way support a directionality change, which in turn could support adaptations to the electricity law. Although adding an information flow as single intervention generally has less potential to change a system compared to higher ranked items, it may play an important supporting role.

Feedback loops are also in innovation systems manifold (Carlsson et al., 2002; Chaminade & Edquist, 2010; Edquist & Johnson, 1997; Jacobsson & Jacobsson, 2014; Markard & Truffer, 2008; Wieczorek & Hekkert, 2012). For emerging TISs specifically, desirable feedback loops have also been identified in literature on motors of innovation (Negro et al., 2008; Suurs and Hekkert, 2009).[13] In addition, we argue that delays in feedback loops are also present throughout innovation systems, for example the delay between providing a research grant

12 An adaptation to the energy law called STROOM, was voted down on 22 december 2015 (Eerste Kamer, 2015).

13 These Motors of Innovation focus on desirable feedback loops between system functions (see discussion section), but since functions are made possible by the system structure, also relate to feedback loops between structural elements.

and research results, between setting up trainings and having a trained workforce, or between planning a new factory and having built it. Therefore, even though innovation systems literature has – so far – not recognized intervening on feedback loops (or on their inherent delays) a possibility, we give them a position on the TIS-ranking. To further illustrate the above, we give the example of the so-called split incentive problem in the renovation TIS. This problem is caused by a missing feedback loop, namely, if housing associations renovate their housing stock energy-efficiently, the renters reap the benefits of lower energy costs, giving housing associations little incentive to invest. This may be solved by making rent height dependent on the energy-efficiency of the house (an extra feedback loop). However, although in the Netherlands a law reform was scheduled that would allow this, it was initially voted down by parliament and thus delayed.[12] What is more, similar to information flows, an intervention on feedback loops may not be allowed by law (institutions) or not fit the directionality. However, it can also support making changes in the higher ranges in the ranking. For instance, making rent height dependent on energy-efficiency may stimulate housing associations to rethink the goals they pursue and thus support a change in the system directionality. Intervening on feedback loops is thus especially useful as part of a larger intervention set rather than as individual intervention.

The physical infrastructure of an innovation system relates to the concept of *material stock-and-flow structure* from systems thinking. The buildup of a TIS often requires phasing out old infrastructures and usually the construction of new physical infrastructures. Although changing the physical infrastructure may be a necessity for increasing the performance of the innovation system, this does not mean that intervening on the physical infrastructure will – on itself – have a large impact on improving system performance. A specific example from the renovation TIS is that most Dutch houses are using gas-fired boilers for heating and gas cooktops for cooking. If these are to be replaced with solar panels and induction cooktops for cooking and heat pumps for heating, it is necessary to strengthen the electricity grid. However, strengthening the electricity grid will on itself not make people buy heat pumps and induction cooktops. For this, additional changes are necessary in higher ranges of the ranking, for instance in the goals that people pursue or in the rules. Although strengthening the electricity grid may be surmountable with a bit of human ingenuity, changing the current physical infrastructure is not always realistic. For example, the current age of the existing housing stock, their orientation towards the sun and their current size constrain the options for refurbishment. Although such physical constraints can theoretically be overcome by demolishing the houses and building them new with ideal sun orientation etcetera, this seems unlikely to happen on a large scale. Although an intervention on the physical infrastructure may be necessary for improving the performance of an innovation system, it rarely has – by itself – a large impact on improving a TIS' performance.

The final item on the ranking is formed by augmentations; the equivalent of numbers in systems thinking terms. In relation to a TIS, we define an augmentation as an intervention that slightly increases or improves an already existing structural element or the links between elements. In other words, an augmentation does not involve the creation of new elements or new links between elements. Examples of augmentations in the renovation TIS are the National energy reduction fund (in Dutch: energiebespaarfonds) and the ratio between the electricity and gas tax. The National energy reduction fund issues cheap loans to homeowners for energy-efficiency measures and in this way increases the available financial capital in the system. However, that it is hardly being used signifies that these type of interventions often have a limited impact. Regarding the tax example, although changing the ratio between the tax on electricity and the tax on gas may discourage the use of gas-based technologies and stimulate electric heat pumps, it also increases the payback time for e.g. solar panels. Similar to information flows and feedback loops, intervening on augmentations is not only limited by items higher on the ranking, but may also support changes at higher items on the ranking. Subsidies may, for instance, provide an additional stimulus for housing associations to make use of a newly created feedback loops between rent height and energy-efficiency. Thus, despite that augmentations are often relatively easy to implement, their potential to alone drastically improve the performance of a TIS is – as the definition already implies – only small. However, even though intervening on augmentations is unlikely to drastically improve a TIS' performance, it may have a supporting role in a larger intervention set.

This empirical illustration suggests that the trade-off between the potential impact of interventions on improving system performance and their ease of implementation is also present in TISs. If a large system performance increase is desired, interventions can best be focused on the higher ranges of the ranking. In this case, this could mean initiating a large scale societal debate on the importance of sustainability (to make sustainability the emergent direction of actor goals) or by pursuing drastic changes to the electricity law (institutions). When this direction is taken, however, the intervenor should be prepared for implementation difficulties. Instead, interventions at the lower ranges of the ranking interventions are usually much easier to implement. For instance, stimulating energy performance guarantees (adding an information flow), solving the split-incentive problem (adding a feedback loop), lowering the interest rate for the loans issued by the National energy reduction fund, or making adaptations to the ratio between the electricity and gas tax (augmentations). In terms of impact, not that much should be expected from interventions that target the lower ranges of the ranking, at least as long as higher items on the ranking are not concurrently targeted.

5.5 COHERENT INTERVENTION SETS IN THE EMPIRICAL DOMAIN OF RENOVATING HOUSES ENERGY-EFFICIENTLY

Next to bringing the considerations for choosing between individual interventions to the forefront, the introduced ranking also provides preliminary insight into how a coherent intervention set for a TIS can be designed. To exemplify this, we will discuss two intervention sets that try to stimulate energy-efficiency renovation in the Netherlands. The first intervention set (related to the traditional approach to renovation) focusses only on the lower ranges of the ranking, while the second intervention set (related to so-called Renovation Concepts) targets the full range of the ranking.

The traditional approach to renovation is based on creating a specific renovation plan for each renovation project, which can be one house or multiple houses. Renovation companies traditionally specialize in a single or a couple of activities, e.g. roofing, windows or foundation. With the advent of energy-efficiency renovation, companies added energy-efficiency measures to their product portfolio and new companies arose that specialized in e.g. insulation or solar panel installation. This approach revolves around 'stacking' measures installed by different companies, which is facilitated by the energy label methodology. An energy label runs from label G (very inefficient) to label A++ (energy neutral) and each measure taken represents a certain increase of the energy label. The first intervention set revolves around stimulating this approach to renovation.

The energy label itself creates an additional *information flow* in the innovation system as it provides homeowners with information about the energy-performance of their house and on the efficiency gains that may be achieved with certain measures. The energy label has been actively propagated in information campaigns, thereby further strengthening this information flow to the general public. Furthermore, this approach to renovation has been supported with short term subsidies for energy-efficiency measures, e.g. wall insulation, and tax benefits specifically for homeowners with solar panels (in Dutch: salderingsregeling), both of which are interventions on *Augmentations*.

The renovation of houses using this traditional approach has only been slow and gradual. Homeowners may take one or a couple of label steps, but large scale renovation to a high energy label (A or higher) is rare. If we compare the type of interventions utilized in this set to the ranking, we can start to understand why. The directionality of the TIS did not change much as this approach to renovation follows the traditional approach of renovating houses by stacking measures. This intervention set also does not fundamentally change the institutions in the system. For example, although the energy label was - on paper - made obligatory when selling a house, no fines have been issued. Finally, this approach strives to change the *physical infrastructure* the least as possible, which is signified by more efficient gas-fired boilers and blow-in wall insulation being the most common energy-efficiency measures when this approach is followed. In addition, both of these measures focus on *reducing* gas-usage instead of *replacing* gas for electricity. We can conclude that this intervention set focusses on the lower ranges of the ranking and – especially in relation to the physical infrastructure – is even there not radical in its approach. Together, to the extent that the ranking is right, this may explain why the implementation of energy-efficiency renovation using this approach has been slow and gradual.

Opposed to traditional renovation, renovation concepts provide an alternative and upcoming approach to energy-efficient house renovation. A renovation concept is a standardized methodology for renovating a particular type of house (e.g. a particular type of row house or flat building). Most renovation concepts are geared to the goal of reaching zero-on-the-meter (in Dutch: nul-op-de-meter). A zero-on-the-meter house annually produces energy equal to the energy-use of an average family. Instead of stacking measures, a renovation concept integrates multiple individual measures into a single proposition. Renovation activities are not performed on site, but construction components are prefabricated in a factory after which the house is stripped and the prefab components are installed in a matter of days. In addition, most renovation concepts are all-electric, which means that the house is no longer connected to the national gas infrastructure after renovation. The use of renovation concepts in this way directly challenges the traditional renovation approach that is based on stacking measures.

The Dutch renovation acceleration covenant (in Dutch: stroomversnelling) is utilizing a coherent set of interventions to stimulate renovation concepts. The covenant actively tries to persuade construction companies, housing associations and other stakeholders to strive for the goal of renovation toward zero-on-the-meter (change of directionality). In addition, to stimulate the development and uptake of renovation concepts that make this possible, it is lobbying for fundamental adaptations to the electricity law and the building code (intervention on institutions). Developers of renovation concepts are also obliged to provide an energy performance guarantee (which depends an additional information flow of energy-use data from the house to the concept developers), and – in a planned reform of the electricity law – the rent height is allowed to increase more after a zero-on-the-meter renovation compared to a label step renovation (feedback loop in favor of renovation concepts). Furthermore, the use of prefabricated construction components reduces the renovation activities on-site, and the gas connection of the house is removed and replaced by an electricity connection (far reaching interventions on physical infrastructure). Finally, maximum mortgage possibilities have been extended for zero-on-the-meter houses, and house valuation methods are being adapted to include the low-energy costs after renovating toward zero-on-the-meter (augmentations). Although it is currently too early to conclude whether this intervention set will be successful in changing the directionality of this innovation system, the implementation of renovation concepts seems to have a positive momentum. Following the reasoning of the ranking, this positive momentum may well be the result of the coherent intervention set that is targeting not only the lower ranges, but also the higher ranges of the ranking.

The above makes clear that both interventions sets act upon different ranges of the ranking. The first intervention set discussed – propagated by actors that pursue the more traditional approach to renovation – is targeting items on the ranking up to feedback loops, whereas the intervention set utilized by the stroomversnelling covenant strives to affect the directionality of the innovation system. What is more, both interventions sets make use of lower ranking interventions to support the highest-ranking intervention. In this way, the ranking may help to design a set of mutually supportive interventions.

The question whether one of these intervention sets is 'better' can be approached from multiple perspectives. Luederitz et al. (2016) have argued for a more nuanced perspective, saying that intervening in the higher ranges of the ranking (which they call 'deep' intervention types) is not necessarily more correct or better than intervening in the lower ranges of the ranking ('shallow' intervention types). They base their statement on the argument that system transformation can also be achieved through 'shallow' intervention types since, in their words, these "also have the ability to stimulate changes in deeper system properties" (Luederitz et al., 2016, p. 11). Contrasting this nuanced perspective, it has also been argued that 'shallow' intervention types are on itself not powerful enough to achieve system transformation, and that 'deep' intervention types should thus be strived for (Abson, 2017). Since – in our illustrative case study - the intervention set that focusses on the lower ranges of the ranking has shown only slow progress, whereas the intervention set that reaches the higher ranges of the ranking has shown positive momentum, our illustrative case study gives preliminary support for the more radical perspective.

5.6 DISCUSSION

In this discussion, we reflect upon (1) the consequence of transferring a line of reasoning *from* Systems Thinking *to* TIS, (2) the usefulness of the ranking for less broadly delineated technological innovation systems, (3) having identified only three factors that influence the impact of interventions on the performance of an innovation system, and (4) the fit of the proposed TIS-ranking with other innovation system strands.

First, the consequence of taking concepts from systems thinking as starting point is that TIS concepts were neglected that have no equivalent in systems thinking or that receive little attention in systems thinking. For example, TIS literature describes that it is possible to intervene on the attributes of structural elements (Wieczorek and Hekkert, 2012). This comes next to what was discussed in section 5.3, namely that the role of actors in systems thinking is restricted to creating resistance to change. If and how attributes of structural elements and a more beneficial role of actors fit in the TIS-ranking, should be explored further. Additionally, this chapter gave limited attention to the key processes or functions of innovation systems, although they are a prominent TIS-concept (Bergek et al., 2008; Hekkert et al., 2007). Since systems thinking does not have a concept equivalent to functions, this chapter focused mainly on the structural level. However, although functions are not *part* of the system structure, they are *made possible by* the system structure. It should thus be possible to extend the reasoning to the functional level. It implies that the trade-off between potential impact on improving system performance and ease of implementation not only plays out differently for intervention points, but also for system functions.

Second, for less broadly delineated TISs analysts may find that especially higher ranking items do not fall within the TIS boundaries. For example, the electricity grid or the electricity law could easily fall outside of the boundaries of a heat pump or solar panel TIS. This suggests that – especially for less broadly delineated TISs – it is important to consider the possibility of intervening in the context of the TIS, underlining the importance of the recently revived attention for TIS context (Bergek et al., 2015).

Third, even though the three factors influencing the impact of interventions distilled from the systems thinking ranking already provide important insights, intuitively there are additional factors that play a role. Other factors that come to mind are, for instance, the range of influence of the actors involved in the intervention (intervenors), their world-views (Griffieon, 1989), the narrative that they follow (Luederitz, 2016), the willingness of these intervenors to put in extra effort if resistance is fierce, their capacity to counteract this resistance, or the timeframe that the intervenors have available for implementing the intervention (e.g. term of office length). Certainly, more can be said about what factors determine the impact of, and thus the choice for, interventions in innovation systems. What additional factors are relevant and whether they change the order of the items on the ranking can be further explored.

Fourth and finally, the choice was made to specify the ranking for technological innovation systems. However, since other innovation system strands make use of similar theoretical concepts and share most assumptions in relation to interventions, it should also be possible to create rankings specific to national, sectoral and regional innovation systems. The above discussion should make clear that we are aware that the ranking as proposed only provides a first step in theorizing about the likely impact of interventions on improving the performance of an innovation systems: much more theoretical work is necessary.

5.7 CONCLUDING REMARKS

This chapter started with the observation that the innovation systems theoretical framework, and thus the TIS intervention framework, currently does not help to answer questions related to what type of intervention, or set of interventions, is likely to have a large impact on improving system performance. Since this clearly is a quite challenging question, we reservedly set the objective to lay a preliminary foundation for a conceptual framework that should increase our understanding on this matter. For this, we found inspiration in a ranking of intervention points from systems thinking, more specifically related to the leverage points concept. Based on the ranking's underlying reasoning, we proposed a ranking of intervention for TISs. An illustrative case study of the TIS of renovating energy-efficiently suggested that the ranking provides a good starting point for understanding what considerations play a role in the process of choosing between interventions. However, we are also the first to admit that our effort also provides room for debate. For instance, the order of items on the ranking from systems thinking is based on only three characteristics (system change potential, resistance to change and physical constraints). Many additional factors can be conceived of that may also have their part (e.g. intervenors' worldviews or their range of influence). This may possibly change the order of items on the ranking. In addition, an illustrative case study cannot provide more than the suggestion that intervening at the higher ranges of the ranking - preferably with a coherent intervention set - should be favored for improving the performance of a TIS. Despite the limitations of our effort, we maintain that the idea of ranking types of interventions in innovation systems based on their characteristics is worth exploring in further detail. We therefore hope that the idea of ranking interventions provokes a broader discussion and that thereby our combined understanding of what influences the impact of interventions in innovation systems will improve.

Chapter 6

Conclusion and discussion

Before anything else, it should be noted that the TIS intervention framework - before the research as put forward in this dissertation started - already largely provided the theoretical means for identifying problems and formulating interventions. Yet, while exploring the TIS intervention framework in more detail (Section 1.2), four theoretical limitations were nevertheless identified. The objective of this dissertation thus became to further strengthen the TIS intervention framework. To help resolve these four limitations, the preceding chapters proposed alternative conceptualizations or alternative analysis methods of which their merits were explored by applying them to case study material. It is now time to not only reflect on what this dissertation contributes to the TIS intervention framework, but also on what questions remain.

6.1 LIMITATION 1: LIMITED ATTENTION FOR HOW PROBLEMS INTERACT, INFLUENCE EACH OTHER, AND MAY FORM CHAINS OF CAUSES

In chapter 2, a case study of the innovation system related to building energy-efficient houses in the Netherlands was carried out during which explicit attention was given to how problems interact. For this analysis, the term blocking mechanism was not used to indicate individual problematic 'factors', but instead to indicate a 'mechanism' consisting of interacting systemic problems. The following research question was posed: What problems inhibit the Dutch energy-efficient housing innovation system, how do these problems interact, does analyzing problem interactions provide additional insights compared to analyzing independent problems, and if so, what are these additional insights? The findings show that, in the case of energy-efficient houses in the Netherlands, many problems can be traced back to how profits from land are distributed among stakeholders. These profits are often not reinvested in the energy-efficiency of the house, leading to weak resource mobilization in the innovation system. In addition, the project-based approach as dominant organizing principle of the building process also creates many problems within this innovation system. These findings differ from an earlier study of the same empirical domain which not only overlooked the land-market as problem, but also the possibility of moving toward a different organization of the building process as alternative to the project-based approach, i.e. based on building concepts.

It must also be noted that many identified problems related not to the innovation system itself, but to the context of the innovation system. For instance, the lack of financial resources within the TIS can be traced back to the problem of profits from land sales not being reinvested into the energy-efficiency of houses. These findings thus imply that failing to identify contextual problems and how these interact with endogenous problems may lead to inaccurate problem diagnosis, and thus to ineffective intervention. This underlines the importance of conceptualizing a blocking mechanism as a combination of endogenous and exogenous systemic problems to the system. For this, a broader meaning of the term systemic problem is necessary, as it so far only indicated endogenous problems. Broadening the meaning of the term systemic problems in this way does justice to the recent discussion about the importance of system context (Bergek et al., 2015).

Another merit of identifying blocking 'mechanisms' was the insight that intervening on problems that are symptoms of other problems can have counterproductive effects. For instance, in the current system, giving subsidies for building houses energy-efficiently will probably not increase financial resources for homeowners in the longer term. Instead, house prices will probably increase, which would only increase profits for land-owners because of the current calculation methodology used to distribute profits among stakeholders (residual land value methodology). In this way, the result of the subsidies could be fully negated, which makes it an intervention with little added value if not counterproductive. The findings thus indicate that understanding how systemic problems interact and can form a blocking mechanism may not only lead to the identification of more problems, but also to better problem diagnosis. To conclude, seeing a blocking mechanism as consisting of multiple interacting systemic problems that go over system boundaries facilitates analysts during the problem identification stage of a TIS-analysis and thus strengthens the TIS intervention framework.

6.2 LIMITATION 2: IT DOES NOT PROVIDE THE THEORETICAL MEANS FOR COPING WITH INCONSISTENT DATA ON PROBLEMS AND POTENTIAL SOLUTIONS

In chapter 3, it was argued that there is an implicit assumption in innovation systems literature that explains the existence of this limitation, namely that problems and solutions are 'out there' and that the striving should always be to reveal the objective truth about what they *are*. However, this is not always necessary or desirable as it may entice an analyst confronted with conflicting opinions to favor one opinion over the other or to neglect the inconsistent data, leading to wrong conclusions. It was argued that in such instances it is beneficial to take a subjectivist view, of which the merits were explored by drawing on the concept of institutional logics. Institutional logics theory holds that actors will perceive not only different problems, but also different solutions for a certain problem, depending on the logics that they are guided by during sensemaking.

In this chapter, the objective was set to explore the usefulness of institutional logics theory for coping with inconsistent data regarding problems and potential solutions during an innovation system analysis, and if useful, how this can be approached. For this purpose, the following research question was answered: What institutional logics guide actor behavior in the Dutch innovation system of renovating houses energy-efficiently, and what insights do these logics provide into the origin of conflicting opinions about problems and potential solutions as collected for this innovation system?

During the analysis, two ideal-type institutional logics were identified, namely the steps logic and the leaps logic. The steps logic reflects a pragmatic stance toward renovation projects. Main reasons for renovating are found in compliance (for housing associations) or achieving quick wins (for homeowners). This renovation approach revolves around adaptation of the house and judging each measure on an individualistic level. Flexibility is an important value under this logic as for each house a specific renovation plan is developed. Contrasting the steps logic, the leaps logic takes a more idealistic stance toward renovation. Main reasons for renovating are found in commitment to reducing CO_2-emissions (for housing associations) or to achieve significant changes in the sustainability or comfort level of the house (homeowners). Instead of adapting the house, it is transformed, during which measures are combined in a holistic way. An important value under this logic is efficiency, which is reflected the use of prefab construction parts.

The steps and leaps logics proved useful to understand why the collected data in relation to problems and solutions for this innovation system was inconsistent. In relation to problems for example, when the leaps logic guides sensemaking, actors argue that additional financial resources are still necessary to further develop and test the integration of technologies. However, when the steps logic guides sensemaking this is not considered necessary since technologies are judged on an individual level. In relation to solutions for instance, to alleviate inconveniences for homeowners during renovation activities, actors guided by the steps logic can only emphasize adequate manners and friendly communication, whereas actors guided by the leaps logic can additionally emphasize that the use of prefab construction parts reduces on-site activities. In this way, taking a subjectivist view, for instance by making use of the institutional logics concept, does not only facilitate analysts in coping with inconsistent data on problems, but also with inconsistent data on solutions. To conclude, the possibility of taking a subjectivist view when confronted with inconsistent data strengthens the TIS intervention framework not only in the problem identification stage, but also in the intervention formulation stage.

6.3 LIMITATION 3: QUESTIONS REMAIN ABOUT WHAT KIND OF INFLUENCE SECTORAL CONTEXT STRUCTURES HAVE ON TIS PERFORMANCE

Chapter 4 started with the observation that current literature casts some doubt on what kind of influence sectoral context structures may have on TIS development. It is explained that any context structure can be dynamic, but also that the sectoral context is generally quite stable. To explore the nature of TIS/context interactions further, a TIS-analysis of the heat pump in the Netherlands was presented for which the following research question was posed: How does sectoral context influence function fulfillment in the heat pump technological innovation system in the Netherlands?

To start with, heat pump technology itself and related technologies (the high-efficient gas boiler, insulation, low temperature heating and solar panels), were analyzed on a technology-technology level to gain insights into their mutual dependencies. This led us to distinguish between two types of heat pumps. Firstly, a standalone heat pump as sole installation for heating a house throughout the year, and the hybrid heat pump which only provides heat part of the year. Since the hybrid heat pump is – in the Netherlands – always combined with a high-efficient gas boiler, these two technologies were analyzed concurrently. It was decided to make the distinction between two TISs, namely the hybrid/gas boiler TIS and the standalone heat pump TIS, which are partly independent and partly overlap. Subsequently, the sectoral context was analyzed for dynamics that influence the choice between either the standalone heat pump or the hybrid heat pump/high-efficient gas boiler combination. It was found that the choice between one or the other depends much on what renovation goal is pursued. The standalone heat pump is the preferred choice for very ambitious renovations (zero-on-the-meter goal or very ambitious energy label renovations), whereas the hybrid heat pump in combination with a high-efficient gas boiler is preferred for less ambitious renovations (smaller label steps as goal). In this way, how the debate about the ambition level of renovations plays out at the sectoral level largely determines whether the hybrid or standalone heat pump is stimulated. As the more ambitious zero-on-the-meter renovation goal was introduced to the renovation sector only relatively recently, the sectoral context of the two heat pump TISs can only be considered quite unstable.

These gained insights contradict with the current notion in literature that the sectoral context of a TIS is generally ‘quite stable’, which has consequences in both the problem identification and intervention formulation stages of a TIS-analysis. During the problem identification stage, the possibility of a TIS having an unstable sectoral context has an important consequence, namely, if the sectoral context has so far facilitated TIS development, a shift in the sectoral context may create unexpected problems. In addition, during the intervention formulation stage, trying to initiate change in the sectoral context for instance through lobbying activities, is currently seen as the main possibility for intervening in system context. Instead, the insight that sectoral context can also be quite unstable, shows that initiation of change is not always necessary. Sometimes, intervention can be limited to joining change initiatives already underway at sectoral level. An example from the case study would be that standalone heat pump manufacturers join a zero-on-the-meter renovation pilot project. This contributes to embedding the standalone heat pump as preferred choice within such renovations, and thereby stimulate its uptake. To conclude, the insight that sectoral context can also be quite unstable sheds new light on both the problem identification and intervention formulation stages of a TIS-analysis and in that way strengthens the TIS-intervention framework.

6.4 LIMITATION 4: IT PROVIDES LITTLE INSIGHT INTO WHAT TYPE OF INTERVENTION, OR SET OF INTERVENTIONS, IS LIKELY TO HAVE A LARGE IMPACT ON IMPROVING THE PERFORMANCE OF AN INNOVATION SYSTEM

Chapter 5 started with the observation that the innovation systems theoretical framework currently does not provide much insight into what type of intervention, or set of interventions, is likely to have a large impact on improving the performance of an innovation system. Since this clearly is a quite challenging question, the objective was set to lay a first preliminary foundation for a conceptual framework that should increase our understanding on this matter. The following research question was posed: What influences the impact of interventions on improving the performance of a technological innovation system, and can interventions be ranked based on these insights? For this, we found inspiration in a ranking of intervention points from systems thinking, more specifically related to the leverage points concept. By disentangling the underlying reasoning of this ranking, it was found that systems thinking holds that the impact of interventions depends on characteristics of the points in the system where the interventions act upon. The first characteristic is the *system change potential* that intervention points inherently possess, the second r*esistance to change* that can be expected from actors, and the third the *physical constraints* confronted with when trying to make changes to a certain intervention point. Using these three characteristics, a ranking of intervention was proposed for TISs.

The ranking consists, from top to bottom, of Directionality, Institutions, Information flows, Feedback loops, Physical Infrastructure and Augmentations. Intervening higher on the ranking is often difficult, but also coincides with more impact achieved if successfully implemented. An illustrative case study of the TIS of renovating houses energy-efficiently suggests that the ranking provides a good starting point for understanding what considerations play a role in the process of choosing between interventions, and for forming coherent sets of interventions. For instance, if energy-efficiency can be made the primary criterion when renovating a house, this would have a major impact on improving the performance of the innovation system (change in Directionality). However, energy-efficiency currently only is a secondary criterion after costs and comfort level. Persuading all actors to pursue a different goal is very difficult at best. In contrast, intervening lower on the ranking is often relatively easy, but not that much should be expected in terms of achievable impact. For instance, lowering the VAT on solar panels (Augmentation) may stimulate some homeowners to invest in solar panels, but if homeowners find solar panels ugly (informal institution) or if they are not allowed to install solar panels because their house is located in a historic city centre (formal institution), lowering the VAT will probably have limited impact. The latter example also shows that the impact of intervening lower on the ranking is often limited by items higher on the ranking, in this case by institutions. In addition, the case study also gave preliminary support for the usefulness of the ranking to design coherent sets of interventions. Two coherent interventions sets were discussed that both try to stimulate energy-efficient house renovation in the Netherlands. The first intervention set does not try to change the system beyond information flows (intervention set related to label step renovations), whereas the second intervention set tries to change the system up to directionality level (intervention set related to renovation concepts). Although both intervention sets target quite different ranges of the ranking, they have in common that lower ranking interventions are supportive of the highest-ranking interventions. Despite the preliminary nature of the effort, it is concluded that the idea of ranking types of interventions in innovation systems based on their characteristics is worth exploring in further detail.

6.5 REFLECTIONS, LIMITATIONS AND FURTHER RESEARCH

Although the above section illustrated how the proposed theoretical adaptations and extensions contribute to overcoming the four identified theoretical limitations, it must also be noted that more work can be done. Therefore, this final section reflects on the outcomes of this dissertation, discusses its limitations, and gives some ideas for further research. During this discussion, the focus lies on the bigger picture as more specific discussions about each chapter's topic can be found in their respective discussion sections. The following topics are discussed here: (1) the importance of TIS context, (2) coherence of interventions, (3) the level of detail required during a TIS-analysis, (4) required analytical skills and time, (5) the illustrative nature of the presented case study material, (6) remaining main conceptual issues, and (7) unexplored conceptual ideas.

First of all, the importance of TIS context came back throughout this dissertation, sometimes explicit and sometimes more implicit. Chapter 2 showed that endogenous problems can often be traced back to exogenous problems. Since a blocking mechanism may consist of both endogenous and exogenous systemic problems, it is important to take the context into account to make sure that no blocking mechanism is missed. Chapter 3 showed how institutional logics that institutionalize at sectoral level can to a large extent determine what problems and potential solutions actors within the TIS perceive, which also reflects strong influence of contextual structures on a TIS. Subsequently, the importance of context in Chapter 4 is obvious as the chapter ends with the insight that autonomous developments in the sectoral context may to a large extent determine the success of a TIS. Finally, Chapter 5 explained that especially for more narrowly denominated TISs, the highest-ranking items on the ranking may fall outside of the immediate system boundaries, implying that the interventions with the most impact may often exist outside of system boundaries. Without a doubt, the recent attention for TIS context (Bergek et al., 2015) is an effort to be applauded.

Second of all, the importance of creating coherence between interventions also came back multiple times. The findings in Chapter 2 imply that intervening on multiple systemic problems that are part of the same blocking mechanism may be unnecessary at best and counterproductive at worst. Chapter 3 explained that, if two logics are guiding sensemaking activities of actors within the TIS, this should also be reflected in the created intervention sets. If an intervention set combines interventions in line with both logics, there is a good chance that interventions will negate each other. At least, such interventions sets will cause frustration under TIS actors, as they will feel stimulated by some interventions and inhibited by others. In Chapter 4, based on analyzing technology/technology interactions, it was decided to distinguish between the standalone and the heat pump TIS as they are each other's competitors in many ways. Distinguishing between a single heat pump TIS would have surely led to an incoherent intervention set with some interventions stimulating the standalone heat pump and others the hybrid heat pump. Finally, chapter 5 discussed the coherency of interventions sets in detail, and even proposed a way to think about how interventions can best be combined, namely by supporting high-ranking interventions with lower-ranking interventions. In all, thinking about how interventions can best be combined, for instance on the basis of what was brought forward in this dissertation, is preferable over cherry-picking intervention strategies. The importance of intervention coherency also links up well with work on policy mixes in relation to TISs (e.g. Reichardt et al., 2016).

Thirdly, it must be noted that not every TIS-analysis requires a level of detail as presented in the preceding chapters. It was a conscious choice to focus on a rather complex empirical domain, because this brings the limitations of a theoretical framework to the forefront. However, for instance, a TIS in an early phase of development may exhibit less strong structural couplings with contextual structures, which not only makes an analysis of how problems interact over the immediate system boundaries, but also taking the sectoral context explicitly into account, less necessary. Or, if a TIS-analyst is not confronted with conflicting data on problems or solutions, there is no reason for identifying institutional logics that may explain this. Every TIS-analysis requires its own approach, depending on the specifics of the empirical domain focused on. The contributions made in this dissertation should thus be seen as additions to the conceptual 'tool-box' that TIS-analysts may, but do not have to, draw from during a TIS-analysis.

The flip-side of the above is that, even though TIS-analyses surely do not need to involve all activities as put forward in this dissertation, it is important to be aware of the risks of not giving attention to them if they are relevant. For instance, not giving explicit attention to problem interactions for a TIS that is more mature, focusing only on internal TIS dynamics for a system that has strong structural couplings with the sectoral context, or not taking a subjectivist view on problems if conflicting opinions on problems are collected, are recipes for wrong problem diagnosis and interventions that not live up to expectations. Thus, although a TIS-analysis does not always have to give explicit attention to problem interactions, to sectoral context, or to the influence of institutional logics, the analyst should always consider whether it is required.

Fourthly, an important limitation of what was done is that most, if not all, of the proposed conceptual adaptations and/or additions require high analytical skills from the TIS-analyst and increase research time. As already mentioned, part of the solution is to remember that not all of what was put forward needs to be incorporated into a TIS-analysis. This depends strongly on the required depth of the analysis and of the complexity of the studied empirical domain. However, there may also be possibilities for making what was proposed in this dissertation more practical. For instance, by working out in more detail for what type of systems it is desirable to give attention to how problem interact or to the influence of institutional logics, and for what type of systems this is not necessary. Furthermore, the analyses presented in this dissertation were tailored to the specific purpose of the analysis, which meant deviation from the standard TIS-analysis stages on multiple occasions. It would be interesting to work out in more detail how the proposed conceptual adaptations and additions of the TIS intervention framework fit within the stage-wise approach of a structural/functional analysis.

Fifth, chapter 3 on institutional logics and chapter 5 on ranking interventions presented only illustrative case study material of parts of TIS-analyses. Although these illustrative case studies already gave important insights, their illustrative nature presents opportunities for further research. For instance, it would be interesting to analyze in more detail to what extent the steps and leaps logic are institutionalized in the innovation system of renovating houses energy-efficiently in the Netherlands. In addition, interesting insights are expected from using the ranking of TIS-interventions as extension to a complete TIS-analysis. Ideally, two concurrently implemented intervention sets are followed during a longitudinal study to see whether the premise holds that intervening at the higher ranges of the ranking - preferably with a coherent intervention set - should be favored. Clearly, more empirical work is desirable.

Sixth, two main conceptual issues remain unexplored. The first one relates to the three characteristics of interventions that together determine the position of items on the TIS-ranking as put forward in chapter 5, namely system change potential, resistance to change and physical constraints. Many additional factors can be conceived of that may also have their part (e.g. intervenors' worldviews, their range of influence, the available timeframe for implementing the interventions). As it is, the TIS-ranking created is based on ideas from systems thinking only and there seem to be plenty of possibilities to more systematically buildup the reasoning behind the TIS-ranking by involving more streams of literature. A second conceptual issue for further consideration is the conceptual clarity of the terms system failure or systemic failure in relation to the alternative conceptualization of the terms blocking mechanisms and systemic problems as put forward in this dissertation. As also mentioned in chapter 2, the terms system failure and systemic failure are sometimes used as synonyms for systemic problem and sometimes to indicate broader issues with an innovation system.

Seventh, this dissertation ends with posing three conceptual ideas. The first conceptual idea is to give a more detailed look at the link between different types of system failures (e.g. as discussed by Weber and Rohracher, 2012), and the items on the proposed TIS-ranking. For instance, directionality is not only an item on the TIS-ranking, but also a type of system failure. This may be a potential direction for dealing with the second unexplored conceptual issue that relates to the term system failure discussed above. The second idea relates to Chapter 4 that utilized institutional logics theory. Although fruitful, the institutional logics concept proved to be a relatively complex theoretical concept for taking a subjectivist view on problems and potential solutions in relation to innovation systems. Other ways for taking a subjectivist view, for instance using the concepts of strategies (e.g. Granqvist et al., 2013) or worldviews (e.g. Griffioen, 1989) remain unexplored. The third conceptual idea concerns the proposed alternative meaning for the term blocking mechanism, namely as 'mechanism' consisting of multiple systemic problems. As there are already categorizations of commonly occurring systemic problems available, in the same manner, it may be possible to create categorizations of commonly occurring blocking mechanisms. Inspiration for this may be found in the system archetypes concept from systems thinking (Senge, 1990; Meadows, 2008). In a similar way to what was done in Chapter 5, the reasoning that underlies the system archetypes concept may be transferred to the TIS framework. It is hoped that these conceptual ideas encourage debate on how to even further strengthen the TIS intervention framework.

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Appendix

Summary

Samenvatting

Curriculum Vitae

SUMMARY

Technological innovation is in high demand (e.g. stimulating economic growth or combatting climate change), making it of value to understand how innovation processes can be stimulated. However, creating this insight is not an easy task as the success of a technological innovation depends not only on the innovation itself, but on a multitude of factors. Despite the magnitude of the challenge, the technological innovation systems (TIS) framework provides a theory to understand under what conditions technological innovations are successfully developed and implemented. The objective of this dissertation is to further strengthen this *TIS intervention framework*, which is the part of the TIS theoretical framework that facilitates the identification of inhibiting problems and the formulation of interventions. Theoretical adaptations and extensions are proposed and their merits subsequently explored during case studies that relate to the empirical domain of energy-efficient housing in the Netherlands.

To start with, although the framework emphasizes the dynamic nature of the innovation process, problems are conceptualized and commonly analyzed as independent entities. During a case study of newly-built energy-efficient houses in the Netherlands, it is explored whether giving explicit attention to problem interactions yields contrasting or additional insights compared to an analysis of independent problems. It is found that problems may together form a problematic mechanism, and that intervention on all the problems that form the mechanism is then of little value and can even be counterproductive.

Secondly, the TIS intervention framework currently does not provide the theoretical means for coping with inconsistent opinions on what the problems and best interventions are. The merits of taking a subjectivist view that allows multiple 'truths' about problems and solutions to coexist are explored during a case study of the Dutch innovation system of renovating houses energy efficiently. It is found that there are two viewpoints on renovation prominent that have their origin in two distinct 'institutional logics', namely the so-called 'steps logic' that leads to renovation in consecutive steps and the 'leaps-logic' that leads to renovation in a single leap. These institutional logics explain why actors are perceiving different problems and are also proposing different solutions for this innovation system.

Thirdly, in literature it is often mentioned that the sector tends to form a relatively stable environment for TISs. However, it is found that the success of the heat pump in the Netherlands (and the type of heat pump) depends much on how the current debate on what renovation approach to follow plays out (either in consecutive steps or in a single leap). As this debate developed autonomously

at sectoral level, it is concluded that sectoral context may also form a rather unstable environment for TISs.

Finally, the question what type of intervention, or set of interventions, is likely to have a large impact on improving the functioning of an innovation system remains unanswered. To help answer this question, this dissertation lays the foundation for a conceptual framework based on an idea from systems thinking theory, namely that the transformational power of interventions relates to the characteristics of the points in a system where the intervention acts upon. This reasoning is used to create a preliminary ranking of interventions for the TIS framework. Through a case study of highly energy-efficient houses it is illustrated how the ranking can be used as addition to an innovation systems analysis.

SAMENVATTING

Technologische innovatie is om meerdere redenen gewild, bijvoorbeeld om economische groei te stimuleren of om klimaatverandering tegen te gaan. Het is daarom waardevol om te begrijpen hoe innovatieprocessen gestimuleerd kunnen worden. Dit is echter niet eenvoudig aangezien het succes van een technologische innovatie afhangt van veel verschillende factoren. Voor deze uitdaging biedt het technologisch innovatiesysteem (TIS) raamwerk een theorie om te begrijpen onder welke condities technologische innovaties succesvol worden ontwikkeld en geïmplementeerd. De doelstelling van deze dissertatie is om het TIS-interventieraamwerk verder te versterken. Het interventieraamwerk is het gedeelte van het TIS-raamwerk dat het identificeren van belemmerende problemen en het formuleren van interventies faciliteert. In deze dissertatie worden theoretische aanpassingen en aanvullingen voorgesteld waarvan vervolgens de meerwaarde wordt onderzocht binnen casestudies gerelateerd aan duurzame bouw en renovatie in Nederland.

Om te beginnen worden problemen, ondanks de sterke nadruk die het TIS-raamwerk legt op de dynamiek binnen het innovatieproces, veelal als losstaande entiteiten geconceptualiseerd en geanalyseerd. Met een casestudie van duurzame nieuwbouw in Nederland wordt bekeken of specifieke aandacht voor hoe problemen op elkaar inwerken tot aanvullende of tegenstrijdige inzichten leidt, in vergelijking met een analyse van losstaande problemen. Het blijkt dat problemen samen problematische mechanismen kunnen vormen. Het interveniëren op alleen individuele problemen die onderdeel van het mechanisme zijn is vaak slechts beperkt nuttig en kan zelfs contraproductief zijn.

Ten tweede biedt het TIS-interventieraamwerk geen theoretische handvatten voor het omgaan met inconsistente meningen van respondenten over wat de problemen en beste interventies zijn. Binnen een casestudie van het Nederlandse innovatiesysteem van duurzame renovatie zijn de voordelen van een subjectieve kijk op problemen en oplossingen onderzocht, waarbij meerdere waarheden naast elkaar mogen bestaan. Er blijken twee verschillende zienswijzen van invloed te zijn, gebaseerd op verschillende 'institutional logics', namelijk de zogenaamde "steps logic" die leidt tot renovatie in stappen en de "leaps logic" die leidt tot renovatie in één sprong. Deze 'institutional logics' kunnen voor dit innovatiesysteem verklaren waarom actoren verschillende problemen zien en andere oplossingen aandragen.

Ten derde beschrijft literatuur vaak dat sectoren (zoals de bouw) veelal een relatief stabiele omgeving voor een TIS vormen. Een casestudie laat echter zien dat het succes van de warmtepomp in Nederland (en de keuze voor het type

A

warmtepomp) sterk afhangt van de uitkomst van de discussie over wat de beste renovatiemethode is (renoveren in stappen of in één sprong). Aangezien deze discussie een recente autonome ontwikkeling op sectoraal niveau betreft, wordt geconcludeerd dat het van belang is om tijdens een TIS-analyse bedacht te zijn op een onstabiele sectorale context.

Ten slotte geeft het huidige TIS-raamwerk geen antwoord op de vraag welk type interventie, of welke combinatie van interventies, veel impact heeft op het verbeteren van het functioneren van een innovatiesysteem. Om deze vraag te helpen beantwoorden legt deze dissertatie de basis voor een conceptueel raamwerk. Het idee uit Systeemdenken dat de transformerende kracht van een interventie afhangt van de eigenschappen van de plek in het systeem waar de interventie op inwerkt, speelt hierbij een centrale rol. Op basis van deze argumentatie wordt een voorlopige ranking van interventies voorgesteld voor het TIS-raamwerk. Een casestudie van energie-efficiënte woningen illustreert hoe deze ranking kan worden ingezet als aanvulling op een innovatiesysteemanalyse.

CURRICULUM VITAE

Work experience

2012 – 2017 **Researcher/teacher at Utrecht University**
- Externally funded research projects: numerous.
- Student supervision: both individuals and groups.
- Course coordinator: Bachelor Thesis and Innovation Systems.

2010 – 2012 **Consultant Sustainability at Primum**
- Implementing sustainability practices in company operations.

Education

2014 – 2017 **PhD-candidate at Section of Innovation Studies**
Copernicus Institute of Sustainable Development, Utrecht University

2006 – 2009 **Master: Science and Innovation Management (Cum Laude)**
Utrecht University

2002 – 2006 **Bachelor: Natuurwetenschap & Innovatiemanagement**
Utrecht University