Eindhoven University of Technology

MASTER

Exploring the potential of sociotechnical systems
"an integrated framework to assess SmartGrids"

Zegers, R.M.G.

Award date:
2009

Exploring the Potential of SocioTechnical Systems

'An Integrated Framework to Assess SmartGrids'

Master-thesis

Roel Zegers
ID nr 0567311
r.m.g.zegers@student.tue.nl

9 February 2009

Eindhoven University of Technology
MSc: Technology and Policy

Part of the EOS project, TREIN

1st Supervisor: Dr. Ir. Geert Verbong
Technology and Sustainability Studies
Eindhoven University of Technology
2nd Supervisor: Dr. Ir. Erik van der Vleuten
History, Philosophy and Technology Studies
Eindhoven University of Technology

Preface

This thesis is the final product for the master's program Technology & Policy, at the Eindhoven University of Technology. While the master thesis normally comprehends a 6 month study, in this specific case it took almost two years, as a result of health issues. The study has been carried out in the transition management group, under the supervision of Geert Verbong and Erik van der Vleuten. This research tradition studies the long term changes of complex sociotechnical systems which likewise forms the foundation of this master thesis.

The transition assessed in this thesis concerns the electricity sector of today and a potential SmartGrids system of tomorrow. This topic is most relevant today as the electricity sector of today is on the brink of change, and the decisions made today will have its effect on the electricity grid of tomorrow. The stakeholders could use the integrated framework, designed in this thesis, to see how they could be affected by the transition process.

I think that the integrated framework can be an added value in the assessment of a technical vision. Additional research is deemed necessary to see if the practical value in the scientific community and in the business world is significant.

Executive Summary

There is much uncertainty in future studies, especially when complex sociotechnical structures are examined. The different focal points of research methods stand in between science based decision making by stakeholders. A new research framework is needed that can assess a technical vision or scenario in a co-evolutionary manner, and answer the research question of this paper: *'Which paths can the electricity regime (not) take to realize the SmartGrids vision?'* First an integrated framework, and corresponding research method, is created. Then its main points are shown in a case-study regarding the SmartGrids vision.

An Integrated Framework

To guide the creation process of the new framework three criteria are formulated, reading as follows: the transition pathways should have a normative focus; the envisioned system has to co-evolve out of the various elements of today's sociotechnical system; the framework has to be able to capture system developments at stable as well as unstable times. Four research methods are selected that meet these criteria: the Multi-Level Perspective (MLP); the Typology of SocioTechnical Transition Pathways; Robinson's backcasting approach; and the Internal Analysis of System Behaviour, by Coleman. The integrated framework, presented below, interconnects these individual research methods.

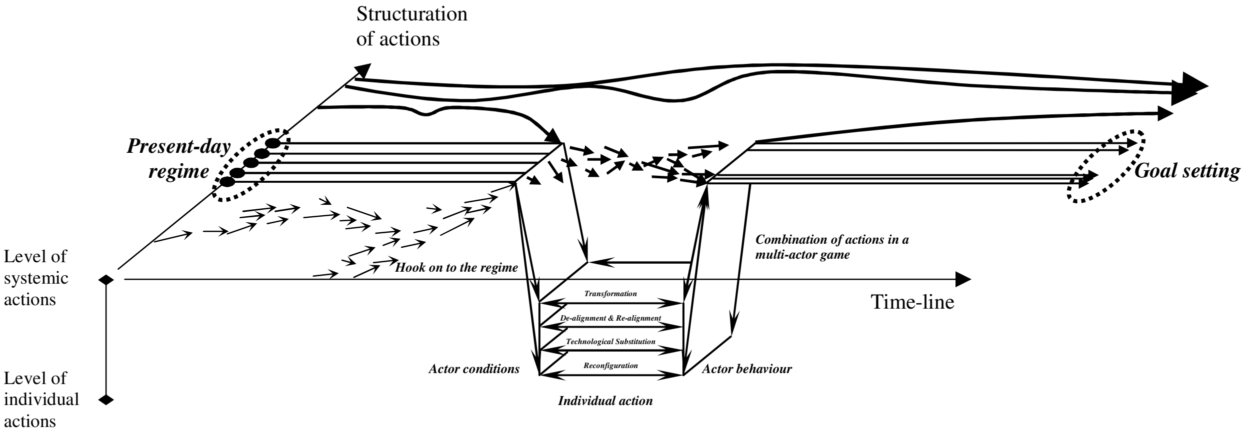


Figure 0.1: An integrated framework to assess technical visions

The starting point of the framework is the present-day regime, which is a connection of actors, with heterogeneous competences, that share a technology set and are nested in an institutional setting. The MLP is used to view technical change that result from interactions been the landscape, regime and niche levels. The endpoint of the framework is a selection of normative goals that require a change of the regime's technical trajectory.

The backcasting approach is used to provide a normative focus and the degree of freedom for interventions.

To get from the present-day regime to the normative goals the landscape, regime and niche levels need to interact, creating a window-of-opportunity. The regime becomes less stable and predictable. Purposeful behaviour by individual actors and specific regime dynamics are used to account for the regime changes needed to reach the normative goals. The typology of sociotechnical transition pathways provides, through four pathways, the multi-level interaction and regime dynamics needed. The Internal Analysis of System Behaviour method is used to explain the realization of the normative goals, as the result of individual behaviour.

The integrated framework is a lens that can be used, in combination with a research method, to analyze sociotechnical change. The research method, presented in this paper, consists of six subsequent steps. In the first step the technical vision is introduced. In the second step transition goals are defined, by looking backwards from the normative vision. Then in the third and fourth step the current sociotechnical structure and the potential external influences are defined. Finally in the fifth and sixth step the transition pathways and the actions that can create transition barriers are devised.

The Case of SmartGrids

The SmartGrids, as envisioned by the European Technology Platform, promises efficient, accessible and reliable transmission and distribution networks situated in competitive market for both generation and consumption. The regime changes needed to reach the SmartGrids vision are described in two steps; the Management regime 2009-2019 and the SmartGrids regime 2019-2029, subsequently. The direction of these transitions is provided by the following goals:

1. The *bi-directional power flows objective* requires of the grid to be able to include 20-25% DG in the Management regime and up to 50% in the SmartGrids regime.
2. The *intelligent control objective* should make the electricity system more sustainable, effective and flexible. In the Management regime the consumer awareness is increased and in the SmartGrids regime efficient control in a systemic manner needs to be achieved.

3. The *market signals objective* should bring the individual actors closer together. The market for electricity starts using real-time usages in the Management regime and is based on end-to-end communication in the SmartGrids regime.
4. The *level playing field objective* should make the electricity system as a whole more competitive. In the Management regime, DG and RES need to gain market share and in the SmartGrids regime decentralized and centralized generation need to be represented equally.

The electricity regime of today is found in a turbulent state, without clear direction. The regime is based on the so called Central Station system. Here, electricity flows down from a few generators to many distributed consumption points. Important landscape developments – geographical factors, socio-political factors, environmentalism and ICT penetration – and relevant niche developments – network assets, network operations, demand systems and supply systems – are defined. These landscape and niche developments are used, as external influences, to create the following pathways.

- *Transformation pathway*

  2009-2019: More stringent environmental legislation, in the form of sharpened emission rights, runs inefficient coal-fired power plants out of business. The cost-efficiency of RES, DG and energy-efficiency technologies increases the volatility of the grid. Intelligent network component, focussing on electricity storage, are used to optimize the available generation capacity.

  2019-2029: The technical trajectory change is judged insufficient as additional services are required to plug-in hybrid vehicles. A dialogue between electricity supplier and car manufacturers makes electricity production possible when electricity prices are high and recharge the batteries when prices are low. The mobile character of these DG systems forces the network operators to install dynamic control techniques to keep the grid controllable.

- *De-alignment and re-alignment pathway*

  2009-2029: Oil shortage results in oil prices going skyrocket. Electricity prices are passed on to the consumers. The global economy is affected leading to less consumption of energy and consumables. Consumers are forces to change behaviour. They switch to home generation systems; efficient consumer products, micro grids and local electricity markets emerge. DG used in micro grids and traded at local electricity markets lower the electricity prices and the regime re-configures.

- *Technological substitution pathway*

  2009-2019: DG systems become competitive technologies. The integrated businesses have not yet unbundled meaning that barriers still exist. DG and RES are not considered in high esteem by households, but a successful campaign focussing on low costs and CO_2 emissions convince households to adopt. Reserve capacity increases rapidly forcing network operators to replace substation to enable bi-directional power flows.

  2019-2029: Demand Side Management (DSM) systems are developed to be integrated in the smart metering systems. The DSM systems have to compete with smart meters that are controlled externally by energy suppliers. Both systems defuse but the DSM system eventually becomes dominant, as the owners of the external control system are plagued by power interruptions. DSM, with fast changing power flows, destabilizes the grid, and as a result a dynamic grid control system is placed with dynamic network tariffs, on a local scale.

- *Reconfiguration pathway*

  2009-2019: Smart meters have reached maturity and are supported by the regime. Other technologies can profit from the new information and control system. Energy suppliers extend their control to the electric apparatuses. The energy suppliers support DG that they can control. New consumer products are developed that improve the consumer/producer interaction.

  2019-2029: A new control system is developed and placed at the most important power junctions, replacing unidirectional power stations. Ancillary services are provided by upgrading the smart meters. This stimulates DG and RES, which demand a shorter time to market, which could negatively affect large scale generation systems.

Finally, the impact of alternative actions is assessed that can create transition barriers. Most of these barriers can be reduced to problems concerning the electricity market. The following six barriers are defined: *1)* Smart meters can create sunk-costs and hamper the introduction of more advanced control systems. *2)* When the integrated businesses are not unbundled they have little incentive to provide access of DG to the grid. *3)* Private electricity markets can lead to discrimination and undermine the working of intelligent components. *4)* Dynamic control, in case of mobile generation capacity and DSM, need dynamic network tariffs, on a local scale, but leads to uncertainty with respect to the return on investments. *5)* Cost-efficient DG can stimulate the diffusion of DG, but when the time to market is not reduced the grid will be used merely to store electricity. *6)* A guaranteed electricity price to DG and RES, using feed-in tariffs, in a market using dynamic network tariffs, on a local scale, will bias market mechanisms and lead to electricity flowing upwards.

Conclusions

In this thesis the potential barriers that can hamper the continuation of the technical transition towards a SmartGrids vision are viewed. The described transition pathways and barriers should not be considered to be comprehensive, nor are they intended. The assessment of the SmartGrids vision leads in the following three questions.

1) Dynamic network tariffs, on a local scale, increase the flexibility, sustainability and economically feasibility of the grid, but can centralized generation systems function in such a dynamic market? *2)* Can the smart meters and the control system positively effect each other's development, is the control by energy suppliers inevitable, or will early standardization prevent the diffusion of intelligent components? *3)* Private DNOs receive no incentive to increase the accessibility of DG and RES and by bringing the distribution networks under public ownership will not lead to a level playing field. Is there a hybrid form possible?

The new integrated framework connects a co-evolutionary and a normative focus. It can thereby be used as an MLP add-on to see what the effect is of meso and micro events in technical transitions. Furthermore, the micro-to-macro problem – the complexity of translating individual behaviour into a collective outcome – is dealt with by using the typology of sociotechnical transition pathways. The case-study shows that the typology leaves enough room for various interventions.

Table of Contents

List of Illustrations

Chapter 1: Introduction

The Dutch electricity system, of today, is found in a turbulent state, without clear direction. According to the SmartGrids visionaries, the hierarchical grid structure of today will be unable to accompany Europe into an information era. (European Commission, 2005, p5) They claim that active transmission and distribution networks are required, optimizing supply and demand in real-time. SmartGrids promise to achieve this by involving consumers, actively, in power control; efficiency improvements; providing Distributed Generators (DG) and Renewable Energy Systems (RES) full access to the grid, while keeping quality, security and reliability levels high. The superiority of a SmartGrids system, over the present-day or alternative electricity systems – like a 'European highway', based on bulk transmission – is not generally accepted. (Meeuwsen, 2007, p.23) Future explorative studies should shed light on the potential of these and other technical systems.

1.1 Problem definition

A sociotechnical system is understood to be a collection of actors, with heterogeneous competences, that share a technology set and is nested in an institutional setting. In a stable situation, progress follows a technical trajectory, restricting the selection of problems and potential solutions. System Innovations (SI) are these changes that affect the system's structure and thereby alter its technical trajectory.

Studies regarding system innovations have branched off into various research traditions, e.g. Sectoral Systems of Innovation; Change and Transformation in Sectors; Transition Management; Evolutionary traditions and other future studies, like Scenario Planning. These research traditions address problems based on their specific methodological foundations, using different focal points, like: general patterns or individual conduct; a theoretical or empirical foundation; a forward or backward orientation; a sectoral, local, national or technical scope; a technical, social or economic interest; a historical or future explorative base.

There is much uncertainty in future studies, especially when they encompass complex sociotechnical structures and changing technical trajectories. The various focal points, of the different traditions, stand in between science based decision-making, by policy makers and other stakeholders. This problem is most relevant today. Dutch energy policies, for example, have resulted in "costly failure, hype cycles, changing visions and policy priorities (almost every five years) and limited learning capabilities". (Verbong *et al.*, 2006)

Bergek *et al.* formulated this problem as follows: "Recent surveys of the literature (e.g. Edquist, 2004; Liu and White 2001) have acknowledged the lack of comparability between these [empirically based] studies as well as the conceptual heterogeneity in the innovation system literature. Perhaps as a consequence of this, the innovation system approach has been criticized for not providing practical enough guidelines for policy makers … there is thus, a need for a practically useful analytical framework that allows for the assessment of system performance as well as the identification of factors influencing performance". (Bergek *et al.* 2005, p2)

1.2 Research approach

To address the problem, defined above, new research frameworks and methods are needed. This thesis' research question –

'Which paths can the electricity regime (not) take to realize the SmartGrids vision?'

– implies that a framework needs to be created that can be used to assess transitions towards an envisioned system, and that factors can be identified that influences the sociotechnical configuration that is formed. This question cannot be answered by the research methods commonly used. An integrated framework, to study technical transitions, is needed.

To make sure that the framework will be satisfactory a set of criteria for selection needs to be formulated. Next, research methods are chosen that meet these criterions. The first sub-question is therefore the following: *'Which research methods contain the necessary elements for the integrated framework?'*

These research methods need to be examined in more detail to expose the important aspects of the individual methods, and to explore potential connections between the methods. The second sub-question is therefore the following: *'What do the individual research methods contribute and how do they relate to each other?'*

Finally, the various methods need to be integrated in a new framework that can be used, in a case-study, to answer the research question. The third sub-question is therefore the following: *'What interconnection of research methods satisfies the selection criterions?'*

By answering the three sub-questions above, the main research question can be answered, in a case-study.

1.3 Contribution and Relevance

The integrated framework is placed between Future studies, on the one hand, and System Innovation studies, on the other. Existing Future studies (like Scenario Planning studies) are perceived, by System Innovation researchers, as being too linear, providing limited room for technical change. (Geels & Schot, 2007) The SocioTechnical Scenario method, as an answer to this linearity, on the other hand, uses continuous transition pathways, thereby ignoring the existence of alternative explanations.

The contribution of this thesis is twofold, namely theoretical (the integrated framework and corresponding research method) and empirical (showing the framework's and method's main points in a case-study, regarding SmartGrids). An integrated framework is created that can assess transition pathways, while leaving room to use specific theoretical and empirical notions, as explanatory theories, by the researcher. The case-study contributes by showing how such an integrated framework functions and can thereby be valued better.

1.4 Thesis' structure

In the next three chapters the integrated framework, and corresponding research method, is constructed – chapter 2 views the research domain and selects research methods, to be used in chapter 3, where building blocks are selected, which are assembled to form an integrated framework in chapter 4.

In the subsequent six chapters the main points of the integrated framework are shown in a case-study, concerning the SmartGrids vision – chapter 5 views the SmartGrids vision, in chapter 6 the transition goals are set, in chapter 7 the present-day regime is viewed, and in chapter 8 the landscape and niche dynamics, in chapter 9 pathways are created which are assessed for potential transition barriers in chapter 10.

Finally, in chapter 11, conclusions are drawn, with respect to the research question, followed by a discussion about their relevance and contribution to future research.

Chapter 2: Research Domain

The new framework uses the power of different research traditions, to assess technical transitions. The research methods, used in these traditions, were not designed to work together, as they are based on different assumptions and have different focal points. The focus, in this thesis, lies on the creation of an integrated framework that views technical transitions and can advise decision-makers.

To build the integrated framework, elements of the different methods need to be isolated and viewed with respect to the new framework. These elements are called building blocks and can be assembled into a new research frame. But, before these building blocks can be obtained the research domain must be assessed. By doing so, the research methods can be singled out that meet the requirements of the new framework.

This chapter is build up as follows. First the selection criteria for the new framework are formulated. Then the research area is examined. The chapter ends by answering the first research question: *'Which research methods contain the necessary elements for the integrated framework?'*

2.1 Selection Criteria

In an evolutionary perspective, innovation processes are uncertain by definition; where "boundedly rational agents act, learn and search in uncertain and changing environments". (Malerba, 2004, p.14) The levels of uncertainty can vary in degree, between, for example, radical and incremental innovations. Incremental innovations follow the technical trajectory and can be forecasted to some degree. Radical innovations, on the other hand, depart from the current trajectory to create their own, and are less predictable. The innovations of interest, in this thesis, are system innovations – denoted as changes of the technical trajectory – being less predictable.

The intention of the integrated framework is to assess a technical vision or scenario. This differs from other future studies as a normative end-point is used. The first criterion therefore has to do with a predefined technical vision that determines the direction of the transition.

Criterion 1: The transition pathways should have a normative focus.

System developments, in an evolutionary perspective, follow or depart from a shared technical trajectory. In case of system innovations, the technical elements change together with other elements; e.g. social and institutional. (Malerba, 2004, p.10) Co-evolution denotes as the change of various elements of a system, by means of social and technical interactions. The second criterion requires that the system structure and technical trajectory co-evolve.

Criterion 2: The envisioned system has to co-evolve out of the various elements of today's sociotechnical system.

A system is a stable structure where technical progress comes from incremental innovations. Technical transitions are rare occurrences that limit technical foresight and increase uncertainty for stakeholders. This implies that at times, the system will follow a technical trajectory and incremental innovations, while at others times certain events will alter the technical trajectory. The third criterion captures next to the requirement of developments inside a stable system also changes of the system itself.

Criterion 3: The framework has to be able to capture system developments at stable as well as unstable times.

The three criteria addressed above are essential to the purpose of the new framework. They will be used, henceforth, to keep the development process of the new framework on track.

2.2 Research Methods

The integrated framework is placed between System Innovation studies, on the one hand, and Future studies, on the other. These two traditions therefore provide most of the research methods required. Additionally, elements from the social network traditions are needed to account for the changing social system. Next, these traditions are described, in short, and viewed in respect to the selection criterions.

2.2.1 System Innovation traditions

The System Innovations (SI) tradition consists, among others, of the Sectoral System of Innovation, Transition Management and Change and Transformation in Sectors research areas. They study the process of change of sectoral systems or regimes. The main difference, between a sectoral system and regime, concerns the system demarcation; the regime focuses mainly on a specific technology set (e.g. electricity generation), whereas the sectoral system focuses on a product group for a given demand. (Malerba, 2004, pp.9-10)

The Multi-Level Perspective (MLP) is based on the notion of technical regimes, by Nelson and Winter (1982). The approach distinguishes between three analytical levels – the landscape, regime and niche level – and views regime changes that result from interactions between these levels. The landscape level (macro level) contains of deep structural trends, making some regime actions easier then others. The niche level (micro level) serves as, so called, incubation rooms for technologies to prevent early regime selection. (Geels, 2001, pp.1260-1261) The MLP can be used to study technical transitions, in a co-evolutionary manner.

Typologies use regularities of change to include empirically based mechanism in a theoretical foundation. The Typology of SocioTechnical Transition Pathways, by Geels and Schot (2007), uses various combinations of multi-level interactions and regime dynamics to characterize technical transitions. (Geels and Schot, 2007, p.405) The typology responds to the former bias, of the MLP, towards niche accumulation – which comprehends to the focus on the development of niche technologies and the following adoption in the regime. The typology can help to guide the transition in times of regime instability.

2.2.2 Future traditions

Scenario planning is an activity that uses ambiguity and uncertainty to turn "planning for the future … in a learning proposition" (Heijden, 1996, p.7) Examples of well established scenario planning methods are the deductive and inductive methods. The deductive method uses driving forces to create a scenario framework, based on logical reasoning. In the inductive method potential events are plotted and grouped by similarities of patterns.

The SocioTechnical scenario approach is a response to the perceived linearity of other scenario approaches. By using a co-evolutionary process the researcher gains more freedom to introduce radical innovations.

The scenario planning approaches, mentioned above, take the present-day system as the starting point and look forward. The backcasting approach, in comparison, works the other way round. A desired future state is defined and interim goals are selected while working backwards towards the present-day regime. The Back-casting method is expected to able to provide the normative focus needed to assess a technical vision.

2.2.3 Social Network traditions

Coleman claims that a central problem in social sciences "is that of accounting for the functioning of some kind of social system". (Coleman, 1990, p.1) The Internal Analysis of System Behaviour framework, proposed by Coleman, uses individual behaviour to explain social phenomena. This explanatory power of individual actors is expected to hold true for regimes as well.

2.3 Conclusion

In this chapter three criterions have been formulated, to keep the framework creation process on track, and the research domain has been examined. From this four methods are selected, being the Multi-Level Perspective, the Typology of SocioTechnical Transition Pathways, the Back-casting, and the Internal Analysis of System Behaviour methods. The individual research methods contain the elements needed in the new framework; a normative direction, co-evolution and a line of action in times of stability and instability.

The methods were introduced briefly to show their position in the research domain. In the next chapter they will be discussed in more detail to reveal building blocks that can form the integrated framework.

Chapter 3: Building Blocks

To make frameworks accountable in scientific research they need to have a sound methodological foundation. By using building blocks from proven research methods it will be possible to make use of the methodological foundation of these methods. It is important to see how these building blocks can be interconnected, to meet with the criteria. In this chapter the second sub-question is answered – *'What do the individual research methods contribute and how do they relate to each other?'*

In the previous chapter, the criteria of the new framework have been defined and an overview was made of the research domain. Consequently, four research methods have been selected, being: the Multi-Level Perspective; the Typology of SocioTechnical Transition Pathways; a Back-casting method; and the Internal Analysis of System Behaviour method.

In the next paragraph these four methods are examined in more detail. Each individual method is assessed base on their contribution to the three criteria. The analytical framework is assessed to select building blocks from and the methodological foundation to make the new framework scientifically valid.

3.1 The Multi-Level Perspective

The Multi-Level Perspective (MLP) has been selected for its analytical frame, comprising of three levels of scale – the sociotechnical landscape, the sociotechnical regime and the technical niches – to view technology change. The MLP can be used to examine technical transitions, also named system innovations, referring to technology changes over a period of several generations. The regime is the system of interest and is therefore, in this study, viewed from an internal perspective. The landscape and niche levels are seen as external influences that can influence only by interacting.

3.1.1 Methodological Foundation

The MLP is based on two traditions, being, Evolutionary Economics and Sociology of Technology. The first pillar, based on the Evolutionary Economics tradition, concerns the role of the external environment on technology change and connects two views on technical evolution. (Geels, 2002, p.1258) The second pillar, based on the Sociology of Technology tradition, stresses that technologies must be valued by the function they provides to social actors. A more comprehensive assessment, of these pillars, is made below.

3.1.1.1 The Evolutionary Economics tradition

In the first view, technical evolution is portrayed as a process of variation, selection and retention. A technological design is successful when selected repeatedly, at the expense of other designs. (Raven, 2005, p.26) As novel designs do not emerge blindly, but result from a creative process of human minds, they become tailored to the expectation of actors, with respect to the behaviour of the selection environment. This process, leading to the inertia of incumbent technologies, is called retention.

In the second view, technical evolution is understood as a process of hybridization of technical designs. (Geels, 2002, 1258) Kroeber has depicted this process, in the figure below, as an organic tree with 'normal' branches on the left and a technical tree with branches that interact to form novel types, on the right. (Basalla, 1988, p.138) In this respect, development pathways, in different demarcated environments, can merge and form novel designs, leading to a new technical trajectory.

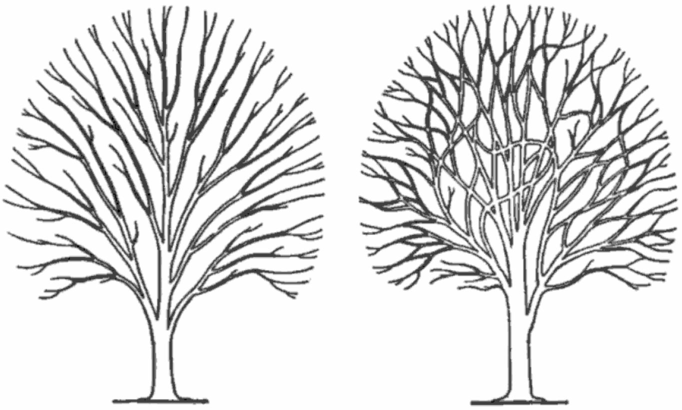


Figure 3.1: Kroeber's tree of organic life; Kroeber, 1948: Basalla, 1988, p.138

The MLP connects these two notions of technical evolution. When the regime is stable, locked-in, innovations follow the expected behaviour of the selection environment, leading to inertia of established technologies. Technology development in the protection of niches can change the technical trajectory through a process of hybridization.

3.1.1.2 The Sociology of Technology tradition

According to the Sociology of Technology followers, technologies should not be viewed as individual entities. As such they have no power. Only in relation to the social settings is functionality created. (Geels, 2002, p.1257) Automobiles, for example, can not be understood, merely, as the sum of their technical elements. Only when placed in a social environment, a chauffeur, they obtain functionality, as transport facilitator.

When technologies are embedded in a sociotechnical configuration 'that works' the interdependency between actors and technologies reinforces the inertia of established technologies. In this case, the selection mechanisms (consumer preferences) become adapted to a certain technological design. For novel technologies to be implemented successfully, the sociotechnical system needs to co-evolve; e.g. change routines, behaviour and perceptions – together with the changing technology. Returning to the automobile example, when the chauffeur buys a new trailer his driving routines need to be changed to enable safe driving with an extension.

3.1.2 The Analytical Frame

The MLP uses three analytical levels of scale – the sociotechnical landscape (macro-level), the sociotechnical regime (meso-level) and the technical niches (micro-level) – to study technical transitions. These levels differ by their degree of structuration and can, at times, interact. Next, these three levels are described more extensively as well as the multi-level dynamics, based on niche accumulation (figure 3.2).

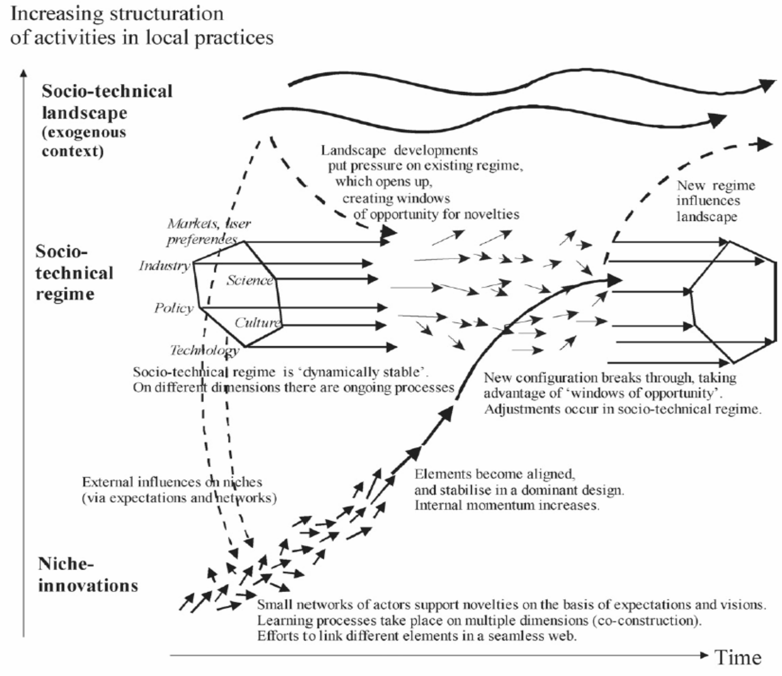


Figure 3.2: Multi-Level Perspective views transitions: Geels and Schot, 2007, p.401 / Geels, 2002, p.1263.

3.1.2.1 The regime level

The regime is located at the meso-level and is the locus for assessing technical transitions. A regime is the sociotechnical configuration that works. Regime actors collectively use a technology set and are nested in institutional settings. Institutions are created as regime actors adopt routines and rules of thumb to solve problems more effectively. These search heuristics cause technical designs to be adapted to the selection environment, leading to the inertia of regime technologies and a technical trajectory, following incremental innovations.

3.1.2.2 The niche level

Whereas the regime developments follow a technical trajectory based on incremental innovations, radical innovations are generally developed at the niche level. (Geels, 2002, p.1260) The niches are 'incubation rooms' for novel technical designs, where they can mature while being protected from 'normal' market selection mechanisms. (Geels, 2005, p. 79) In these niches, novel technologies can overcome their economic and technical disadvantage, as social networks, routines and search heuristics have yet to be formed. The development path of niches runs parallel to the regime developments. At times, Window-of-Opportunities are created at which the niche and regime levels can interact. The parallel development pathways can then hybridize, creating in a new technical trajectory.

3.1.2.3 The landscape level

The landscape level is a structure external to the regime consisting of a 'set of deep structural trends'; e.g. demographic and cultural trends. This structure forms the backdrop of regimes and cannot be affected by individual actors. It helps shape the technical trajectory of regimes by making some paths easier then others. The landscape structure is viewed in most instances as slow changing trends, but can at times, also appear in the form of fast changing events.

3.1.2.4 Multi-level interactions

Technical transitions result from successful interactions between the regime, niche and landscape levels. These interactions are called multi-level dynamics or multi-level interactions. In the past the MLP was focussed mainly on niche accumulations. The process of niche accumulation can be viewed as follows; see figure 3.2.

Landscape developments put pressure on the regime and create opportunities for niche actors. The niche technologies have to mature in local experiments to become competitive in an economic and technical sense. When a niche technology has matured, multi-level interactions create a window-of-opportunity, by which niche technologies can enter the regime. The regime then needs to co-evolve to sustain a sociotechnical configuration that works.

3.1.3 Conclusion

The transition pathways should have a normative focus.

Technical transitions are the long term changes of complex technical systems and the locus of the MLP analysis. To study pathways in a desired direction the outcome of the transition needs to be laid down in advance. But the MLP does not provide a structured method to study various pathways. Firstly, the potential multi-level interactions and resulting regime developments need to be widened, to overcome the niche bias. Secondly, the MLP is not designed to assess transitions, using a combined forward and backward orientation in a single study.

The envisioned system has to co-evolve out of the various elements of today's sociotechnical system.

Retention and technology functionality are responsible for regime lock-in, as the technology developers and the selection environment become intertwined. Multi-level interactions can destabilize the regime. By viewing regimes as sociotechnical configurations that work, it is possible to view co-evolution as the interaction between actors, technologies and institutions. The MLP views change from a systemic point of view, but does not explains how this relates to the individual actors.

The framework has to be able to capture system developments at stable as well as unstable times.

Regime developments follow a technical trajectory influenced by the landscape level that makes some paths easier then others. At times of stability the landscape level supports the current regime, whereas at times of instability support ceases, creating a window-of-opportunity. At this point hybridization of internal and external development pathways is possible; regime niche interactions. By looking at the regime dynamics and the multi-level interactions the system can be studied in stable and unstable time, respectively. A more extensive assessment of the regime dynamics and multi-level interactions is needed.

3.2 Typology of SocioTechnical Transition Pathways

Next to the Multi-Level Perspective the typology of SocioTechnical Transition Pathways is selected. It was developed in response to the niche bias criticism – claiming that the MLP only concerns bottom-up processes, based on nurturing of niche technologies – by Geels and Schot (2007). A typology is a systematic classification, based on the distinguishing characteristics of, transition, processes. In this case technical transitions are classified by their effect on the sociotechnical configuration.

3.2.1 Methodological Foundation

The Typology of SocioTechnical Transition Pathways is based on potential realizations of the MLP in case-studies. The foundation, of the MLP, has already been described in the previous paragraph and is not repeated here. The methodological foundation of the pathway typology concerns the timing of multi-level interactions (embryonic or mature niche technologies) and the nature of multi-level interactions (competitive or symbiotic niche technologies). Various combinations of multi-level interactions have sprouted the Transformation, De-alignment and re-alignment, Technological substitution and Reconfiguration pathways.

3.2.1.1 Timing of multi-level interactions

From the evolution of technology pillar of the MLP, examined in the previous paragraph, has been concluded that new technology trajectories can be created when the development pathways of niches and the regime hybridize. These development pathways are influenced by developments at the landscape level. Niches anticipate opportunities created by regime developments. The effect of the timing of multi-level interactions on the regime is examined here.

Geels and Schot use the dimensions of external change, from Suarez and Oliva's (2005) typology on environmental change, to characterize various landscape patterns. Suarez and Oliva's use the frequency, amplitude, speed and scope to create the following types: Regular, Hyperturbulence, Specific Shock, Disruptive and Avalanche change.

Geels and Schot only use variations in speed and scope, as very high frequencies do not occur in technical transitions, and low amplitudes do not have the necessary power to create a window-of-opportunity. This implies that the landscape patterns of Disruptive, Specific and Avalanche changes are used.

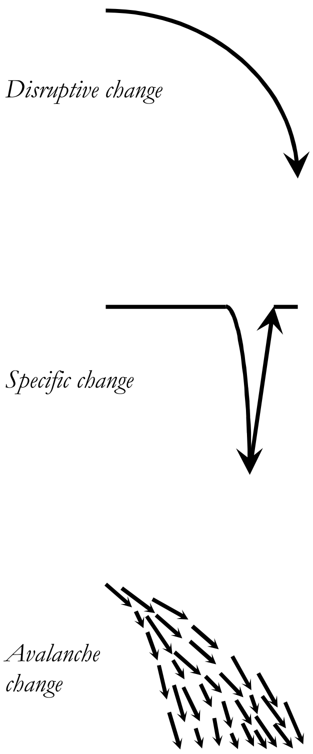


Figure 3.3: Types of landscape pressures: based on Geels and Schot, 2007, p.404

Disruptive changes are low in speed and scope. The changing landscape patterns can be perceived, by the regime and niche actors, well before the full amplitude becomes tangible to the regime.

Specific Changes are high in speed and low in scope. An event, occurring at the landscape level, will affect a particular part of the regime. These events cannot be predicted by the regime and niche actors, whom are taken unprepared.

Avalanche changes are low in speed and high in scope. The changes start slow, where one event triggers another, causing a domino effect that affects the regime on all terrains.

Niches form based on perceived opportunities at the regime level. In the two figures below two extreme cases of timing of multi-level interactions – mature and embryonic niche technologies – are presented. In the upper figure, niche actors perceive new opportunities early (e.g. disruptive change) from the landscape and regime level. In this case niche technologies and their support network have sufficient time to form and mature. The lower figure, on the other hand, depicts the situation where opportunities manifest late (e.g. specific change) and niche technologies are exposed to 'normal' selection mechanisms while being in an embryonic state.

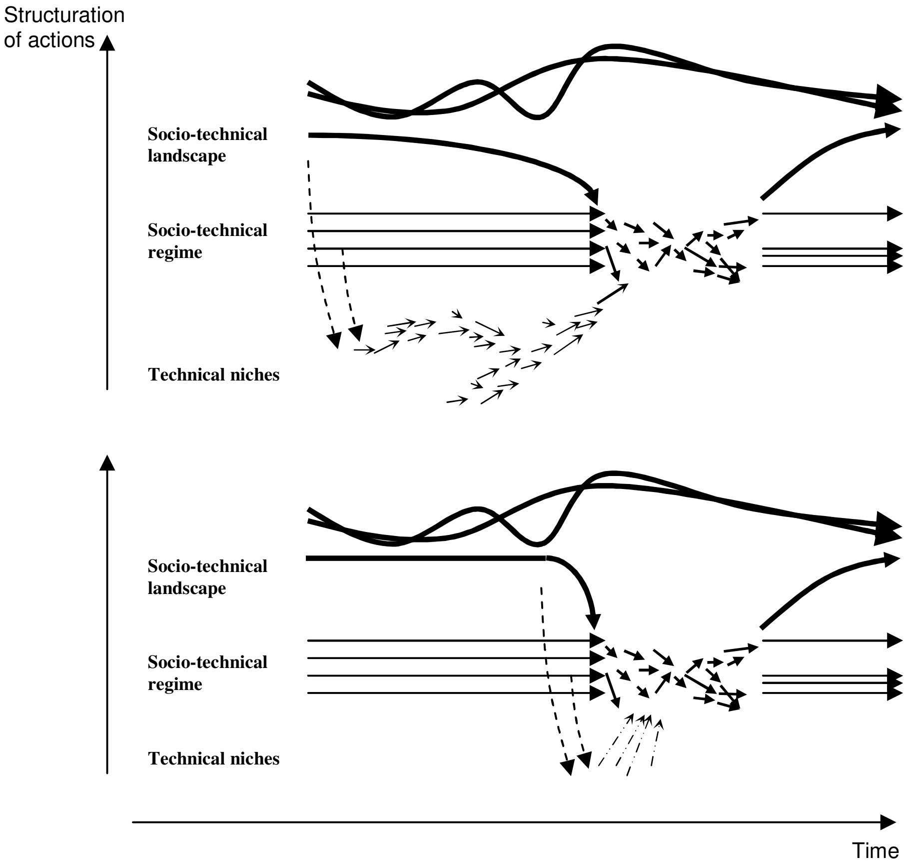


Figure 3.4: Timing of multi-level interactions; mature niches (above) and embryonic niches (below)

3.2.1.2 Nature of multi-level interactions

The landscape regime relationship can either be reinforcing or disruptive. (Geels and Schot, 2007, p.406) The regime's technical trajectory is shaped, on the one hand, by the landscape, by making some paths easier then others, and on the other hand by the interests, competences and limitations of the regime actors. At times of pressure from the landscape, while the regime is unwilling or unable to make the required changes, the regime could face a deadlock. In general, when the landscape favours the regime technologies, niche technologies become more symbiotic, while they are more competitive when the landscape is unfavourable.

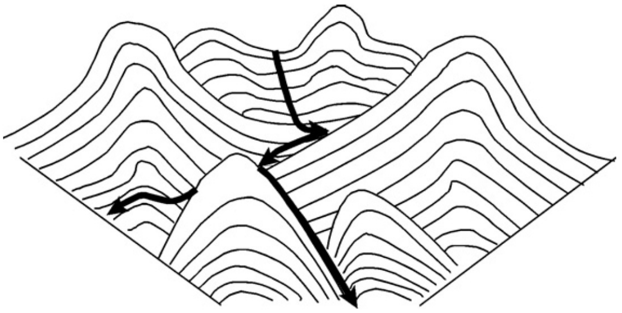


Figure 3.5: Topography of development trajectories (Geels & Schot, 2007, p.403: Sahal, 1985. p79)

Symbiotic technologies are developed as a regime add-on. Niche actors can serve as a technology supplier to the regime when the regime needs specialized technologies. Regime actors could also participate in the development of these technologies, as the support the incumbent technologies.

Competitive technologies are developed in order to replace (a part of) the incumbent regime technologies. In some cases a radical niche technology aims to over through a single regime technology, to form a new sociotechnical structure with the remaining actors and technologies. In other cases the niche technology brings about a paradigm shift that will overthrow the entire regime.

3.2.2 The Analytical Frame

The power of the typology of sociotechnical transition pathways is the characterization of multi-level interactions and the resulting regime dynamics. By connecting patterns found in historical case-studies on technical transitions, Geels and Schot created four pathways based on different interactions. In the next sections these transition pathways – the transformation path; the de-alignment and re-alignment path; the technological substitution path; and the reconfiguration path – are addressed, by looking at multi-level interactions and regime dynamics involved.

3.2.2.1 Transformation path

In the Transformation path the regime is forced to change direction, as changing landscape patterns make it harder for the regime to follow the technical trajectory then to follow an alternative path.

- *Multi-level interactions*

Patterns at the landscape level are translated in a regime pressure at a time when niche technologies are still underdeveloped. The technical trajectory is challenged, either through: pressure groups and social movements, arguing about an undesired regime performance and negative externalities; or scientists and engineers, arguing that a novel technology leads to a higher level of performance; or outside firms, demonstrating an alternative trajectory.

- *Regime dynamics*

Regime actors change the regime's technical trajectory to meet the changing environment. It is ensued by adopting a symbiotic niche technology or by changing the regime's search heuristics. As the niche technologies have not yet stabilized they can be adopted more easily as a symbiotic add-on. The new regime eventually grows out of the old, leaving the basic architecture intact.

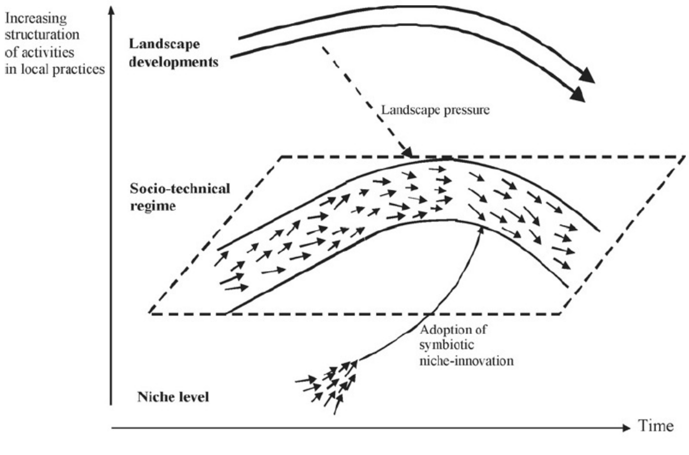


Figure 3.6: Transformation pathway: Geels & Schot, 2007, p.407

3.2.2.2 De-alignment and re-alignment

The De-alignment and re-alignment pathway differs from the transformation pathway by the disruptiveness of the pressure from the landscape level, causing the regime to fall apart.

- *Multi-level interactions*

An avalanche change – high in scope and low in speed – causes an accumulation of regime problems. Both regime and niche actors are taken by surprise. As a result niche networks have not yet stabilized and their technologies have not faced an early selection. The regime's main technology base is starting to become obsolete, rendering regime actors out of business. The regime starts to erode further, when actors loose faith, and is eventually pulled apart.

- *Regime dynamics*

By absence of a high performing niche technology, multiple embryonic niches will fight for domination. The regime re-aligns when a new technology base is selected. It will be based on the victorious niche technology, becoming the core component in the new regime.

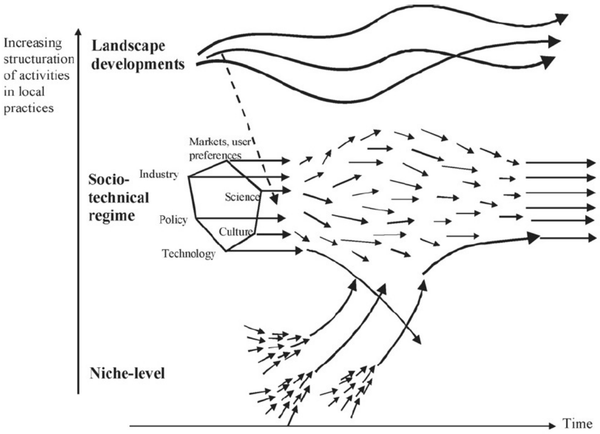


Figure 3.7: De-alignment and re-alignment pathway: Geels & Schot, 2007, p.409

3.2.2.3 Technological Substitution

In the Technological substitution path at times of much landscape pressure and sufficiently developed niche technology, technical substitution is possible.

- *Multi-level interactions*

The landscape pressure must be high enough to break the resistance of the regime and the internal momentum of niche technologies must be high. Niche technologies have been kept off by the regime, until large pressure from the landscape level. The incumbent regime technology meets the niche technology in the market competition.

- *Regime dynamics:*

Niche accumulation – where the niche steadily enters bigger markets – usually proceeds in this pathway. When regime actors can improve the performance of the incumbent technology it might result in the ‘sailing ship effect’. The sailing ship effect refers to the technical improvements of the sailing ship, improving its competitiveness, at the time of the introduction of the steam engine. When the niche technology becomes the dominant technology the regime needs to co-evolve, creating new functionalities around the new technology base.

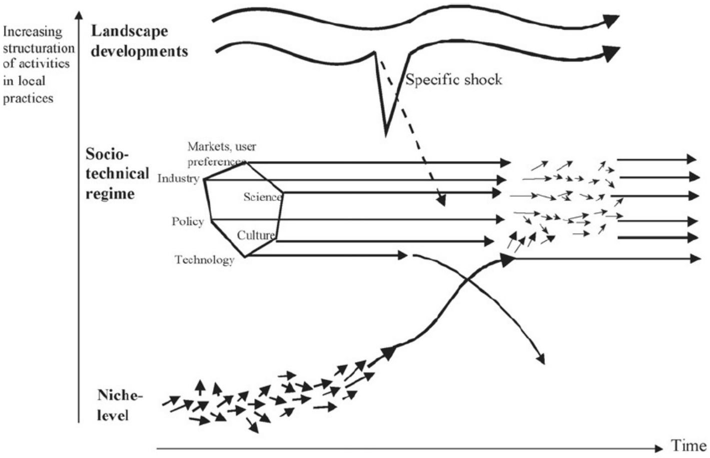


Figure 3.8: Technological substitution pathway Geels & Schot, 2007, p.410

3.2.2.4 Reconfiguration

In the Reconfiguration path, symbiotic niche technologies are adapted to the needs of the regime where they can solve local problems.

- *Multi-level interactions*

Niche technologies start as a regime supplier. The niche technology does not require, of the regime, large changes in routines. Niche actors must be able to anticipate special circumstances, emerging at the supplier side of the regime. It is difficult to plan for a reconfiguration process, being flexible to take new opportunities is key.

- *Regime dynamics*

Pressures from the landscape level and regime learning processes will stimulate the reconfiguration of the regime, and thereby change the basic architecture of the regime. Niche technologies eventually evolve into a core regime technology. Over time these changes add up to a major reconfiguration of the regime, as the new regime actors become stronger and prefer different social-technical interactions.

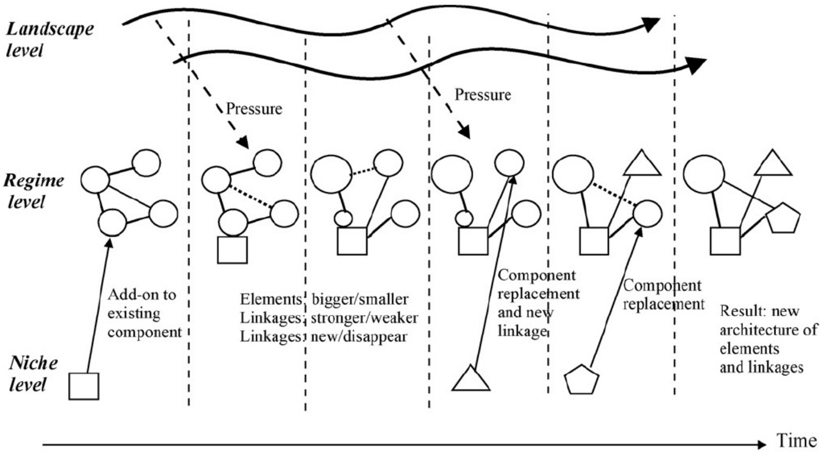


Figure 3.9: Reconfiguration pathway: Geels & Schot, 2007, p.412

3.2.3 Conclusion

The transition pathways should have a normative focus.

The MLP provides a structured method to study various pathways, but has been biased towards niche accumulation. The four transition pathways, discussed above, provide alternative successions of multi-level interactions and regime dynamics. Still needed is a way to direct these pathways towards the same normative endpoint.

The envisioned system has to co-evolve out of the various elements of today's sociotechnical system.

Through the regime dynamics the pathways take in the regularities of change in times of regime co-evolution. These regularities can serve as a guideline in explorative studies of future developments. But although they can guide the regime developments, they do not provide case specific system behaviour. An additional explanatory theory will be needed.

The framework has to be able to capture system developments at stable as well as unstable times.

The transition pathways provide additional insights in the regime dynamics at times of regime instability and how the instability results from various multi-level interactions.

3.3 Backcasting

Analogous to the MLP, the Backcasting method focuses on changing complex technical systems that can take several generations. The backcasting approach is considered here for its normative focus to view the potential of a vision or scenario. A vision is a normative image of the future, as it focuses on desirability instead of likeliness. Backcasts are used to examine the freedom of policy makers to steer the transition towards predefined goals.

Well established backcasting approaches are, for example, Robinson's, The Natural Step (TNS) and the Sushouse backcasting approaches. Robinson's approach is examined here for its goal-orientation that might provide some guidelines in determining the direction of transition pathways.

3.3.1 Methodological Foundation

The Backcasting methodology originated in the energy field in the 1970s and gained renewed interests in the 1990s, as awareness grew about the negative effects of unsustainable actions (Quist, 2007, p.11). It is an appreciative method used in cases where the most likely future is not the same as the most desirable future, or when insights in the underlying structure of sociotechnical system are unsatisfactory to forecast future developments.

Backcasting methods assess the desired future state instead of the likely future state, as in forecasts. It provides policy makers a tool to assess the freedom of action to departure from the regime's technical trajectory towards a preferred state. The two pillars of the Backcasting method are the normative scenarios, on the one hand, and the degree of freedom of actions, on the other.

3.3.1.1 A normative focus

The normative focus of backcasts refers to a state that is preferred over others. This state is determined in advance. Subsequently, this state is assessed on the feasibility of policy goals, by studying the range of possible outcomes and their consequences. By looking back from a desirable end-point interim goals can be selected that can used to guide the transition process.

3.3.1.2 Degree of freedom of actions

Backcasts are used to determine the freedom of actions of possible futures, whereas forecasts rely on the underlying structure of sociotechnical systems. (Roberson, 2003, p.84) The figure below shows how the degrees of freedom are to be used in normative scenarios.

The degree of freedom is the area between the business-as-usual projections and the heritage of the current regime design. The business-as-usual plot shows the developments when no unanticipated interventions are taken. The heritage plot refers to the case of maximum interventions, not resulting in a total regime collapse. By working backwards from a normative scenario the interventions necessary to meet the goals can be assessed.

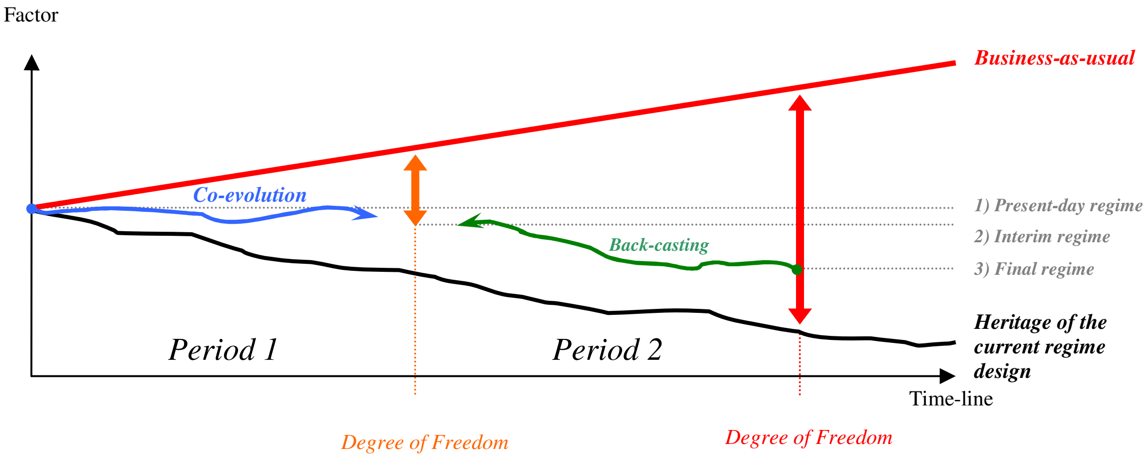


Figure 3.10: Robinson's backcasting method: based on European Community Research, 2006a, p. 14

3.3.2 The Analytical Frame

Robinson used the following steps to construct the scenarios: 1) determine objectives; 2) specify goals, constraints and targets 3) describe the present system and its material flows; 4) specify exogenous variables and inputs; 5) undertake scenario construction; and 6) undertake [scenario] impact analysis. (Robinson, 1990, p.824) These six steps are described here to show the inner workings of the backcasting approach.

Step 1: Determine objectives

In the first step, the purpose and the design characteristics of the scenarios are set. The number of scenarios and the time horizon are determined as well as the area of interest; e.g. sustainability or prosperity norms.

Step 2: Specify goals, constraints and targets

The normative objectives, determined previously, are translated in specific transition goals and targets. Qualitative goals are preferred over quantitative goals and performance indicators over specific technical solutions. These goals create the freedom of various actions.

Step 3: Describe present system

The keys to a technical transition lie in the present-day regime. Robinsons suggests using the physical consumption and production processes as the internal drivers of system change. In a Multi-Level Perspective this would comprehend to a regime characterization, like the technical trajectory, the interaction of actors and the institutional embedding.

Step 4: Specify exogenous variables

The system, described in the previous step, operates within a socioeconomic environment. These exogenous variables influence system developments in the long term. In Robinson's method these variables are used to constrain system developments. In the Multi-level perspective these external influences would refer to the landscape and niche dynamics. By taking these variables into the approach they can be used to explain the creation of novel technical designs.

Step 5: Undertake scenario analysis

The fifth step links the sociotechnical structure of the present-day regime to the goals set earlier. Technical designs are introduced that can explain the working of the system that meet these goals. Scenarios are created based on the system characterization at the interim and end-points. The transition, needed to bring about these technical designs, is not addressed explicitly.

Step 6: Undertake impact analysis

In the final step the impact of the scenarios is assessed in a socioeconomic sense, as well as the overall consistency with respect to the preconditions set earlier. At this point the policy implications of the scenario creation process can be assessed. This means that the policy measures that are needed to reach the goals, set earlier, are made explicit. The analyst, or stakeholders, can then rethink their chosen objectives when interventions turn out to be too intensive.

3.3.3 Conclusion

The transition pathways should have a normative focus.

The normative foundation, of the back-casting method, provides the direction of system developments, by specifying interim goals and targets. The degrees of freedom then provide room for various intervention strategies, or pathways, to make the transition successful.

The envisioned system has to co-evolve out of the various elements of today's sociotechnical system.

In step three of the analytical frame the current regime needs to be defined. The sociotechnical foundation is then used in the fifth step to create scenarios from. This implies that in the back-casting approach the desired system needs to co-evolve out of today's system.

The framework has to be able to capture system developments at stable as well as unstable times.

The normative focus, of the pathways leading to a scenario, does not imply that the regime needs to stay stable. External influences and intervention strategies can cause regime instability and regime change leading away from the business-as-usual plot.

3.4 The Internal Analysis of System Behaviour

The last analytical frame of interest was created by Coleman and named the Internal Analysis of System Behaviour. (Coleman, 1990, p.2) Coleman points at the existence of a gap between social theory and research. Social theories can be used to explain social behaviour. The empiric data, on which they are based, comes from individual actors by using interviews or questionnaires. The analytical frame is to be used for explaining social behaviour when research data concerns individual behaviour.

"What is necessary to account for the growth of occurrence of any social organization … is how the structure of positions constituting the organization comes into being, how persons who come to occupy each of the positions in the organization are motivated to do so, and how this interdependent system of incentives is sustainable". (Coleman, 1990, p.9) These notions of the social organization are equally important to sociotechnical systems. This paragraph will examine if the frame can be used for describing technical transitions.

3.4.1 Methodological Foundation

The methodological foundation is based on two pillars, being social network theories and a theory of purposeful action. Firstly, social networks consist of individual actors that interact according to shared rules. Secondly, when individual actions are assumed to be purposeful, individual behaviour can be explained. These actions do not in all instances need to be rational though.

3.4.1.1 Social network theories

Social sciences study the behaviour of social systems. A social network is a structure consisting of at least two actors. The position of actors is secured using formal, normative and cognitive rules. These institutional settings can facilitate and restrict conduct by actors.

Changes, at the systemic level, can be viewed as the behaviour of a supra-individual actor; being a group representative or leader. The gap between theory and research, mentioned earlier, is important as such an actor does not exist in social networks. Instead of a supra-individual actor, social behaviour is the result of interactions between various individual actors. When studying how interventions affect the social system researchers need to turn to the individual actor.

3.4.1.2 Purposeful action

Social theories assume that actors control certain resources and are interested in resources controlled by others. (Coleman, 1990, p.28-29) When observing individual behaviour it is assumed that people act purposefully. This implies that actions are intentional efforts to work towards a specific goal. (Coleman, 1990, p.13) When the interests of actors are related to the actions permitted in the social network the most likely action can be defined.

3.4.2 The Analytical Frame

Coleman's framework distinguishes between two levels of explanation; the systemic level and the individual level. At the systemic level, the social system is viewed in the form of a hypothetical correlation between social conditions and a social phenomenon. At the individual level, purposeful action describes how individuals pursue their own interests. This implies that the frame explains a certain social phenomenon, at the systemic level, by using purposive actions, at the individual level.

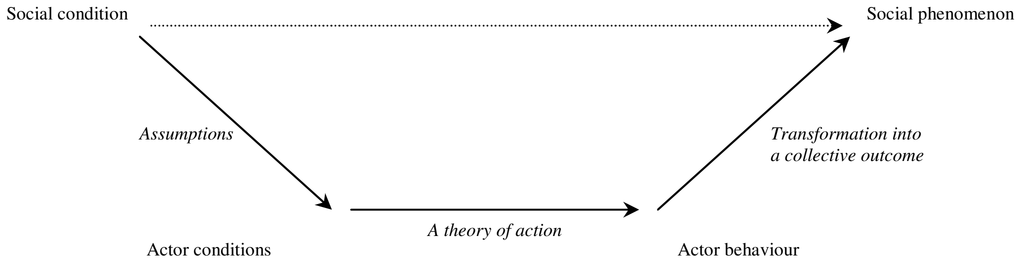


Figure 3.11: Coleman's method of the individual analysis of system behaviour: based on Coleman, 1990, p.5

This is achieved through the following steps. Firstly, in the macro-to-micro transition the social structure determines which individual actions are allowed, by the social system. Secondly, likely actions are devised that mirror the goals of individual actors. Thirdly, in the micro-to-macro transition the actions of individuals, in a multi-actor game, result in a systemic outcome. These three steps are addressed in more detail below.

3.4.2.1 The macro-to-micro transition

The transition from the systemic level to the individual level is named the macro-to-micro transition. Individual actors, interconnected in a social structure, find that certain actions are restricted while others are permitted or facilitated by the network. To determine the actor conditions the consequence of actions needs to be assessed. This refers to the freedom of individuals to act within the rules of the social structure.

The relevant question for the macro-to-micro transition is: Which actions are permitted by the individual actor within the social context?

3.4.2.2 Individual action

At the level of the individual actor, Coleman uses a theory of action. This theory lays down how individual actors would act purposefully in case of certain actor conditions. These actions can therefore be seen as being boundedly rational as they need to be seen in the context of the person making the judgement. Coleman described this as follows: "We say that we understand the 'reasons' why the person acted in a certain way, implying that we understand the intended goal and how the actions were seen by the actor to contribute to that goal" (Coleman, 1990, p.13)

Here the notion of individual actions is used. But this does not necessary mean that the subject needs to be a single person. It rather refers to a part of the social system. This could therefore either be a single actor or an actor group that is most suitable to explain social changes. Coleman described this as follows: "an explanation is sufficiently fundamental for the purpose at hand if it provides a basis for knowledgeable intervention which can change system behavior". (Coleman, 1990, p.4)

The relevant question for individual action is: What is the most likely action, within the freedom of the social context, and the goals pursued?

3.4.2.3 The micro-to-macro transition

The transition from the individual level to the systemic level is named the micro-to-macro transition. This step concerns how system behaviour results from the combination of interactions. Someone's actions could, for instance, affect others through positive or negative externalities, or the systemic outcome can be the result of a majority vote.

This step is often the hardest, because of the complexity that is introduced and has been named the micro-to-macro problem. "The major problem for explanations of system behavior based on actions and orientations at a level below that of the system is that of moving from the lower level to the system level. This has been called the micro-to-macro problem and is pervasive throughout the social sciences." (Coleman, 1990, p.6)

The relevant question for the micro-to-macro transition is: How do the individual actions, affect the actions of others, and result in a systemic outcome?

3.4.3 Conclusion

The transition pathways should have a normative focus.

By using Coleman's framework the relationship between a social phenomenon and certain social conditions can be studied. When the normative endpoint is set, using a back-casting method, the freedom of individual actors can be studied to see how they can effect the transition.

The envisioned system has to co-evolve out of the various elements of today's sociotechnical system.

The macro-to-micro transition implies that the conditions of today's system are used. The micro-to-macro transition then combines various action theories. The system co-evolves as change is brought about by interactions in a multi-actor game; based on the interests of individual actors.

The framework has to be able to capture system developments at stable as well as unstable times.

The social network restricts certain actions which result in a stable system. When a window-of-opportunity is created the individual actor can manoeuvre more freely by changing rules. At these times, of instability, the actions of individuals are important as the former rules no longer predict system behaviour.

3.5 Conclusion

Four research methods were assessed in this chapter by looking at the methodological foundation and the analytical framework. Now can be seen how building blocks from these methods can be used in an integrated framework.

In the individual paragraph has been concluded that all four methods contribute to one or more of the selection criteria, and violate none. The Multi-Level Perspective, and especially the regime, forms the developments at the systemic level. The typology of sociotechnical transition pathways can be used to guide the construction of the pathways in times of regime instability. The backcasting frame can be used to determine the freedom of action and intervention at the individual level. The Internal Analysis of System Behaviour framework forms the final piece necessary to create an integrated framework, by providing a theory of social behaviour.

Chapter 4: A Proposed Framework

The framework proposed in this chapter connects goal-oriented and co-evolutionary approaches. It needs to enable the creation of pathways towards normative endpoints. In this chapter the third sub-question is answered – *What interconnection of research methods satisfies the selection criterions?*

Most scenario approaches use variations in patterns or events to create images of how the future could be. These approaches mainly focus on macro-level driving forces, thereby ignoring pathway specific conditions, at the meso and micro-level essential to these scenarios. By including these meso and micro level developments into these macro-biased scenarios they can be coloured in different ways.

First the integrated framework is introduced showing how the research methods, described in the previous chapter, can be linked together. Next a research method is formulated that shows how the framework can be used to answer the research question of this thesis.

4.1 The Integrated Framework

The figure below depicts the new framework, integrating the four research methods, described in the previous chapter. The framework is depicted in a three dimensional setting with the time-line, the structuration of actions, and the levels of systemic/individual actions at the axes.

When one would view the integrated framework, figure 4.1, from above one would see a model quite similar to the MLP as the visualization of figure 3.2. The thick wavy lines represent the landscape developments, the straight lines depict the regime groups (technology, culture, science, policy, industry and markets and user preferences), and the thin short arrows represent the niche developments; figure 4.2 shows the model in more details.

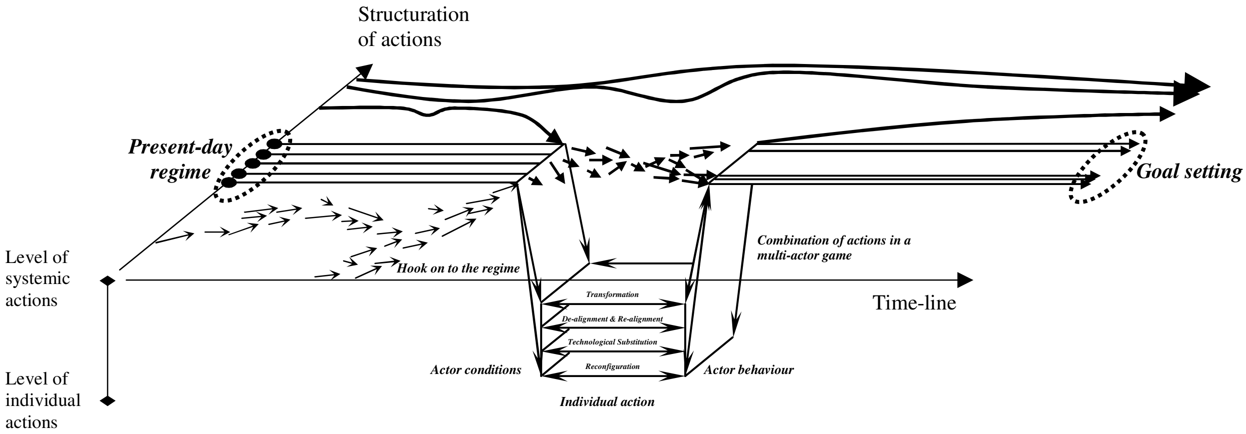


Figure 4.1: An integrated framework to assess technical visions

In this paragraph the interconnection between the various elements, of the research methods, is viewed. The construction of the new framework is described by viewing: the regime developments in times of stability; a normative focus; unstable regime developments; and accounting for regime behaviour, subsequently.

4.1.1 A stable regime structure

The present-day regime is the transition's starting point and therefore set at the beginning of the time-line. It is a connection of various actors groups – e.g. consumers, suppliers and public authorities – using a shared technology set and is embedded in an institutional setting.

In the framework the sociotechnical configuration is presented by horizontal lines, denoting the regime groups. They are fixed, sustained by rules, and run in the same direction following a technical trajectory. There is inertia of incumbent technologies as variation and selection have become intertwined. Caused by retention, where technology developers restrict variation and functionality where consumers lock-on to a specific technology base.

4.1.2 A normative focus

The technical vision of interest is a normative one. This means that the endpoint is not represents the most desirable outcome, viewed by the researcher, not necessarily being the most likely one. In the framework, the transition works towards a selection of goals. These goals are deduced from the vision by looking backwards.

By determining these goals some desired regime developments are set in advance. As these goals use qualitative objectives they provide room for various interventions to colour the vision. This degree of freedom is studied to see how different action can create new barriers.

4.1.3 An unstable regime structure

At some point in time a window-of-opportunity is created at which the landscape, regime and niche levels can interact. The landscape makes certain paths easier then others, reducing the importance of the technical trajectory. The protecting forces of the regime become unstable and regime change can result.

In the framework the regime developments, at unstable times, are denoted by small, bold, arrows going in various directions. The development pathways of regime and niche can merge and form novel designs, leading to a new technical trajectory. At these unstable times the regime actors are less restricted by shared rules. The outcome of the transition is not guided by systemic interest, but instead it is based on the interests of the individual actors.

4.1.4 Accounting for regime behaviour

But as interventions take place at the level of the individual actor – being a single consumer, organisation or actor group – it is necessary to zoom in at this level in times of regime instability. The transition pathways, described earlier, can help by providing various directions at these times. The multi-level interactions and regime dynamics are used to provide various translations – these translations are based on empirical research – between the systemic and individual levels.

The first transition concerns the macro-to-micro transition. Here the landscape level makes some pathways easier then others and niche actors can hook on to the regime. The pathways typology has provided various multi-level interactions based on the disruptive, specific, or avalanche change and symbiotic or competitive niche technologies. Depending on the path specific multi-level interaction the actors are affected differently.

Then the most likely action theories are formulated based on purposeful conduct. The goals specified must provide enough room – degrees of freedom – for various potential interventions.

The second transition concerns the micro-to-macro transitions. Important here is how combinations of actions in a multi-actor game result in a systemic outcome that meets the selected goals. These combinations are based on the pathway specific regime dynamics, defining how the individual regime and niche actors interact resulting in system behaviour.

4.2 The Research Method

The integrated framework provides researchers a lens that views transition pathways running in the direction of a vision. To answer the research question of this thesis the research method presented below. Figure 4.2 visualizes how the research method uses the integrated framework.

Step 1: Determine the objective / vision

The integrated framework is designed to analyse the promises of a vision regarding a technical transition. The choice for a future state is a normative one and does not say anything about its likeliness. The first step examines the promising technical system as set forth by the visionaries.

The usefulness of a vision can be answered by knowing 1) what the visionaries promises; 2) why adequate intervention is deemed necessary; and 3) which technical systems have been proposed to realize the vision. By using this information the first design demarcations of the transitions paths can be set, like the time span and the regime of interest.

Step 2: Specify goals, constrains and targets

In this step the vision is translated in a number of qualitative performance goals. By looking back from this point one, or more, interim goals can be defined.

The heritage of the current regime design constraints the possible regime changes. These constraints determine the degree of freedom for back-casting. The targets are set by looking at how the normative vision deviates from the business-as-usual developments. They can then be used to define the goals that form a guide for the transition pathways.

Step 3: Describe the present system

The keys, to a sociotechnical transition, lie in the present-day regime. Robinson suggests using the physical consumption and production processes as the internal drivers of system change. In a Multi-Level Perspective this would comprehend to a characterization of the regime.

The sociotechnical configuration has to be assessed that can be used latter on to determine the conditions of individual actors and how their actions affect each other.

Step 4: Specify the external influences

In the integrated framework technical transitions are viewed using the Multi-Level Perspective. The socio-technical pathway typology, using multi-level interactions, is used to view change in times of regime instability. The relevant landscape patterns and niche areas must be examined that can influence the transition towards the vision.

First the factors at the landscape level are examined and thereupon the potential niches are introduced based on technological promises of the vision. The external influences will not be assessed in full detail. The specific niche technologies and landscape pressures need to be described when they are introduced in the pathways (step 5).

Step 5: Undertake pathway creation

The four pathways – Transformation, De-alignment and re-alignment, Technological substitution and Reconfiguration – are formulated, in the fifth step. The goals, of step 2, are connected to the present-day regime, using the specific multi-level dynamics and regime dynamics of the pathway typologies.

The speed and scope of the landscape pressure and the maturity and competitiveness of niches are the distinguishing characteristics of the multi-level dynamics. The regime dynamics describe how the individual regime actors respond to the new situation and each other.

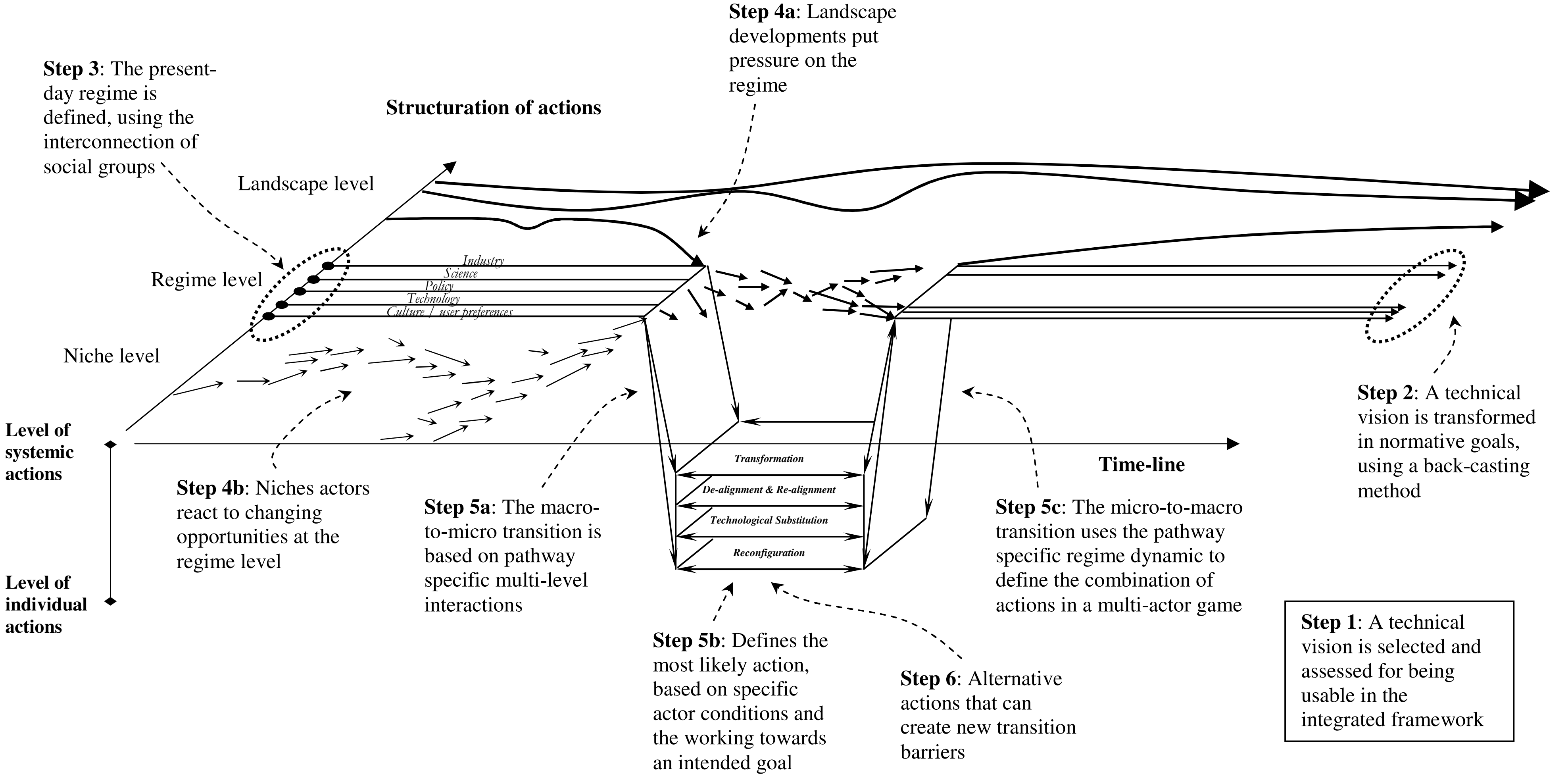
First, the effect of the external influences on the individual actors is described, using the pathway specific multi-level interactions (macro-to-micro). Then the purposeful action theories are formulated and finally the combination of various action theories to form a comprehensive story, using the pathway specific regime dynamics (micro-to-macro).

The research method assumes that all pathway types are likely to lead to the normative goals (the technical vision). If this is would not be possible in a case-study this can be a valuable conclusion altogether.

Step 6: Undertake impact analysis

In the final step the pathways are judged for consistency between the expected change at the systemic level and the likely behaviour at the individual level. If the pathways described in the previous step are the most likely their plot can be used to see how variations in events or interventions affect the technical designs and the formation of transition barriers.

Define the factors most significant to the direction of technical transitions; define alternative interventions; and how these interventions result in transition barriers.



Step 1: A technical vision is selected and assessed for being usable in the integrated framework

Step 2: A technical vision is transformed in normative goals, using a back-casting method

Step 3: The present-day regime is defined, using the interconnection of social groups

Step 4a: Landscape developments put pressure on the regime

Step 4b: Niches actors react to changing opportunities at the regime level

Step 5a: The macro-to-micro transition is based on pathway specific multi-level interactions

Step 5b: Defines the most likely action, based on specific actor conditions and the working towards an intended goal

Step 5c: The micro-to-macro transition uses the pathway specific regime dynamic to define the combination of actions in a multi-actor game

Step 6: Alternative actions that can create new transition barriers

Figure 4.2: The research method visualized

4.3 Conclusion

The integrated framework meets the three criterions set in chapter 2; by using normative goals that lay down the direction; by using the MLP to include the co-evolution of the present-day regime; by viewing the transition at the individual level, using the pathway typology, makes it possible to study regime developments in times of stability and instability.

The research method is used in the next chapters to highlight the main points of the framework and answer the research question in the SmartGrids case-study.

Chapter 5: The SmartGrids Vision

Visions, concerning potential technological systems, can provide direction to research and development activities by regime or niche actors. Here, the usefulness of the SmartGrids vision is assessed in order to test the main points of the integrated framework. First the promise of the SmartGrids vision is described; subsequently the socio-economic foundation and the technical foundation are assessed.

Step 1: Determine the objective / vision

The integrated framework is designed to analyse the promises of a vision regarding a Technical Transition. The choice for a future state is a normative one and does not say anything about its likeliness. The first step examines the promising technical system as set forth by the visionaries.

The usefulness of a vision can be answered by knowing 1) what the visionaries promises; 2) why adequate intervention is deemed necessary; and 3) which technical systems have been proposed to realize the vision.

By using this information the first design demarcations of the transitions paths can be set, like the time span and the regime of interest.

5.1 The SmartGrids' promise

The SmartGrids, as envisioned by the European Technology Platform, promises efficient, accessible and reliable transmission and distribution networks situated in competitive market for both generation and consumption. (European Commission Research, 2006, p.5)

> *"Smart Energy Networks aims to increase the efficiency, safety and reliability of the European electricity transmission and distribution system by transforming the current electricity grids into an interactive (customers/operators) service network and to remove obstacles to the large-scale deployment and effective integration of distributed and renewable energy sources".*
>
> *(European Commission Research, 2007, p.75)*

The figure below portrays a framing of a SmartGrids system. Electricity is produced centralized by low emission power plants, off-shore wind farms, solar power plants and hydro power stations and are connected, mostly, to the transmission network (HVDC). The decentralized production of electricity takes place by fuel cells, solar and photovoltaic systems and are connected, together with thermal or electricity storage, to the local distribution network. The use of information and communication systems to control electricity and the use of for example micro grids make the grid flexible.

Figure 5.1: SmartGrids a concept: European Commission Research, 2006, pp. 20-21

5.2 Socio-Economic Foundation

The SmartGrids vision assumes that the future needs cannot be satisfied by the current electricity system. In this paragraph the underlying principles of the vision are assessed, to show if these claims have roots that can account for a changing research & development activities. Although the visionaries have a European focus for SmartGrids, in this thesis the transition towards a SmartGrids system is viewed in a national sense – of the Netherlands – to reduce the complexity of the study.

5.2.1 Production and Network Capacity

Electricity demand is expected to rise annually by 2 percent, requiring new production capacity to cover the rising demand. (Dril v. & Elzenga, 2005, p.81) Additionally large parts of the distribution networks have surpassed their technical lifespan of approximately 40 years and need to be replaced. Because of these two notions sunk costs are less of an issue, when the network components are replaced by intelligent systems and distributed generators meet the rising demand.

5.2.2 Consumers and Ancillary Services

The production of electricity using Renewable Energy Sources (RES) leads to an intermittent character of electricity supply. The fluctuation in the power flows have to be absorbed to keep the stability of electricity supply in the Netherlands high. Distributed generators can fill this gap by supplying ancillary services to the grid in the form of balancing power and grid contaminations.

The visionaries assume that consumers want to become active participants in the production and consumption of electricity. At the moment consumers have limited understanding of the electricity system and their own consumption behaviour. (Eck v., 2007, p.149) Can consumers be educated to take on the role the visionaries have allocated to the consumers?

5.2.3 The Environment

The negative effect of today's electricity system on the environment can be an important factor to speed-up the transition towards a SmartGrids system. The CO_2 targets set in the Kyoto protocol, for example, require far-reaching changes of today's fossil fuel based electricity system.

Fossil resources are depleting and most Renewable Energy Sources have the disadvantage of have a fluctuating supply. Energy efficiency improvements in the current system and in RES systems need to become more intelligent to be able to react effectively in a fast changing environment of renewable energy and to diminish the negative effect of fossil fuels. By developing a better understanding of the working of the sociotechnical system new grid components can be developed that use generation system more intelligently to benefit the environment.

With intelligent grid components is meant that they have access to information about the current state of the grid, consumption and generation, as well as about prediction of the future state. Further they need to be able to determine the optimal state of the grid and be flexible enough to reach the desired state.

5.2.4 Power Quality

The digital age has had a negative effect on the power quality by creating harmonic distortions and disturbances. The visionaries assume that the digitalization will be slowed down by limitations of the electricity grid in urban areas. Distributed generation at these locations could be used to improve the power quality.

5.2.5 Conclusion - The Underlying Principles

Adequate intervention is necessary because intelligent systems are needed to: react effectively in a fast changing environment; provide consumers with new services and products; keep the power quality high. The transition can be accelerated as the sunk-cost of network and production capacity is not extremely high.

5.3 Technological Foundation

According to the SmartGrids platform the problems arising from the socioeconomic forces, described above, can be solved by increasing the intelligence of the grid. Here two topics are examined that include the main technical aspects of the vision, namely the internet-like structure, smart meters and the demand control systems.

5.3.1 The Internet-like structure

A potential systems design is a smart grid based on an internet structure. Here, control is distributed across various nodes in the network. These nodes interconnect electricity networks, creating a flexible grid, where power flows can be controlled at numerous locations. In the case of SmartGrids the network configuration is self-determined, where no single actor controls the network in real-time. (European Commission Research, 2006, pp. 24-25)

Further, the flow of electricity and information is bi-directional. This means that electricity can flow down, from centralized generators and is distributed to multiple actors, or flow up, from distributed generators and converges to be supplied to higher voltage levels. With respect to information flow, this implies that consumers, producers and network operators are (can be) informed about the real-time condition of the network. The individual actor can act in real-time, creating a more dynamic control system.

5.3.2 Smart meters

A smart meter can be used to gather real-time process information and control power flows. The promised benefits of smart meter are decreasing metering cost of consumers; increasing flexibility of the distribution network; DNOs can save on additional capacity upgrades; the potential to introduction ancillary services and attune DG; and increase network reliability. (Gerwen *et al.*, 2006, p.2-3)

The figure below shows a schematic overview of the smart meter. In this specific visualization an electricity meter and gas meter are controlled in an integrated setting. Via a modem, using for example an ADSL or GPRS connection, the real-time electricity and gas consumption patterns are send to an external database. The consumer can view their individual demand and home appliances can be controlled. It is yet uncertain who will eventually control the smart meter. This can be done either internally, by the consumer in the form of a Demand-Side Management system, or externally, by electricity suppliers/network operators as a part of the SmartGrids systems.

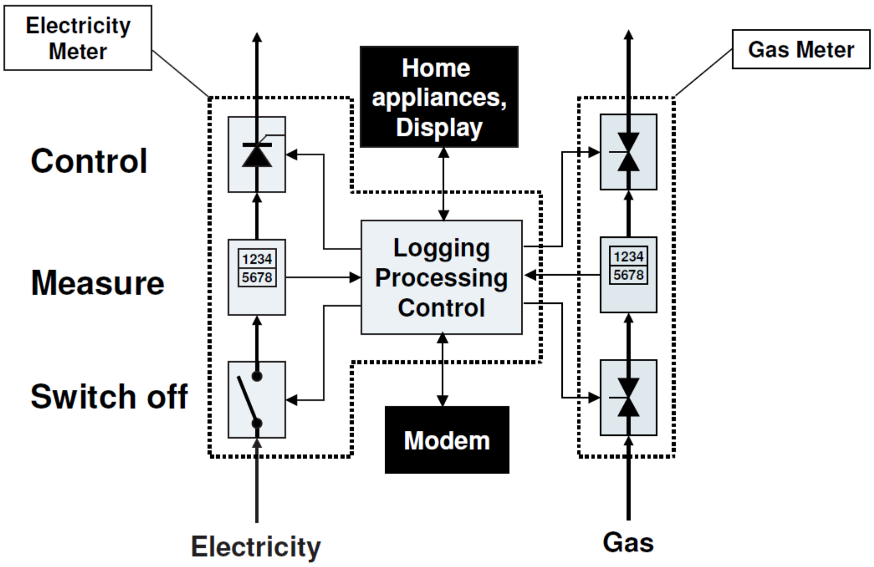


Figure 5.2: A schematic overview of the smart meter: Gerwen *et al.*, 2006, p.2

5.3.3 Demand Control

Next to electricity supply, by means of centralised and distributed generation, Demand Side Management (DSM) can be used to control loads. When consumers respond to a dip in the electricity supply, by reducing demand, it has the same effect as electricity produced by DG. Power quality and system reliability will then become the shared responsibility of generators, consumers and operators.

Consumer products will need additional functionalities to make active demand control possible; e.g. steered washing machines and dishwashers based on electricity prices. To make this possible the consumer needs to be charged based on real-time consumption. Smart metering systems can make this possible by providing information on electricity consumption and production in real-time.

Besides DSM consumers can respond to shortages by supplying electricity, using distributed generation. These generators can provide ancillary services, correcting variations in voltage and current waveforms as well as shifts in phase.

The electricity grid forms a complex network of cables/lines, power stations (with transformation, switching and breaking technologies) and electricity sources and sinks at numerous locations. Balancing the dynamic process, of demand and supply, asks for advanced control systems. SmartGrids increase the complexity by more generation distributed generation capacity, more volatile demand patterns and use of the distribution networks. This asks for more advanced dynamic control techniques to be developed that can handle the increasing complexity.

5.3.4 Conclusion – The Technical System

The significant factors on which the SmartGrids system is based are: the bi-directional flow of both information and power flows; numerous interconnected nodes; Demand Side Management; smart metering systems; DG providing ancillary services; and dynamic control techniques.

5.4 Conclusion

The SmartGrids vision encompasses an active and flexible infrastructure, in which all users, generators and consumers, compete freely, while the quality, security and reliability of supply is kept high. It is a variant on today's electricity regime and is controlled in an intelligent way. It includes the production, transmission, distribution and consumption of electricity and related services.

There is no single factor accountable for a transition towards a SmartGrids electricity system. Consumers have to become active participants, and require additional services from their electricity suppliers. Various technical systems are possible, but Renewable Energy Sources, distributed generation and the bi-directional flow of information and power are the main characteristics.

The numerous potential developments pathways and the large effect on the society and the economy make the SmartGrids vision suitable to show the main point of the integrated framework. Similar to the SmartGrids visionaries a 20 year period is used for the transition, as environmental problems, an aging grid, rising demand, and a declining power quality requires action in the next decades.

Chapter 6: The Transition Goals

Having examined the SmartGrids vision, in the previous chapter, it is translated in a set of qualitative performance goals. First the constraints are defined, based on the heritage of the current regime design, and then backcasting is used to define the normative targets and goals.

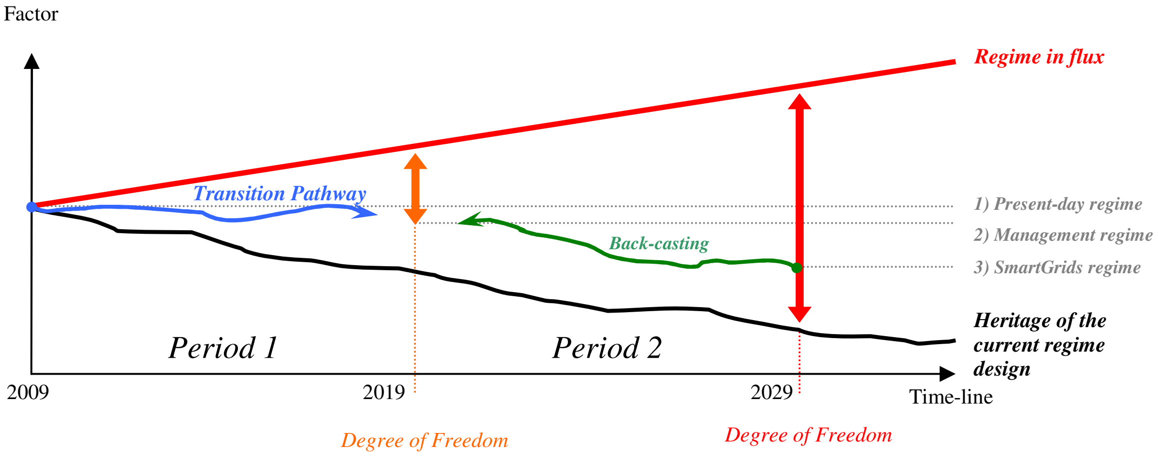


Figure 6.1: Backcasting method applied to the SmartGrids vision

The transition towards a SmartGrids regime is subdivided in two periods; as shown in figure 6.1. In the first period, 2009-2019, the transition towards the so named management regime is assessed and thereupon in the second period, 2019-2029, the transition towards the SmartGrids regime. Two periods are chosen as most of the pathways, with the exception of the de-alignment and re-alignment path, are not likely to lead directly in the SmartGrids regime.

Step 2: Specify goals, constrains and targets

In this step the vision is translated in a number of qualitative performance goals. By looking back from this point one, or more, interim goals can be defined.

The heritage of the current regime design constraints the possible regime changes. These constraints determine the degree of freedom for back-casting. The targets are set by looking at how the normative vision deviates from the business-as-usual developments. They can then be used to define the goals that form a guide for the transition pathways.

6.1 Constraints

In this paragraph the heritage of the regime's technical systems is assessed by looking at the sunk-costs of the grid and power plants and how construction times can hamper change.

6.1.1 The Grid

A large part of the Dutch electricity grid surpassed its technical lifespan. Total substitution of these parts is not likely, though. Historical studies have shown that when the grid is upgraded technical components are not replaced but integrated in the new system designs. (Verbong *et al.*, 2002, p. 25-26) A transition of the electricity regime will therefore depend largely on an evolved version of, the present-day regime.

6.1.2 Power plant

Power plants usually have a lifespan of approximately thirty years, and can be upgraded to last an additional ten to fifteen years. The high capital investments and powerfulness of the plant owners make early shut-down unlikely. They are on the other hand sensitive to changing oil prices, and shifts in fuel consumptions have been seen in the past; e.g. from coal to gas.

6.1.3 Construction time

The construction time of conventional generation and network assets ranges from 3 year for small generation units, 4 to 6 years for high voltage transformers, and 5 to 10 year for 'Integrated Gasification Combined Cycle' and nuclear-units. (Kling, 2003, pp.1.5-1.14) Because of the long construction times regime actors have to plan years ahead. These long term plans affect the outlook of the electricity system in the short and medium term.

6.1.4 Conclusion – Heritage

The high sunk-cost of power plants and the transmission network makes radical changes of the regime less likely. The long construction time of large scale generation systems creates opportunities for DG and intelligent grid solutions.

6.2 Targets

The normative vision presented in the previous chapter assumes that the current development trajectories lead to a situation that is, in their perspective, undesirable. The heritage, described in the preceding paragraph, presents the restrictions for transitions and thereby provides the degree of freedom to undertake action. Here, the targets are determined that are essential for the successfulness of the vision. From the previous chapter the reliability, flexibility, accessibility and economically feasibility have been selected.

6.2.1 Reliability

The reliability of a technical system applies to the ability to meet the services to consumers at all times. The reliability of the Dutch electricity system is already very high but digitalization and the intermittent character of Renewable Energy Sources can destabilize the grid. The SmartGrids need to keep reliability high.

6.2.2 Flexibility

The second requirement of the vision is the creation of an active and flexible grid. The bottleneck to an active grid is the distribution network. Many more interconnected nodes must be created with automatic steering to generate a high level of control. (EnergieNed, 1996, p.137)

6.2.3 Accessibility

The access of the electricity grid of today must be non-discriminative and transparent, according to the EU directive 2003. (EU Directive, 2003, p.38) The monopolistic structure of the network operators and the robustness of the network make network accessibility, at all times, not realistic. The target of the SmartGrids is for households to be able to supply electricity to the grid.

6.2.4 Economically feasibility

The electricity grid of today is biased towards centralised generation. The high sunk-costs of power plants and of the transmission network makes that early replacements are unlikely. The distribution network needs to be redesigned towards decentralised generation and energy markets need be made accessible to consumers and producers of all energy quantities.

6.2.5 Conclusion – Normative Targets

The SmartGrids visionaries have determined that SmartGrids should be reliable, flexible, accessible and economically feasible.

6.3 The Goals

The goals make sure that the targets are reached, while taking the degree of freedom of actors to intervene into account. Performance indicators are used to make various transition pathways possible. This means that no specific technical systems are defined. By looking back goals are defined for the SmartGrids regime and the Management regime, subsequently.

6.3.1 The First Goal: Bi-directional Power Flows

Distributed generation is a key technology for an active distribution grid. SmartGrids integrate both central and distributed generation in an effective manner. The grid of today can only include DG effectively for as long as local supply is lower then local demand.

In the *SmartGrids regime (2029)* the distribution network is capable of handling bi-directional power flows on a large scale. The technical components of the grid do not form a bottleneck for power flows.

In the *Management regime (2019)* the distribution network is capable of handling bi-directional power flows on a medium scale. An estimated of 20 to 25% of distributed generators can be connected to the distribution network, technically.

6.3.2 The Second Goal: Intelligent Control

Electricity needs to be controlled in an intelligent manner to make environmental friendly, cheap, reliable and flexible electricity possible.

In the *SmartGrids regime (2029)* grid control systems make a highly sustainable electricity sector possible. A sustainable electricity sector can be achieved by implementing more renewable and distributed generators, but only when the individual generators are controlled in such a way that efficiency improvements are reached at the systemic level.

In the *Management regime (2019)* customer awareness and influence should be increased significantly, to obtain a grid, which is transparent and controlled in an efficient manner. Households need to learn how to influence electricity demand and use new communication channels.

6.3.3 The Third Goal: Market Signals

The electricity market should take the needs of the individual actors into account. Energy trade should lower prices when market signals bring suppliers and consumers closer together. These market signals could contribute to a higher reliability or lower electricity prices for consumers.

In the *SmartGrids regime (2029)* real-time market signals determine the market equilibrium using end-to-end communication. The market must be transparent in a way that information is shared among regime actors which is used to determine an electricity production, demand and flows.

In the *Management regime (2019)* electricity trade is based on real-time usages. Preceding a market based on real market signals, it is based on real-time electricity usage, without providing any ancillary services.

6.3.4 The Forth Goal: A Level Playing Field

To satisfy the accessibility requirement the concept of a level playing field for competition is introduced. At the moment households can chose their own electricity suppliers but are too small to trade at the wholesale markets. For a level playing field to exist consumers and supplier should not be hindered in their connection to the electricity network or trading electricity.

In the *SmartGrids regime (2029)* the grid is accessible to all. The only way to achieve a level-playing field for production and consumption is to make the distribution and transmission grids accessible to all. This means that centralised generation should not be privileged over other ways of production.

In the *Management regime (2019)* the position of Distributed Generators is improved. To achieve this distributed generators need to gain market share, this might only be possible when DNOs and electricity markets change as well.

6.4 Conclusion

The vision, supported by the European Technology Platform SmartGrids, is a normative one and therefore needed to be translated in goals; being 1) bi-directional flow, 2) intelligent control, 3) market signals and 4) a level playing field. These goals can be used to guide the transition pathways, as they include the basic characteristics that make up the SmartGrids regime.

Chapter 7: The Present-day Regime

In this chapter today's regime configuration is analysed, based on the presentation of figure 7.1. In the integrated framework the present-day regime is the starting point of the transition. The regime's underlying structure needs to be defined that can be used to predict future developments. The following questions are answered: How does the sociotechnical configuration of today correspond to the SmartGrids vision of tomorrow and what are the interests of regime actors to block or initiate a regime change?

Step 3: Describe present system

The keys, to a sociotechnical transition, lie in the present-day regime. Robinson suggests using the physical consumption and production processes as the internal drivers of system change. In a Multi-Level Perspective this would comprehend to a characterization of the regime.

The sociotechnical configuration has to be assessed that can be used latter on to determine the conditions of individual actors and how their actions affect each other.

7.1 The SocioTechnical Configuration

The electricity regime of today is the result of over 100 years of sociotechnical evolution. Most notable changes have been scaling-up of production and network capacities. The electricity regime is found in a state of flux as there is no general consensus on the future direction of technical development (Elzen *et al.*, 2002, p.27).

Liberalization of the electricity market in Europe altered the balance of power from an engineering oriented to a market orientated regime. (Verbong, 2004) This change of business framework increased the heterogeneity between regime actors. (Elzen et al, 2002, p.18) Financial managers extend their control to technical systems. Investments in production and network capacity are judged based on estimated payback-times.

The figure below shows the electricity regime and interrelated regimes, by looking at the socio-technical interactions. The physical grid is the central point, in the electricity regime, and connects electricity consumers and producers. The DTE (and indirectly the ministry of economic affairs), the trade and program responsible parties have a regulatory and administrative relationship with consumers, producers and network operators.

Two external interactions are important. This concerns the supply of fossil fuels coming from the primary fuel regime - transportation regime and technology development conducted by, or together with, specialized machinery designers - consumer product designers. The individual actor groups and their position, in relation to the electricity regime, are discussed in the following paragraphs.

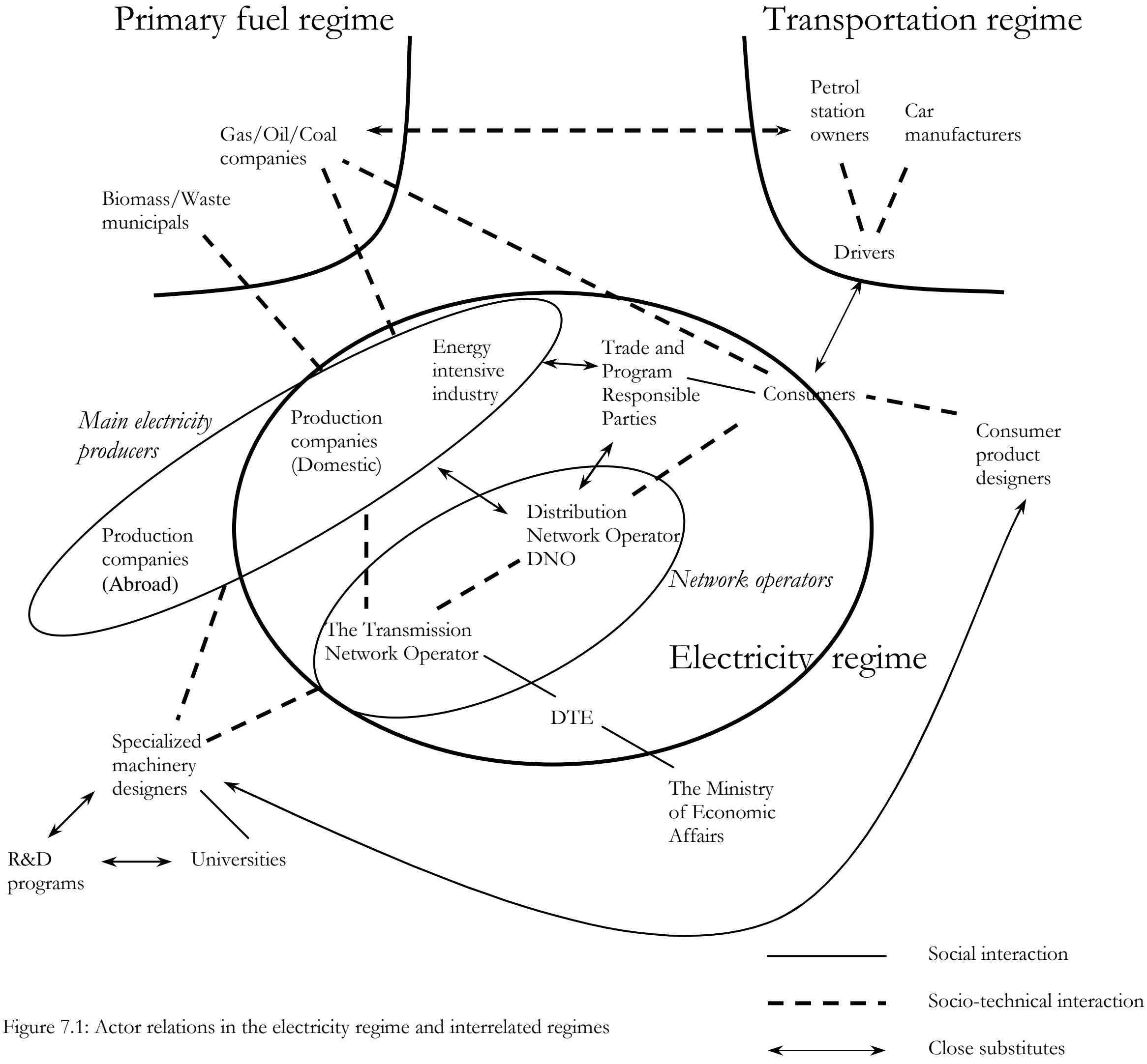


Figure 7.1: Actor relations in the electricity regime and interrelated regimes

7.2 Network Operators

The electricity grid is based on the so called 'Central Station' system. This implies that many consumers, connected to the distribution network, are supplied by a few generators, connected to the transmission network. The basic architecture of today's regime is based upon this principle. Although electricity can be supplied to the distribution grid, the procedures are labour intensive, and controlled by interested parties.

The electricity grid is the main technical component of the electricity regime. The Transmission Network Operator (TNO) and the Distribution Network Operator (DNO) are responsible for providing a reliable, accessible and sustainable grid. The earlier operates the high voltage (110kV and 150kV) and the extra high voltage (220kV and 380kV) levels whereas the latter operates the low voltage (0,4kV) and medium voltage (10kV 20kV and 50kV) levels. (Tennet, 2002, p.21)

The objective of the network operator is to facilitate the transportation of electricity, between the injection points (source) and the consumption points (sinks) of electricity.

7.2.1 Distribution Network Operator

The DNOs are responsible for the distribution of electricity in a designated area. The DNOs obtained a legal monopoly. Figure 7.2 shows that the largest three DNOs – Essent, Continuon and Eneco – obtain over 90 % market share.

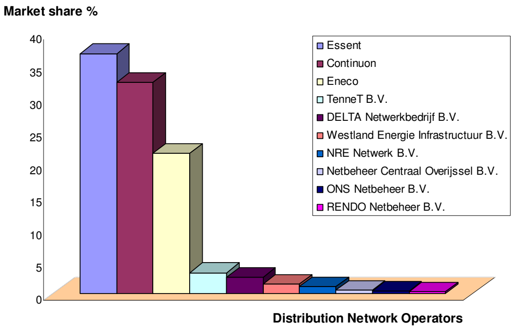


Figure 7.2: The market distribution of DNOs; created using data from NMA, 2005, p.8

The connection costs of distributed generation are calculated according to the so called shallow costs structure. These tariffs cover the cost of the physical connection, transport, system service, energy balancing, and electricity measuring, but not for bringing about additional cost to the grid.

7.2.2 Transmission Network Operator

Tennet is the only Transmission Network Operator in the Netherlands. Besides being responsible for the security of the transmission network Tennet is responsible for the cross-border flows, with Belgium, Germany and Norway.

At the moment, Tennet is responsible for the power balance, as the imbalance controller, and system control, as the System Responsible Party. Tennet designates the so called Program Responsible Parties that are made accountable for the predicted usage of consumers in a designated network. Tennet checks these estimations on consistency and offers them to the so called Trade Responsible Parties to be traded at the wholesale markets (APX or Endex) or off-the-counter. Afterwards Tennet checks the expected with the actual power flows, purchases balancing power and fines, when necessary, the accountable 'Program Responsible Parties'.

7.3 The Main Electricity Producers

The electricity generation is still compliant to economies of scale. Integrated producers profit from their size and services and the Energy Intensive Industry can supply a part of the energy needed from their core-business to the electricity grid.

7.3.1 The Integrated Electricity Companies

The integrated electricity companies have a high degree of vertical integration and can have generation, network, and trade - program responsibility. (Eck, 2007, p. 143-147) They are usually powerful regime actors, resource intensive and operate across regime boundaries and national boundaries. Their interests lie in high profit for the total value chain.

This business framework is still operational today, in spite of attempts as the Separation Act (splitsingswet). It states that as long as these integrated businesses don't hamper the security and reliability of supply, they do not have to unbundle completely. These companies have successfully survived power struggles in the past. It is likely that they will continue to use their power in the future, but on a larger more international scale.

These actors can more easily create new, and remove old, barriers. In transitions these actors take the lead either in protecting the old regime structure or ensuring a place in the new regime configuration. Examples of such companies are Nuon (Continuon) and Essent (Enexis). Companies without network operation activities (like Eon) sometimes profit from network activities in other EU Member States.

7.3.2 The Energy Intensive Industry

The Energy Intensive Industry has contributed largely to the adoption of distributed generation. "In the 70s and 80s [as] large industries started supplying electricity in a decentralized manner by means of incorporating CHP production units and a connection to the electricity grid". (Verbong & Geels, 2006, p. 1029) By producing and trading electricity the Energy Intensive Industry can lower production cost and increase the reliability of production processes.

7.4 Consumers

Consumers find environmental issues important but give precedence to high comfort and low costs. They are only willing to pay more, for an environmental friendly solution, when the burden is shared equally. The high reliability of the Dutch grid makes that uninterrupted services are perceived as important. (Eck v., 2007, p.149)

Contractual agreements connect households and small companies with electricity traders or integrated producers. Consumers have limited bargaining power and can influence regime developments only indirectly through these actors.

7.5 Specialized Machinery and Consumer Product Designers

The specialized machinery and consumer product designers are the actors responsible for the development of new technical systems. They develop technical systems by implementing incremental innovations in generator, network and consumer products. They work together with other companies in R&D programs and with universities.

As suppliers to the regime they control the gateway of novel technical designs to the regime. These companies find competitors in technical niches. Although these actors might not belong to the regime, they have as much to lose, from effective regime breechings.

7.6 The Dutch Government

Direct intervention of the Dutch government in the electricity regime started in the 70s and 80s. The Electricity Act, of 1989, initiated a transition resulting in loss of momentum and no harmonized technical vision. (Verbong, 2004) The government withdrew from the regime and left the Office of Energy Regulation (DTE), a sub-department of the NMA, as the direct link to the electricity regime. Its position is based on formal rules, set down in the Electricity Act, which provides the DTE with monitoring and planning authority over the TNO.

The ministry of economic affairs generates formal rules, determines the import capacity to be auctioned, determines the network tariffs and allocates R&D financing and subsidies. Changing support, by the Dutch government, for technical visions, hampered investments in new technologies. The industry only participated when the government took the greater part of the investment of approximately 80% of the costs. The wish of the government, to create new industries, only intensified these skewed investments. (Verbong *et al.*, 2006)

7.7 The Fossil Fuel Infrastructure

The fossil fuels infrastructure denotes as the interconnection between the electricity, the primary fuel and transportation regimes. This interconnection is of interest to the SmartGrids vision by showing how consumers (DG) can get access to the fossil fuel infrastructures.

Most households, in the Netherlands, are connected to the natural gas infrastructure and can acquire gasoline by visiting the local petrol stations. In most cases these stations are owned by oil companies. They belong to the transportation regime though, as they are bound by transportation institutions. The main electricity producers on the other hand acquire fossil fuels in bulk and often need custom made connections. Natural gas and bio-fuels can be used by households to generate electricity; using for example micro-CHP units.

The hybrid car can be a potential electricity consumption and production system, in the near future. The basic idea is that vehicles can use multiple power sources; e.g. the internal combustion engine, fuel cells, and electric motors. In the case of SmartGrids the use of electricity as one of the power sources is of interest. Many improvements have been made with respect to electric motors; e.g. better acceleration, recharging times and a higher normative range. By plugging these hybrid cars into the grid they can either be recharged or be used as an electricity generator.

7.8 Conclusion

The actor relations in the electricity regime and interrelated regimes have been discussed. How does the sociotechnical configuration of today match with the SmartGrids vision and what are the interests of regime actors to block or initiate a regime change?

The Distributed Network needs to become active. Some of the responsibilities of the Transmission Network Operator, like power balance and quality, need to be shared with other regime actors. The integrated electricity producers and Tennet are powerful members of the regime. They could potentially influence the direction of the transition if it does not match with their interests. The specialized machinery and product designers are the gatekeepers of novel technical designs to the regime. They supply applied knowledge to the regime in to form of technical products.

According to the SmartGrids visionaries consumers need to become active participants, as they are not yet a strong member of the regime. The electricity networks need to incorporate more DG and RES. The local character of biomass collection and the connection of households to the natural gas infrastructure create opportunities for DG. For DG and RES to become successful electricity should be settled in real-time. The responsibility of trade and program responsible party needs to change to make this possible.

Chapter 8: External Influences

In this chapter the fourth step of the research method is worked out. The external influences to the electricity regime are assessed in the form of the landscape and niche dynamics. In the chapter the question is answered of which external factors can be connected to a transition towards the SmartGrids vision.

Step 4: Specify the external influences

In the integrated framework technical transitions are viewed using the Multi-Level Perspective. The socio-technical pathway typology, based on multi-level interactions, is used to view change in times of regime instability. The relevant landscape patterns and niche areas must be examined that can influence the transition towards the vision.

First the factors at the landscape level are examined and thereupon the potential niches are introduced based on technological promises of the vision. The external influences will not be assessed in full detail. The specific niche technologies and landscape pressures need to be described when they are introduced in the pathways (step 5).

8.1 Landscape dynamics

The landscape level consists of slow changing patters – that cannot be affected by individual actors – forming the backdrop of regimes. They influence the regime's technical trajectory by making some paths easier then others. These patterns create window-of-opportunity that could be translated in a regime problem.

The factors assessed here are the most likely candidates to affect the electricity regime in the future. The selection – geographical factors, socio-political factors, environmentalism and ICT penetration – is based on the factors that have changed electricity regimes in Europe; by Verbong, van der Vleuten and Scheepers (2002). (Verbong *et al.*, 2002, pp. 27-30) The intention of this paragraph is to define the landscape factors that can make pathways, leading to the SmartGrids system, easier then others.

8.1.1 Geographic factors

Geographic factors influence the cost efficiency of production systems, the density of electricity demand, and the network capacity needed. Globalization, localization of natural resources and urbanization affect how electricity demand is distributed in the Netherlands. Demand densities determine the network capacity needed and which technical components are most suitable with respect to transmission losses.

The outlook of electricity regimes in Europe is affected by the availability and accessibility of natural resources. The domestic gas fields have shaped, to a great extent, the production systems used today to generate electricity. Fossil fuels are a scarce resource putting pressure on energy prices and creating opportunities for renewable energy systems.

Cross-border connections have been constructed between the Dutch and Norwegian electricity grid, and the relationship with Russia is intensified. In the first case Norwegian hydropower and large scale storage capacities becomes available to the Dutch electricity grid. In the second case Russian natural gas could be processed in, and distributed from, the Netherlands.

8.1.2 Political factors

Political factors are another element that helped shape the electricity regime. Formal rules and subsidies can be used by governments to steer the direction of regime and niche developments. The Dutch and European parliaments have been strong forces in shaping the electricity regime.

The Ministry of Economic Affairs can influence regime developments through the Electricity Act and the DTE. An important tool is the capacity plan that determines the production capacity expansions of large scale generators.

The actions of the European Parliament and Commission are to be transformed by the national governments of the member states in formal rules. One of the main pillars is the Lisbon Strategy aiming for European integration and the harmonization of member states. Another is the liberalization of the electricity system which faltered recently. The future degree to which liberalization is enforces will shape the business framework of the electricity regime of the future.

8.1.3 Environmentalism

The negative environmental impacts, and especially global warming, have gained much attention lately. Among experts there is still much uncertainty on what the global effects will be. The Kyoto protocol is an international agreement to reduce CO_2 emissions. This has not yet led to a major domestic reduction; at the moment only 2,7% of the energy usage in the Netherlands is sustainable. (CBS, 2008)

Most renewable energy systems use biomass or wind energy to produce electricity. Generally this concerns large scale installation owned by large energy suppliers. Households still hold a large, latent, capacity to install RES based systems.

8.1.4 ICT penetration

ICT integration can be seen as a regime innovation, but also as a landscape factor, when perceived as the global penetration of ICT in the day-to-day activities. In this case the attitudes and basic skills of consumers will change. An information dependant system like SmartGrids could benefit from these developments.

8.1.5 Conclusion

The Netherlands is a favoured facilitator to process oil products and to trade various energy carriers, because of its favourable geographic location and political ambitions. The Lisbon Strategy will be important to the electricity regime in for example cross-border power flows and in the design of international control facilities. ICT and environmentalism can demand an intelligent and a sustainable system.

8.2 Niche dynamics

This paragraph examines the general characteristics of the technical niches. The SmartGrids vision requires a level-playing field; active and flexible networks; and high quality, security and reliability. The niches studied here – (1) network assets, (2) network operations, (3) demand systems and (4) supply systems – regards the integration of smart systems to meet these requirements.

8.2.1 Network Assets

The first niche concerns the technical assets of the electricity networks. R&D activities take place mostly in the power electronics research area, focussing on improving quality, security and flexibility. The transmission network is in contrast to the distribution network more active; these two networks are discussed here.

8.2.1.1 Distribution assets

Unidirectional flow is one of the major barriers for DG systems. Especially the switching and breaking systems are based on unidirectional power flows, with a feeding rail and a descending rail. Smart systems need flexible power control using sensors and actuators. At the moment the transformers in the MS-LS grids are manual and not linear variable.

Quality control can take place at different levels – central, group or individual – depending mostly on the density of access points in the downward networks. A better adjustment of reactive power supply, distribution and loads increases the overall efficiency. The highly saturated fast-internet connections can be used for communication purposes.

8.2.1.2 Transmission assets

Tennet is a monopolist and therefore controls which new technological systems are implemented in the transmission network. Research and development takes place by the specialized machinery designers and universities. Challenges of the transmission network are for example subterranean cables, HVDC and Superconductive transmission.

8.2.2 Network Operations

The current electricity grid is dimensioned according to the ability to handle load flows in case of failure of one of the technical components. These power flows are based on the maximum power load and expected growth rates of demand. High levels of DG would decrease the predictability of these power flows and therefore the ability to dimension and control flows. Tools are needed that can predict and control power flows effectively.

First, new simulation tools need to be developed that can analyse the effect of high levels of DG and RES at the different voltage levels. The current software is based on the central station system and needs to take in the intermittent character of electricity generation, changing weather patterns and network disruptions. These concepts are to be implemented in tools that can control the grid at these voltage levels. The focus will be on finding the optimal location of sensors, actuators and capacity; on flow assessment tools; and on a self-healing control system.

8.2.2.1 Assess system designs

Today, system upgrades are being calculated using computer algorithms that represent the conduct of today's network. These programs are mainly based on top-down supply and on maximum load flows; not on flexible power rerouting at the distribution networks. These simulation programs do not take the effect of real-time changes of supply, demand and grid structures into account. An important niche technology is choosing the optimal location of network assets in an active setting. Small scale field tests are realized at this moment. Rapid increasing complexity forms the main barrier.

8.2.2.2 Control load-flows

A control system needs to be devised that is capable of influencing system parameters towards dynamically changing set points. This means that the control system should be capable of calibrating the system actuators in real time based on forecasts. Actuators are the switches and breakers at various connection points in the system. Technical barriers are for example forecasting methodology, like weather forecasts, demand forecasts, supply capacity forecasts, quality forecasts, and political barriers protecting the privacy of households. To an extent this is already possible, but when the market share of DG increases the stability of the grid is negatively effected. More advanced control systems will then be needed.

8.2.2.3 Self-healing tools

Here, self-healing tools are understood to be technical systems intended to increase the reliability of the network. A self-healing system needs load-flow control system and sensor and actuators to diagnose its state; and advanced tools to control the grid. Chip technologies and protection systems are important for a successful implementation.

8.2.3 Demand systems

In the SmartGrids vision consumers become active players in the electricity regime. Smart meters are an essential element to make active demand in grid control systems possible. Initially these meters will be used as a consumption indicator to the planning responsible parties and individual consumers. Later on they can be used to control DG and consumption apparatuses. The apparatuses used today are not yet fit to be controlled by an external party. New functionalities must be added to be controlled in a residential control system, using local storage facilities.

8.2.3.1 Product functionalities

Radical innovations often come in rough shapes, but these systems require a high form of plug-and-play. Communication systems are essential to make new functions possible. A Grid and residential control systems can shape opportunities for new product functionalities. Important are the installation and maintenance service companies that compensate for the knowledge gap of households. Lead times are expected to be short in the fast changing consumption sector.

8.2.3.2 Residential Control Systems

Smart metering systems can take on the control functions of master or slave, depending on an internal or external orientation. Communication could also take the current electricity wiring or use a new wireless system. A synchronised development of control systems and peripheral equipment is essential. Smart Meters can be the first step to such systems.

8.2.3.3 Storage facilities

Electricity storage facilities can take place internally, in various apparatuses, or externally, in a single residential system. There are various storage technologies available which have become much more efficient in the past decades. At the moment, batteries are a widely used technology to create secure and mobile electricity systems. Applying batteries in the important apparatuses means that there is no need for a fully developed control system that differentiates between apparatuses. The potential of storage facilities depend largely on the development of the control system. ICT penetration and increasing mobility requires internal storage facilities, whereas island operation requires external storage.

8.2.4 Supply systems

The level playing field of production and consumption, promised by the SmartGrids vision, will create a market where generators, with various returns to scale, can compete freely. The centralized generators, distributed generators and storage facilities need to be attuned to supply new products and services.

8.2.4.1 Centralized generation

Centralized generation systems have a solid position in the current regime. The prospects of these systems depend mainly on the availability of other infrastructures and resources, like the oil reserves, nuclear waste processing systems and a CO_2 transportation system. The regime barriers are the high R&D costs and lead time. High electricity prices will lead to new possibilities regarding technology developments and the availability of natural resources.

8.2.4.2 Distributed generation

There is currently no true interest from regime actors in DG unless electricity suppliers can make money on them. The current distribution grid can take in a small amount of electricity produced by distributed generations. When a supply outreaches demand on a local scale power will flow upwards, requiring bi-directional power flows. Distributed generation system can have a negative effect on the power quality in rural areas, quality monitoring will then be essential. In urban areas the abundance of generation systems means that the impact of single actors on the power quality is less significant.

8.2.4.3 Autonomous Storage Facilities

To store energy efficiently will depend on natural geographic factors like underground water basins; some forms are already used. These storage facilities need to be integrated in the local control systems. Market and regulatory barriers should make energy storage facilities more profitable. The intermittent character of the regime will create new opportunities. Information and grid control systems need to be developed though.

8.2.5 Niche related conclusions

Which part of the SmartGrids promise do the niches try to fulfil? The network assets focus on Bi-directional flow; the network operations on Intelligent Control; the demand system on market signals; and the supply system on creating a level playing field.

8.3 Conclusion

In this conclusion the following question is answered: which external factors can be connected to the SmartGrids vision?

Geographic factors will determine where supply systems and network capacity is needed and wanted. Dense populated areas might need intelligent systems to keep the power quality high and determine which supply systems are most suitable.

Governmental agencies can influence the direction of the transition by distributing R&D funding in various directions. If these subsidies go to RES, DG or a European Highway will depend on the political climate at that time.

Environmentalism will create new opportunities for RES and DG. When consumers are more aware of their contribution to the environmental pollution they might be willing to learn how to voice their needs become actively involved; resulting in novel demand systems.

Information and Communication Technologies can stimulate network and demand system designers to use the new information that become available.

Chapter 9: Transition Pathways

This chapter concerns the fifth step of the research method. Transition pathways are created that lead to the SmartGrids vision, using specific multi-level and regime dynamics. These pathway specific dynamic processes are described in depth in paragraph 3.2, p 22-25.

The transition towards the Management regime and the SmartGrids regime are described for the periods of 2009–2019 and 2019-2029, respectively. First, the landscape and niche developments are formulated that effect the stability of the regime. Then the purposeful actions of regime, and former niche actors, are described in a chronological order.

Step 5: Undertake pathway creation

The four pathways – Transformation, De-alignment and re-alignment, Technological substitution and Reconfiguration – are formulated, in the fifth step. The goals, of step 2, are connected to the present-day regime, using the specific multi-level dynamics and regime dynamics of the pathway typologies.

The speed and scope of the landscape pressure and the maturity and competitiveness of niches are the distinguishing characteristics of the multi-level dynamics. The regime dynamics describe how the individual regime actors respond to the new situation and each other.

First, the effect of the external influences on the individual actors is described, using the pathway specific multi-level interactions (macro-to-micro). Then the purposeful action theories are formulated and finally the combination of various action theories to form a comprehensive story, using the pathway specific regime dynamics (micro-to-macro).

The research method assumes that all pathway types are likely to lead to the normative goals (the technical vision). If this is would not be possible in a case-study this can be a valuable conclusion altogether.

9.1 Transformation path

In the transformation path, regime outsiders – pressure groups, technical experts or outside firms – translate landscape patterns into a regime pressure. The landscape regime relationship changes from reinforcing to disruptive. Consequently, the regime needs to change the direction of the technical trajectory; either by altering their R&D activities or by hybridizing with the technical trajectory of a technical niche.

9.1.1 Management regime

Social movements, like WWF and Greenpeace, urge for more stringent environmental legislation. They predict that the electricity regime of today will not lead to a Dutch success of the post-Kyoto protocol. The usual approach of electricity suppliers, investing in wind farms and co-firing of biomass, will not be sufficient in the long term. The Dutch government takes these arguments seriously and sharpens the emission trading system, by lowering the 'cap' of emission permits granted to polluters. (Frontier Economics, 2006, pp 1-8) This runs inefficient coal-fired power pants out of business.

9.1.1.1 Inefficient generation capacity

The main objective of electricity producers is to optimize profits of their business activities. The sharpened emission trading system forces these producers to write off inefficient generation capacity. Consequently, efficiency improvement technologies and renewable generation systems become more appealing. Gasification systems are built near coal-fired power plants, as are wind farms at sea and biomass combustion systems are implemented in an increased rate. The investments in wind farms results in increasing volatility at electricity markets. The research and development efforts of other efficiency improvements, like CO_2 storage facilities, are increased. High development and construction times imply that these technologies do not form an attainable solution in the short term.

9.1.1.2 DG uptake

Only large scale electricity generators, with a collective thermal capacity of 20 megawatt or more, are subjected to the emission trading system. Distributed generation is therefore not affected directly by the changed legislation. But as the costs of large scale generators rise, the price of electricity rises, making distributed generation systems more cost-efficient. An increasing number of household will adopt RES based DG systems to contribute to a more sustainable world, when conventional electricity becomes more expensive. The uptake of DG adds to the volatility of electricity markets, and has a negative effect on the reliability of the electricity grid. This increases consumer awareness and stimulate more households to adopt DG systems.

9.1.1.3 Grid reliability

The network operators have the responsibility of keeping the reliability of the electricity grid high. When reserve generation capacity is low, while power volatility is high, they are incited to develop network components that can optimize the use of the available generation capacity. They invest in facilities to store electricity. But to do so they need to invest in smart meters, to provide the operators with information on electricity demand, and advanced weather forecasting tool, to determine generation capacities, in real-time. Electricity suppliers can use the information in combination with actual electricity prices to determine when it is profitable to store electricity and when to sell.

9.1.2 SmartGrids regime

The trajectory change, towards a more energy-efficient regime, is judged by technical experts as being insufficient. They claim that regime actors have missed the perfect opportunity to create a reliable grid in the long term, by placing more intelligent grid components. Their argumentation is based on the fact that the regime actors have failed to take in the steep increase of hybrid cars that can be plugged-in to the grid.

9.1.2.1 Plug-in hybrid cars

Owners of hybrid cars require additional services from network operators and energy suppliers. Although they can plug their cars in to the grid, both the smart meters and the hybrid cars are not able to control the production and consumption of electricity.

Electricity suppliers approach car manufacturers to consider a design that the electricity suppliers approve of. Onboard computers are installed that can communicate with the smart meters. When the vehicle is plunged-in to the grid the electricity price is used to determine if the batteries should be recharged or electricity should be delivered. The vehicle is then used as an energy storage facility for grid surplus. Besides using the batteries the combustion engine, or fuel cell, can be used to generate electricity or produce hydrogen.

9.1.2.2 Control of DG

New applications are developed to use these new functionalities. An example of such an application is, parking places that are being equipped with grid connections and a crediting system. As during office hours, when electricity prices are generally high, the vehicles cannot be plugged-in at home.

The network operators need to control these new distributed generators. The mobile character of these generation systems makes them less predictable as reserve capacity. New prediction models need to be designed that takes the mobility of generation capacity into account. In certain instances additional network capacity might be needed. Flexible control components are placed that increase the dynamic character of the grid. These techniques use actual demand and supply quantities to optimize the use of grid capacities.

9.2 De-alignment and Re-alignment path

In the de-alignment and re-alignment pathway, a sudden avalanche change will initiate a regime collapse, and many embryonic niche technologies competing for dominance. The winner becomes the core technical component and will, together with others, form a new stable regime. As the de-alignment and re-alignment path is a rare and radical transition process, only one such regime change, running directly to the final goals, is described here.

9.2.1 SmartGrids regime

The Club of Rome was the first to bring the depletion of natural resources to notice. Since then the magnitude of the oil reserves has been a much debated topic, as it depends greatly on the improvements of oil extraction technologies. The technologies, to exploit less economically feasible oil fields, develop slowly, as they are not expected to be profitable in the short term.

Oil prices are stabilized by the OPEC (Organization of Petroleum Exporting Countries) in order of providing producers a reasonable return on their investments. The stabilizing power of the OPEC decreased when Iran decided to postpone its membership. Oil supplies are further reduced as a result of civil wars in Nigeria and Iraq and through hurricane-related supply reductions in the US. In the same year shell announces to have miscalculated the magnitude of their oil reserves. Conflicts between oil producing countries eventually results in oil prices going skyrocket.

9.2.1.1 Regime de-alignment – prohibitive electricity prices

Integrated businesses, like Essent and Nuon, own many power plants negatively affected by the high oil prices. They are forced to pass these costs on to electricity consumers. High sunk-cost of power plants makes it profitable to make these plants ready for the combustion of relative cheap coal; e.g. by using coal-gasification systems. Consequently the price of coal rises rapidly.

The energy intensive industry is struck hard as consumers are unwilling to pay the higher costs for consumables. Orders drop and people are loosing their jobs. Energy efficient products and processes are needed, which are developed with increased effort.

The high oil prices lead to high prices of consumer products and eventually to less consumption. Many consumers are having a hard time obtaining energy for central heating, transportation and electrical products. They are forced to change their behaviour with respect to the consumption of energy.

The liquidity of the DNOs and the TNO is shrinking, as households start to consume less electricity. They have little options to improve their situation. While DG can increase the stability of the grid, by using the power surplus, it doesn't cover the increasing costs of DNOs.

9.2.1.2 Competitive stage – energy efficiency

Al throughout electricity sector there is a demand for cheap energy and electricity. To meet the needs of the electricity consumer, products are designed that are more energy efficient and have more power related functionalities. These products have not yet fully matured, which means that they are sold while they might have some shortcomings.

Simultaneously, the market for distributed generators, based on RES, like solar panels and CHP running on bio fuels, leaps up. The performance of these systems has increased throughout the years but they are not available in the quantities needed, at least not in the short term. As a result the price of distributed generation system increases.

As the generation capacity declined, with the regime de-alignment, the reliability of the grid has decreased dramatically. While there are many consumers whom can hardly afford the high electricity prices, there are others that demand electricity at all times. They invest, together with others in a local community, in micro grids that can be disconnected from the distribution network when necessary.

Others invest in local energy generation systems, based on biomass collection by municipals. Consumers are interested in saving money on energy when possible. Biomass is sold to local processors whom provide biogas on a local scale. In combination with micro grids local electricity markets arise. When successful these individual markets grow out of the physical barriers of the individual micro grids, as outsiders want to join.

9.2.1.3 Regime re-alignment – electricity markets

Re-configuration of the electricity regime takes place around distributed generators, which are used in micro grids and traded at local electricity markets. These producers lower the electricity prices radically, although not as low as prior to the energy crisis.

The abundance of electricity markets has created a more complex trading system. Still new markets arise, by providing ancillary services to distributed generators. The role of the DNOs has changed; some have split up in micro grid, while others work together with private network owners, to improve the stability of the electricity grid.

9.3 Technological Substitution

In the technology substitution path a mature niche technology awaits its chance to compete with an incumbent regime technology. When a specific landscape development puts pressure on the regime, the former niche technology and the established regime technologies have to compete for domination. When the customer base of the former niche technology grows, the social, cultural and institutional aspects of the regime change as well. The former niche technology will eventually be adopted in the sociotechnical configuration.

9.3.1 Management regime

Various DG systems, based on fossil fuels or RES, have matured. While they are not yet competitive in real markets, their market share is rising when helped by subsidies. The diffusion of DG systems is still low. When these systems become competitive they need to overcome the monopoly of the large scale generators.

9.3.1.1 The protection mechanisms of the regime

The electricity producers anticipated the increasing price competitiveness of DG and have deemed it necessary to protect their place in the electricity regime. They intend to position themselves in such a way that small scale producers do not have enough power to enter the regime. Furthermore, they intend to make their processes more cost-efficient to keep off distributed generations.

The integrated businesses have not yet unbundled completely, which means that the electricity producers can still have DNO responsibilities. Although these companies are obliged to take DG in the network, in practice barriers still exist. DNOs can, for example, refrain from network upgrades that support more DG.

9.3.1.2 The adoption of DG

Commercial companies need to sell these products to households in large quantities to keep them cost-efficient. Households have to adopt distributed generators for the diffusion to take-off. These actors are not used to operating these technologies and because of the long take-off period households hold these technologies in low esteem.

The companies, selling DG systems, start working together with environmental movements and raise a massive campaign to promote RES based DG systems. The low CO_2 emissions, in combination with low costs eventually convince household to adopt DG systems. The installation of DG increases awareness of households with respect to their own consumption behaviour.

9.3.1.3 Reserve capacities

Through the adoption of DG systems the reserve capacities have increased. This reduces power fluctuations but can have a negative effect on the power quality. The distribution networks are not yet able to cope with the increasing number of DG. They are forced to upgrade network capacities and replace substation early on at places where bi-directional power flows are present.

9.3.2 SmartGrids regime

Besides the use of network control systems, electricity can be controlled using load control mechanisms. Such a system is the Demand Side Management (DSM) system. Consumers can actively control the price of electricity, by helping to counter power imbalances. A DSM system can be created using smart meters. Entrepreneurs need to convince consumers to adopt these technologies and become active players in the energy market.

9.3.2.1 DSM commercialization

The DSM systems are bundled to new consumer products and smart meters. Consumers find it important that electrical products are controlled in a consumer friendly manner and are not cut-off haphazardly; as comfort is a major requirement for consumers. Electricity products are controlled wireless, either by using an on-off click system, or by integrating them in consumer products.

The DSM systems have to compete to a system that is controlled by the energy suppliers. They claim that to keep the reliability of the grid high in the future they need to be able to control consumer demand. Pressure groups on the other hand claim that consumers should be able to stay in control.

9.3.2.2 Controlled external or internally

The smart meters that are installed make it possible to be controlled either by the consumer or by the energy suppliers. Both external and internal control systems find implementation. The systems that are controlled external are plagued by power interruptions and faults. Consequently, households want to stay in control of apparatuses and adopt DSM systems.

At first only a specific part of the consumer equipment can be controlled by the DSM system. Examples of such products are washing machines using real-time electricity prices to optimize their program, as do refrigerators, air-conditions etc. Other products like personal computers and the lighting system cannot be switched off on demand. By placing electricity storage facilities, at the private residences, the flexibility of the DSM system is increased.

9.3.2.3 Network tariffs

The success of DSM systems results in less stable networks. Power flows can take various routes as demand and supply vary constantly. The TNO and DNOs turn to dynamic control techniques to increase the reliability of the grid. The dynamic control techniques open opportunities for local electricity markets, where production and consumers have to pay for the distances travelled in the distribution and transmission networks; the distance between power source and power sink.

The local electricity markets might bring about additional costs to the centralised electricity producers, as they need to pay the tariffs for both the transmission and distribution networks. The distributed generators, in most cases, only pay for the use of a part of the distribution network. This strengthens the positions of distributed generators and stimulates the adoption of DG systems.

9.4 Reconfiguration

A mature niche technology enters the regime as a regime supplier. As a result, new technologies become available to the regime actors. Some of these new technologies are adopted and change the formal rules, as well as the functionality of regime technologies. The changed rules create opportunities for novel technical designs. New actors gain access into the regime, changing the sociotechnical configuration until the regime stabilizes again.

9.4.1 Management regime

The smart meter was developed as a niche technology and has reached maturity. The Dutch government decides to support the introduction of smart meters, removing the legal and financial barriers. The adoption of smart meters, in the electricity system, opens up various technological opportunities. These meters provide information, to DNOs, about consumption in real-time. Other actors and technologies can profit from the data provided by households as well.

9.4.1.1 Program responsible parties

The installation of smart meters has provided DNOs and energy suppliers with real-time data on energy consumption. As a result, the program responsible parties, appointed by Tennet, are no longer needed to predict the electricity demand, like has been done in the past. A data-analyses unit is operational to predict electricity demand according to historical data and real-time usages.

9.4.1.2 External control

The energy supplier would like to extend their control to these smart meters. By upgrading the smart meters they can control distributed generation as well as consumption apparatuses. Through contractual agreements the energy suppliers can control the electricity consumption of households, when electricity prices are high. Furthermore they stimulate the adoption of distributed generation systems that they can then control.

9.4.1.3 Consumer products

New products are designed that communicate with the smart meters. First a connection is made between the smart meter and personal computers. Consumers can login to a personal website that provides them with the actual and historical data on power usages. They can communicate with the energy supplier to help predict the electricity consumption; e.g. a vacation button.

9.4.2 SmartGrids regime

A new control system for the distribution network is developed. It concerns components that are placed at the most important power junctions. It can make the distribution grid more flexible and push the use of smart meters to the next level. These systems will replace the unidirectional power stations; containing transformers, breakers and switches.

9.4.2.1 Ancillary services

The new control systems have made the distribution networks more flexible. The DNOs perceive new opportunities regarding ancillary services that these systems can facilitate which were provided earlier by the TNO. By using the connection to the individual actors using smart meters the DNOs can provide these services to households.

The consumers have become more familiar with their power consumption through the introduction of the smart meters. The same lay-out can be used to include ancillary services, where distributed generators can be used for reactive power and voltage support. The smart meter systems need to be upgraded though to include these advanced control services. The new functionalities of smart meters will stimulate the diffusion of DG and RES.

9.4.2.2 The time to market

The centralized generators no longer have the sole responsibility to absorb the intermittent character of Renewable Energy Systems. Households owning DG systems require the time to market to be reduced; for both centralised and decentralised generation. This can have a negative effect on the stability of the production process of centralised generation, as they cannot as easily follow the volatility of the electricity markets.

9.5 Conclusion

In the previous paragraphs four transition paths have been formulated all ending up in the SmartGrids vision. They represent likely combination of actions within the room provided by the specific pathway type. Although these pathways are being considered here as being likely, based on knowledge of the underlying structure of the electricity regime, another connection of events can alter the co-evolution process, and thereby the transition.

The following points of interest, with respect to the continuation of the transition, have been selected and will be elaborated on further in the next chapter. Can conflict of interest, when integrated businesses have not yet unbundled completely, hamper the transition? Are alternative intervention strategies by governmental organization as effective to change the direction of the regime's technical trajectory? Is the introduction of a smart meter sufficient to create SmartGrids? Is being cost-efficient enough for the DG to take-off? Will private electricity market and dynamic control techniques always have a positive effect on the transition?

Chapter 10: Impact Analysis

In this chapter the final step of the research method is discussed. It concerns events or actions that shape the future differently and thereby hamper the continuation of the technical transition. They are discussed here briefly and could be studied in depth in follow-up studies.

Step 6: Undertake impact analysis

In the final step the pathways are judged for consistency between the expected change at the systemic level and the likely behaviour at the individual level. If the pathways described in the previous step are the most likely their plot can be used to see how variations in events or interventions affect the technical designs and the formation of transition barriers.

Define the factors most significant to the direction of technical transitions; define alternative interventions; and how these interventions result in transition barriers.

10.1 Smart meters

Substitution of conventional metering systems by smart meters is an important requirement for the development of SmartGrids. It connects households to the distribution grid and makes bi-directional information flows possible.

The smart meters find implementation in all four pathways. Initially, in the reconfiguration path, only the electricity consumption and generation are measured; first generation smart meters. Ancillary services and advanced control functionalities are not yet provided. Electricity providers can choose to place first generation smart meter that cannot easily be upgraded to include more advanced functions.

These first generation meters can create sunk-cost to more advanced metering systems and control facilities in the future. When no ancillary services are provided to households centralised generators and network control system stay responsible for the power quality. Potential DSM systems cannot be provided by the smart meter and becomes a private investment to consumers. When the DSM system is not standardized it cannot be as easily integrated in consumer products.

10.2 Unbundling

Integrated businesses can own generation capacity as well as have network responsibilities. Network investment could therefore be influenced by the needs of the business's production department and their general interests. They are in a privileged position in a competitive market.

In the technology substitution pathway distributed generation systems have become competitive technologies. Distributed and centralized generation systems have to compete for a dominant market position. As the government decided that the integrated businesses do not have to unbundle completely – as long as the integrated businesses don't hamper the security and reliability of supply – these businesses can exert their power as a DNO to hinder the diffusion of DG. Furthermore, the increasing DG capacity leads to volume reduction for DNOs. They therefore have little incentive to support the diffusion of DG.

When the distribution network operators are not fully supported by governmental institutions, but based on network tariffs, there will be no incentive to improve access possibility of DG to the distribution grid. In all four pathways the network operators have been the key actors which co-evolve, making the network more intelligent.

10.3 Electricity markets

At present electricity is traded mainly at the wholesale markets, APX and ENDEX. The APX offers the so called spot markets, day-ahead and within-day cervices. Endex facilitates the listed contracts, for 3 months, 4 quarters or 2 year. (NMA, 2005a, p.8) Although these markets are accessible to all, economy of scale is still the norm. They are dominated by electricity suppliers which use these markets to make high profits.

When the regime falls apart, in the de-alignment and re-alignment path, consumers seize all opportunities to save costs on energy. Local energy markets arise, where fossil fuel products are sold, and local electricity markets that are better equipped to handle local demand. As a result private electricity network and markets are created.

These local markets can lead to discrimination of certain users; by excluding actors based on their geographical location, social status etcetera. When the interests of local markets and networks are considered more important then the stability of the grid it would undermine the working of intelligent components. Such a system could then not be considered as being SmartGrids.

10.4 Dynamic control

Dynamic control systems should be capable of calibrating the system's actuators in real time, using forecasting tools. The system uses dynamic control techniques that can handle changing network configurations and fluctuating power loads.

In the Transformation and the Technological substitution pathways the DNOs switch to dynamic control techniques to overcome mobile generation capacities and active Demand Side Management, respectively. The power flows determines, to a large extend, the network configuration, and is fine-tuned using weather forecasts, demand forecasts, power quality forecasts, etcetera. Electricity prices can be based on the specific part of the electricity network they use. Consumers and producers then need to pay dynamic network tariffs in a local area.

This can have a negative influence on the diffusion of distributed generation systems. The risk to households with respect to the return on investments has increased, which depends largely on local demand and supply.

10.5 Distributed Generation

The SmartGrids vision requires that distributed and centralised generation are represented equally. The electricity regime of today is based on the so called Central Station system. Electricity is generated in a centralized setting and the technical infrastructure is based on top down power flows.

In the technical substitution, and other, pathways the price of DG systems drops, resulting in an increased adoption. The rapid diffusion of DG alters the local demand supply balance and affects electricity quality negatively. DG can contribute to the stability of the distribution networks when a new electricity market is created based on shorter times to market.

When the time to market is not reduced, household have no incentive to produce electricity, based on real-time demand. Households produce electricity to cover one's own demand whereas the grid is used, merely, to store electricity. The diffusion of DG will slacken and the power quality decreases.

10.6 Feed-in tariffs

Intervention mechanisms that the government can use to support renewable electricity systems are, for example, the feed-in subsidy and emission rights system. The feed-in tariffs guarantee a certain electricity price for RES based distributed generation for a certain period of time. It lowers the risk of DG with respect to the return on investment. The emission rights system makes the polluter pay, while supporting efficiency improvement technologies.

In the transformation pathway the regime is forced to change direction as a result of new environmental legislation. Instead of sharpening the emission right system, feed-in tariffs can be used to support distributed generation. But by doing so they'll bias electricity markets in the long term in favour of DG.

The location of generation and consumption locations helps to determine the electricity prices in the future. When distributed generation is supported using feed-in tariffs it will bias the market mechanisms in local networks. Market mechanisms will have no real power to match supply and demand locally. This could result in electricity flowing upwards and transmission losses.

10.7 Conclusion

The barriers that are formulated in this chapter result from alternative actions in the pathways, described in chapter 9. Most of these barriers can be reduced to problems concerning the electricity market. They concern the market for ancillary services; discrimination of private markets; dynamic network tariffs in a local area; a short time to market for DG; biased market mechanisms.

In the SmartGrids vision the electricity market bridges the interests of the various regime actors. In a well performing competitive market, using intelligent technical components, a stable electricity price insinuates a reliable, flexible, accessible and economically feasible system. An important topic of study, regarding SmartGrids, should concern the formation of an electricity market that facilitates the use of the electricity system in an intelligent way.

Chapter 11: Conclusions and Discussion

A new framework has been created of which the main points were shown in the SmartGrids case-study. The research method, used to assess the SmartGrids vision, focuses on the most likely transition pathways, leading to a desired outcome, and alternative interventions, leading to new transition barriers. The framework and research method were designed to be able to answer the following research question: *Which paths can the electricity regime (not) take to realize the SmartGrids vision?*

11.1 The SmartGrids Vision

In the previous chapter barriers were formulated, resulting from individual actions in times of regime instability. The intention of the approach is for niche and regime actors to get new insights and a better understanding of what the transition towards SmartGrids can comprehend. The described transition pathways should not be considered to be comprehensive, nor are they intended. The framework focuses on a technical vision and the factors that can influence the direction of the transition. These factors are assessed here.

An important foundation of the SmartGrids vision is to create an environmental friendly system. Such a system should limit transmission losses. By balancing supply and demand on a local level these losses could be reduced dramatically. Dynamic network tariffs, on a local scale, would provide the incentives for consumers and producers to balance power in an economical and environmental friendly manner. But does this increase the flexibility of the network and create a level playing field? Centralized generation systems are aided by a high and stable electricity demand. Can they function in such a dynamic market, do they need to switch to more flexible generation systems, or do they need to turn to large scale energy storage systems?

The smart meter is an important technical component to effect the direction of the transition. When consumers can be motivated to involve themselves, actively, in electricity generation and consumption, they can help manage the stability of the electricity grid. But does the influence of many distributed actors add to grid stability or instability? Can a control system be devised that adapts electricity prices, or alternative steering signals, based on forecasts of external influences, to stabilize the local, national and international networks? A direct information connection between regime actors is essential and the potential functionalities of consumer products depend largely on the design of the smart meter system. Can the smart meters and the control system positively effect each others development, is the control by energy suppliers inevitable, or will early standardization prevent the diffusion of intelligent components?

The level playing field objective, formulated in step 2, does not only apply to the electricity producers. Network operators need to be motivated to innovate and reach high performance levels as well. Private DNOs receive no incentive to accept DG that result in volume reduction of power flows. Integrated businesses would be inclined to protect their generation capacity, being centralized generation capacity. Bringing the distribution networks under public ownership will not lead to a level playing field. Is there a hybrid form possible, in which the income of DNOs is not based on network tariffs and power flows? Government policy can negatively effect market mechanisms; e.g. with feed-in tariffs. Mechanisms should be devised that do not restrict consumers, producers and network operators.

11.2 The Integrated Framework

The main points of the new framework are shown in the SmartGrids case. Now, conclusions can be drawn about its usefulness in a case-study. Overcoming the micro-to-macro problem (p.33) and the framework as an add-on to the Multi-Level Perspective are discussed below.

11.2.1 The micro-to-macro problem

The micro-to-macro problem refers to the complexity of translating individual behaviour into a collective outcome. In the original framework Coleman formulates combinations of interactions leading to social behaviour. For the integrated framework this problem has been tackled by introducing the typology of sociotechnical transition pathways. But does the typology provide sufficient guidelines to overcome the micro-to-macro problem?

The typology provides regularities of change in the form of pathway specific regime dynamics, with an empirical base. Together with the use of normative goals it reduces the room to create large differences between the pathways, as is shown in the case-study. The goal of the transition pathways is, in contrast to scenario studies, not to create large differences, but rather to show how micro and meso events can have a major effect on the continuation of the transition. The pathways are based on a line of action rather then an end product, as is often the case in scenario studies. The case-study shows that there is still enough room to formulate various action theories and overcome the micro-to-macro problem.

11.2.2 A MLP add-on

The Multi-Level Perspective is a proven tool to study technical transitions. It relates technical change to interaction between the landscape, regime and niche level. By using the analytical frame, of the MLP, only regime changes can be studied from a co-evolutionary standpoint. The integrated framework changes this scope by including a normative basis. But can the bi-directional orientation add value to the transition management research group?

The objective of the framework and research method is to assess a technical vision, as different interventions can shape the development of new regime configurations differently. By combining a co-evolutionary and a normative orientation it is possible to see what the effect is of meso and micro level forces on the formation of the socio-technical regime. Future studies often provide various scenarios, while stakeholders need ways to test these scenarios. The proposed framework and research method provide a way of doing so.

11.3 Recommendations

The barriers deduced using the new framework can effect the transition towards SmartGrids. These barriers were viewed only briefly and need to be examined in more detail. By studying these barriers, niche actors, can anticipate and intervene flexibly when the situation requires it.

In this paper the framework and research method have been tested in the SmartGrids case-study. By using the research method to study other technical visions the method can be refined and judge based on its applicability.

The framework is a lens that can be used to study technical transitions. The research method is a way of using the framework, but can be adjusted to the specific needs of the researcher. Alternative application of the framework can be devised; e.g. with a pure technical orientation, or viewing the effect of various policy plan on the transition, or by focussing on a specific regime actor.

The framework supports out of the box thinking, where a problem or a desired end state is determined that can be achieved by various interventions. The out of the box thinking methodology is beyond the reach of this thesis. In follow-up studies the framework can be linked to other research frames, to see how they can strengthen each other.

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SmartGrids

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Appendix

A1 Distributed Generation

There is no generally accepted definition for distributed generation (DG) in the scientific community. (Pepermans *et al.*, 2005, pp. 796 – 797) It can therefore be hard to compare the findings of different studies. Here the characteristics are discussed that are most widely used to group DG.

The most distinctive characteristic of DG can be deduced from the term distributed generation itself, as being the opposite of centralized generation. In this case production capacity should not be controlled by a small number of actors, but instead it needs to be spread over many actors. DG producers should thereby be able to follow their own agenda, which might not be the case with Virtual Power Plans – where many small scale generation systems are controlled by a single actor.

The production capacity of the generation systems needs to be relatively small. Some studies only include units connected to distribution network while others include small scale generation systems connected to the transmission network. Often production capacity between approximately 1 and 100 megawatts are used to distinguish distributed generators. (Pepermans *et al.*, 2005, pp. 796 – 797) These generation capacities are small enough to not be able to single-handedly influence electricity markets or cause grid instability.

Finally, there is no need for DG to use renewable sources, but the electricity needs to be consumed in the same local area as it is produced, to keep the transmission losses at a minimum.