Understanding Socio-technical Change

A System-Network-Agent Approach

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PROEFSCHRIFT

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Table of Contents

List of Figures

List of Tables

Introduction

What do ploughs, engines, and telephones have in common? They are artefacts or technologies that have helped propel great changes in society: ploughs enabled humanity's transition from nomads to settlers; engines, from handcraft to serial production; and telephones, from delayed to real-time telecommunication.

The above-mentioned examples portray processes of change within systems. Although these changes are often enabled by new technology, they involve other elements, such as social and economic ones. Such conjugations of several processes of change are referred to as 'transitions' and generally involve time spans of several years. Transitions take place in order to satisfy a latent need in society, be it material (such as the use of turbo propellers that made possible the connection of long-distance destinations in a shorter time) or abstract (such as voting rights for women, and illiterates in Peru). Transitions are complex phenomena due to the intertwining of social and technological aspects: various parties in society are involved in designing, developing, using or discarding artefacts or technologies to satisfy their needs. Transitions often emerge without any intentional push, such as the use of cell phones with their overall mobility and the increasing number of applications coupled to the phone, but are sometimes the result of a specific social desire, such as the use of bio-ethanol in Brazil for light vehicles. Transitions in society happen at different speeds: they can take several hundreds of years, as did the adaptation of living beings to the environment, or a few decades, such as with the spread of the World Wide Web. Transitions sometimes happen smoothly, as with the use of engines in different applications, but also sometimes with shocks, for instance as a result of major incidents like the nuclear calamity of Chernobyl in April of 1986 or natural disasters like the earthquake and ensuing tidal wave in Japan in March of 2011. All in all, transitions as processes of change are present in everyday life and show that people are able to adapt in order to continue with their existence.

In their search for survival and prosperity, people, communities and societies in general are consuming resources while adapting to the existing environment. It is the consumption of natural resources, especially since the industrial revolution, that is having an unwanted side effect: the intensive use of different forms of energy sources to industrially transform raw material is causing the depletion of natural resources, as in the case of oil, or the saturation (Daly, 1990) of the soil, water or atmosphere, as happens with emissions of carbon dioxide and other greenhouse gases (Metz, Davidson, Bosch, Dave, & Meyer, 2007). This situation implies a possible risk to the survival of the industrialised society as it now exists, and this is an important reason why a transition with regard to consumption is widely desired.

1.1. Research background

As societies desire to achieve a sustainable existence and to preserve their lifestyles, they sometimes need to undergo certain transitions. In this sense, a transition can be seen as a process of fundamental change[1]. Although one could wait for such a transition to happen 'spontaneously', one could also take a more active approach by trying to bring about a certain transition, or at least influence the direction or speed of the process. For example, in order to preserve their current way of living, European countries have actively started their transition toward being low-fossil-fuel economies by searching for alternative energy

[1] See Chapter 3 for the specific definition of transitions used in this thesis.

sources while emitting less CO_2. As this is a major transition of society, it requires different processes of change extended to the whole of society, because all together they contribute to the profound metamorphosis.

It is obvious that the dynamics of such complex processes are not straightforward to understand, which makes transitions an interesting object of study. It is useful to gain a better general understanding of how transition processes unfold. Moreover, given the current desire of several countries to (actively) bring about certain transitions, it is worth-while to analyse this type of transition more specifically. Basically, this concerns transition processes for which the direction has officially been declared (by government) and in which one could expect that the government(s) involved would try to influence the transition process. In this research, we refer to this type of transitions as 'desired transitions'.

An example of a small desired transition which contributes to the larger-scale transition towards a low-fossil-fuel economy in the European context is the introduction of 10% bio-ethanol in the gasoline blend for light vehicles in Germany. In December 2010, the German federal government introduced a regulation increasing the percentage of bio-ethanol in the gasoline blend to 10%, following the EU directive 98/70/EC for the quality of petrol and diesel fuels ("Zehnte Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes (Verordnung über die Beschaffenheit und die Auszeichnung der Qualitäten von Kraft- und Brennstoffen - 10.BImSchV)," 2010). This blend has received the name of E10.

Because only minor adaptations to the current (fuel) distribution infrastructure were necessary to accommodate the distribution of this new blend, E10 could already be distributed in the first quarter of 2011. Consumers are supposed to be able to use E10 directly in the existing cars without modifications. Although the German Automobile Trust (Deutsche Automobil Treuhand GmbH) has published a list of car and motorcycle models that are able to run on E10 without problems (Deutsche Automobil Treuhand GmbH, 2011), there is still distrust among consumers: it is not clear to them whether their cars will bear E10 or not and whether or not producers' guarantees will cover any possible damage caused by E10 in their engines (Hawley, 2011). Even car dealers have advised negatively about the use of bio-ethanol in new cars (Deiters, 2011). Furthermore, there are interest groups that point out that bio-ethanol production, based on food crops, happens in conjunction with deforestation (Hawley, 2011). Recently BMW manifested its support to the introduction of E10 on its blog (BMW blog) but states that there are some old types of BMW vehicles which will not be able to cope with E10.

This situation has resulted in a shift by consumers back to the types of gasoline without bio-ethanol, which is placing the fuel distribution system under pressure due to the increased demand of normal gasoline and the imposed quotas of blended gasoline. What initially seemed a relatively simple technological transition – due to the little technological change and investment required – has turned into a difficult task for the German government due to the resistance of consumers to accept the new product. This clearly shows that not only technological issues are relevant in a transition, but also social ones.

Furthermore, even though European policy supports this trend by means of directives which focus on the encouragement of the use of alternative energy sources while promoting sustainable development (European Commission & Directorate-General for Energy and Transport, 2001), the achievement of European countries regarding the transition to a low-fossil-fuel economy varies among countries (Ernst & Young Renewable Energy Group, 2007), as can be seen in Figure 1.1.

The achievements of European countries can be observed in the evolution of the Renewable Energy Country Attractiveness Index, published by Ernst & Young (Ernst & Young Renewable Energy Group, 2007). This index rates the attractiveness of a country for sponsors or financiers based on the opportunities in renewable energy markets and renewable energy infrastructure and their suitability for individual technologies. Countries like the Netherlands and Spain exhibit a decreasing index (despite their governments' commitment to the achievement of a certain target share of renewable electricity by 2020), while for Belgium and Greece the index is on the increase. For countries like Germany and France the index has remained more or less the same since 2005.

As can be seen, a technological replacement such as the introduction of bio-ethanol in the gasoline blend in the German fuel market is difficult to achieve. If such a relatively straightforward desired transition encounters hurdles, it can be inferred that the introduction of innovations or even inventions, or the change of large-scale infrastructures, will be doomed from the outset. The reason may be that for these larger transitions significant investments are necessary, or that major adaptations to (or even total replacement of) infrastructures and goods are unavoidable. At the same time, social change may be required, including the modification of behavioural patterns, the adjustment of perceptions and expectations, or support from a critical part of society. It seems that the achievements of European countries regarding the transition toward low-fossil-fuel economies will remain limited due to the complex nature of the transitions: these countries are focusing on technological solutions, while the social aspect of the transition has so far been neglected.

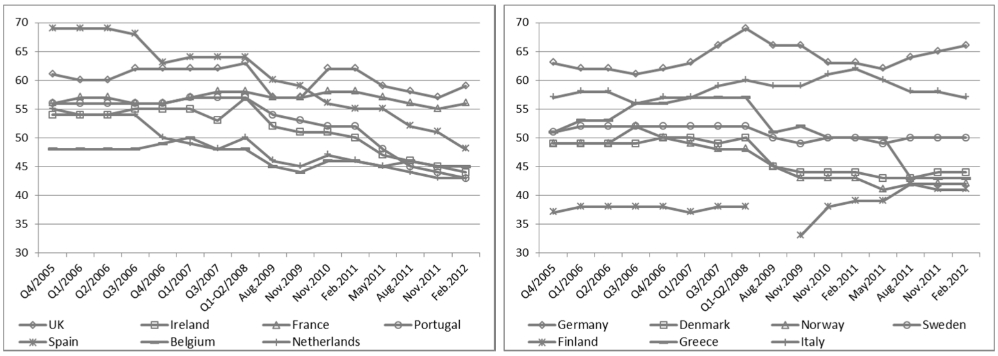

Figure 1.1: Renewable energy country attractiveness index (Based on: (Ernst & Young Renewable Energy Group, 2007))

1.2. Understanding the complexity of transitions

The above example of the introduction of bio-ethanol as an additive only (not even as an independent fuel) in the gasoline blend in Germany has shown the true nature of transitions: they are complex phenomena because several issues play a role at the same time.

One issue relates to the fact that the current systems in transition include social and technological components (Geels, 2002). They involve not only artefacts, techniques and technologies, but also different kinds of societal actors, such as government, producers, consumers or interest groups. Each of these groups have their own particular instruments with which to execute changes in society: government develops legislation, producers create goods, and consumers and other groups within society can show acceptance and trust. The predicament is how to deal with the social and technological aspects of a desired transition simultaneously.

A second issue refers to the different types of interaction that exist within the systems in transition. Each actor has his or her own problems, interests and resources (H.

de Bruijn & ten Heuvelhof, 2000; Teisman, 1998), but for a transition to happen they are dependent on each other; the interacting actors should form a network. Moreover, there can be networks of technologies, for instance of technologies that reinforce each other, such as smart phones and Internet applications ('apps'). If different technologies reinforce each other, this may support a transition: they may bring about a particular (new) technological paradigm that could be sustained in society. However, a mismatch between technologies may hamper a transition. Additionally, there also are different types of social and economic arrangements between actors, such as legislation, institutional arrangements or contracts. The dilemma is how these networks and arrangements can be harmonised so that the system as a whole benefits and that losses are minimised for as many parties as possible.

A third issue is the point of view taken to grasp a transition. Transitions can be appreciated at different levels of aggregation: one could see a system that changes from one paradigm to another (e.g. from a fossil-based to a low-fossil-fuel economy) as networks that transform the interactions between actors and technologies (e.g. the adoption of new legislation); or one could consider the transition at the level of individual agents (actors or techniques) that adapt to the existing environment. The difficulty here is that once a level of aggregation is fixed, it seems hard to keep in mind how other levels are affected once a change is introduced.

A fourth issue is the scope of transitions. Transitions involve the change of large-scale systems, such as the energy infrastructure and the political and legislative arrangements that support the functioning of this infrastructure. This means that several major changes have to occur at the same time. Also, it implies that changes take place over long periods of time, this being several years or decades. When studying transitions, the challenge is to pinpoint the moment which could be considered the start of a transition as well as that when the system has reached the (relatively) stable state which 'ends' the transition process.

A fifth issue is the difficulty in foreseeing the impact of a certain transition on society. If we see societies as systems composed of networks of agents, the changes in the system are difficult to foresee due to the interconnectedness of agents through those networks. Even trying to be ahead of undesired changes in order to avoid unwanted consequences has proven to be difficult. Already in 1970s, Meadows, Meadows and Randers (1972) and Kahn, Brown and Martel (1977) did research on possible global scenarios regarding the use of natural resources. Thirty years later, Meadows, Randers, & Meadows (2004) have shown that little has happened to change the forecasted trend of depletion of natural resources despite the efforts of several parties, such as the Club of Rome, to warn about it.

As it can be seen, transition processes are complex, and hence it is difficult to analyse them and grasp their dynamics. Consequently, it is not easy to identify the catalysts in a transition process and suggest what could be adequate instruments to affect the current state of the system or to identify the relevant actors at different instances of society with enough commitment to help introduce the changes in a viable way so that a desired transition can occur. This predicament appeals to carrying out research to better understand transitions in general, which is in turn expected to be helpful in shaping desired transitions.

1.3. Relevance and objective

Considering that societies – or parts of them – may want to bring about certain 'transitions', but that such processes are complex, difficult to steer, and even more challenging to be ahead of and to cope with, it becomes clear that there is a societal need for the study of transitions.

Socially, three needs are identified. The first is to understand how transitions happen (with a focus on *desired* transitions) and what kind of signs show that systems are ready to undergo a transition. By understanding this, societies could be better prepared to recognise the occurrence of transitions and be more aware of the 'windows of opportunity' for the introduction of changes to a particular system.

The second need is to comprehend how transitions are triggered in a particular system and which parts of society need to be set in motion to achieve certain objectives. With this it is essential to find an approach that helps identify significant elements for (desired) transitions in a particular system and to grasp how these elements connect with each other so that a transition can occur. Particularly when there are different stakeholders in society, the importance lies in recognising what instruments are available for each party to influence such transitions. In this way, it is expected that the choice of suitable transition monitoring indicators will support stakeholders in measuring their impacts on transitions.

The third is to study whether transition processes can be steered in order to prevent foreseeable consequences of current practices. This includes the analysis of the available levers for steering transitions. Specifically for policy makers, this thesis intends to provide some insight into the consequences of their decisions before the implementation of new policies with respect to (desired) transitions by providing a basis for the modelling and simulation of transitions.

Because of the complexity of transitions, it has been suggested that current practices of governance for steering transitions are not sufficient. 'Transition management' (Rotmans, Kemp, & van Asselt, 2001) has been introduced as a new mode of governance, one which is still in development (Sondeijker, Geurts, Rotmans, & Tukker, 2006). Transition management is based on the presumption that the transition process can be influenced and steered towards the desired direction. However, this requires a thorough understanding of how transitions happen (See (Frantzeskaki, 2011)).

Therefore, we identify a general scientific need to understand the dynamics and complexity of transitions, with special attention to 'desired transitions'. More specifically, because this research is carried out in the field of study of technology and policy, we are mostly interested in transitions of socio-technical systems. We call these transitions 'socio-technical transitions'. Examples of this type of transition are the introduction of electric lighting or the (desired) transition to a low-fossil-fuel economy in Europe. By studying real-life cases of transitions we can perhaps gain a better understanding of how such processes evolve and what mechanisms play a role.

With a view to the analysis of such socio-technical transitions, we see a need to find (or if necessary, develop) theories that can describe the phenomenon of a socio-technical transition in such a way that both the social and the technical aspects are taken into account in a balanced manner. In this way, attention can be paid to both dimensions, and this could improve communication of researchers with policy makers about the nature of transitions.

Additionally, it seems important to be able to comprehend (socio-technical) transitions from the point of view of institutional economics, as transitions normally involve the re-structuring of existing institutional arrangements, the opening up of existing markets to new goods, services or parties, the acceptance of novelties by society, or large investments with uncertain result.

Our literature review (See Chapter 2) will reveal that there is neither a theory nor a conceptual framework available which can deal with the social, technical and economic aspects of transitions in a balanced manner, which underlines the (scientific) need to develop at least a conceptual framework and, if possible, a theory. Although such a framework could probably be applied to socio-technical transitions in general (both 'spontaneous' and 'desired' transitions), we shall focus on desired transitions if any (practical) limitation of the research is necessary. In the case of 'desired transitions', there is an officially established direction for the transition, and the official authorities ('government') can be expected to try in several ways to influence the transition in order to achieve the stated objectives. Government makes a policy and uses its policy instruments to influence the course of the system. This central role of government and its policy means that these 'desired transitions' constitute the class of transitions that is of prime interest for this research in the field of technology and *policy*.

Moreover, we do not only identify a (scientific) need to develop a framework that simply integrates the different relevant dimensions of socio-technical transitions; it could furthermore be useful if such a framework were also to be a suitable basis for modelling the process of a transition with a view toward the simulation of (parts of) that process. The simulation of (parts of) a transition could help researchers in their exploration of the dynamics of (potential) transitions and could assist policy makers in their *ex-ante* evaluation of (policy) measures. Because our literature review showed that neither such a framework nor a method to transform a real-life case into a useful model for simulation yet exist, we identify this as another (scientific) research need.

Therefore, it is crucial to investigate in this research the extent of the support that modelling, as simplification of reality, can provide toward the understanding of transitions, particularly when the models can be used as a basis from which to perform simulations, as this may contribute to the (theoretical) exploration of how transitions occur, taking into account different (sets of) objectives and instruments. This might provide insight for the management of transitions.

The social and scientific relevance are translated into a research objective:

> *To gain a better understanding of how (socio-technical) transitions evolve, by developing a systematic approach for the analysis of transitions and applying that in the study of real-life transition cases, with special attention to the possibility of modelling transitions in such a way that the models can serve as a basis for simulation.*

As explained above, we have limited this research to the study of transitions of socio-technical systems, with an emphasis on desired transitions. It is important to note that we have not limited this study to a certain (geographical) area; in principle we consider transitions anywhere in the world. Moreover, this research is primarily about the analysis of how transitions develop. This involves questions such as what are the relevant actors for a socio-technical transition, what are the triggers or catalysts for a socio-technical transition, what is the effect of policy measures, how do actors interact, and how are the different domains of e.g. technology and society connected. This means that this research is not about 'transition management' (as a new governance approach focusing on developing intervention strategies to steer transitions). Nevertheless, our study of how transitions evolve (in particular from the case studies we examined) offers more insights into the issue of the extent to which (socio-technical) transitions can be influenced (or even steered). It also provides some information about certain intervention strategies and levers for transitions.

1.4. Main research question

As explained in the previous section, there is a social and scientific need to understand transitions. Such an understanding is expected to help societies to more effectively cope with long-term processes of change. The research objective has been translated into a main research question to guide the whole study. The main research question is formulated as follows.

> *Is it possible to design a method and a conceptual framework which are suitable for the systematic analysis of socio-technical transitions (covering the relevant social, technical, economic and policy dimensions) and which could help explain the dynamics of such transitions?*

This main research question has been broken down in the following secondary research questions. The first three sub-questions relate to the conceptual framework that can be used to describe socio-technical systems in transition and to a method to systematically analyse actual transitions.

1. Which levels of aggregation should be taken into account in a conceptual framework to describe large-scale socio-technical systems in transition, and what are the relevant elements at each level?
2. Can we find (and if not, propose) a method that can be used to systematically analyse transitions?
3. To what extent can the selected conceptual framework and method for studying transitions support modelling with a view to simulation?

The selected conceptual framework and method are applied in two elaborate case studies of actual (desired) transitions, which lead to the last two sub-questions.

4. What lessons can be learned from the studied transition cases
   a) with regard to the utility of the conceptual framework and method, and
   b) regarding the dynamics of (desired) transitions of socio-technical systems?
5. Based on the studied cases, to what extent does it appear possible to design intervention strategies to steer and/or speed up desired transitions?

Question 1 focuses on the search for a framework that helps identify, first, the 'levels' of aggregation in socio-technical systems that are relevant for the conceptualisation of such systems in transition. Subsequently, we try to identify the relevant elements at each of these levels, such as the actors in society that take part in transitions. We expect that this framework can help clarify transitions as a coherent whole.

Question 2 concentrates on the search for a method that allows a researcher to analyse socio-technical transitions in a systematic way. After the selection of case studies it provides the researcher with a strategy to cope with the richness of information of such a transition case and to transform the available information into qualitative models.

Question 3 aims at finding the added value of the framework and the method for modelling for explanatory and communication purposes. Moreover, we analyse whether the structure of the framework and the method provide a basis for quantitative modelling, with a view toward computer simulation to allow exploratory purposes.

Question 4 focuses on the obtainment of lessons from two actual transition cases that were studied, by applying the framework designed in question 1. In the first case, the framework and the method are verified for their workability. This case is related to a transition at the front end of a supply chain (different raw material to produce fuel for transportation), which is an example of depletion of resources (as interpreted by Daly (1990)). In the second case, the revisited framework is validated for its usability with a transition case at the back end of a supply chain (the transformation of garbage into raw material or new products). This is an example of saturation (as interpreted by Daly (1990)). In addition to the results of the validation, the case studies also yield several lessons about the dynamics of the studied transitions, which may help us to gain a better understanding of these processes of change of socio-technical systems.

Question 5 concentrates on transforming the findings from the case studies about the dynamics of transitions into an assessment of the circumstances under which we can expect that the transition process of a socio-technical system to be influenced and the implications of that for shaping desired transitions.

1.5. Reader's guide: structure of the thesis

The main research question, decomposed in the secondary research questions, is dealt with in this thesis as follows. With a view to provide an answer to sub-question 1, we first perform a literature review, which can be found in Chapter 2. This literature review looks for perspectives that define the nature of transitions, identify the relevant aspects of transitions, and offer a generic framework to describe and explain transitions respecting the dual nature of systems in transitions: being both social and technological.

As the literature review shows that there is no suitable generic framework for the study of transitions, in Chapter 3 we propose a framework to study transitions. This chapter begins with the definition of three levels of aggregation and a basic set of relevant elements at each level that, in our view, are necessary to describe transitions. Then a method is presented with which to study transitions and which answers sub-question 2. This method includes a case study design to search for the necessary information and to apply the framework for analysis, as well as a strategy for the qualitative modelling of causal relations and agents to simplify the information of the case study in such a way that a functional design suitable for computer simulation is done.

Next, the framework and the method are applied to two case studies in order to address the workability of the framework and the method and to perform a substantive review of two transition cases. The applicability of the designed framework is first tested with a case related to the consumption of natural resources. This case is the transition to sugarcane ethanol as fuel for light vehicles in Brazil and is presented in Chapter 4. As this is a test case to verify the framework and the method proposed in Chapter 3, small adaptations to the framework are presented at the end of Chapter 4. Additionally, the lessons about the dynamics of transitions obtained from this case are also presented.

The same framework is applied to a case related to the disposal of used materials in order to validate the usability of the framework. This case is the transition to a supply-chain approach for the treatment of household waste in the Netherlands and is presented in Chapter 5. Together with the substantive review of this transition case and the extraction of lessons, the framework is also reviewed for adaptations.

Chapters 4 and 5 further illustrate how transitions can be modelled (sub-question 3). Moreover, these chapters present the lessons about the dynamics of transitions obtained from each (separate) case study (which relates to sub-question 4) and explore the possibility to influence transitions (sub-question 5).

In the Conclusion of this thesis, the answers to the secondary research questions are presented. Here, the final design of the method and the framework is depicted, together with the basic elements for a functional design of agents (which form an important basis for modelling and possible simulation). In addition, we make a confrontation of the two case studies in order to draw lessons about transitions based on that comparison, which further answers sub-questions 4 and 5. As a result of these answers, an answer to the main research question can be found at the end of the Conclusion.

Considerations on the research topic, project and process as well as issues for further study are presented in the Reflection. A schematic view of the link among chapters is presented in Figure 1.2. Figure 1.2 also shows the improvement process of the framework for analysing and modelling transitions by applying it first to the transition in Brazil and later to the transition in the Netherlands. As a result of this improvement process, the final design of the framework is reported in the Conclusion.

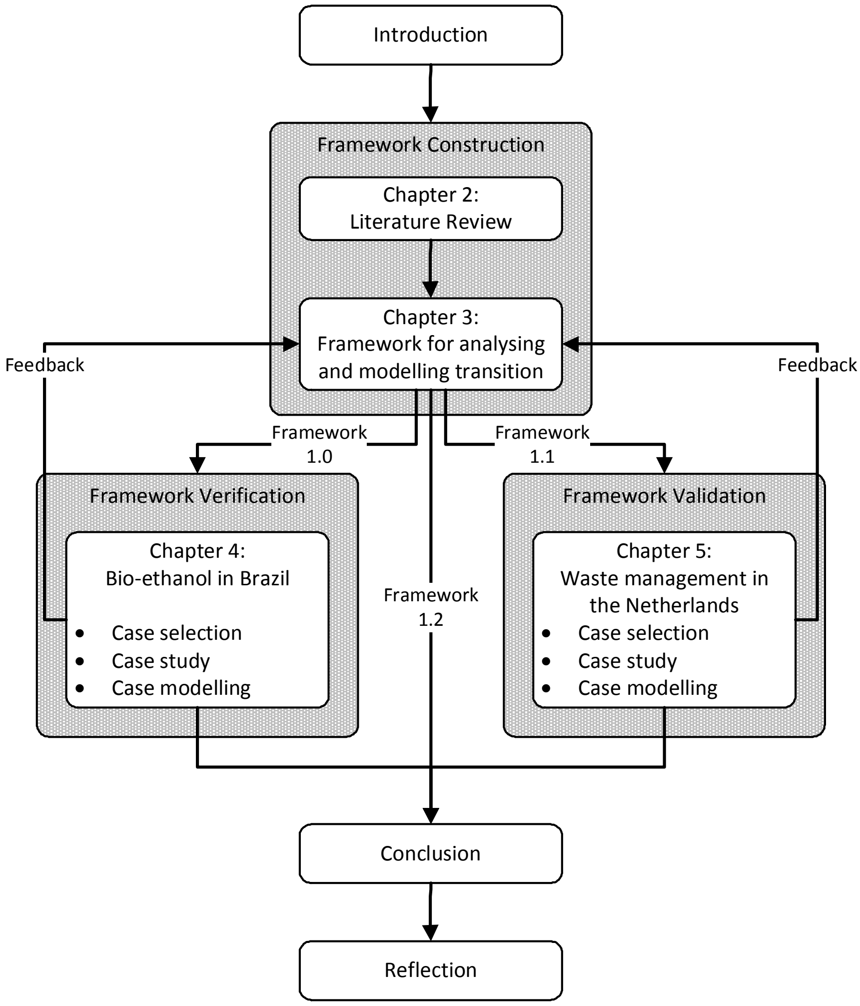

Figure 1.2: Structure of the thesis

Chapter 2
Literature review for the analysis of transitions

The Oxford English Dictionary on Historical Principles defines a *transition* as "the action or process of passing from one condition, action or (occasionally) place, to another" (Brown, 1993). This definition explains that a transition has a dynamic character because it is a process of change from an existing state of affairs to another one. This definition is applicable to all types of transitions. This broadness, however, makes necessary to operationalise it in order to focus on the relevant elements that play a role in the transition of large-scale socio-technical system.

2.1. The search for a definition

Although (the process of) change have been mentioned in the past in different ways, researchers in the Netherlands are mostly 'concerned with fundamental changes in functional systems of provision and consumption' (Kemp, 2010). Kemp (2010) recognises four traditions in the transition thinking in the Netherlands. From these four traditions, only '… the work on sociotechnical transitions by Frank Geels and others, the work on transition management by Jan Rotmans and others …' use the term transition to hint at change and the process of change (at the same time) where technology plays a transformative role (Kemp, 2010), specifically to achieve 'greater sustainability (Sondeijker, et al., 2006)'. The other two traditions differ from the focus here sought: the social practices approach concentrates on transitions of practices in everyday life (See e.g. (Shove, 2004; Spaargaren, 2003)) while the reflexive modernisation approach puts emphasis on the relevance of power, legitimacy and conflict in the change of governance aspects (See e.g. (Voß, Smith, & Grin, 2009)) (Kemp, 2010). However, they can be a valuable input for future research in the identification of the transition specificities in each domain.

Considering the need to introduce changes in existing societies and within the traditions of socio-technical transitions and transition management, definitions of transitions have been found. A sample of those definitions is presented in Table 2.1.

As it can be seen, a transition is here defined as process of change of existing social structures (institutions, culture and practices) where technology plays a role to abandon existing paradigms, mainly to achieve sustainability (Elzen & Wieczorek, 2005). At the same time, these definitions of transitions also recognised the need of an interdisciplinary approach for understanding transitions given the multi-disciplinary nature of this phenomenon (Rotmans, 2003). The interaction among different domains – expressed in those definitions – and this need for an interdisciplinary approach coincides with the principle of multiple formalisms, as introduced by Mikulecky (2001) within the field of complex adaptive systems. Interpreting Mikulecky, the real world is complex by nature and it is not possible to capture with any single formalism all properties of a system. Different disciplines (that are not derivable from each other (Mikulecky, 2001)) are necessary understand and model a system. The environment is a domain that attains a particular place in these definitions. Elsewhere, it has also been recognised the strong interaction of humankind and nature and that its "global scaled, social and technological project" affects the ecosphere in multiple ways (Broekaert & Weyns, 1999).

Furthermore, society and its complex sub-systems are the basic units of analysis in this definition. As such, transitions originate from system innovations arising from project, product and process innovation (Rotmans, 2003). Therefore, it can be said that "the re-identification of concepts and redefinition of relations between entities or systems" are relevant mechanisms behind transitions (Broekaert & Weyns, 1999) because by reidentifying and redefining, change - understanding it as transition – is constantly present in every activity in society. The perspective of transition as a process of continuous change is also included in the definition above. However, it has a deep contrast with a later conceptualisation in the management field in which there is a matter of small and long transitions, even assigning a certain amount of years to it (Rotmans, 2003). Additionally, and if the perspective of complex adaptive systems is taken, the constant learning process of agents imply that any system is in dynamic balance and, even in equilibrium, it is always adapting.

Table 2.1: Definitions of transitions

Author	Definition of Transition
(Kemp, 1994)	It is a change in our basic technologies of production, transport and consumption rather than modifications of existing products and processes or the adoption of end-of-pipe technologies.
(Rotmans, et al., 2001)	Transition is a gradual, continuous process of change where the structural character of a society (or a complex sub-system of society) transforms.
(Rotmans, 2003)	A transition is a structural societal change resulting from the mutual influence and mutual reinforcement of developments in the domains of economics, culture, technology, institutions and nature & environment.
(Rotmans, 2005b)	A transition is a structural societal change that is the result of economic, cultural, technological, institutional as well as environmental developments, which both influence and strengthen each other (Rotmans et al. 2000).
(Elzen & Wieczorek, 2005)	A transition denotes a long-term change in an encompassing system that serves a basic societal function (e.g. food production and consumption, mobility, energy supply and use, communication, etc.).
(Geels, 2006)	Transitions from one techno economic paradigm to another are complex and co-evolutionary processes. A new technology emerges in a world that is still dominated by the old paradigm, and demonstrates its advantages first in one or a few sectors.
(Loorbach, 2007)	Transitions are transformation processes in which existing structures, institutions, culture and practices are broken down and new ones are established.
(Voß, et al., 2009)	Transitions to sustainability consequently imply a destabilizing of existing socio-technical structures as well as nurturing alternative systems that can fill the opportunities created by structural change.
(Frantzeskaki & Haan, 2009)	A transition is understood as having occurred when the societal system functions in a different way for which the composition of the societal system had to change fundamentally.

Additionally, it has been stated that it is possible to alter the direction and the speed of transitions with the creation of right initiatives at the right moment (Rotmans, 2003). Indeed, agents in complex adaptive systems are constantly creating new opportunities to be used to cover gaps in society (J.J. Holland, in (Waldrop, 1992)). This means that complex adaptive systems are always changing and a stable state could not be achieved. This denotes that novelty is another property of complex adaptive systems, and therefore, of systems in transition. However, finding the 'right initiative' or 'the right moment' may be difficult to achieve due to the constant change of the system.

In the same line, it is said that transitions can be managed by taking a system perspective, while creating space for agents to build up alternative regimes (Rotmans & Loorbach, 2009). Although it has been acknowledged that systems in transition are complex, the knowledge gap with the management of transitions is that it has little correspondence with the property of complex adaptive systems regarding the controllability of the system. Complex adaptive systems are formed by agents, which continuously revise and rearrange their building blocks as they learn in time due to their parallel and interacting behaviour; these agents are arranged in networks, and act in parallel and interact with other agents, which results in a decentralized control of the whole system (J.J. Holland, in (Waldrop, 1992)). This means that it might be very difficult to steer the whole system from a central position and towards a particular direction.

Additionally, transitions can have desirable as well as undesirable consequences: "(Transitions) can be welcomed and induced, but as well, unwanted and without identifiable origins or without definite causality, ultimately beyond mankind's control." *(Broekaert & Weyns, 1999)*.

This means that societies face two types of transitions. On the one hand, there are spontaneous transitions, which occur without any conscious actions of agents to change the whole society; on the other hand, there are goal-oriented/desired transitions, in which agents expect changes in society and in which agents may need to work together to achieve those social changes.

Nevertheless, agents in complex adaptive systems try to foresee the future with models of reality, the refinement of these models, and the application of those, but their capacity to do so is limited (J.J. Holland in (Waldrop, 1992)). This makes any welcomed or induced transitions difficult to foresee.

Due to changes at different ranges of time scales, decision making by a variety of actors, multiple types of interaction and information exchange, the phenomenon of transitions has to be defined as complex. In this context, it appears difficult to create and select proper initiatives and find the adequate timing for implementing them. There are several factors affecting transitions, such as path dependency or new knowledge, which are beyond the reach of a 'transition manager'. Also, the attainment of common objectives will depend on the equilibrium of the diversity between stakeholders and the coordination among the relevant stakeholders involved in a transition.

Based on the discussed definition of transition and to close the knowledge gap between complex adaptive systems and the management of transitions, the next sections will present a literature review to give an answer to the following secondary research question 'Which levels of aggregation should be taken into account in a conceptual framework to describe large-scale socio-technical systems in transition, and what are the relevant elements at each level?'

To provide delimitation to this search, we consider the object of our study large-scale socio-technical systems in transition. These systems are conceptualized as sets of human beings plus their means (Szántó, 1999). These systems include people and their artefacts with techniques produced and used; in other words, it is a combination of society and technology, where actors influence each other and give shape to the future technology based on the current knowledge and artefacts (See Figure 2.1). It has been argued that these socio-technical systems evolve (Nikolić, Dijkema, & van Dam, 2009) and follow a particular path depending on the choices made, creating fixation to existing social arrangements or technologies, better known as lock-in effects.

This literature review will be executed while taking into account the following issues:

- Theories dealing with social and technological aspects
- Theories dealing with the arrangements between these two sub-systems, with an special emphasis on policy and economic arrangements
- Theories that simplify reality in such a way that thought experiments can be done.

This search will be done while keeping in mind the perspective of complex adaptive systems. The focus of the literature study will be on the topics of technology and society (to address the main components of a socio-technical system), complemented with institutional economics and actor-network theory (to address the liaison between the social and the technological parts of the system). The four fields will be used to define, describe and provide an explanation of the underlying mechanisms of transitions as processes of change. Therein, it will be sought a definition that can reconcile aspects of the management of transitions and the properties of complex adaptive systems.

In the next section, technology will be dealt with from the innovation perspective. Then, section 2 will introduce the social perspective of change. Later, section 3 will deal with the institutional economics perspective. Afterwards in section 4, the perspective of networks and its change is presented. Finally, a synthesis on the reviewed perspectives will be provided, in which the strong point of each perspective, their knowledge gaps and the commonalities among perspectives are addressed.

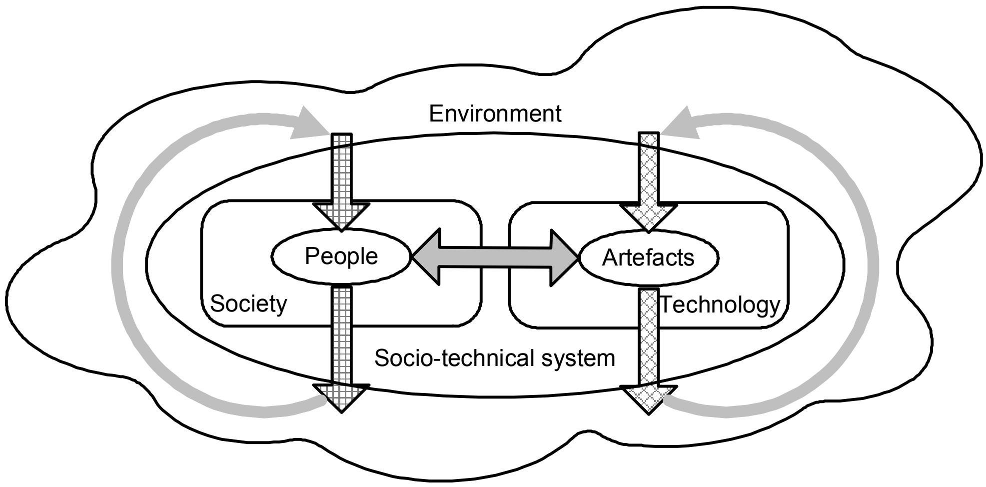

Figure 2.1: Conceptualisation of socio-technical systems

2.2. Technological perspective

This perspective portrays the technological view on transitions while including some social aspect in the form of social agreements and some economic features.

Within this perspective, transitions were initially defined as processes of transformation from a technological (set of) regime(s) to another, being technological regimes sets of rules – science, techniques, routines, practices, norms and values – that totally describe a technology or an organisation mode (Kemp, Rip, & Schot, 2001).

Later, technological transitions have been defined as 'a change from one, more or less stable sociotechnical configuration to another' and this definition is applied at the level of sectors fulfilling a societal function, such as transportation, housing and communication, while recognising technological change as an inherent element of transitions (Geels, 2002), rather than an input to it. Within this technological point of view, transitions occur because a niche – or novelty – succeeds to be aligned with developments at regime level and socio-technical landscape (Kemp, et al., 2001). In other words, a new technological paradigm replaces the existing one by being shaped by individual technological attempts – niches – to break through the current paradigm and the social and physical constraints – socio-technical landscape – (Geels & Kemp, 2004). This perspective, lengthily developed by Geels (2002), focuses on understanding fundamental technological regime shifts while indicating the relevance of the relation between economics and technological change. In this perspective, Geels (2002) addressed socio-technical regimes by studying seven dimensions from which five of those dimensions are dedicated to technology, one to policy and one to economics. Figure 2.2 synthesises the Multi-Level Perspective (MLP) of Geels. Here, transitions start with the activation of a (technological) niche at the micro-level; this niche displaces an existing regime at the meso-level; the displacement of the existing regime is supported by landscape conditions at the macro-level. The way transitions are here explained neglects the role of factors constraining the activation of niches (e.g. lock-in effects, scale benefits, network effects) as it focuses on radical technological change. Figure 2.2 also includes the topics that could be helpful to incorporate so that technological replacement could also be explained by this framework.

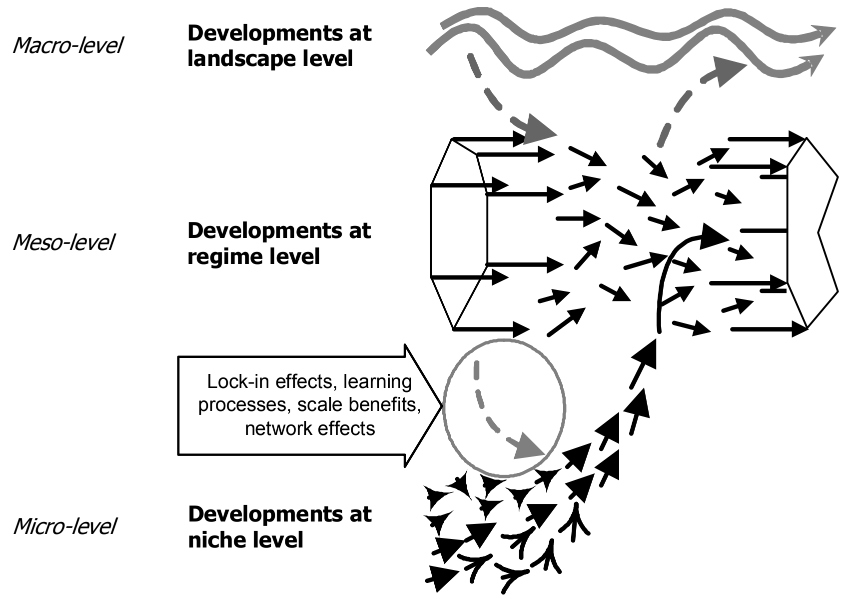

Figure 2.2: Landscape, regimes and niches (Adapted from (Geels, 2002)

Another way to look at technological change was proposed by Hekkert, Suurs, Negro, Kuhlmann and Smits (2007). Here, the unit of analysis is an innovation system. The scope is reduced to a specific technology as a way to limit the complexity of the system. The diffusion of a technology can be encouraged or blocked by the performance of seven functions (Hekkert & Negro, 2009):

'1. Entrepreneurial activities
2. Knowledge development (learning)
3. Knowledge diffusion through networks
4. Guidance of the search
5. Market formation
6. Resource mobilization
7. Creation of legitimacy / counteract resistance to change'

Hekkert et al (2007) already mentioned the following shortcomings: (1) quasi-static analysis of innovation systems and (2) the emphasis on the institutions of the innovation system, rather than individual entrepreneurship. Specially the last contradicts with the first function of the innovation system approach.

Elsewhere, fundamental regime shifts are considered as one type of technological change, which is related to the choice of a new (radical) technological paradigm; another type of technological change is related to changes along an existing path (Dosi, 1982). Related to the latter, technological evolution happens in long periods but with incremental change as the main mechanism and, eventually, discontinuous changes, where path dependence shape the future technology and path creation puts forward technologies that break with past configurations (Baum & Silverman, 2001).

Later on, technological transition has been related with sustainability and, while the system now includes somehow a social aspect, transitions have been redefined as the application of a search heuristics for finding solutions to problems considering the economic consequences of such solutions (Geels & Kemp, 2004). When elements and rules of several domains arrive to a coordinating mechanism around a particular technology, it is possible to talk about a socio-technical regime (Geels & Kemp, 2004).

Current transitions to sustainable schemes rely mostly on technological developments under the assumption that those will provide more benefits (Vollebergh, 1989). However, this trust might be misleading because technology, on the one hand can create wealth or prevent losses, and on the other hand can consume and destroy wealth (Garud, Nayyar, & Shapira, 1997). In this sense, technological foresight refers to the adoption of a successful technology (and therefore creating wealth) or to the not adoption of an unsuccessful technology (and therefore preventing losses), while technological oversight refers to the adoption of unsuccessful technologies (and therefore creating losses) or to the not adoption of successful technologies (and therefore preventing wealth) (Garud, et al., 1997). An example of losses is the side-effects of earlier technological development that currently affect the environment (Vollebergh, 1989), such as the ozone hole provoked by the use of chlorofluorocarbons (CFCs) in sprays or in refrigerator units.

To exert some influence on the direction of the transition, it seems important to consider other factors, such as economic impacts, social structures, and the fixation of well-established technological paradigms, as well as their sources, so that losses to society could be prevented or at least minimised. For example, path dependence is a factor that can hinder transitions. Bassanini and Dosi (2001) relate path dependency with:

'(a) the cumulative characteristics of knowledge accumulation,
(b) the nature of organisations (…) with their "epistatic correlations" in behavioural traits, mechanism of coordination, routines, patterns of organizational learning,
(c) the externalities and dynamic increasing returns that the process of economic growth most often entails,
(d) the network of social relations path dependently constraining and shaping the action sets, decision algorithms, and preferences of agents, and more generally,
(e) the very nature of institutions as "carriers of history"'

Irremediably, path dependence pervades multiple aspects of society and, as such, there is a certain degree of 'lock-in' effect present. However, it can have a temporal nature if good sources of 'de-lock' can emerge from of new technological paradigms, the variety of actors in society, the coevolution of socio-economic adaptation processes in society, or the irruption of other forms of organisations from elsewhere (Bassanini & Dosi, 2001).

Additionally, it seems relevant to keep in mind that technological replacement or gradual regime shifts towards a particular technology are also a form of transition and that learning processes, lock-in effects, path dependence and scale benefits play a role in the choice of a transition path.

2.3. Social perspective

This perspective presents the social view of the dynamics of transitions while including some technological aspect in the form of objects and some economic features when dealing with control over resources.

For Coleman (1990), the social sciences focus on the explanation of the system behaviour as a whole when analysing social systems and, in order to study a social system, two approaches can be used: on the one hand, the system in its entirety is studied by sampling cases of similar system behaviour or observing the system behaviour in a certain period; on the other hand, the system is analysed by studying its component and internal processes. Coleman (1990) though acknowledges the relevance of studying transitions of social systems by means of its individual elements as socialized elements of the system and not as a plain aggregation of individual behaviour. Hedström (2006) further develops this view by stating that '[i]n sociology the basic entities of a mechanism [of action and interaction] always tend to be actors, and the basic activities tend to be the actions of these actors.'

Based on the above-mentioned, transitions in social systems occur at two different but interconnected levels of aggregation: system – i.e. macro / upper – level and individual – i.e. micro / lower – level where three types of developments occur: type 1 corresponds to dynamics from system-to-individual; type 2 describes actions of individuals; type 3 relates to changes from individual-to-system (Coleman, 1990). In other words, three types of mechanisms are present: type 1 – or situational mechanism – corresponds to events or conditions that influence individuals, type 2 – or action-formation mechanism – describes to the way individual adjust to the influence coming from system level and type 3 – transformational mechanism – relates to how a system changes based on the aggregation of individual behaviour and the interaction among those individuals (Hedström & Swedberg, 2007).

Figure 2.3 portrays the interconnection of dynamics between the macro and the micro level as well as the mechanisms behind these dynamics.

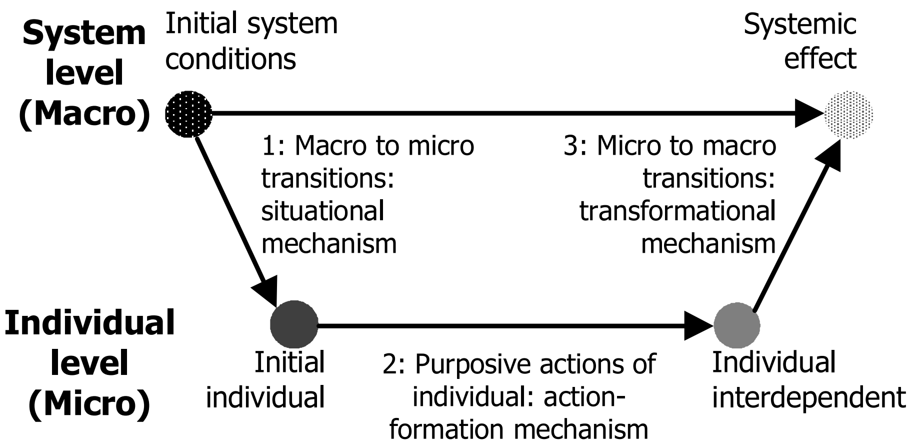

Figure 2.3: Relation between system and individual (Based on (Coleman, 1990) and (Hedström & Swedberg, 2007))

Additionally, actions of individuals can be conceptualised as the result of what actors believe or desire and the opportunities these actors have (Hedström, 2006). The differences in believes, desires and opportunities can help distinguish different roles of actors in society.

The individuals' actions produce diverse system's behaviours depending on the combination of individuals involved and the context around the individuals. In this sense, this social theory of system behaviour (Coleman, 1990) elaborates on the development of rules that a certain group of individuals use and apply, given the effects between system and individual levels. Depending on the combination of individuals involved and the context around the individuals, they produce interdependent responses or actions. These actions produce diverse system's effects and the behaviour of the system therefore changes.

Here, the system level is an abstraction of the combination of individual interdependent dynamics and the results thereof at a higher aggregation level, which is also perceived as an emergent property of the system (Coleman, 1990). Individuals in this context represent either persons or groups of different sizes (From local associations to nations, including local and transnational companies). These individuals have interests and perform control over things in order to realise their own interests.

For defining a (sub-)system, three elements are required: actors, things and the initial distribution of control of resources among actors (Coleman, 1990). In this context, things can be resources, issues or even events (Timmermans, 2004). Figure 2.4 presents a graphical representation of these three elements.

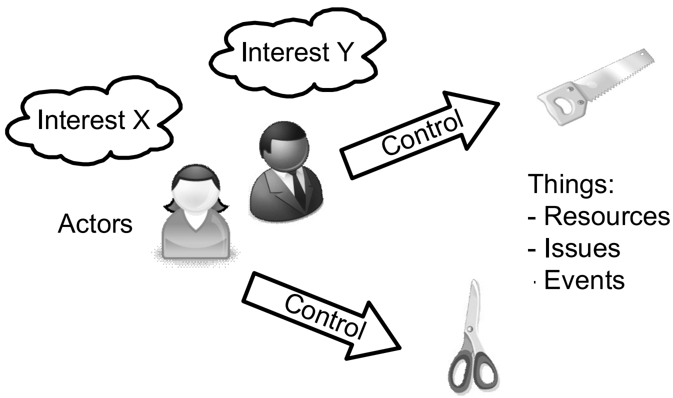

Figure 2.4: Elements of a social system (Based on (Timmermans, 2004))

Actors, based on the realisation of their own interests and depending on the context and the recipient of the action, can perform direct control over things, transfer the control they have or make transactions with other actors (Coleman, 1990). Figure 2.5 portrays the activities actors can perform.

Two additional concepts need to be taken into account: these are the power of an actor to control events and the value of events based on the interest of actors (Coleman, 1990). In this sense, it is made clear that power is an attribute of an actor as well as value is for an event within a system.

The relation between actors is of two kinds: simple, if the relationship is self-sustaining in time or complex if the relationship depends on third parties (even for a two actor system) for maintaining their relationship (Coleman, 1990). Complex relationships are of the interest of this research since social organisations are built upon this kind of relationships, which in turn are based on a structure of obligations, expectations and incentives.

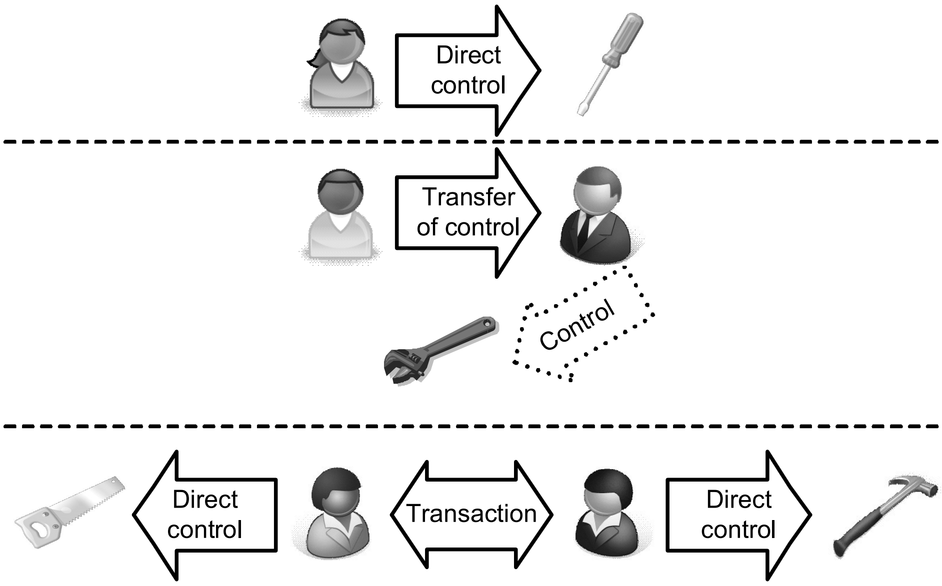

Figure 2.5: Actions of actors (Based on (Coleman, 1990))

This social theory of system behaviour elaborates on the development of rules that a certain group of individuals use and apply, given the effects between system and individuals. Coleman's social theory of change (1990) includes a mathematical foundation of social change based on Neoclassical Economics Theory, which assumes technology as given and fixed in the analysis of social dynamics.

2.4. Institutional Economics perspective

Institutional Economics provides another perspective to understand the process of institutional change and changes in the system based on the interactions between actors and the environment (North, 1990).

The elucidation of what an institution is depends on the focus of the author (See Table 2.1). The commonality among these descriptions is that institutions are social constructions to standardise relations and interactions among actors. The same selection of authors (Aoki, 1995; Hodgson, 1988; North, 1990; Sjöstrand, 1993; Young, 2001) perceive the social entity - i.e. human beings at individual level or organisations at group level – as the initiator and as the receiver of institutions.

When the existing institutions do not reduce the uncertainty in the interaction of entities, a transition starts depending on the expectations of entities about the future, the existing institution and the uncertainty about the environment in which these interactions occur: in this context, uncertainties arise from incomplete information with respect to the behaviour of other entities and the environment (North, 1990). This phenomenon could be interpreted as an emergent (bottom-up) institutional change. Figure 2.6 presents a scheme of the interaction of entities with the environment. Here, the knowledge gap between entities and the environment or with other entities is called uncertainty. This uncertainty is the result of the limited capacity of entities to understand the complexity of the environment or other entities.

As said before, the environment also plays a role when changing the existing institutions. The environment includes contracts, norms, customs, conventions and agreements, which are also considered as background conditions (Williamson, 1993). The environment affects not only the interaction between entities but also the internal mechanisms of the entities themselves. From the new institutional economics perspective, these internal mechanisms are reflected in endogenous preferences (Williamson, 1993). The effect of the environment on the coordinating mechanism and the entities could be considered as a top-down influence.

Table 2.2: Definition of Institutions

Author	Definition of Institution	Label	Source of Change
(Hodgson, 1988)	Social organisation which tends to create durable and routinized patterns of behaviour to reduce costs	Routines for interaction	Individuals, as a response to pursue their goals
(North, 1990)	Human devised constraints shaping human interactions to reduce uncertainty	Rules of the game	Organisations[2], when they perceive that changes are necessary to be better off
(Sjöstrand, 1993)	Human mental construct to regulate individual interactions in recurrent situation	Construction for regulation	Individuals and organisations, when a gap exists between thoughts and regulations
(Aoki, 1995)	Social device to coordinate expectations of agents in a certain domain	Coordinating mechanism	Agents, when expectations are dramatically changed
(Young, 2001)	Repeated coordination of people's behaviour in various spheres of interaction	Equilibrium outcome	Individuals, when interacting over long periods of time

The three presented elements – entity, institution, and environment – were already arranged as a framework for the study of economic organisation (Williamson, 1993), in which the three elements influence each other through main – solid arrows – and secondary – dashed arrows – effects (See Figure 2.7). An interesting feature of this schema is the feedback between elements and the intensity of those.

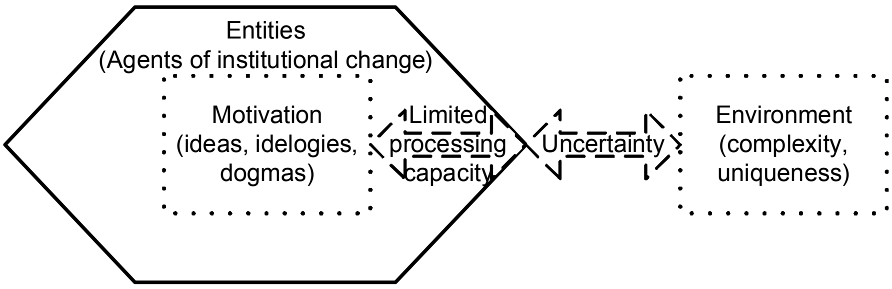

Figure 2.6: Interplay between entities and the environment (Based on (North, 1990))

[2] "Organisations" comprises political, economic, social and educational bodies, which are formed by a group of individuals bounded by a common purpose in order to achieve some objective(s) (North, 1990).

This three level scheme was later rearranged in four levels in order to provide a particular place to the informal institutions, such as customs, traditions, norms, or religion. In the four level scheme (See Figure 2.8), the social embeddedness – i.e. customs, traditions, norms, or religion – is considered to change very slowly and is normally neglected although it has a persistent influence on the activities of any society; below comes the formal institutions or rules of the game organising economic activity in lower levels, mainly based on property right but also the main government functions are here located; beneath is located the institutions of governance for the play of the game, based on transaction cost economic; finally comes the resource allocation based on neo-classical economics and agency theory (Williamson, 1998). Within the four levels scheme changes occur in the institutional environment, the governance structure and the marginal conditions. Again, it is possible to appreciate the influence of a higher level on a lower level, expressed by thick arrows, and the influence of lower level on higher level, portrayed by broken arrows. However, this kind of feedback among levels are neglected in this analysis (Williamson, 1998)

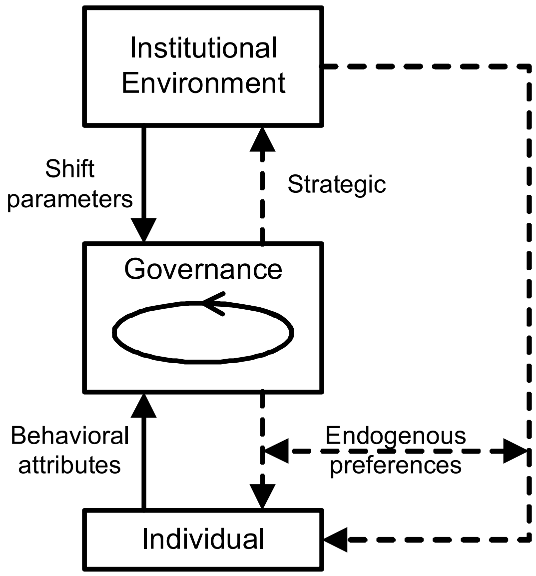

Figure 2.7: Three-layer schema for economic organisation (Williamson, 1993)

The different perspectives inside Institutional Economics can be combined in a general framework for shaping interactions between entities as follows. It is possible to assume that entities need rules for constraining the range of actions as well as coordinating mechanisms for harmonizing interactions and regulating social constructions for matching complementary effort or needs. Through repeated interaction each entity develops formal or informal routines in order to simplify repeated interactions. These routines arrive in time to a certain dynamic equilibrium, providing features at a macro level. This means that the developed routines prevail in time, even with marginal changes, until they become inadequate for shaping current interactions.

Based on Institutional Economics, the dynamic equilibrium of these interaction' structures are modified by entities either by incremental (marginal) changes or fundamental changes (North, 1990). It is worth mentioning that, although institutions arrive to a dynamic equilibrium, they may not be by definition efficient (North, 1990), departing in this way from Neo Classical definition of equilibrium.

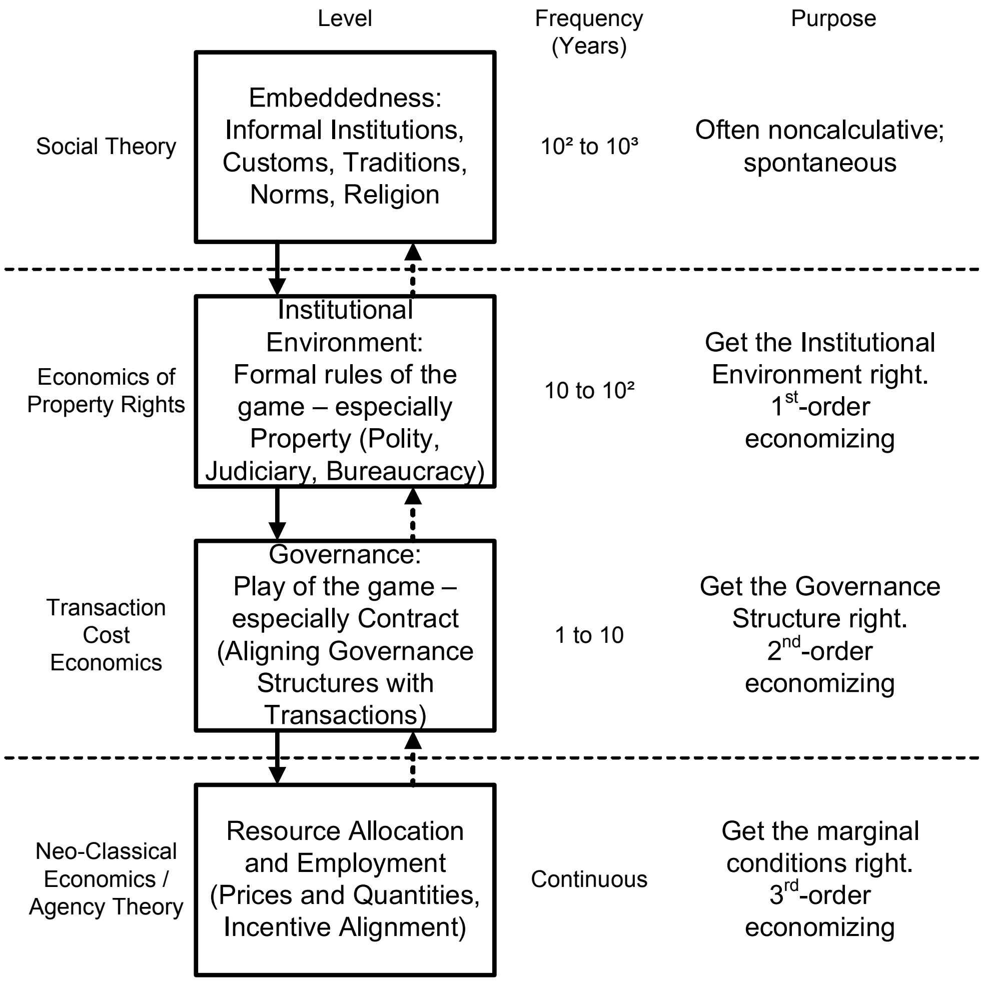

Figure 2.8: Economics of institutions (Williamson, 1998)

Institutional Economics portrays the shift of social structures from an economic perspective but it is unacquainted with the effect of technological change since the main focus is on economics, regulation and organisational matters with a smaller component of psychology in the form of opportunistic behaviour.

2.5. Network perspective

When actors are somehow dependent on each other in a complex pattern, their relation takes place in a network (Teisman, 1998). Within networks, actors are not centrally controlled towards a particular objective: they are different, each of them with particular objectives, but dependent on each other to look after those objectives (Hufen & Ringeling, 1990) by exchanging what they have for what they need (March, 1994). Networks are therefore dynamic and within them, actors, also called stakeholders, are the units of handling (Teisman, 1998) and are responsible of the decisions taken (H. de Bruijn & ten Heuvelhof, 2000).

In a network, actors occupy a particular position depending on the way they behave and the resources they possess. While Teisman (1998) talks about role patterns, De Bruijn and Ten Heuvelhof (2000) elaborate on allies with a particular kind of power. Table 2.3 provides a summary of those two classifications of actors with the behaviour they portray or the resources they possess, and the equivalence between authors. It is worth mentioning that these are theoretical actors and that different sets of actors as well as different combinations of roles could be found in reality.

Table 2.3: Typology of actors in networks

Actor		Description
(H. de Bruijn & ten Heuvelhof, 2000)	(Teisman, 1998)	
Initiator	Initiator	Actor that wants to accomplish certain objectives; when this initiator is not taken seriously, it becomes an isolated initiator (Teisman, 1998).
Supporter with production power	Supporter	Actors that can effectively contribute to the initiator's objectives
Opponents with production power	Adapters	Actors with resources but are not eager to provide their support
Opponents with blocking power	Critics	Opposing parties, with different preferences than the initiator
Unclear actors	-0-0-0-0-	Actors without clear preferences and clear power position, with a 'wait and see' attitude
Little foxes	-0-0-0-0-	Actors with a subordinate position in a network, but with a 'swing vote' power
-0-0-0-0-	Intermediary	Actors that mobilise necessary actors to stand for the initiator's objectives
-0-0-0-0-	Broker	Actors that watch over the arriving-to-consensus procedure
-0-0-0-0-	Arbitrator	Actors with legal status to pronounce verdict about conflicts between actors
-0-0-0-0-	Facilitator	Actor with specific knowledge of the topic and without any particular objective

Teisman (1998) recognises that relations between actors in a network are asymmetric, which might be related to the kind of resources actors possess. For example, government may become a driving force for changing different sectors in society because government policies trigger different kinds of reactions and changes in the institutional context (i.e. in the network) (Hufen & Ringeling, 1990).

Actors interact by means of rules (norms or agreements), which provide some stability to the network, but these rules may change in time due to the following reasons (Klijn & Koppenjan, 2006):

- Conscious action, by design or intervention
- Reinterpretation of existing rules
- Non-compliance with existing rules

For the understanding of desired transitions, conscious action is of relevance since the transition is socially desired.

To introduce a change by design or intervention and depending on the objective of the leading actor, other actors may support or constrain the decision-making process given their power, resources and strategies (H. de Bruijn & ten Heuvelhof, 2000). It is possible then to create coalitions for the sake of the achievement of the objectives or to prevent them to occur. Different arrangements may arise from the creation of coalitions at different levels of aggregation and within levels to allow or block the introduction of change.

To provide solutions to highly technical problems (i.e. introduce changes to existing systems), decisions should be taken in a network of interaction between stakeholders to reduce uncertainty (van Bueren, Klijn, & Koppenjan, 2003). Even more, elsewhere it has been acknowledged that the transition of an industrial society toward sustainable development based on system innovation, in the technological and the institutional field, is beyond the scope of an individual firm (T. de Bruijn & Norberg-Bohm, 2005) because the problem-solving power is distributed among actors in the network (Glasbergen, 1989). However, the found solutions might not be optimal because actors in the policy network may hinder the selection of some alternatives (Hufen & Ringeling, 1990). In any case, the selection of instruments is determined by the structure and the cultural characteristics of networks (Glasbergen, 1989).

Qualitative analysis regarding network construction is already present in literature (See: (H. de Bruijn & ten Heuvelhof, 2000), (van Bueren, et al., 2003); (Klijn & Koppenjan, 2006)). This may imply that the focus of the actor-network perspective is on the management of the decision making process.

The importance of networks as a kind of a system of stable interaction rules has already been recognized (Klijn & Koppenjan, 2006) and the need for understanding its functioning and the way these networks can be changed could be crucial for the elucidation of transitions.

2.6. Synthesis of the literature study

This literature review was executed to provide answer to the following secondary research question:

> Which levels of aggregation should be taken into account in a conceptual framework to describe large-scale socio-technical systems in transition, and what are the relevant elements at each level?

The purpose here is to find a perspective that helps identify elements that play a role in desired transitions and helps provide an explanation of the underlying mechanisms of desired transitions as processes of change. Within the body of knowledge of the Faculty of Technology, Policy and Management and the conceptualisation of societies as socio-technical systems, this literature review has concentrated on the topics of technology, society, institutional economics and actor-network theory.

In the sections above, these four topics have been reviewed to find out how they address transitions oriented to achieve particular social goals. In the following section, the significant features of each perspective are presented. Next, the knowledge gaps of each perspective are indicated. Later, the commonalities among these four perspectives are introduced. Finally, the conclusion of this literature study is provided.

2.6.1. Significant features of each perspective

Each reviewed perspective has also some significant features that are valuable to be taken into account when studying desired transitions of socio-technical systems.

Regarding the technological perspective, the following issues are considered to be relevant:

- The definition of transitions as processes of change between states: this definition seems to be neutral enough to avoid bias towards certain topics or exclude other kind of transitions.
- The notion of three levels to observe and decompose systems: the use of three levels to decompose systems pleads for an orderly observation of the different elements in a system in transition and well as the visualisation of the influence between levels.
- The relevance of emergent behaviour of niches: niches, if they develop enough critical mass in the system, can emerge as the new regime that influences several aspects in society.
- The role of path dependence in the evolution of systems: as a characteristic that spreads through an entire system, path dependence is a factor that can play a significant role in the achievement of transitions because it can allow certain alternatives to progress or block others.
- The way technological evolution occurs: incremental and discontinuous changes are sources of change, which means that not only gradual transitions occur but also transitions may occur as a result of disruptive events.

Concerning the social perspective, attention is given to the following issues:

- The role of the individual in a social context: individuals are source of purposive action, based on their believe system, to achieve their interests; however, their actions are limited by actions of other individuals or by rules applicable to all individuals.
- The adaptation capability of individuals: when confronted with new situations, individuals are, in greater or smaller measure, resilient enough to adapt to new circumstances by creating new interaction rules.
- The interaction of individuals as source of emergent systemic behaviour: different combination of individuals can elicit different kinds of systemic behaviour because adaptation among individuals depends on each individual's interests.
- The relation between individuals and 'things': individuals are in possession of 'things', may them be resources, issues or events; especially in the case of resources, this relation portrays the connection of the social with the technical or technological aspects.
- The use of two levels of analysis: it appeals for an orderly analysis of systems as a result of the interaction of multiple individuals, and the analysis of individuals as creators of emergent system behaviour.

About Institutional Economics, the next topics receive special consideration:

- The social entity as initiator and as the receiver of institutions: this means that social entities create and use their own interaction patterns in order to facilitate relations with other entities.
- Institutions as regulating mechanisms among entities: due to the interaction among social entities, the activities among them need to be regulated and harmonised so that complementary interests could be coupled.

- The multiple level of analysis (at least environment, governance, individual): being three or four levels of analysis, the use of multiple level of analysis pleads for a structured analysis of different types of institutions, which changes at different speeds depending on the level of analysis.
- The notion of dynamic equilibrium: this means that existing interaction structures or patterns remain somewhat stable in time but they are in constant adaptation to the circumstances and the entities involved, which implies that these structures or patterns are not necessarily the optimum.

As regards the network perspective, the following matters are considered significant:

- Actors as holders of different kind of resources and different kinds of power: actors in a network are unique because of the asymmetrical distribution of resources and power.
- The relevance of networks in decision-making: the uneven distribution of resources and power compels actors to coordinate efforts if they want to achieve particular objective(s).
- The mechanisms to encourage or discourage new ways of operating: Because there is no central control in a network, actors can only partially affect interaction mechanisms among actors by urge or dissuasion but they cannot fully impose new practices (e.g. policy-makers are confronted with no compliance of rules).
- The focus on the solving of technical problems: especially when talking about technical issues, it seems necessary to involve several actors in the network so that they can contribute with their resources to a solution.

Having identified the significant features of each perspective examined, the next section will pay attention to the knowledge gaps of each perspective.

2.6.2. Knowledge gaps of each perspective

When performing the literature review, each perspective has a particular focus that may create a knowledge gap:

- Technological perspective: the application of technological transitions only in cases where environmental sustainability is involved might hinder the study of other cases which are not related to sustainability; in the same line of reasoning, transitions towards sustainable scheme may also be achieved by other ways than technological transitions, such as by changes in belief systems (e.g. recycling) or regulations (e.g. separation of waste at the source).
- Sociological perspective: even though the use of two levels of analysis to describe transitions in social systems provides significant structure to study transitions, the interactions among individuals remain somehow hidden to the eye of the analyst as the interactions are assumed to be part of the system description; also, technology is assumed as fixed, limiting the power technology has to affect social structures (e.g. mobile phones with internet functions).
- Institutional Economics perspective: although feedback is a feature present in all conceptualisations in Institutional Economics, it is disregarded by most economists and therefore a transition approximates more to a top-down phenomenon; even though it includes regulatory and organisational issues, technology and its change, as well as culture is not included in the analysis.

- Network perspective: although actors are placed within networks due to their interdependence, the impact of these networks is kept to the level of the achievement of agreed objectives; furthermore, little is said from a system perspective: how other systems are affected by changes in particular networks, and technology is taken as an input of the problem and not as an active element.

Additionally, there is a general issue that is common to all four perspectives. It has been noticed that each of these perspectives deal with processes of change in their particular field of study or it at most uses one additional topic as boundary condition of the study. For example, the technological perspective has included economic issues, such as the role of markets, in the conceptualisation but gives little attention to social aspects, such as culture or policy; the social perspective has included economic equilibrium between supply and demand in their analysis but it mostly takes the role of technology as given in the analysis of social dynamics; the institutional economics perspective includes regulation and organisational matters while it disregards the role of technology in the analysis of institutions; finally, the network perspective is embedded in the policy making context, paying little attention to economics matters while it is applied to technical problems.

Although it shows acknowledgement that describing transitions from a single perspective has some shortcomings, it also means that each perspective is not derivable from each other up to some extent because each one concentrates on the particular mechanism within its particular perspective.

Together with the identification of significant features and knowledge gaps at each perspective, there are several important commonalities among perspectives. Those will be dealt with in the next section.

2.6.3. Commonalities among the perspectives

The reviewed literature presented in the previous chapter has provided different perspectives by which systems in transition can be described. Not only they describe and explain transitions from different perspectives, but also they show some parallel as follows.

One parallel is the multi-level perspective of transitions. Three of the four studies perspectives – technological, sociological and institutional economics – present their analysis in levels: just the network perspective is less specific about levels. In the case of the technological and Institutional Economics perspectives, there is a matter of three layers – and even four in the case of institutional economics – while the sociological perspective, and implicitly the network perspective, deals with only two. In general, the four approaches acknowledge an Agent level and three of them – technological, sociological and institutional economics – a System level. We believe that the two-layer sociological perspective and the network perspective could be expanded to a three-layer schema in order to detach the decision making of actors and the interactions between different networks from the system level and therefore favour the evaluation of different networks of interactions given different environments with even the same actors.

Another parallel is the influence among agents, networks and system. In the technological, sociological and institutional economics perspectives, there seems to be mutual feedback among different levels considered. This means that each level is affected, shaped and constraint by the others in a direct or an indirect way. The speed of the feedback increases at the Agent –micro– level and decreases at the System –macro– level.

One more parallel is the 'motor' of transitions. Agents, in the form of niches, actors, entities, or stakeholders, are considered as the basic unit capable of activating any transition, as a reaction to changes in higher levels. Without their purposive behaviour, little could be achieved to produce any transformation at higher levels of aggregations. This kind of emergent behaviour seems to be relevant for the study of desired transitions.

An additional parallel is the use of a higher level of aggregation to observe the results of the introduced changes. The technological, sociological and institutional economics perspectives make use of a system level to analyse the aggregate behaviour of agents and their reaction to events at system levels. Although the network perspective refrains from the active use of a system perspective, it surely looks at system innovation when tackling sustainable development.

The presented commonalities offer a superb opportunity. By means of these commonalities, each perspective can be related to the other perspectives. In this way, cross-discipline learning among disciplines is allowed, which is assumed to enhance the understanding of desired transitions from multiple perspectives. Since these disciplines are not derivable from each other, a complex adaptive systems perspective can be taken to broaden the comprehension of desired transitions.

2.7. Conclusion of the literature review

It seems that any single formalism comes short when trying to explain the complexity of transitions and its multiple facets. We invoke here that transitions should be dealt with respecting their multiple facets in order to achieve a better understanding of the interplay of the technical sub-system as well as the actors' decision-making. To achieve this, a conceptual framework that considers relevant aspects of a socio-technical system in transition is needed. It is assumed that this framework should inherently be interdisciplinary to be able to address the dual nature of societies (the social and the technical aspects) and the interplay of those. Also, this framework should be able to provide a way to conceptualise societies in one unit of analysis, e.g. systems with identifiable elements, to allow comparison between cases and make possible future generalisations.

The literature review presented above has presented four different perspectives that address the process of change, here called transitions. These four perspectives are not derivable from each other as they use their own set of concepts to describe transitions. It allows us to embrace these four perspectives as building blocks for explaining transitions due to the commonalities (mentioned in section 5.3), significant features (mentioned in section 5.1) and knowledge gaps (mentioned in section 5.2) they present. This is possible because we adopt a complex (constituted by several agents with discretional decision power), adaptive (agents act in parallel but influence each other and react to the influence of the environment) systems perspective, where insights can be obtained by using several disciplines to analyse the system under study. The combination of these building blocks in a framework for the analysis of transitions is a key contribution of this research and will be dealt in the next chapter

To conclude, it seems necessary to empower transitions towards the achievement of social goal where technology plays a relevant role and to improve the scientific knowledge on the topic of transitions. In this sense, we must not only understand what transitions are, but also define a set of essential elements suitable for framing transitions of socio-technical systems. This framework should allow us to identify, analyse and understand the relevant elements playing a role in a transition, as well as the coordinating mechanisms at work when transitions are in progress. This is the topic of the following chapter.

Chapter 3
A three-step approach to the analysis of transitions

From the literature study it was concluded that there are single formalisms dealing with transitions but none of them proposes a suitable way to study transitions in their breadth. To address this knowledge gap, we propose that each perspective can contribute to an overarching explanation of transitions in socio-technical systems so that the multi-disciplinary nature of transitions can be addressed. We suggest that these perspectives are intertwined as follows. Coleman's social theory helps to explain which individual reactions to the environment or system level (i.e. the landscape in a socio-technical regime) produce changes at system level. Coleman's social theory also provides additional grounds for institutional change based on the preferences of agents, being these individuals or groups. Institutional Economics also helps explain shifts in technological regimes by offering the economic rationale behind institutional change. These three approaches could be complemented by the Actor-Network theory (H. de Bruijn & ten Heuvelhof, 2000) to visualise the decision rules of different actors at the agent level, and how these actors interconnect in networks via interaction mechanisms. The latter is relevant for the study of system behaviour of socio-technical systems. Supplemented by the technological perspective (Geels, 2002), these perspectives cover the basic elements of socio-technical systems. At the same time, these four perspectives can become the basic set of theories that will support the framework for the analysis of transitions 'in order to address questions of reforms and transitions' (Ostrom, 2005).

We present in this chapter an approach to the study of transitions based on the perspectives reviewed in Chapter 2, which consists of three items:

1. A System-Network-Agent (SyNeA) framework for analysis.
2. A method for studying transitions using case studies and the SyNeA framework.
3. Methods to simplify the transition using step-by-step modelling.

This proposition for a framework for analysis and a strategy for modelling at different aggregation levels rests on the significant features of the technological, sociological, institutional economics and actor-network perspectives.

Keeping in mind the concept of modularity, the modelling strategy builds upon the application of the System-Network-Agent (SyNeA) framework to study a transition case. Along these lines, a systematic simplification of a transition case has been worked towards, which could provide a basis for (quantitative) modelling. Modelling could then be applied when and where needed.

In this chapter we will start the next section with an explanation of the framework for analysis to provide the basic vocabulary. In the following section we will stipulate a definition (as proposed by (Verschuren & Doorewaard, 1999)) of 'transitions' in general and 'desired transitions' in particular, and the elements and mechanisms that elicit such transitions. In section 2 the criteria for case selection and a methodology to study transitions using the framework introduced will be presented. Finally, in section 3 we will introduce a modelling strategy to simplify information from the real world to create information units suitable for modelling and knowledge development.

3.1. Analysing transitions with the SyNeA framework

Based on the principle of multiple formalisms in Complex Adaptive Systems, we have integrated the significant features of the four reviewed perspectives – technological, social, institutional economics and the actor-network – to unravel the phenomenon of transitions. By taking this integrated approach we aim to explain desired transitions based on an existing paradigm to find a new one as a process of technological substitution (by the introduction of new technological advancements). These transitions are triggered by dynamics at system level in such a way that these dynamics affect the network of interaction mechanisms, which change in reaction to actors operating at agent level.

Our framework adopts a multi-actor perspective in which government is one of a constellation of actors arranged in a network. Our point of view differs from the analysis of Allison (1971), in which a managerial perspective is taken in order to break down government into several interdependent units engaged in a bargaining game.

The framework for analysis will be introduced as follows. The next section will first present what is considered to be under study and what are the essential characteristics of transitions. Based on this, we will then identify the three levels of aggregation that need to be considered when analysing socio-technical systems in transition. Thereafter, the different elements in these levels are introduced into this framework. Finally, we will explain how these different elements work together so that transitions can take place.

3.1.1. Definition of transitions

In socio-technical systems (as defined in Chapter 2) change is endemic and occurs both in society and in technology, as well as at the system level where the socio-technical assembly exhibits particular systemic characteristics that are more than the sum of the individual parts of society and technology, or their particular components. Under this conceptualisation, it can be seen that interaction and feedback are the key characteristics of transitions (Chiong Meza & Dijkema, 2008) because they shape present and future technology, knowledge, systems and artefacts while creating path-dependencies, and lock-in effects in the way that they affect each other.

Under this view, a system in transition can be broken down into a social sub-system where actors interact with one another to create webs of relationships, and a technical sub-system, in which artefacts and techniques combine to create supply chains. In the social sub-system, actors interact by means of agreements, contracts, policy and regulation. The technical sub-system is represented by resources and production of output and emissions, which are all connected by a current technological paradigm. A system in transition conjugates both sub-systems by means of materials, energy, money, information, and knowledge flowing within and between these two sub-systems (Dijkema & Basson, 2009).

Changes in socio-technical systems take place due to various causes, such as emergent developments (e.g. urbanisation) that slowly affect the existing system, or inventions (e.g. the electric bulb or telegraphy), or innovations (e.g. the steam engine or mobile phones), that radically change the structure of the system. However, there are more and more changes in society that are initiated by the will of particular actors and which carry on because society agrees to persevere to achieve the change (e.g. voting rights, first for all classes in society, later for both genders). Both types of transitions are considered to provide relevant insight for the understanding of these processes of change. However, this research concentrated on how these processes of change occur in socio-technical systems and, where possible, to identify relevant mechanisms to influence these transitions.

Taking a variety of transitions from the past and present, this study will look at those transitions where groups in society have taken a conscious stance in order to tilt the existing system in a certain direction by using new technology. This 'conscious choice' would generally be advocated first in civil society (e.g. through non-governmental organisations) but could eventually be officially adopted as a policy objective that the government wants to achieve. Owing to the special position of government (e.g. its authority to enact legislation and its financial resources) transitions in which the public authorities have officially established the preferred direction, constitute a distinct category of transitions which we will refer to as 'desired transitions'.

Unlike the field of 'transition management', we have opted not to include the issue of (environmental) sustainability in our definition. In our view, the goal of (environmental) sustainability is just a specification of the preferred direction of the transition and therefore part of the objective, and not a separate class of the phenomenon of a socio-technical transition. The concept of sustainability (which is usually included in the definition of 'transition' in the field of transition management) has furthermore been given a particular bias in industrialized countries, towards more extraordinary objectives (e.g. climate change mitigation) in comparison with more quotidian objectives (e.g. combating hunger or unemployment) in developing countries. If we take Maslow's hierarchy of needs to describe society's needs as Frei (2006) did with energy economics (see Figure 3.1), industrialized countries are busy with satisfiers at a system level (natural resources viability) because their prosperous economies, social security, and political stability allow them to do so. In countries where survival is the primary objective, achieving access to supplies and the security of those supplies to meet their basic needs, are the only objectives that count and they disregard the effects of using the available means in the broader context. By going beyond the issue of environmental sustainability, we assume that the range of transition case studies available will be wider.

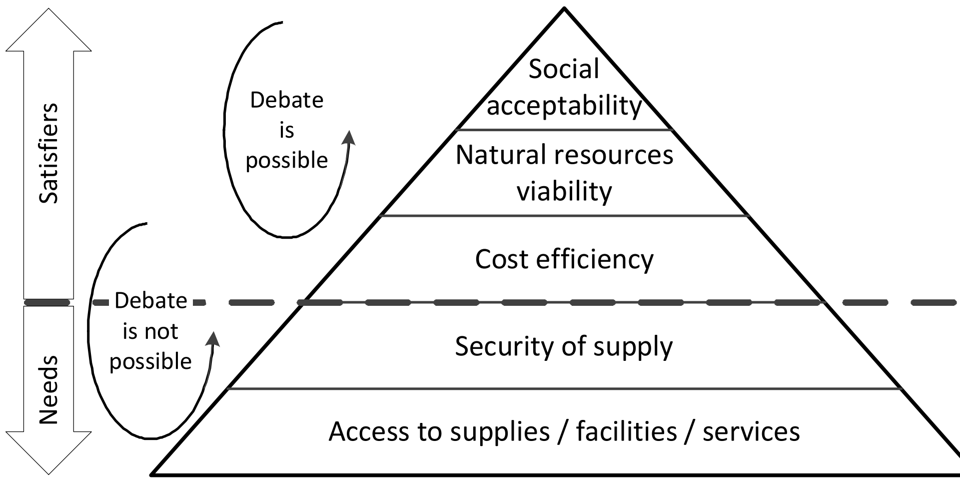

Figure 3.1: Application of Maslow's hierarchy of needs to society's needs (Based on (Frei, 2006))

Considering the object of the study as described above, we have defined transitions in socio-technical systems as follows:

> Socio-technical transitions are long-term processes of social and technological transformation from one state of dynamic equilibrium to another.

Specifically with 'desired transitions' it is attempted to reach established social objectives for the purpose of facilitating an enduring society; normally, these objectives are established when the function of a society, or part of that society, is considered to be at risk. Although our framework and method for analysing transitions will essentially be generic, we would prefer to focus on desired transitions if the research has to be limited (see section 1.3).

In transitions, a system shifts from a previous equilibrium (e.g. of decision rules, relationships and ideas) to another through changes in the social and the technological sub-systems and the way they relate to one another. Specifically in desired transitions, the changes in each sub-system and in the relationship between them are guided by common social objectives established at some point in time to guarantee the functioning of the whole system.

As we are dealing with complex adaptive systems, these changes in a system in transition come from the decision-making of existing actors in the system (each of them in their own playing field) about their own functioning and their interaction with other actors. Although there could be a certain measure of coordination in desired transitions, the combined decision-making of actors and the combined change in technology produce an emergent behaviour of the system that is difficult to pinpoint beforehand. It is therefore difficult to direct the whole transition as such, but it may be possible to encourage certain preferred alternatives above other less preferred (or unwanted) alternatives.

To unravel transitions, we have proposed an analytical framework which rests on the complexity framework for understanding complex adaptive systems of Nikolić (2009). This framework identifies three conceptual levels:

a. System: the aggregation of several networks connected by agents.
b. Network: the aggregation of agents by patterns of interactions.
c. Agent: the smallest element of the system with states and rules.

In this way we present three different levels or 'maps' of the same reality to help understand transitions by using a combination of these maps, as proposed by Ostrom (2005). Figure 3.2 provides an abstract rendition of the three conceptual levels.

Based on the above description of the object under study and the definition of desired transitions, in the next section we applied elements of the analytical framework to understand systems in transition.

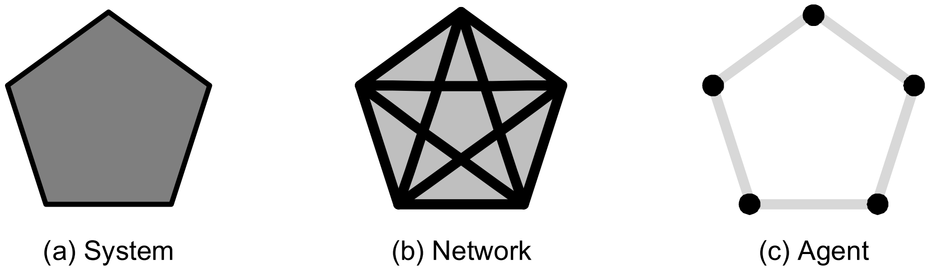

Figure 3.2: Abstract representation of (a) system, (b) network and (c) agent

3.1.2. Elements of the System-Network-Agent (SyNeA) framework

To study a system in transition, we made use of the three conceptual levels of the complexity framework for understanding complex adaptive systems, as interpreted by Nikolić (2009), to zoom in from a high level of aggregation to a low one. We believe that in the analysis of transitions, at least an Agent and a System level must be acknowledged, while a Network level is required to identify relationships that determine the interactions at Agent level. Information feedback between the different layers implies that each layer is directly or indirectly affected, shaped and constrained by the others (Chiong Meza & Dijkema, 2008). At each level we have presented relevant elements to be taken into account when studying transitions in large-scale socio-technical systems.

<u>A. System level</u>

At system level, we identified two main units: the system itself, characterized by the cultural background, and compelling forces that may speed up a system transition, which in this study we have called 'drastic events'. A diagram of both is presented in Figure 3.3 with a description below.

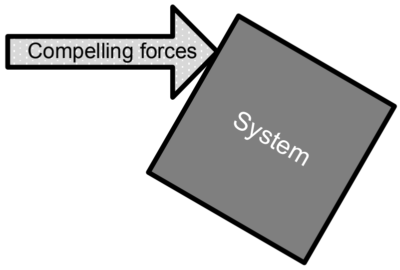

Figure 3.3: Units of study at system level

Cultural background

Cultural background is a relevant aspect to consider when dealing with transitions because it is inherent to any society and pervades all actions of individuals in a society. Williamson (1998) in his four level framework of social analysis, defines culture as "having a lasting grip on the way a society conducts itself." Ostrom (2005) also speaks of culture as "values shared within a community". As Edward Hutchins, cited by North, states:

> *"Culture, context and history… are fundamental aspects of human cognition and cannot be comfortably integrated into a perspective that privileges abstract properties of isolated individual minds", (in (North, 2005)).*

As such, culture represents the aggregation of features of actors at agent level (Nikolić, 2009). Therefore, it determines the type of interaction mechanisms that can be accepted by most (if not all) actors in a system. Identification of the cultural background of a system is relevant for a transition to start and to continue: the way a new paradigm is introduced may succeed or fail, depending on the state of mind of the relevant actors involved.

To explain cultural features, we used the study of Hofstede (1991), where four dimensions, plus one more, are used to describe countries. The dimensions Hofstede referred to are:

"1. Social inequality, including relation with authority
2. The relationship between the individual and the group
3. Concepts of masculinity and femininity (…)
4. Ways of dealing with uncertainty (…)"

The additional dimension refers to whether people's orientation tends to be toward the short or the long term. Hofstede (1991) gave each of the above dimensions a name and a definition, which have been summarized in Table 3.1.

In our study, these dimensions will be used as proxies to provide an outline of how systems are characterized. At no point it is claimed here that this outline came from a thorough socio-cultural study; instead we have opted to make use of Hofstede's dimensions to show the underlying cultural background to socio-technical structures and the need to take cultural features into account in any study related to transitions.

Table 3.1: Definitions of social dimensions (Based on (Hofstede, 1991))

Dimension	Name	Definition
Inequality and its relationship with authority	Power Distance	"… the extent to which the less powerful members of institutions and organisations within a country expect and accept that power is distributed unequally."
Relationship between the individual and the group	Individualism and Collectivism	"… pertains to societies in which the ties between individuals are loose …. Collectivism … pertains to societies in which people from birth onward are integrated into strong, cohesive in-groups …."
Concepts of masculinity and femininity	Masculinity-Femininity	"A society is called masculine … when emotional gender roles are clearly distinct …. A society is called feminine when emotional gender roles overlap …."
Dealing with uncertainty	Uncertainty avoidance	"… the extent to which the members of a culture feel threatened by ambiguous or unknown situations."
Orientation towards short or long term	Long and short-term orientation	"Long-term orientation stands for the fostering of virtues oriented toward future rewards … short-term orientation, stands for the fostering of virtues related to the past and present …."

It is worth mentioning that because Hofstede's study was based on scores of people in the same company in different countries, it shows the relative positions of different countries in each dimension. This means that in any interpretation of the results it is important to be aware of the fact that there is no absolute position for any of the dimensions presented. When conducting intercultural comparative studies, there is also an understandable bias towards issues that are more interesting in a researcher's own society (Hofstede & Hofstede, 2005) and therefore interpretations of the results should take cultural differences into account.

Drastic event

In this study a drastic event is considered to be a disruptive occurrence that breaks with the current trend in several fields of society or technology, and affects the whole system. This is comparable to the triggers identified by Frantzeskaki (2011) which are forces that destabilize a system.

A *drastic event* could be seen as a compelling force that affects the system in such a way that the attention of several actors focus on the same aspect and the existing state of affairs is rethought.

In transitions, a *drastic event* works as a catalyst in favour of or against the transition because it signals a window of opportunity for the introduction of new measures. Drastic events can also help to create a sense of urgency in a society in such a way that the objectives of different groups in that society could become coordinated in desired transitions. In this way, the existing system is encouraged to change, affecting interaction mechanisms between actors in the existing system. An example of a drastic event is the invention of the steam engine. This led to changes in industrial organisation and operating procedures which resulted in a large lay-off of workers, less intensive physical work, and more structured production processes. Over time, these new skills and procedures gave rise to many new industrial activities, drastically changing both industry and society.

The drastic event and the cultural background are the elements which are considered to shape the network and the agent level.

B. Network level

At this level, it is possible to recognize the rules actors use to interact with one another. By means of these interactions, actors create networks in order to exchange resources for the transition to occur. Here, networks represent the aggregation of interactions of actors at agent level (Nikolić, 2009).

Following the concept of multiple formalisms in Complex Adaptive Systems, it is here acknowledged that multiple dimensions (expressed in different issues) are necessary to describe the different ways actors interact with one another. For example, Geels (2002) acknowledges the relevance of broadening the concept of technological regimes – purely related to rules regarding the design and production of technologies – to include the social component – the actors executing those rules – to obtain a semi-coherent web of rules in a socio-technical system. Hedström (2006) also attributes relevance to networks as "an unintended by-product of the actions of interacting individuals", or "emergent phenomena".

At the network level, the focus is on social and technological arrangements, as they represent the sub-systems of a system in transition, and the policy and economic arrangements, as ways in which interactions between both sub-systems are established. In institutional economics, North (1990) ascribes to institutions the power to "structure economic exchange (together with the technology employed)". In this way, this framework differs from the seven dimensions of the socio-technical regimes of Geels (2002), in which five dimensions are dedicated to technology, one to policy and one to economics.

Figure 3.4 shows a diagram of networks and the fields included.

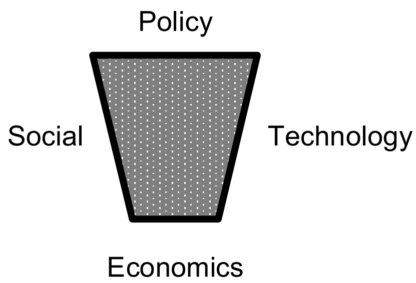

Figure 3.4: Topics involved at network level

The social and economic aspects in a transition are brought together in descriptions of the polity of the system (to provide an idea of the social organisation and administration of a particular region or country). Polity then becomes the substrate for the development of new policy and can help introduce technological changes and new social arrangements into the system in such a way that those changes endure over time. The multi-dimensional network is considered to define the decision-making playing field of each actor at agent level.

C. Agent level

At this level, it is possible to observe the relevant actors in the system which are the source of change at the network and system levels.

While in studies of past transitions the focus has been on shifts as a result of the supremacy of a particular emerging technological paradigm, the dominant characteristic of the desired transitions that are currently unfolding – such as the transition from fossil to renewable energy sources – is that they are subject to the interest of different interrelated actors – a network of actors in a social sub-system. Each of the actors in this social sub-system attempts to steer the transition process in accordance with their own set of objectives and interests.

Actors in the social context are entities that have interests and have control over 'things' to realize their objectives (Coleman, 1990). If actors do not have what they need to realize their objectives – this may be control over rules, resources or preferences – they exchange what they have for what they need (March, 1994). Their beliefs, desires and opportunities play a role in their motivation to do so (Hedström, 2006). In decision processes involving multiple actors in a system, and to meet their own desires under the existing rules (March, 1994), actors may create networks through coalitions with other actors, not only at different aggregation levels but also with different power bases and varied resources, when those actors are unable to control things (H. de Bruijn & ten Heuvelhof, 2000). When these relationships remain stable over time or in nature, they become a new interaction structure or institution. In this way, actors are the originators and the receivers of the designed institutions or governance structures (North, 1990). Here we assume that unless actors create coordinated networks by means of coalitions at different aggregation levels, any desired transition would be difficult to achieve.

Actors play a particular role in desired transitions depending on their interests, priorities and capabilities. Based on existing classifications (Algemene Energieraad & VROM-raad, 2004; Rotmans, 2003), our approach identifies the following roles, with particular capabilities and specific decision-making structures:

- Government: is capable of making policy (for the introduction of new paradigms) and enforcing rules and regulations (supporting the continuity of new paradigms in the system). It may act as a transition coordinator (for the harmonisation of actors' objectives and to translate them into common social goals), or even as an initiator of a desired transition (Rotmans, 2005b).
- Producers: are capable of transforming resources, such as physical assets, capital, human resources or, eventually, innovation capacity; they usually participate in transitions as incumbents or even as new entrants into the market, and occasionally provide new technological arrangements by the invention or use of new paradigms.
- Facilitators: are capable of providing supplementary products or services to facilitate the consumption by end-users of products from producers; they may act as promoters of transitions by introducing new paradigms for the use of new or existing products.
- Consumers: are capable of exploiting products or services as end-users and are key in desired transitions, as they determine the success of the market penetration of products or utilisation of services.
- Infrastructure Intermediaries: are capable of transporting, distributing and commercializing products or services to consumers from producers and facilitators, to provide essential services and utility products via their networks.

- Research Organisations: represent actors with the capability to innovate; they are relevant for the development of innovation in current technologies, the discovery of new technologies and new applications of these technologies.
- Interest (or Pressure) Groups: are capable of influencing opinions and promoting ideas, and play a part in the valuation of products and technological systems.

The above roles are examples of how actors operate in reality. However any role here can be found in different actors and different actors could be included in any one category. The roles of actors here focus on the main capability of actual actors in a particular socio-technical system as a means to simplify reality for the purpose of this analysis. A diagram of actors at agent level is given in Figure 3.5.

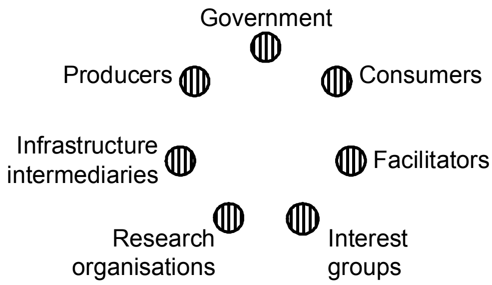

Figure 3.5: Types of actors at agent level

Actors arranged in networks become the driver of transitions as they try to switch from a current paradigm to another (Chiong Meza & Dijkema, 2008); in desired transitions, the paradigm is such that it better fits a set of common social objectives.

After describing all the elements of desired transitions, the working mechanisms to propel (desired) transitions will be described in the next section in terms of the elements introduced.

3.1.3. Mechanisms propelling transitions

In principle, transitions can start at any level of aggregation. At agent level, transitions in socio-technical systems can start with the introduction of a new device into society, e.g. the mobile phone. As consumers embrace this new device, new possibilities open up, such as making phone calls from remote places. Therefore the relationships between actors also change: new rules are created to regulate this new type of interaction, e.g. turning off mobile phones before a concert, or giving a call when someone runs late. In addition, the culture adapts to accept a new concept of personal accessibility.

At network level, transitions in socio-technical systems can start with a change of policy that affects the technical system. The liberalisation of the electricity market in the Netherlands has led to an increase in the number of actors in the network due to splitting apart the production, transport and delivery of electricity, thus switching from one actor to several, without changing the technical system (Knops, 2008). This means that consumers have to deal not with one but several actors to connect, change or terminate an electricity connection. At the system level, the idea of having the flexibility to switch from one company to another is encouraged.

Transitions in socio-technical systems can start at the system level with a compelling force affecting the system. Disasters are an example of this (e.g. Chernobyl in the former Soviet Union) or war. Most of the time, networks are badly affected or almost destroyed as a result of such disasters. At the agent level, each actor or even individual has to take care of themselves to meet their basic needs (e.g. food, clothing, safety). At the system level, the culture may change in the sense of looking ahead to prevent future disasters.

In the specific case of desired transitions, transitions in socio-technical systems may start due to the effects of compelling forces at the system level which affect the interaction mechanisms between actors at network level. These interaction mechanisms then affect the dynamics of actors at the agent level. When the existing interaction mechanisms are unable to simplify relationships between actors, these actors introduce new decision processes which, in turn, change the interaction networks by means of new policy, new technology or new economic arrangements under the existing polity. Additionally, new technologies are developed and new infrastructure is deployed, but only technologies with enough critical mass and diffusion in society will become the next technological paradigm: they will also affect the way actors interact and will eventually alter the system. The passage from one dynamic equilibrium to another is portrayed in Figure 3.6. Figure 3.6 shows the complete information feedback from the occurrence of a drastic event and its cascade effect at the system, network and agent levels and from the reaction of actors at agent level to new decision rules that affect the network and system levels, resulting in an emergent new dynamic equilibrium.

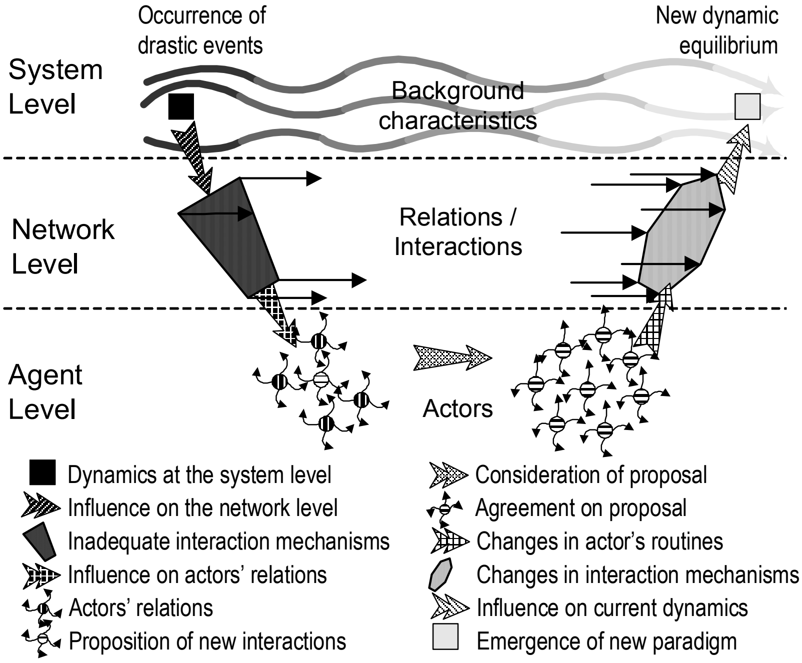

Figure 3.6: The SyNeA framework (adapted from (Chiong Meza & Dijkema, 2008))

In this framework a desired transition can be triggered by the incidence of a drastic event when depletion or saturation (as proposed by Daly (1990)) occurs in the system. This situation affects the dynamics at system level in such a way that the current situation is forced to change. Changes at system level affect the network level by making the existing interaction mechanisms between actors at agent level inadequate. Actors must then experiment with how they act in their own playing field and how they relate to other actors until new networks emerge, for example, after a leading actor with policy-making and organisational resources starts promoting new ways of interacting (e.g. a new law).

Based on the effect of the drastic event and the underlying culture, the process of transition as a desired process starts on the initiative of a particular actor who 'feels' the need to change the current state of affairs. This actor may use the drastic event as a catalyst for desired transitions by creating a sense of urgency in the system. This actor must have sufficient resources to be able to attract other relevant actors and elicit their participation in the desired transition in a coordinated way. Figure 3.7 shows the impact of changes at the system level and the influence at network and agent levels.

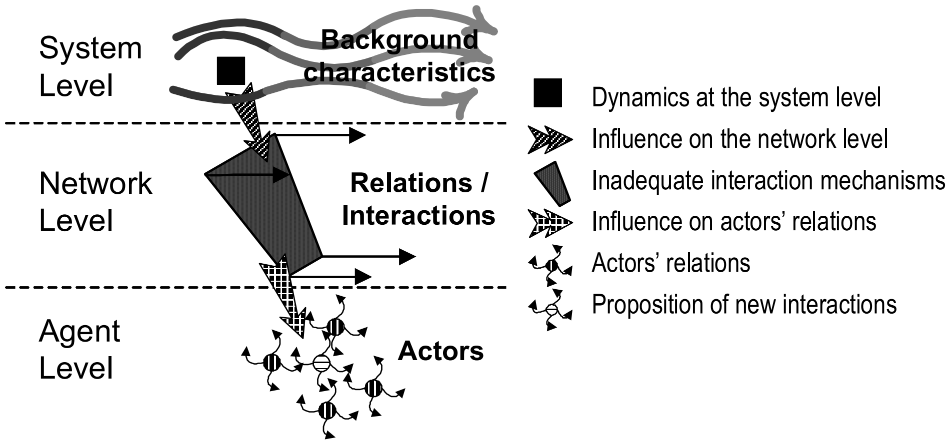

Figure 3.7: Changes at system level and their impact at network and agent levels

Depending on the objective of this leading entity or initiator (Rotmans, 2005b) other parties may support or constrain the decision-making process given their power, resources and strategies (H. de Bruijn & ten Heuvelhof, 2000). Then, it will be possible to create coalitions for the sake of achieving the objectives or, alternatively, to prevent them from being met. In this way, an actor's decisions and decision-making processes will affect current policies, regulations and institutions which, in turn, affect actors' performances.

When actors at the agent level start to consider new interaction mechanisms and, if they agree on using them, actors start to make changes in their customs, in this way they can elicit a desired transition through their decision-making and deployment of resources, thereby altering the interaction mechanisms between actors at network level. Changes in the interaction mechanisms, in turn, alter the current dynamic equilibrium of the system, creating a new state of affairs. Figure 3.8 shows the impact of changes at agent level and the influence at network and system levels. In this figure the shape representing the interactions at network level has changed with respect to the shape representing the interactions at network level in Figure 3.7. This difference is intended to portray the changes at network level when the number of actors involved changes at agent level.

To fill in all the elements and changes in the SyNeA framework, we will make use of case studies combined with modelling to comprehend the transition taking place in a selected case. In the following section, we will explain how a case study can be applied to make use of this SyNeA framework.

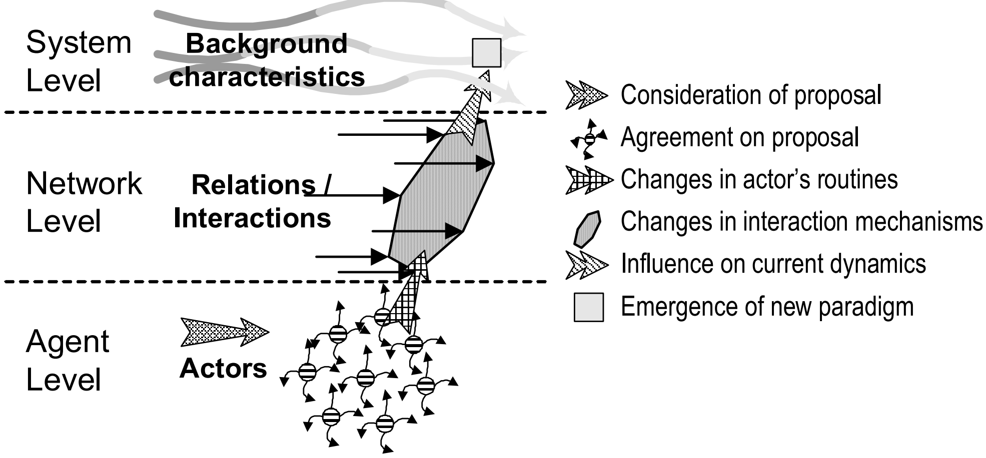

Figure 3.8: Changes at actor level and their impact at network and system levels

3.2. Studying transitions with case studies

As large-scale socio-technical systems are made up of a social and technical sub-system in constant interaction, it is important to understand the complexity of a socio-technical system in transition as a whole. It is recognized that transitions can be understood by examining case studies because these can be defined as systems with boundaries that can be inferred:

> *"(…) from the implicit boundaries of time, geography, place, and event, and are thus almost pre-existing, real and empirically bound." (C.C. Ragin, in (Luck, Jackson, & Usher, 2006))*

Here it is understood that the boundaries of a system can be easily recognised from the natural boundaries of time and space. To study large-scale socio-technical systems using case studies, it is necessary to adopt an appropriate methodology because the volume of information in a case study has to be organized, simplified, compared and possibly generalized for future application. Therefore, we will use case studies as our methodology because:

> *"[A] case study is the study of the particularity and complexity of a single case, coming to understand its activity within important circumstances.(…) We look for the detail of interaction with its contexts" (Stake, 1995)*

In addition, it is stated that:

> *"[A] case study is defined as a detailed, intensive study of a particular contextual, and bounded phenomena that is undertaken in real life situations." (Luck, et al., 2006)*

In general, it can be said that case studies can be used to understand complex phenomena as they retain holistic and meaningful characteristics of real life events (Yin, 2003). The use of a case study is relevant in connecting theoretical abstractions to complex practice, which is valuable in multi-disciplinary research (Luck, et al., 2006). Additionally, Ragin (2006) indicated that case studies help to reorient and enrich quantitative analyses because they "are all 'good instances' of the outcome under investigation" and therefore deserve careful attention.

3.2.1. Justification for the use of case studies

In this study our aim is to investigate what transitions are, and more specifically, how they come into being. Our expectation is to find a systematic way to analyse different kinds of transitions and draw lessons from the transitions studied to understand what the relevant mechanisms are within transitions. Moreover, it is useful to study contemporary events to overcome historical differences and possibly to be able to identify significant elements to influence transitions. Given that transitions are complex phenomena researchers cannot experiment in this field. Here, the use of case studies for this type of research is justified because:

> *"a 'how' or 'why' question is being asked about a contemporary set of events, over which the investigator has little or no control" (Yin, 2003)*

These questions invite us to use case studies to describe and explain how and why transitions happen. Given that the SyNeA framework has been designed based on different perspectives, case studies can also be used to explore how this framework performs in terms of explaining current transitions. In this sense, case studies can be used for descriptive and explanatory purposes (Yin, 2003).

As transitions can take years to occur and the focus of this research lies on how a socio-technical system evolves over time, it will be applied to cases of a longitudinal nature: these are cases studied at several points in time (Yin, 2003). Additionally, the case studies will be embedded because of the multi-disciplinary approach: several analysis units are taken into account simultaneously (Yin, 2003), i.e. agents, networks and the system. As longitudinal cases can also be used in combination with other cases, the final design of the case study was that of multiple cases. In this way, we have attempted to reduce the vulnerability of a single case study and to use the results of each case study to provide feedback (Yin, 2003) into the original SyNeA framework design. In this sense, the use of multiple case studies in this research project is justified for two reasons.

The first relates to the tuning of the SyNeA framework for analysis and modelling of what happens in reality: the case studies will be used to test the developed framework in terms of its ability to elucidate a transition, identify the relevant levers for actors to steer a transition and to define indicators to measure the transition progress. A suitable case study for this purpose was selected, i.e. Brazil's transition from a fossil fuel consumer to a bio-fuel producer, with less dependence on fossil fuels. This case study is longitudinal in nature as this transition has several milestones during the course of its development, most of them related to abrupt changes in oil and sugar prices and improved knowledge about the sustainability of the production process of bio-ethanol.

The second reason is the (partial) validation of the SyNeA framework for analysis and modelling, and the exploration of how transitions develop in a certain region given a distinct set of institutions, actors, their relationships, available resources and impact on technology and, where possible, to determine the current state of the transition given the overarching objectives. For this we have selected the transition of the Netherlands from locally and decentralized waste management to a supply-chain approach for the management of household waste. It is expected that this case study will support the validation of the SyNeA framework because there are significant differences compared with the previous case: the cultural background of the Netherlands is different to Brazil (see (Hofstede, 1991; Hofstede & Hofstede, 2005) for a comparison of both countries) which affects the polity at network level and the heuristics at agent level.

3.2.2. Objective of the case studies

To maintain focus on the qualitative outcome of interest, it is recommended to:

> *" … conduct in-depth research on the best instances of the outcome in question, with special attention to the issue of 'how' the outcome comes about. (Ragin, 2006)"*

Additionally, it is necessary to focus on the best instances of the outcome of interest to search for potentially necessary conditions (Ragin, 2006).

To be able to address the related question of: "what lessons can be learned from the studied transition cases regarding the dynamics of (desired) transitions in socio-technical systems?", it is necessary to first focus on the question "how does a transition occur"? In this research project, and to answer the leading question in this case, the objective is to identify:

* The kind of 'drastic' event(s) that affect interaction between actors and actors' concerns in such a way that they feel compelled to make a transition.
* The kind of new interaction mechanisms, in the form of networks, that are proposed at the beginning of a transition and remain in place during the course of the transition.
* The presence and activity of different kinds of actors (according to the introduced typology) during a transition.
* The evaluation criteria for assessing the degree of change compared with the initial stage.

The focus of the study will be on the (national, regional) transition strategy heading towards a system shift. Based on these objectives, the intention is first to understand the evolution of a particular case from the introduction of a new paradigm, until its completion, if possible. When the two cases are completed, it would be desirable to discover the leverage points that influence the diffusion of a new paradigm in a system and the changes in relationships between actors, in the form of networks, and the changes in the actors' heuristics in terms of decision-making. Based on the case studies it will be useful to observe to what extent it is possible to influence desired transitions. This hierarchy of research questions will help answer the main research question by providing an answer to sub-question four on lessons learned from the case studies regarding how technological replacement is achieved based on desired social objectives.

In this study, two case studies were selected to examine the transition of large-scale socio-technical systems. Each case study addresses a supply chain in which inputs and processes are changed in order to obtain outputs for the same purpose (and sometimes even with improved properties). The first case study is at the front-end of a supply chain (different raw material to produce fuel for transportation): the transition to sugarcane ethanol as fuel for light vehicles in Brazil. The second case study is at the back-end of a supply chain (the transformation of household refuse into raw materials or new products): the transition to a supply-chain approach for household waste management in the Netherlands. It is assumed that these case studies will support the examination of gradual shifts or technological replacement in which common social objectives are necessary to lead the transition.

3.2.3. Procedure for the case studies

To meet the objectives of this research and to answer the research questions, adequate case studies need to be selected. Here, we looked for case studies that would be suitable to "investigate the theory" (Johnston, Leach, & Liu, 1999), following a replication logic – not a sampling logic – to develop a rich theoretical framework (Yin, 2003) by feeding the relevant findings of each conducted case study back into the SyNeA framework.

For the purposes of the replication logic, the selection of particular case studies was based on several criteria, as follows:

1. The identification of a particular need in society that could be met by a technological change.
2. The design of a specific objective in order to alleviate a social need.
3. The choice of a particular alternative solution to define the direction of the transition.
4. The number and type of actors involved in the transition.
5. The geographical influence of the transition in question in view of the political boundaries.
6. The formalisation of new preferences by a public declaration of governments.

Once the case studies have been selected, attention needs to be paid to the complexity and contextuality of the cases. To facilitate this, Stake (1995) proposed focusing on "issues as [a] conceptual structure". Basically, the issues relevant for this study are related to:

1. How does a transition begin?
2. Why does a transition last or not last (succeed or fail)?
3. How does a change get established after a transition?

Bearing in mind the above questions, attention should be paid to collecting information about the situation before and during the transition, as well as the current state of affairs. To be able to get enough information, topical questions are required to guide the collection of information to describe the case study (Stake, 1995). In accordance with the above issues, a topical outline of the information to be collected is presented in table 3.2.

Each case study makes use of different ways to gather information. This is useful in case studies because it enables us to address a broader range of issues and helps corroborate the same fact with different sources, improving the accuracy of the findings (Yin, 2003). In this research, the following methods were used to gather information about the topics given in Table 2:

- Interviews with selected parties, based on the typology of actors in the developed framework.
- Study of policy documents (legislation acts or bills, government decrees, reports, etc.)
- Literature study of scientific articles and books.
- Review of newspaper articles.

After the information about the cases has been collected, the SyNeA framework will be used to disentangle the transition at three levels of aggregation by concentrating on key issues at each level. Then, a stepwise modelling technique will be applied to capture the complexity of the case, facilitate communication of the insights obtained, and provide a basis for the simulation model.

Table 3.2: Topical information to be obtained for the case study

A. Past dynamics and initial state
  A1. System dynamics:
    * Country situation before the transition
    * Reasons for the transition
  A2. Network dynamics
    * Existing policy
    * Existing polity
    * Existing supply chain
  A3. Agent dynamics
    * Available choices and ranking
    * Perspective of the existing situation

B. Transition
  B1. System dynamics
    * Factors promoting the use of the new preference (order)
    * Factors obstructing the use of the new preference (order)
    * Indicators to measure the transition (e.g. usage of new preference, market share)
  B2. Network dynamics
    * Type of polity change (if any)
    * Objectives of the introduction of a new preference (order, if any)
    * Parties involved in defining objectives for policy-making
    * Introduction of the policy change (effectiveness, supervision, regulation)
    * Introduction of the technological change
    * Other regulations supporting the policy change
    * Other technologies supporting the new technological preference
    * Other institutions supporting the transition
    * Changes in the supply chain
  B3. Agent dynamics
    * Changes in decision heuristics
    * Changes in available resources
    * Changes in existing operations

C. Current state and retrospection
  C1. System dynamics
    * Evolution of the system with key figures (e.g. evolution of market penetration)
    * Achievement of initial objectives (e.g. usage compared with established targets)
  C2. Network dynamics
    * Drawbacks to the transition
    * Handling of deviations from the original strategy
  C3. Agent dynamics
    * Expectations regarding future developments

3.2.4. Report structure for the case studies

After the case studies had been completed and the SyNeA framework for analysis and modelling applied, the results will be reported according to the following structure:

1. Introduction of the case study: this section explains the nature of the chosen case and the arguments for meeting the selection criteria.

2. Historical developments: this section describes the developments before the start of the transition, the formalisation of the preferences to start the transition, the evolution of the transition itself, and the current status of the transition concerned.
3. SyNeA characterisation of the case: this section presents a description of the state of the system (drastic events, cultural background), network (polity, policy change, and technology change), and agent (per role of the typology).
4. Evaluation of the transition: this section explains the triggers, circumstances and evolution of the transition in line with the SyNeA framework, and the evolution towards the current dynamics by means of key figures.
5. Learning opportunities and risks of the case: this section describes the lessons learned about the transition from the studied case and new insights for improving the SyNeA framework for analysis and modelling.

After systematically presenting the information concerning the case following the above structure, it will become the basis for applying different modelling techniques. These will be introduced in the following section.

3.3. Qualitative modelling of transitions

As explained above, it is assumed that a system in transition is a complex adaptive system formed by two sub-systems, the social and the technical, repeatedly interacting through policy and economic institutions. As a complex adaptive system, it is difficult – if not impossible – to model this type of system (Mikulecky, 2001). However, since models are important tools for system analysis because of the simplification of reality that they represent (Miser & Quade, 1985), efforts have been made to undertake simulation modelling of the behaviour of socio-technical systems.

One such attempt was made by Yucel (2010). This author positions his actor-option framework as a perspective for modelling transitions that can complement existing perspectives for the study of transitions. However, the generic framework of Yucel is based on the principles of System Dynamics and uses causal loop diagrams for the modelling on-demand of actors in a particular system, where the social component is reduced to a ranking of preferences of existing alternatives. Nevertheless, the actor-option framework could be used to quantify causal relationships already modelled with the SyNeA framework, and to simulate the transition studied at a high aggregation level.

Another contribution was made by Chappin (2011). This author focused on the modelling of energy transitions to support transition management. A generic framework based on agent-based models was applied to study cases of energy transitions. These cases were built based on one type of actor (as well as their technologies) and modelled as agents, while other actors in the same system were modelled as boundary conditions or neglected. Again, this is another example of modelling on demand. However, the Agent-Based modelling framework is useful to transform causal relationships, by rearranging actors in the SyNeA framework into agents, and then simulate the behaviour of actors.

Finding proper methodologies for the modelling of these kinds of systems is critical because the scope of these systems, the multiple levels, and the combined decision-making of actors result in so many factors and dynamics to observe and analyse that these cannot easily be visualized, validated and explored. Nikolić, Dijkema and van Dam (2009) proposed an Action-Oriented Industrial Ecology (AOIE) modelling approach to capture the characteristics of complex adaptive systems and transform the insights obtained into simulation models for ex-post evaluation of the system structure, content and behaviour (see Figure 3.9).

The AOIE modelling approach presents a sequence of activities to reduce information from real-world industrial clusters to simulation models. This modelling approach entails two cycles of activities: the knowledge application cycle and the simulation cycle. The knowledge application cycle is defined as "the process of influencing a large socio-technical system", while the simulation cycle is defined as "the process of determining which influence to exert" (Nikolić, Dijkema, van Dam, & Lukszo, 2006).

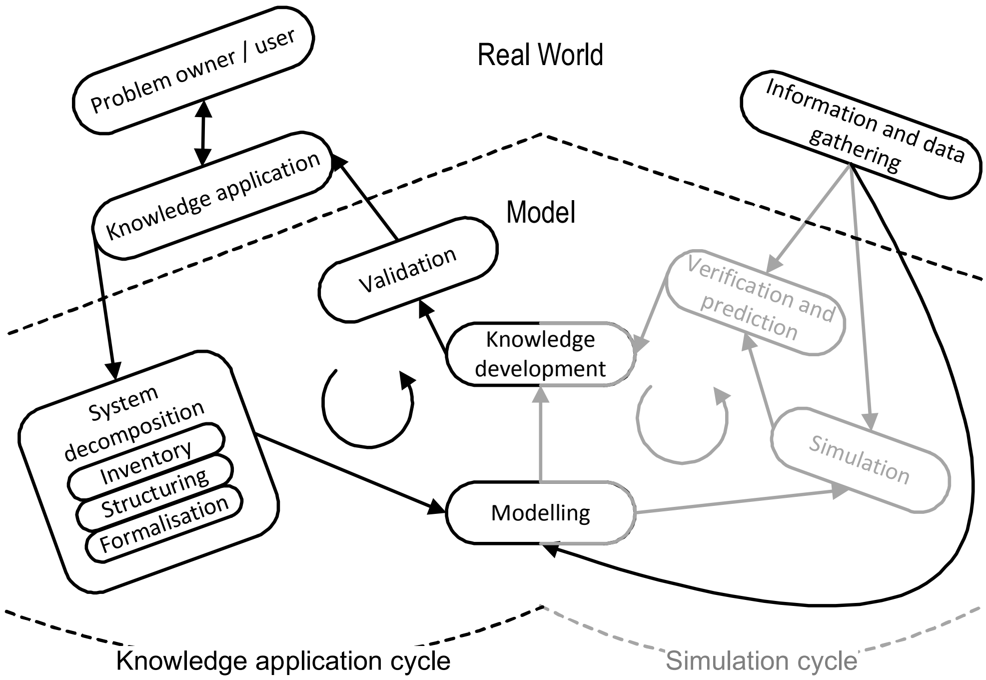

Figure 3.9: Use of the knowledge application cycle of the AOIE approach (based on (Nikolić, et al., 2009))

The AOIE modelling approach offers a suitable starting point given that the object of our study is socio-technical systems in transition. Although the AOIE modelling approach offers heuristics for the simplification of information obtained from socio-technical systems to make it suitable for modelling, tools to break down systems in transition still need to be developed. In view of the scope of this research project, our focus will be on taking the knowledge application cycle and adapting it to capture elements of the real world in an inventory, to structure the inventoried elements according to the SyNeA framework, and to formalize them in qualitative models and knowledge of systems in transition that may be useful for simulation purposes.

The level of aggregation of the available information also plays a role when selecting a modelling perspective. Top-down approaches work with a higher aggregation level which, in turn, facilitates long term decision making, while bottom-up approaches provide grounds for microcosmic behaviour at a low aggregation level and for emergent structures. The corresponding simulation techniques will also influence the opportunities for further experimentation. A comparison of different simulation techniques is presented in Table 3.3.

The application of any particular modelling approach in an exclusive way may diminish the possibility of addressing the complexity of transitions, considering the numerous elements in a socio-technical system. It is also important to consider that top-down and bottom-up factors could even perform in opposite directions (Posey et al., 2002) shaping the intermediate level in an unexpected way. Any modelling approach has its own strengths and weaknesses. For example, bottom-up approaches lack "the macroeconomic feedbacks of different energy pathways and policies in terms of changes in economic structure, productivity and trade that would affect the rate, direction and distribution of economic growth" while top-down approaches lack "technological flexibility beyond current practices" (Hourcade, Jaccard, Bataille, & Ghersi, 2006), which means that the future remains a mystery given that real systems continue changing their structure in response to external influences.

Table 3.3: Comparison of social science simulation techniques (Gilbert & Troitzsch, 1999)

Simulation Techniques	Number of Levels	Communication between Agents	Complexity of Agents	Number of Agents
System Dynamics	1	No	Low	One
Queuing models	1	No	Low	Many
Micro-simulation	2	No	High	Many
Cellular Automata	2	Yes	Low	Many
Multi-level simulation	2+	Maybe	Low	Many
Multi-agent models	2+	Yes	High	Few
Learning models	2+	Maybe	High	Many

While studying large-scale socio-technical systems in transition, we observe that information feedback occurs in actors' internal decision-making processes, among actors (Forrester, 1992), and between actors and their surroundings. This means that continuous processes are linked with discrete elements. Information feedback is identified not only in macro-indicators (e.g. production levels, prices), which become an input for actors' internal decision-making processes, but also as micro-indicators inside the decision-making process of each actor (e.g. fuel needs, savings). To transform the transition breakdown into elements for qualitative modelling and to provide a basis for simulation, it is necessary to look more closely at actors' decision-making processes and interaction mechanisms.

The rationality of an actor in decision-making is limited owing to the imperfect information they receive, due to constraints in attention, memory, comprehension, or communication (March, 1994). According to Forrester (1992), delays in information flows can exemplify the imperfect information that actors capture from the environment. However, information can also be obtained from other actors. By slowing down an actor's access to information, an imperfect distribution of information is created in the model and actors obtain different information from the environment at different rates. In this way heterogeneity in the distribution of information between actors can be modelled and this particular simplification makes it possible to model the decision-making process of actors (Forrester, 1992).

However, before individual or collective decisions are made, actors engage in a discovery and learning process in their environment, and from other actors, in order to close their knowledge gaps as much as possible, and make informed decisions. The knowledge gap identified is transformed into a knowledge target, and a decision is taken only when this target has been reached. Under these assumptions, the process of arriving at a particular decision can be seen as a continuous process, while the decision itself can be seen as a discrete event. This decision-making structure has already been applied in supply chains (Schieritz & Größler, 2003) where agents engage in a continuous decision-making process in order to arrive at decisions. With this in mind, the purpose is to adapt the qualitative analysis carried out by applying the SyNeA framework to a case study with a qualitative formulation of actors for a simulation model, by providing the basis for a functional modelling of actors.

Suggestions for hybrid modelling have already been made (Schieritz & Größler, 2003; Yücel & Chiong Meza, 2007). This hybrid modelling approach combines elements of System Dynamics which facilitate the display of continuous processes (e.g. fossil fuel production, modelled with System Dynamics) as well as discrete events (e.g. decisions, with Agent Based Models).

To unravel the dynamics of a case in a systematic way we will apply, in a stepwise manner, the principles of System Dynamics (Forrester, 1961; Sterman, 2000), specifically using causal-loop diagrams to help show the dynamics at system level, and then break it down to network and agents, with the principles of Agent Based modelling (Gilbert & Terna, 2000; Gilbert & Troitzsch, 1999) to use the results as a basis for a functional specification of agents and decision rules for agent-based models, as proposed by Van Dam (2009), so that once all variables have been quantified, they can be used to feed the overarching simulation engine for the implementation of different large-scale socio-technical systems (Nikolić, Dijkema, & van Dam, 2008).

3.3.1. From case study to causality

The notion of causal relationships, extensively used in System Dynamics (Richardson, 1991; Sterman, 2000), supports the design of a conceptual model. The associated tool for this task is an influence diagram, also referred as causal-loop diagram (Coyle, 1996).

In a causal loop diagram, sequences of causes and effects (Richardson & Pugh III, 1981) form the interactions in a system (Sterman, 2000). Causes and effects become the variables in the model which are connected by arrows. The relative position of the variable with respect to the arrow determines the order of the causality. The variable at the tail of the arrow prompts a change in the variable at the head of the arrow. Additionally, arrows hold signs to indicate the direction of the causality. A plus (+) indicates a direct relationship between variables: the variable at the head of an arrow changes in the same direction as the variable at the tail of the arrow; a minus (-) indicates an inverse relationship: the variable at the head of an arrow changes in the opposite direction to the variable at the tail of the arrow (Coyle, 1996). Figure 3.10 shows a causal-loop diagram.

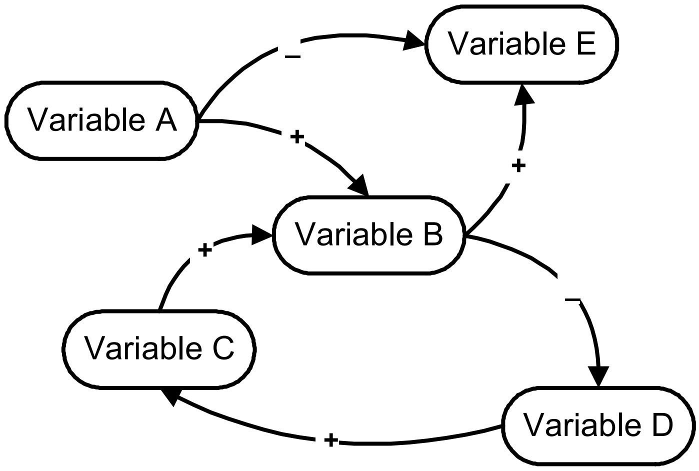

Figure 3.10: Causal-loop diagram

The information structured by means of causal-loop diagrams can then be organized into a system diagram (Miser & Quade, 1985; Walker, 2000) in which the factors and relationships of the causal diagram are grouped per actor, so that it becomes possible to identify the common outcomes of interest, to enable the progress of the transition to be observed. Figure 3.11 presents a system diagram showing the basic elements.

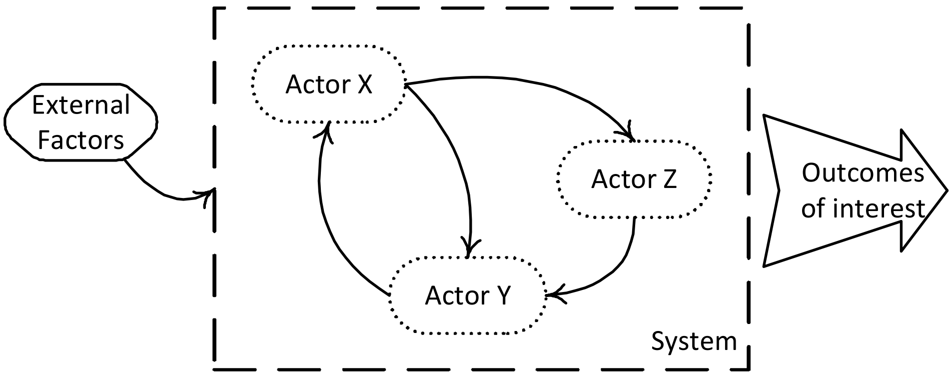

Figure 3.11: System diagram

3.3.2. From causality to agents

The system diagram arranged by actor provides the basis for the modelling of agents, as introduced by Van Dam (2009). Van Dam (2009) uses nodes and edges as the basic elements for modelling socio-technical systems (see Figure 3.12). Here, nodes are intersections of edges and represent agents – social nodes with decision-making power on physical nodes – or technologies – physical nodes with transformation power – while edges are relationships between nodes, and these represent social or physical connections. Nodes represent the actors and the technologies in an agent-based representation of the system, and edges represent the relationships between actors and the technologies in the system.

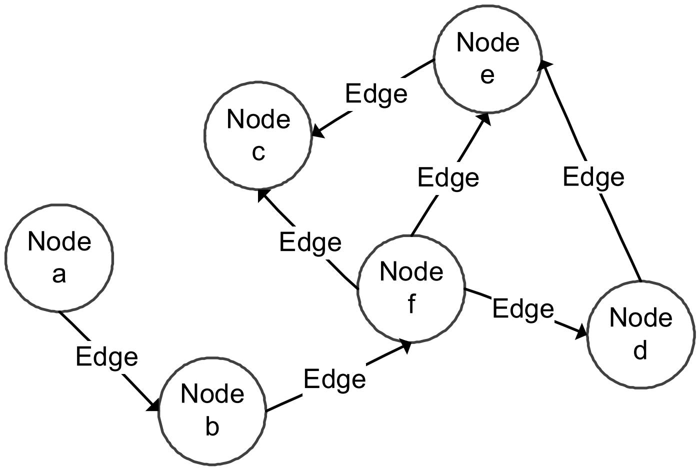

Figure 3.12: Network of nodes and edges

Van Dam (2009) described the following types of edges:

* Social edges: these are social relationships, normally expressed as contracts between social agents or ownership of a particular technology.
* Physical edges: these are technical relationships expressed as a connection (way in which material is transported) and a flow (the actual material being transported).

Based on the notion of nodes and edges, the system diagram can be re-arranged such that the social and the technical sub-systems become visible. In this way, the relationships between actors, among technologies and between the two sub-systems can be clearly displayed as agents, and later inventoried for quantification. Figure 3.13 shows how agents and edges will be modelled, as nodes and relationships, respectively.

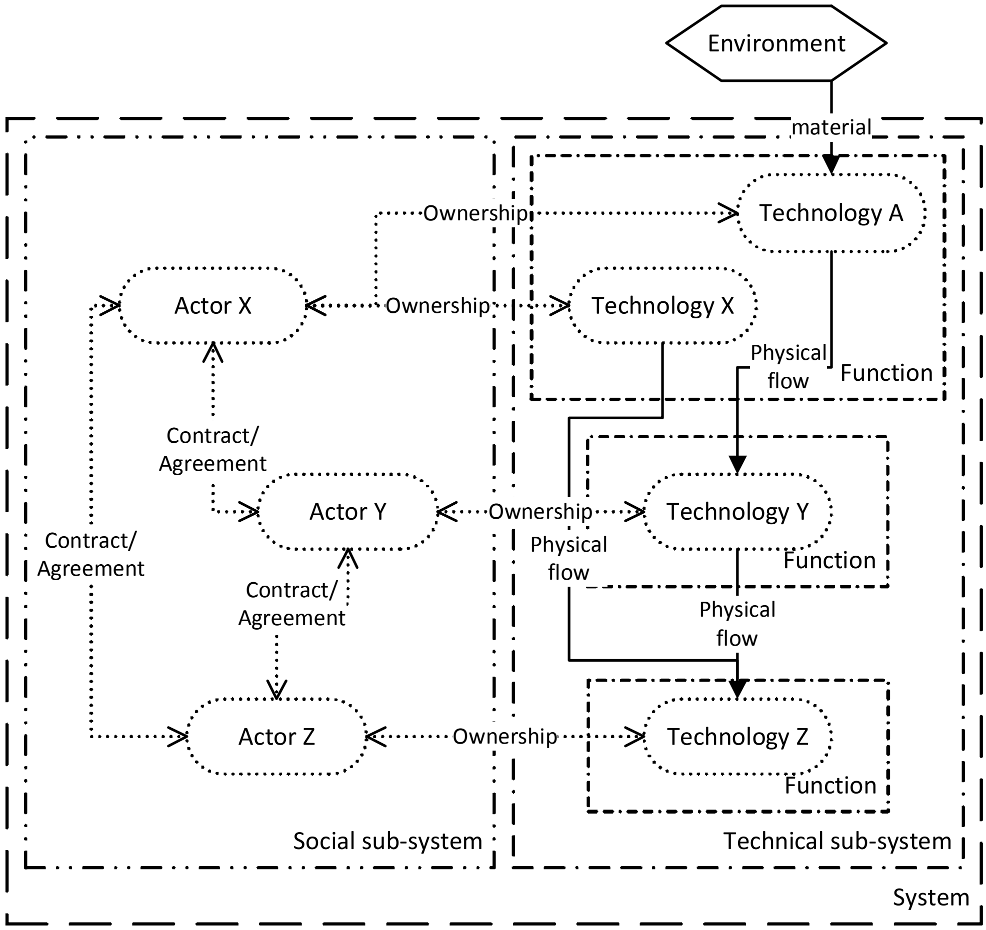

Figure 3.13: Arrangement of agents in a system

3.4. Conclusion concerning the framework construction

Based on this step-by-step approach to modelling systems in transition, our SyNeA framework for analysis and modelling benefits from the principles of information feedback of System Dynamics. Information feedback, when modelled as causal-loop diagrams, shows the relationships between the three levels of our framework: dynamics at the system level affect the interaction mechanisms of actors at the network level which, in turn, affect the characteristics of actors at the agent level. The inverse feedback between levels takes place when actors react by altering the interaction mechanisms and consequently shifting the equilibrium at system level.

Additionally, our SyNeA framework benefits from the principles for the formalisation of actors, because actors in our typology require a systematic means to catalogue the objectives, resources, and decision rules that are relevant for the interplay between actors. In this way, actors are able to "behave" in a discrete way, allowing them to create input for the system model according to the information they receive at the moment they receive it, and introduce heterogeneity into the continuous model of the energy system.

Our approach furthermore benefits from the combination of the significant features of four disciplines. Given that they are theoretical, they provide the basis for the developed framework for analysis and the design of the modelling strategy. In this way, we have attempted to meet the methodological requirements of Ostrom (2005) in terms of a scientific approach to reforms and transitions, and to achieve a sound and well-founded approach to understanding transitions in socio-technical systems.

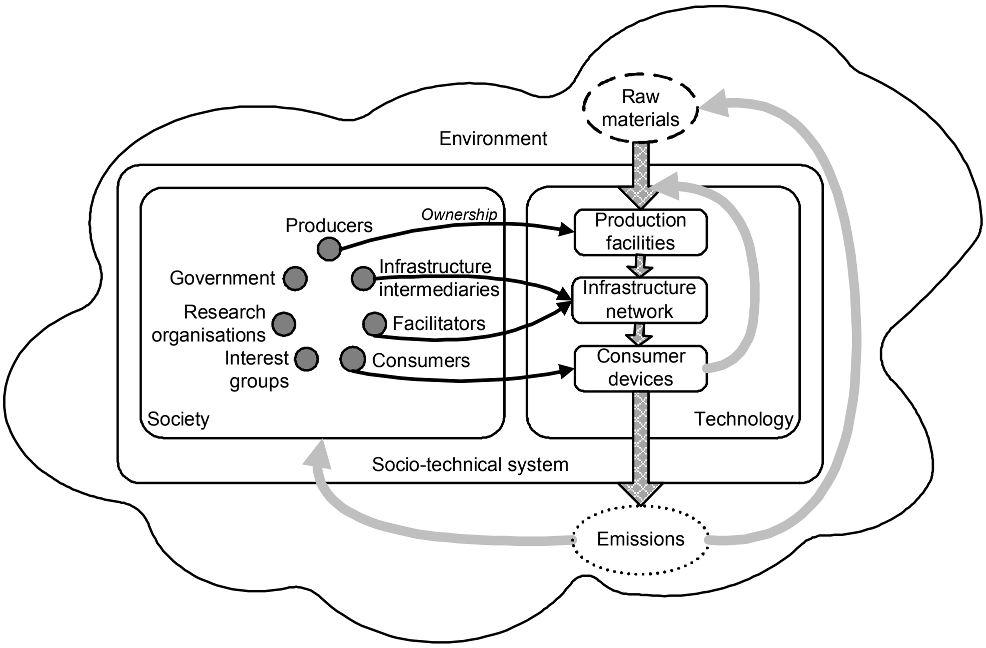

Figure 3.14: Socio-technical system, conceptualised with the SyNeA framework

In this chapter an analytical framework has been set out to help analyse and model transitions at three levels of aggregation: system, network and agent. Together with this, a methodology has been proposed to gather information in a systematic manner to analyse transitions using the analytical framework. To determine the viability of this analytical framework, it is tested by applying it to two case studies. In the case studies it is considered whether:

a. The elements of the SyNeA framework were present.
b. The elements of the SyNeA framework were connected to causal relationships.
c. The conceptualised relationships of agents are sufficient to describe the connections between different roles of actors, their technologies, and between both sub-systems.

The next two chapters are devoted to the application and testing of the SyNeA framework and the method to model transitions in socio-technical systems.

Chapter 4
Case Study I: Brazil and the transition to sugarcane ethanol as fuel for light vehicles

Thirty five years ago, the Brazilian government decided to become less dependent on oil imports and its derivatives: it started research and subsidy programmes to find alternative energy sources for transportation purposes, especially light vehicles, and ventured to design and carry out policies to introduce new energy carriers at a large scale.

Given its geographical, economic and social situation, Brazil started to produce ethanol, not from oil, but from various crops. Later, sugarcane became the prime crop for the production of bio-ethanol due to the high yield of this crop in comparison to others, and the existent know-how of the production process of bio-ethanol. This breakthrough provided Brazil with new business and job opportunities with an environmentally sound product.

The Brazilian transition spans a period of more than thirty years, having a rebirth in the last five years with the introduction of Flex-fuel cars that can use gasoline and bio-ethanol in any proportion.

4.1. Introduction to the Brazilian case

The case of Brazil is an outstanding case for the study of transitions of socio-technical systems: the introduction of bio-ethanol in the market has tilted the existing system in order to accommodate, not only a new supply chain, but also new policy and technology – in light vehicles for the use of bio-ethanol – to nurture the use of this fuel at national level and when possible, also beyond its borders.

This paradigm shift would not have been possible with a lonely work of government: it required the commitment of a variety of actors to fulfil different roles in the supply chain and in the innovation process. From producers to consumers, also research organisations were included in this transition process in order to make use of each actor's expertise to achieve a common goal.

Brazil fulfils the selection criteria of our study because it was a country that was almost totally dependent on oil and its derivatives, especially in the transport sector; whose government saw the need to openly declare the start of a new national project that could lead to the liberation of the oil addiction and has had the local agricultural capacity to produce crops from which bio-fuels could be obtained. Additionally, Brazil has had installations to refine, store and distribute oil and its derivatives since the 1950s with the creation of a state-owned petroleum company: PETROBRÁS.

Using the SyNeA framework we will try to unravel the complex process of Brazil's transition to sugarcane ethanol as fuel for light vehicles and portray the changes at three different aggregation level: system, network and agent. At the system level we will focus on the drastic events that triggered the Brazilian transition and the cultural background that made possible such transition. At the network level, the focus is on the polity, the policy change and the technology change that put in motion this transition process. Especially at the agent level, we want to investigate to what extent the role of government could be considered as initiator of this transition process among other actors involved.

In the next section we present a historical overview of the introduction of bio-ethanol in Brazil. In section three we present a description of the different elements of the Brazilian transition at each of the three level of our approach. Section four contains the evaluation of the Brazilian transition regarding the information exchange between actors at the agent level, the current situation as compared with the initial objective and the lessons learnt of this transition. Finally, conclusions of the case study and in relation to the research methodology and approach are presented in section five.

4.2. Historical development of the introduction of ethanol in Brazil

Brazil has a long history of bio-ethanol use that dates back to the beginning of the XX century. It is possible to identify five phases in the historical developments around the use of bio-ethanol as fuel for light vehicles as follows.

4.2.1. Pre-Oil Crisis developments

The first government attempt to introduce bio-ethanol as blends in oil engines dated back to 1931, when the mixture of ethanol (anhydrous alcohol) with gasoline, at a minimum of 5% was enforced by Decree 19717 of February 20th, 1931 ("Decreto Nº 19.717," 1931). In 1933, government founded the Sugar and Alcohol Institute (Instituto do Açúcar e do Álcool, IAA) during the regime of Getulio Vargas ("Decreto Nº 22.789," 1933). This institute was meant to address the problems of overproduction of the sugar agribusiness, through the annual planning and control of production, by suiting the needs of the internal (national) and external consumption, and encouraging the production of alcohol as fuel in Brazil (Moraes, 2000). The main purpose was to save on oil imports, especially during World War II (Boddey, Soares, Alves, & Urquiaga, 2008).

At that moment, low oil prices prevented the use of alcohol as fuel to succeed. While efforts continued to introduce bio-ethanol in the Brazilian energy portfolio, government founded PETROBRÁS for oil promotion, transformation and distribution in 1953, during the democratic regime of Getulio Vargas (Boddey, et al., 2008). This reduced the chances for a breakthrough of bio-ethanol in the energy market.

When the first Oil Crisis in 1973 occurred, Brazil had become almost fully dependent on oil and its transportation derivatives (Goldemberg, 2006) due to its flexibility to be raw material of diverse energy carriers, such as gas, gasoline, or diesel, without causing detriment to the production of lubricants and chemicals as well as its ease for manipulation, transportation and storage (Confederação Nacional do Comércio et al., 1979). Especially in the transport sector (passengers and freight), gasoline covered 56% of the consumption and this share was higher in the passengers transport (Cooperativa de Produtores de Cana Açúcar e Álcool do Estado de São Paulo (COPERSUCAR), 1989). At that time, it was concluded that the oil consumption was closely related to the changes in gross domestic product and a shortage of oil could slow down the Brazilian economy (Confederação Nacional do Comércio, et al., 1979).

To reduce this dependence and protect its national interest, government focused on three lines of action (Rotstein, 1978):

* Investment in an electrical system of increasing capacity, powered by water resources in which the country is rich
* A plan for alcohol production as a first step for the intensive biomass use
* Use of non-metallurgical coal in thermoelectric plants and the production of gas and liquid fuel

Rotstein (1978) points out that it was already realized that there were oil fractions that could be not substitute, such as lubricating oil, paraffin, asphalt, and some raw materials of petrochemical industry.

4.2.2. Start-up of the Pro-Alcohol Programme

Two years after the first oil crisis, in 1975 and due to a hike in oil prices, the military regime of Ernesto Geisel developed three parallel programs for the substitution of diesel, oil fuel and gasoline by other alternative sources (Natale Netto, 2007) and started with the enactment of a decree to introduce the National Program of Alcohol – Pro-Alcohol (Programa Nacional do Álcool – Pro-Álcool). The program promoted the production and commercialisation of bio-ethanol as a substitute for oil and its transport derivatives and to achieve security of supply (Colares, 2008).

At the same time, government tried to overcome a negative balance of trade (Leite, 1987), due to the dependence on oil and its hikes in prices and to rescue the sugar industry, which was suffering from low sugar prices (Goldemberg, 2006) and from excess production and processing capacity (Puppim de Oliveira, 2002) as well as idle land and underemployed people (Rotstein, 1978). The technology to produce bio-ethanol from sugarcane was already available and used in Brazil and thus the production of this new energy carrier was possible. It is worth mentioning that the Pro-Alcohol decree did not restrict the feedstock to be used for bio-ethanol production to sugarcane, but instead promoted the use of any source from which bio-ethanol could be produced, such as yucca ("Decreto Nº 76.593," 1975). The decree included an investment program with the objective to support the production and distribution of bio-ethanol at national level, while it was complemented with other measures such as taxation on gasoline, subsidy for bio-ethanol on the consumer side (Puppim de Oliveira, 2002) and dedicating part of PETROBRÁS' capacity to accommodate the bio-ethanol distribution (Moreira & Goldemberg, 1999).

To stimulate ethanol consumption, government signed an agreement with the automotive industry on September 19th, 1975, where the automotive industry propose to put the new Otto-cycle motor – capable of using up to 22% anhydrous ethanol in gasoline mix – in their assembly lines and government was committed to guarantee the production of 10 billion litres of alcohol and to make ethanol available in a fully satisfactory manner throughout the national territory (Natale Netto, 2007).

After the second Oil Crisis in 1979, the alternative of vegetable oils, in combination with diesel fuel or as a single fuel, was more effectively studied and its promotion was officially approved by the National Energy Commission, through the creation of the Pro-Oil (Pro-Óleo), the National Program of Vegetable Oil for Energy Purposes, in October 1980 (Melo, 1981); unfortunately, Pro-Oil ceased to exist in 1986 due to the drop of oil prices. The same fate followed Pro-Coal (Pro-Carvão), which failed to use of coal in gasification or liquefaction processes to produce energy (Moraes, 2000). These processes were still very expensive despite the high investments in research and development. However, research on bio-diesel continued (Suarez & Plentz Meneghetti, 2007).

4.2.3. Stabilisation of the Pro-Alcohol Programme

The initial success of the Pro-Alcohol programme was supported by regulation, such us the exemption of taxes on the purchase of bio-ethanol cars for taxi (Moraes, 2000) and a protocol with the automotive industry for the production of cars running only on hydrated ethanol and the fixation of bio-ethanol prices at initially 65% (and later at 60%) of gasoline prices (Queiroz, 1983). This kind of initiatives increased the amount of bio-ethanol produced from 3,4 billion litres of alcohol in 1980 to 7,7 billion litres of alcohol in 1984 (Pro Cana, 2004) as well as the purchase of bio-ethanol cars due to the price difference.

The sharp drop of oil prices at the end of the 1980s initiated a true bio-ethanol crash. With low oil prices, the subsidies from government became unsustainable. Nevertheless, bio-ethanol remained competitive because of the taxation of gasoline

(Boddey, et al., 2008), which were used to cross-subsidize bio-ethanol and to lower its price. However, due to high sugar prices and low rainfall at the end of the 1980s, the bio-ethanol production was endangered and consumers started to lose faith in this alternative fuel due to the shortages in supply and the loss of value of their bio-ethanol cars in the second-hand market. At that time, it was estimated bio-ethanol production and use would only be feasible at oil prices above US$ 30 per barrel (Serôa da Motta & Rocha Ferreira, 1988).

4.2.4. Dismantling of the Pro-Alcohol Programme

In 1990, President Collor de Mello declared the end of the program (Pro Cana, 2004). On March 15th, the Sugar and Alcohol Institute (Instituto do Açúcar e do Álcool, IAA) was dismantled and its competencies were transferred to the Regional Development Secretary of the presidency. Under these circumstances, sugarcane producers urged to keep Pro-Alcohol running by emphasizing the large unemployment that the stop of this program would probably cause (Boddey et al., 2008). Government, under the Presidency of Itamar Franco, supported the sugarcane producers by the creation of a law which made obligatory the mix of 22% of anhydrous ethanol in gasoline ("Lei Nº 8.723," 1993). Although the process of liberalisation was announced in March 1996 by the Ministry of Finance, it was postponed three times, until 1999, when the resources for Pro-Alcohol were limited (Moraes, 2000).

The 21st century brought several changes to the development of the Pro-Alcohol programme. Government mandated the addition of 20 – 24% of anhydrous ethanol to gasoline ("Lei Nº 10.203," 2001). As an additive that substitutes tetra-ethyl lead ($C_8H_{20}Pb$), it turned out to have a better performance to combat lead air pollution; as a matter of course, this change in the legislation aided the sugarcane producers (Boddey, et al., 2008) to keep producing bio-ethanol with the related consequences on the Brazilian economy and employment level.

4.2.5. Rebirth of the bio-ethanol use and the bio-diesel programme

Recent incentives to the bio-ethanol use comprise the emergence and commercialisation of the Flex-Fuel cars (Associação Nacional dos Fabricantes de Veículos Automotores (ANFAVEA), 2008), the rising oil price due to the Gulf War and the instable political situation of oil-producing countries, and the contribution of bio-ethanol to lessen the greenhouse effect and its effects on climate change. Flex-Fuel cars are part of a new generation of cars capable of using gasoline and bio-ethanol in different proportion; high oil prices imply high gasoline prices and make bio-ethanol competitive without any cross-subsidy; the political situation of oil-producing countries (mainly OPEC countries) reinforced the idea of national security-of-supply; compared with other crops, bio-ethanol from sugarcane yields are enough to compensate for the energy that is put in the production process (Blottnitz & Curran, 2007; Isaias de Carvalho Macedo, Seabra, & Silva, 2008).

With the current promising horizon of bio-ethanol in Brazil, a law was passed for introduction of bio-diesel into the Brazilian energy matrix, mandating that the bio-diesel share should be a minimum percentage of 2% of the current diesel market, and this percentage should grow to 5% in eight years ("Lei Nº 11.097," 2005). This percentage could be adapted while considering the following criteria:

1. Availability of raw materials and industrial processing capacity
2. Participation of family farming in the supply of raw materials
3. Reduction of regional disparities
4. Performance of engines using bio-diesel
5. Industrial policies and technological innovation

As it has happened with bio-ethanol, bio-diesel is not restricted to a particular raw material. However, there are enough indications that soya is becoming the preferred raw material in the Brazilian context (Campos & Moraes, 2008), raising the controversy about the use of land for food versus fuel.

4.3. A SyNeA characterisation of the Brazilian case

Using the SyNeA framework, as explained in Chapter 3, we try to unravel the complexity of the Brazilian transition towards a bio-ethanol paradigm for light vehicles. The elements at system, network and agent level are detailed in the next sections to portray the dynamics occurring at these three levels.

4.3.1. Description of the Brazilian system conditions

At the system level, we describe the "drastic event" and the underlying cultural background of this period.

A. Drastic events

In the case of Brazil, the combination of two economic triggers has become the "drastic event" that started this transition process. One of them is the high oil price. The Brazilian economy was almost fully dependent on oil (Cooperativa de Produtores de Cana Açúcar e Álcool do Estado de São Paulo (COPERSUCAR), 1989). Brazil's transportation and energy production were dramatically dominated by oil. As activities that pervade other industrial activities of this country (Confederação Nacional do Comércio, et al., 1979), the oil crisis of the 1970s due to a hike in price (See Figure 4.1), forced government to take measures to diminish the dependence on this energy source and to counterbalance its negative balance of trade.

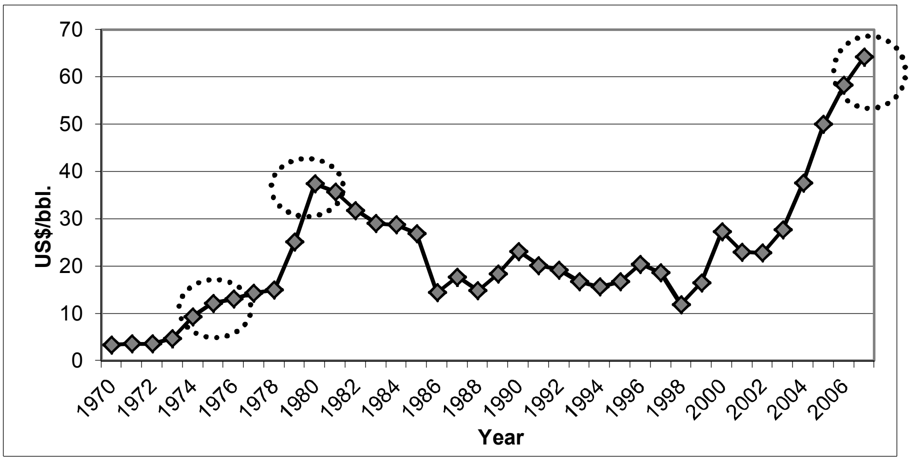

Figure 4.1: Annual average crude oil prices (InflationData.com, 2008)

At that time, the Brazilian government took the initiative to start some programs to try to substitute the use of fossil fuels for transportation purposes: Pro-Alcohol, Pro-Oil, and Pro-Coal.

Given that the sugarcane industry was and is an important source of income for the country and for employment, the drop in sugar prices became another trigger complementing the oil crisis. According to the Brazilian Trade Confederation (1979), the sugar prices drop (See Figure 4.2) made available an important amount of sugarcane, which would not be transformed into sugar. This surplus of sugarcane could be transformed into ethanol in the distilleries annexed to the sugar factories, which were deployed by means of the loans coming from the Pro-Alcohol programme.

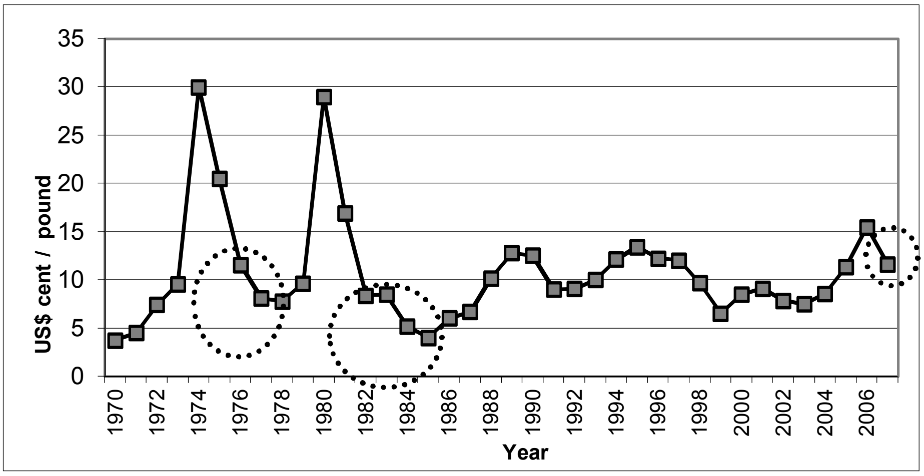

Figure 4.2: World raw sugar prices (United States Department of Agriculture, 2009)

The hike of oil prices and the drop of sugar prices together helped the actors in this system look at the same direction (getting out of the oil crisis), and created the incentives to depart from the intensive use of oil and its derivatives, especially gasoline (by seriously looking for other alternatives such as ethanol from sugarcane). As a result, the system shifted towards the use of bio-ethanol as an alternative energy carrier for transportation purposes.

B. Cultural background

Regarding the underlying the cultural background, Rotstein (2004) has already pointed out some basic reasons that make Brazilian citizens feel peaceful, safe and feeling part of the community. He has translated these reasons into a definition of social welfare, which is the combination of:

a. Personal safety: education, health, employment - housing - public transport[3], food, protection against violence.
b. Family safety: protection to the elderly, opportunities for the young.
c. Inclusion in the community: access to infrastructure (water, sewage, housing, energy, mass transportation, slums for the environment, flooding, retention of man in field), the confrontation of state and citizens.
d. National pride: a sense of social value, socio-economic development, prospects for personal and community valorisation, valorisation of national symbols (anthem, flag, etc.).

[3] The three T's (teto (roof), transporte (transport), trabalho (work)) are considered the basics for Brazilians

Considering the above definition of social welfare in the Brazilian context and based on Hofstede's cultural dimensions, Brazil can be described as a country where power is perceived as unequally distributed, the sense of belonging to a group is relatively strong when compared with developed countries, gender roles are relatively balanced, uncertain or unknown situations are experienced as threats, and where a relatively long-term orientation prevails (Hofstede, 1991). This particular combination of cultural dimensions allows to work as a "Pyramid of people" as interpreted by Owen James Steven (Hofstede, 1991), in which government acts as a general manager at the top of this pyramid and the other actors have a particular place in one of the layers of this pyramid, under the general manager. This perception was already acknowledged in 1979, at the seminar about Pro-Alcohol and Free Initiative. Here, it was considered that Government is capable enough to face problems and it is complemented by the private sector, which is the productive force invoked at the right time (Confederação Nacional do Comércio, et al., 1979).

Apparently, the above order of reasons for welfare and the organisation of country organisation yields some progress to the Brazilian population. The evolution of Brazilian life conditions could be somehow appreciated in the evolution of the Human Development Index, which is a summary composite index that measures a country's average achievements in three basic aspects of human development: health, knowledge, and a decent standard of living (Watkins, 2007). As it can be seen in Figure 4.3, the Brazilian Human Development Index has a steady growth since 1975, with a smaller slope between 2000 and 2005.

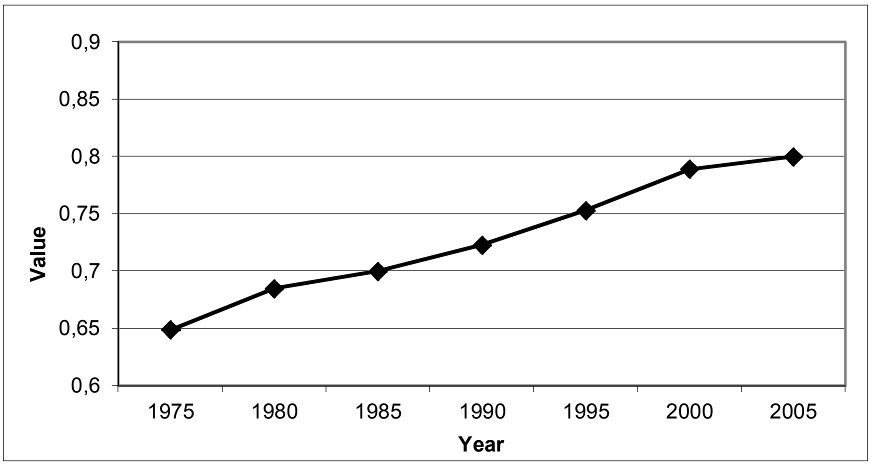

Figure 4.3: Evolution of the Brazilian Human Development Index (Watkins, 2007)

4.3.2. Description of the Brazilian network conditions

At the network level, we deal with the rules in which actors interact. In the Brazilian case, two main interaction mechanisms can be recognised. One is related to the polity ruling the country during the years of the introduction of a new alternative energy source. The other is related to the way this introduction was done.

A. Polity

Brazil has undergone a shift from a military regime to a democracy in the last 40 years. Parallel, the economic policy of these governments has shifted from almost an autarchy and central control towards a liberalised market-oriented country.

From 1964 until 1985 Brazil was ruled by a military junta, which allowed the Congress to continue with its legislative functions. After this period, presidents were elected. The Brazilian Democratic Movement Party (Partido do Movimento Democrático Brasileiro, PMDB) has occupied the presidency until 1995. Originated from the Brazilian Democratic Movement (Movimento Democrático Brasileiro, MDB) working as an umbrella organisation for the opposition during the military junta, the PMDB has a more populist character with centre-leftist ideas. After the PMDB, the Brazilian Social Democracy Party (Partido da Social Democracia Brasileira, PSDB) ruled this country with a social democratic ideology, trying to apply ideas coming from socialism and capitalism. The performance of this party in government allowed them to stay for two consecutive periods. Figure 4.4 portrays the evolution of governments in Brazil since 1930.

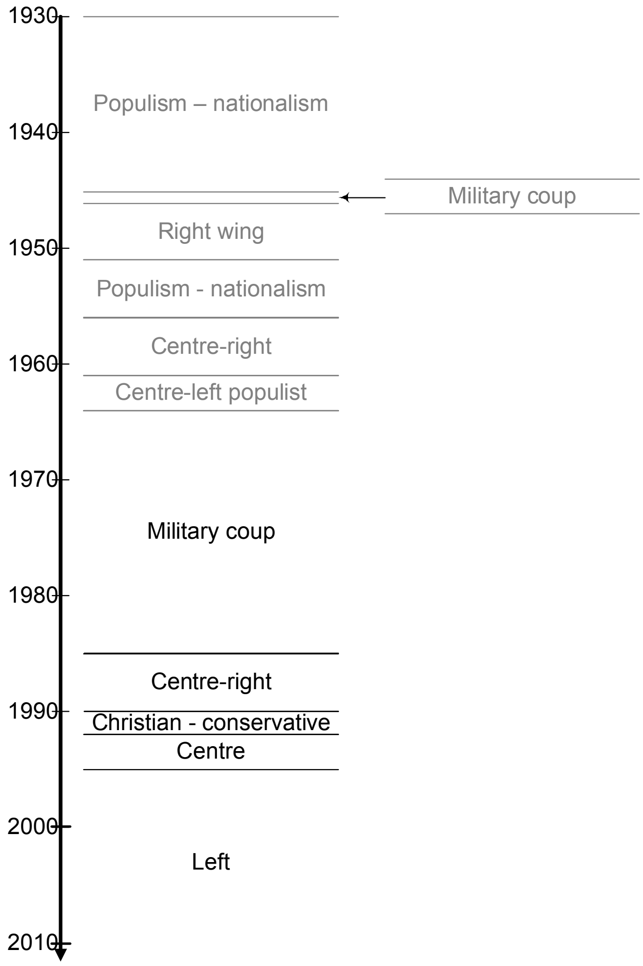

Figure 4.4: Evolution of governments in Brazil

In 2003, the Workers' Party (Partido dos Trabalhadores, PT) led by Luiz Inácio Lula da Silva got the opportunity to lead the country. Starting as a left socialist, this party has been ruling the country with more social democratic ideas. As it could be seen, a common characteristic of these presidencies is that they come from socialistic-oriented and populist ideologies.

B. Policy change

The drastic events made evident the instable situation in the country and the lack of fit of the existing interaction mechanisms. To address regional and individual income disparities, gross domestic income level, capital goods level and a negative balance of payments (Cooperativa de Produtores de Cana Açúcar e Álcool do Estado de São Paulo (COPERSUCAR), 1989), policy changes were needed.

The government started to promote the use of alternative energy sources by means of programmes. Pro-Alcohol ("Decreto Nº 76.593," 1975) was created by Decree 76.593 of 1975 to look after the need of automobile fuels, was ascribed to a set of ministries and was led by a branch of the Presidency. Strategically, the programme aimed at (Fernández, Magalhães, Contador, Alanio, & Kufermanu, 1984):

* Reduction of external vulnerability of the country
* Technological knowledge of the sugarcane sector
* Competition with imported oil
* Contribution to the decision-making of social problems of the country

The purpose of this decree was to create council that could outline the investment strategy in the production, transformation, distribution and storage activities, regulate the funding with loans through the national bank system, establish parity prices and technical standards, and consumers' incentives, as well as time make use of the existing organisations to avoid the creation of new ones (Fernández, et al., 1984) while using their expertise in the field. The existing supply chain was modified in order to accommodate this alternative energy source in a top-down manner. To support this change in policy, government also (Cooperativa de Produtores de Cana Açúcar e Álcool do Estado de São Paulo (COPERSUCAR), 1989):

* Increased gasoline prices, to inhibit its consumption
* Encouraged exports of goods and services, to compensate for higher costs of oil
* Adopted new foreign policy, to prioritize relations with oil producing countries
* Rose the domestic production of oil

Additionally, the signature of an agreement between government and the automotive industry in 1975, to make modifications on Otto-cycle motors to cope and guarantee with up to 22% ethanol mixed in gasoline, provided sufficient grounds to support the use of ethanol by opening a market for ethanol cars and the assurance of ethanol production and distribution. This also meant the creation of a technological lock-in effect in the automobile industry, and loss of face of government if commitments regarding ethanol production and distribution assurance are not achieved.

C. Technological change

To become less dependent of oil and its derivatives in the transportation sector, it was necessary a new energy carrier and appropriate machinery to use it. A technological change was here necessary in order to break through the current paradigm of oil use. The new energy carrier was actually an old acquaintance: ethanol, produced from sugarcane. The use of ethanol required new motors for cars, to be able to use ethanol as fuel.

In Brazil, sugarcane is the main raw material for ethanol production. From sugarcane it is possible to obtain cane juice and bagasse in mass proportion of 13:1

(Wheals, Basso, Alves, & Amorim, 1999). The cane juice is used for sugar and/or ethanol production, depending on the choice of the three possible configurations of a factory (Modesto, Zemp, & Nebra, 2009). Figure 4.5 shows a scheme of the different steps, necessary to transform sugarcane into sugar and ethanol in a combined factory.

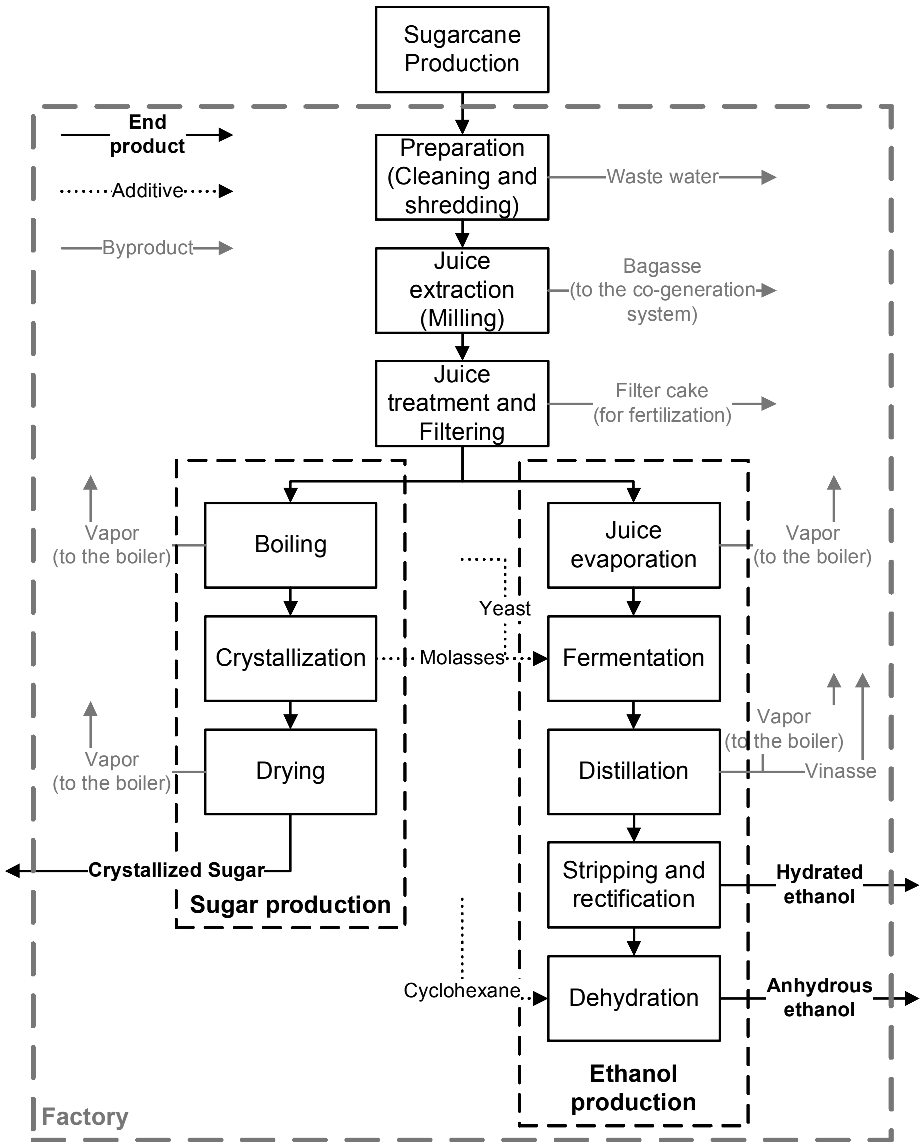

Figure 4.5: Overview of sugar and ethanol production (Based on (Ensinas, Modesto, Nebra, & Serra, 2009; Isaias de Carvalho Macedo, 2007; Wall Bake, Junginger, Faaij, Poot, & Walter, 2009))

The production of ethanol has been and is still based on fermentation and distillation of cane juice. These two processes, as well as the treatment processes, have been improved in the course of the time in order to reach greater processing capacity, recycling of by-products and energy independence (Isaias de Carvalho Macedo, 2007). It is worth mentioning that the sugar-alcohol industry has reach the point of electricity self-supply (See Figure 4.6) and is even able to export electricity to the network by using bagasse as raw material (Empresa de Pesquisa Energética (EPE) & Ministério de Minas e Energia (MME), 2007).

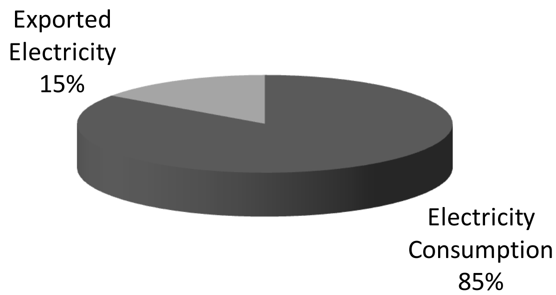

Figure 4.6: Distribution of the electricity produced by the sugar-alcohol industry in Brazil in 2006 (Empresa de Pesquisa Energética (EPE) & Ministério de Minas e Energia (MME), 2007)

The most notorious technological change is the use of ethanol in light vehicles in order to reduce the gasoline consumption. This was only possible with the combination of two events, namely the large scale production of ethanol, using sugarcane as raw material, and especially the modification of gasoline cars to make them capable of using gasoline mixed with anhydrous ethanol at a higher percentage than what gasoline motors could tolerate (Joseph Júnior, 2007) and the serial production of cars running on exclusively hydrated ethanol.

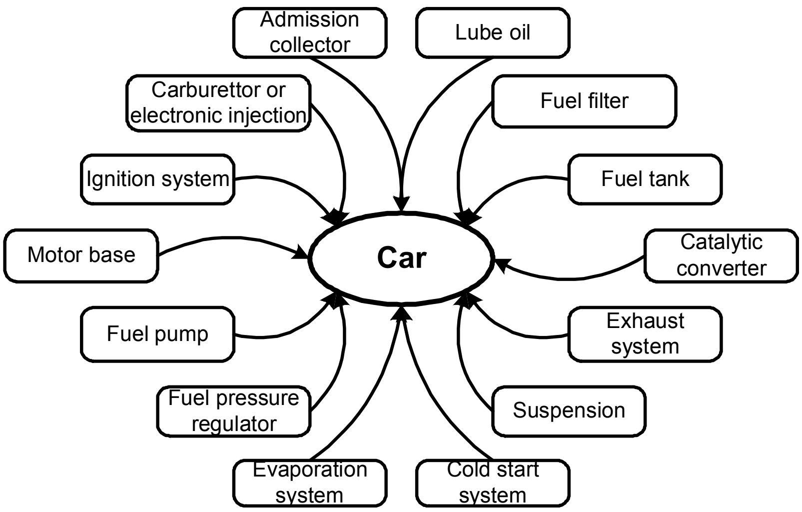

Figure 4.7: Modifications for an ethanol car (Based on (Joseph Júnior, 2007))

Regarding the modifications of gasoline cars, the changes were not superfluous (See Figure 4.7) and could not be properly executed in the garages, although their certification was regulated. Only an agreement with the car industry could guarantee a car that is able to deal with mixed gasoline from the factory.

Regarding the ethanol cars, with regulation put in place by government car factories in Brazil were encouraged to start to produce ethanol cars, knowing that consumers were also stimulated to buy them.

4.3.3. Description of the Brazilian agent conditions

At the agent level, the focus is on the relevant actors of the system. In the Brazilian case, six of the seven actors of our framework have been identified in the transition process, each of them with an active role.

<u>A. Government</u>

In this case, (national) government was confirmed as the initiator and coordinator of this transition process; its actions were backed up by the occurrence of a "drastic event", as explained above.

The situation of the country (e.g. small GDP, high inflation, large unemployment rate) put government in the unique position to support to other actors with policy and economic resources, and standard financial and economic instruments (e.g. subsidies, taxes, facilitation of loans). A first example is the decision to leave the ethanol production with the private sector at the production poles, supported with loans and subsidies, while keeping the distribution with PETROBRÁS at fixed prices and volumes (Rotstein, 1978).

A second example is the support to the ethanol engine. After much discussion, the state backed up the technology of alcohol engines, which was developed by the Technical Centre for Aeronautics (CTA) of the Ministry of Aeronautics and the automobile industry, under the supervision of the Department of Industrial Technology (ITS), Ministry of Industry and Trade (Moraes, 2000). However, it was already acknowledged in 1979 some major drawbacks of the Pro-Alcohol programme (Confederação Nacional do Comércio, et al., 1979):

* Bureaucratisation of credits due to insufficient funds and poor administration of the Central Bank, which was appointed to administrate the loans
* Inadequate pricing policy due to its close relation to sugar by means of the same raw material (sugarcane)
* Governmental intervention in the alcohol activity through the institution of a Commission that was only effective when the members were summoned to produce policy that sometimes conflicted with the Pro-Alcohol programme

<u>B. Producers</u>

The new producers of bio-ethanol, originally sugar producers, were given the chance to diversify their production by adding an annexed distillery to their existing factories in order to produce both sugar and bio-ethanol. In this way, the sugar producers were not only rescued from the sugar price crisis, but also they could safely enter into a new market because government assure them market prices of 70% of the gasoline price, which is an equivalent conversion price given that a car consumes more ethanol than gasoline to run the same distance. The main instruments used were quotas of bio-ethanol in the fuel mix ("Lei Nº 8.723," 1993), and later on, cross subsidies from taxation on gasoline.

While having influence in the Brazilian economy, these sugar producers, grouped in associations, such as the Brazilian Sugarcane Industry Association (União da Indústria de Cana-de-Açúcar, UNICA), could maintain their position in the energy market, by applying their lobbying power to government, to persevere and change the old fossil-fuel paradigm.

This was supported by the fact that the incumbent firm in the energy market, PETROBRÁS, is state owned (Rotstein, 2004).

With the experience of the diversification, the sugar producers are searching for new ways to improve their position as energy producers by using their waste – bagasse and thatch – as raw material for electricity production. Seasonality plays here an important role because the abundance of sugarcane waste coincides with the dry season, where hydro-electric power has water shortage. This is an important argument of the Brazilian Sugarcane Industry Association to be considered by government as a new player in the energy arena.

C. Facilitators

There is a presence of Facilitators together with Producers to get through the use of bio-ethanol by Consumers. There is a sense of patriotism of the Brazilian Automobile Industry (today: Associação Nacional Dos Fabricantes De Veículos Automotores - ANFAVEA) to modify the motors at the factory before sales to use 22% ethanol mix in gasoline. Without this compromise, consumers should have taken care of their own cars' modifications at a garage. Although those garages had certification, it would not assure the quality of motors to use higher percentages of bio-ethanol in the gasoline mix.

However, this commitment created a technological lock-in effect in gasoline cars in Brazil: The adaptation of the cars' motors to 22% ethanol mix in gasoline required that the mixture at the service stations should be kept rigorously: otherwise, the Brazilian Automobile Industry could not assure the quality of the cars' motors already sold. This lock-in was legally supported by government with a law of 1993, which is still in force.

Parallel, the Brazilian Automobile Industry started to produce cars running exclusively on ethanol. It was success as long as the bio-ethanol was available at the service stations and the economic incentives existed. With the liberalisation of the ethanol price, the low production of bio-ethanol due to weather conditions and the elimination of tax reduction for consumers, ethanol cars were slowly abandoned but the knowledge was preserved and invested in the development of a new type of car, which is flexible enough to run at any proportion of gasoline and ethanol.

D. Infrastructure Intermediary

In the role of Infrastructure Intermediary, it is important to point out the unique role of the incumbent fuel producer, PETROBRÁS, in this transition process. PETROBRÁS owns the energy infrastructure for the distribution of fluid fossil fuels: pipelines, docks, tanks (PETROBRAS, 2006). As a key state-owned company in the energy sector, PETROBRÁS was the monopolist of the energy market.

At the beginning PETROBRÁS tried to hold the total control of both the production and distribution of ethanol, but it caused adverse reactions not only from the car retailers, as the ANFAVEA, but also from the liberal press (Moraes, 2000). The creation of a new subsidiary – ALCOBRÁS – to manage the new fuel was not enough and government gave away the production of alcohol and focused its efforts in controlling the system for storage and distribution of the product (Moraes, 2000). A consequence of the Decree 76.593 of 1975 to support the use of bio-ethanol was that PETROBRÁS had to accommodate the new product in its distribution network. Later, the relevant role of PETROBRÁS in the transport, storage, distribution and mix of ethanol was acknowledge by PETROBRÁS itself as well as its role in the test of Otto-cycle motor with different ethanol proportions in gasoline mix, the use of ethanol as main fuel for its own vehicle fleet and export of the ethanol surplus (Ueki, 1983).

In doing so, PETROBRÁS became an important piece for the gradual adjustment to the situation with a new type of fuel, in which PETROBRÁS would administrate the new fuel from acquisition to distribution (Rotstein, 1978). Although it became the infrastructure intermediary for bio-ethanol, PETROBRÁS remains the incumbent actor in the energy market dealing with the oil transformation and distribution.

E. Consumers

For the general public, the decision-making was simplified by means of economic incentives: higher taxation of oil derivatives (e.g. gasoline) and fixation of bio-ethanol prices under gasoline prices in order to guarantee a comparative lower bio-ethanol price. This kind of cross-subsidy (Leite, 1987) created commitment in individual consumers to buy a car running on bio-ethanol, which was also encouraged by a tax reduction on sales of ethanol cars, reduction of the annual rate for license extension of ethanol cars, longer opening times of service stations for ethanol distribution and longer (Fernández, et al., 1984), which helped keep the ethanol consumption even during the period of low oil prices. The government and car industry support to the Pro-Alcohol programme was complemented with consumers' trust on the alcohol car and there was a peak in sales in 1986 (See Figure 4). However, this trust did not last long.

At the beginning of the 1990s, only the scarcity of bio-ethanol brought distrust to the consumers; consequently, they started to use more gasoline while discarding cars running on bio-ethanol. Faced with this lack of consumers' trust, government made mandatory the increment of the percentage of bio-ethanol in the gasoline mix. Government policy was backed up by the fact that the use of ethanol as an additive for gasoline performed better regarding air pollution. Thus, the bio-ethanol consumption was kept at sustainable levels while the sales of cars running on bio-ethanol almost disappeared, until the Flex-Fuel cars appear in the market. This simplifies consumers' choice because they are allowed to make a choice at the gas station, depending on real time prices of competing fuels.

F. Research Organisations

Regarding research organisations, they are mostly government founded and funded, as it is the case of IAA or attached to ministries, as it is the case of Brazilian Agricultural Research Corporation (Empresa Brasileira de Pesquisa Agropecuária – Embrapa) as part of the Ministry of Agriculture, Cattle breeding and Supply (Ministério da Agricultura, Pecuária e Abastecimento), or the national Agency of Oil, Natural Gas and Bio-fuels (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis – ANP) as part of the Ministry of Mining and Energy (Ministério de Minas e Energia). However, there have been independent research initiatives, such as that of the ANFAVEA to improve cars' performance when using mixed fuels, the sugarcane producers to improve the crops yield, and the Sugarcane Technology Centre (Centro de Tecnologia Canavieira – CTC) to improve the bio-ethanol production costs (Magalhães, Kuperman, & Machado, 1991).

G. Interest Groups

The presence of interest groups is limited at the beginning of this transition process; it is hardly mentioned in the literature because the environmental concern was not a core interest of the parties involved (Moraes, 2000). However, social concern was raised regarding the production of vinasse, as a rest product of the bio-ethanol production, which was handled technically with the reduction of the percentage produced and storage of the non-reducible fraction, usage as fertilizer and raw material of bio-gas (Magalhães, et al., 1991).

A positive side effect of the use of bio-ethanol is the reduction of lead emission due to the use of tetra-ethyl lead as anti-knock additive in gasoline. With the substitution of tetra-ethyl lead with bio-ethanol, air pollution was reduced considerably (Magalhães, et al., 1991).

The past few years, however, international organisations together with local NGOs have increased their participation in the discussion of the use of bio-ethanol, questioning the "sustainability" of this transition when it goes at the expense of the Amazonia rain forest, which is the largest "lung" on earth.

4.4. Evaluation of the Brazilian transition process

The information presented in the previous section provides us with evidence to outline the transition process of Brazil when introducing bio-ethanol in the energy portfolio for transportation purposes. In the first section, we address the information feedback that gave shape to the transition and; in the second section, we address the current dynamic equilibrium of this transition, and in the third section we focus on the opportunities and risks of learning from this transition.

4.4.1. Triggers and supporting conditions for the Brazilian transition

Before the oil crisis happened, light vehicles in the Brazilian system had worked based on gasoline. At this time, the Infrastructure Intermediary produced and distributed gasoline for consumers, while the Facilitator (the automobile industry) produced gasoline cars for the same consumers. Government affected the other three actors mainly by taxes. The above-mentioned system is presented in Figure 4.8.

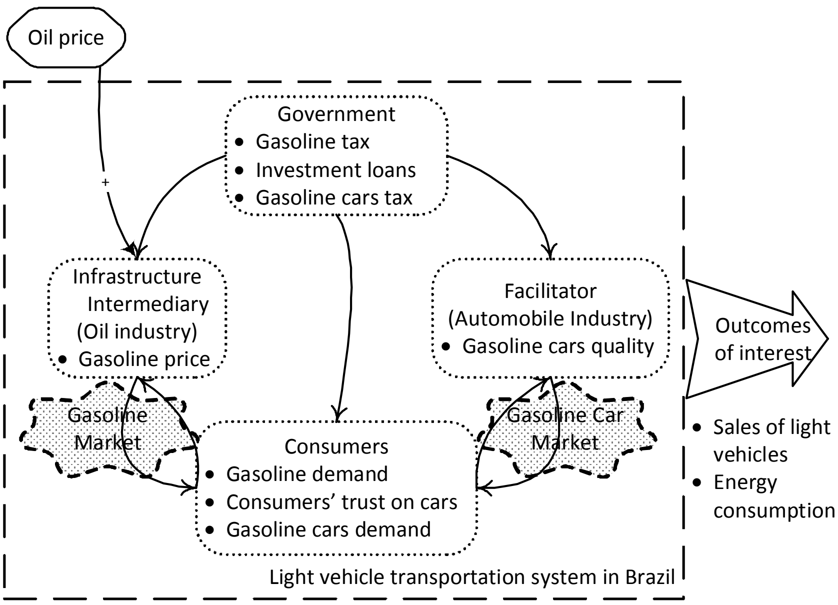

Figure 4.8: System diagram before the transition in Brazil

The same system diagram is rearranged to portray the elements of the social and the technical sub-system. In the social sub-system, agents relate to each other by means of relations, such as regulation or sales, while in the technical sub-system agent relates by physical flows. Still, the social and the technical sub-systems relate to each other by ownership. A schematic representation of the agents in the Brazilian system before the oil crisis is presented in Figure 4.9.

From the system level towards the agent level, there are two elements that were important to support the introduction of changes to the Brazilian energy system of the 1970s. One is a fertile cultural background where decisions are made in a top-down style to reduce uncertainty and to simplify decision-making, and the other is a catalyst such as the 'drastic' events of the oil crisis and the sugar price-drop.

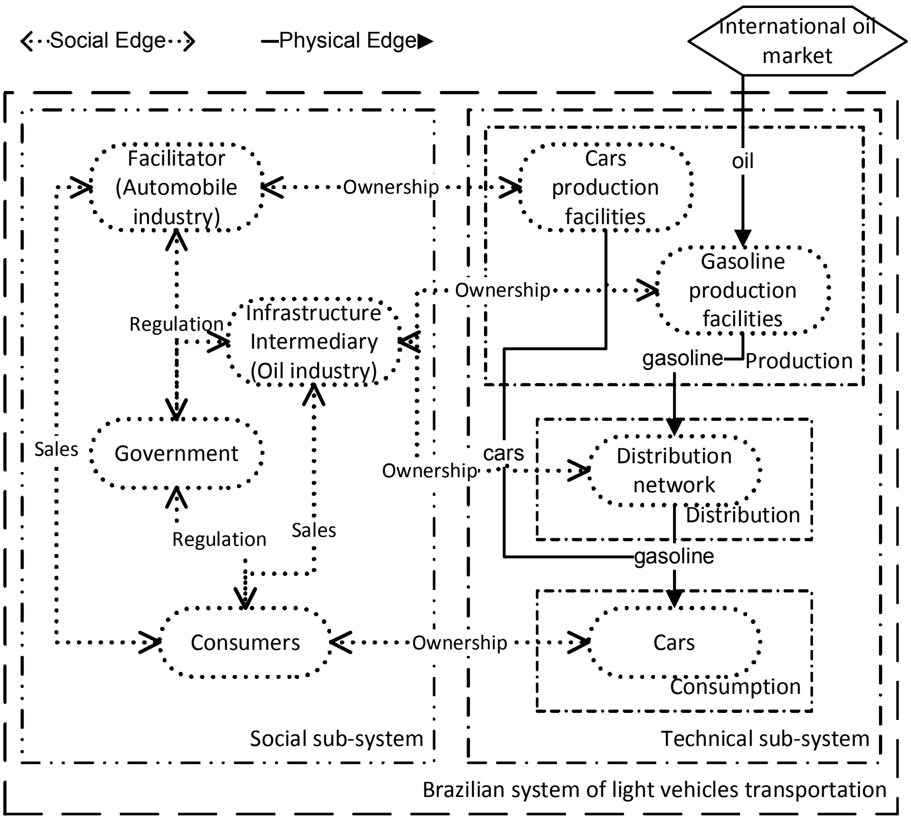

Figure 4.9: Agents in the Brazilian system of light vehicles before the transition

These changes materialised at the network level through the creation of different programmes for promoting alternative energy sources under a military regime.

At the agent level, the most promising alternative – bio-ethanol – was accommodated in the existing distribution infrastructure and supported through financial and economic instruments during the military regime. In the meantime the other programmes – such as Pro-Oil – were dropped, which was probably due to little development in product innovation and the difficulties to directly substitute other oil derivatives when world oil prices dropped. After the cancellation of the Pro-Oil program, research in the field of bio-diesel still continued. Figure 4.10 shows how a higher level has an impact on a lower level.

With a new entrant in the system, the original constellation of four actors in the social sub-system had to make place for the sugar-alcohol producers with their sugar-alcohol facilities and their bio-ethanol. They are also subject to the regulatory power of Government and the demand of bio-ethanol by consumers through the infrastructure intermediary.

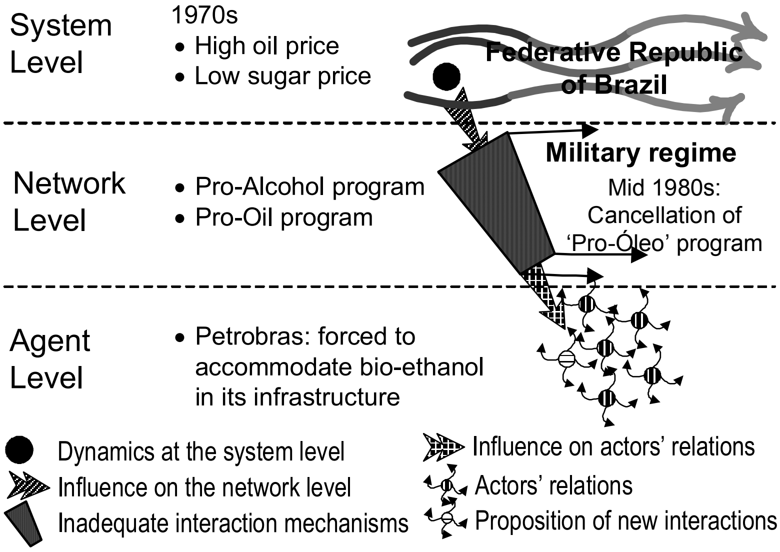

Figure 4.10: Downward impact of drastic events on the Brazilian system, network and agent level

Due to the arrangement of government and the infrastructure intermediary to accommodate bio-ethanol in their distribution network, there was no need to create a complete parallel bio-ethanol distribution network; yet it was necessary to invest in additional infrastructure for the appropriate storage and transportation of bio-ethanol from the sugar-alcohol producers to the consumers. A schematic representation of the agents in the Brazilian system after the introduction of bio-ethanol in the market is presented in Figure 4.11. This scheme also follows the conventions of Figure 4.9 for the separation of the social and the technical sub-systems.

While zooming out to the system level, it is possible to recognise three networks, namely the fuel producer market (With bio-ethanol as product), the fuel consumer market (With bio-ethanol and gasoline as products) and the car market (With bio-ethanol cars, gasoline cars and Flex-fuel cars as products), as it can be seen in Figure 4.12. An additional outcome of interest is the sugar production and the land use and yield, to evaluate the efficiency of the sugar-alcohol production in Brazil

The movement from the agent level towards the system level started with the continuity of the sugarcane producers in the new energy market design: they developed enough critical mass to endure, despite the drop of oil prices, the scarcity of bio-ethanol and the deactivation of the Pro-Alcohol program in the 1990s, the latter supported by new polity and economic problems.

At the network level, through process innovation and continued research on crops, the production level and output of bio-ethanol has increased in such a way that Brazil has become a new player in the energy carriers' market. The fact that Pro-Alcohol has achieved such a success has encouraged the Brazilian government to re-introduce the former Pro-Oil programme with a specific product: Bio-diesel.

At the system level there has been a shift towards competition between gasoline and bio-ethanol after thirty years of the introduction of Pro-Alcohol. While being complementary for several years, the development of Flex-Fuel cars – running with any mix of gasoline and bio-ethanol – created the possibility of transforming complementary goods to supplementary ones. This could also be seen in the evolution of oil and sugar prices and quantities. Figure 4.13 shows how a lower level has an impact on a higher level.

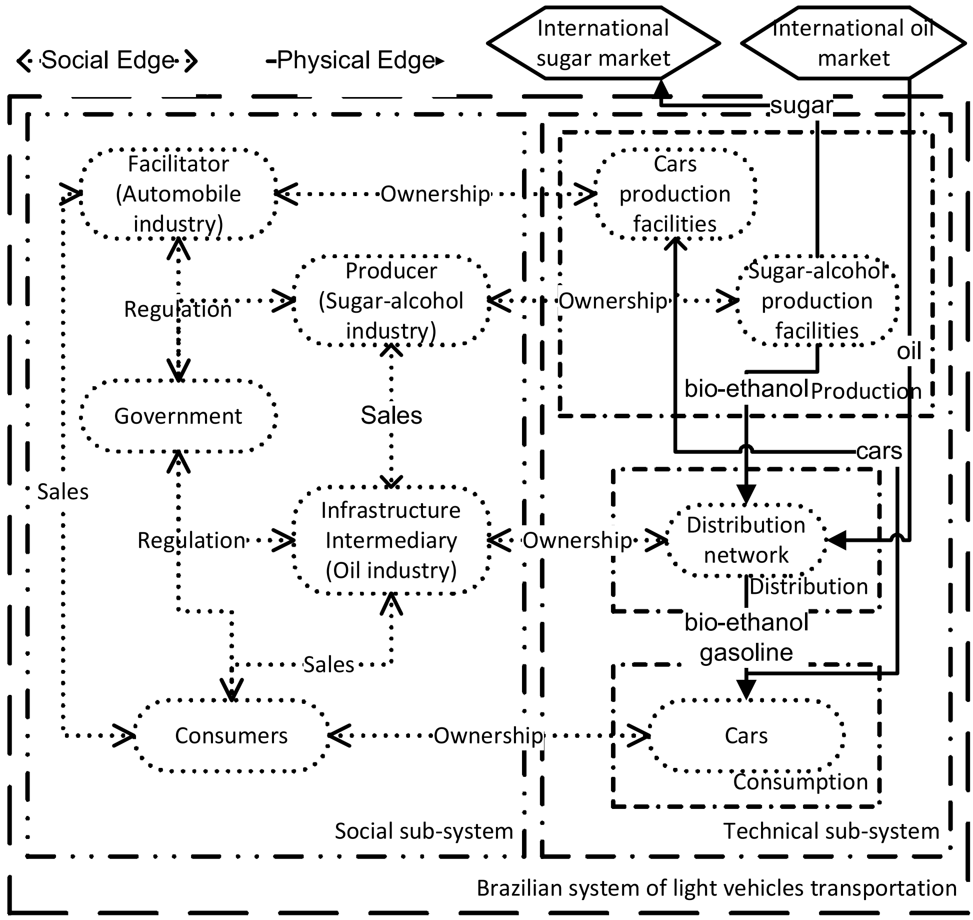

Figure 4.11: Current Brazilian fuel system

Figure 4.14 portrays a consolidated information feedback from the system level towards the agent level and back to the system level, as well as a time reference of the events in the Brazilian transition process at the beginning and thirty years later. A total picture would portray twice the movement from the system level down to the agent level and vice versa, showing, on the one hand, the impact of low oil prices and sugarcane shortage on agents' behaviour: distrust in consumers, abandonment of bio-ethanol cars production, and the cancellation of the Pro-Alcohol programme, and on the other hand, the revival of bio-ethanol in a liberalized market with the emergence of the Flex-Fuel cars, the hike in oil prices, and the increasing concern of greenhouse gasses (GHG) emission and its effect on climate change.

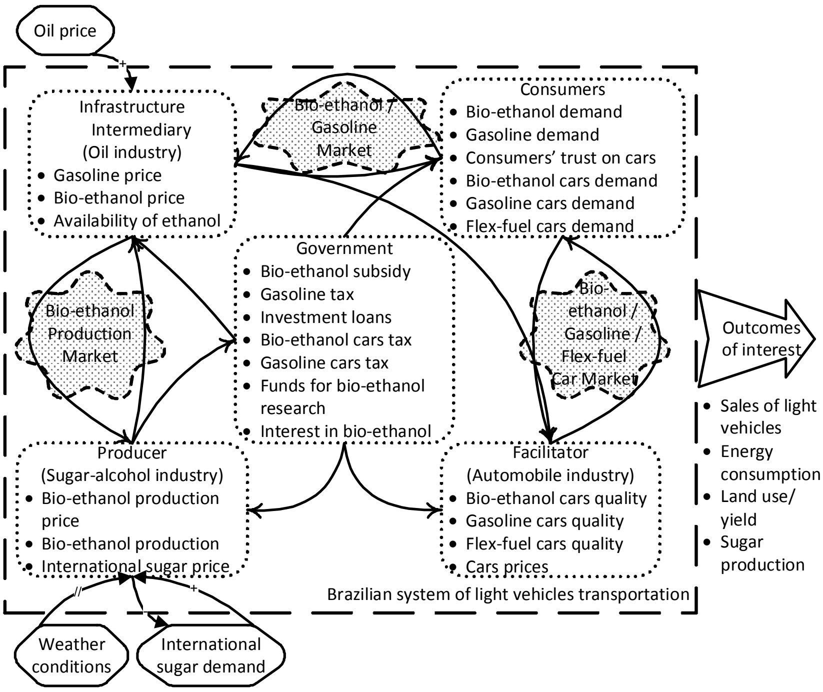

Figure 4.12: System diagram of the transition in Brazil

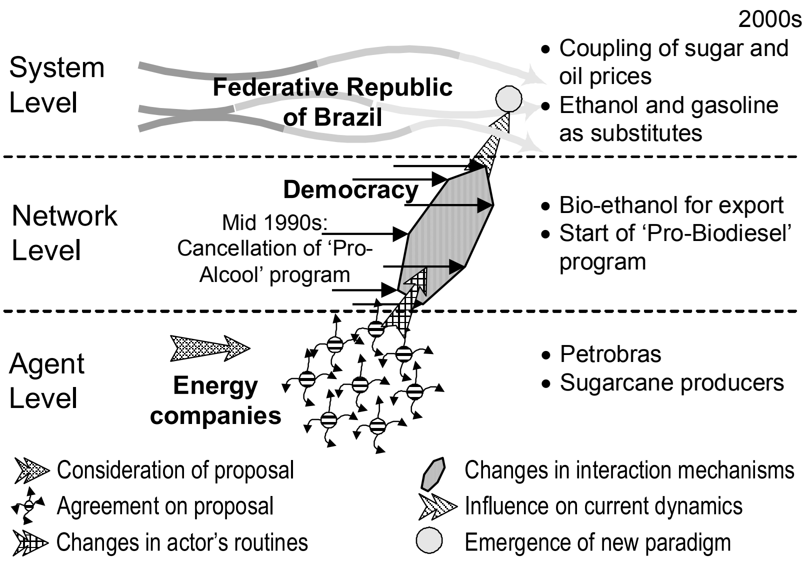

Figure 4.13: Upward impact of drastic events on the Brazilian agent, network and system level

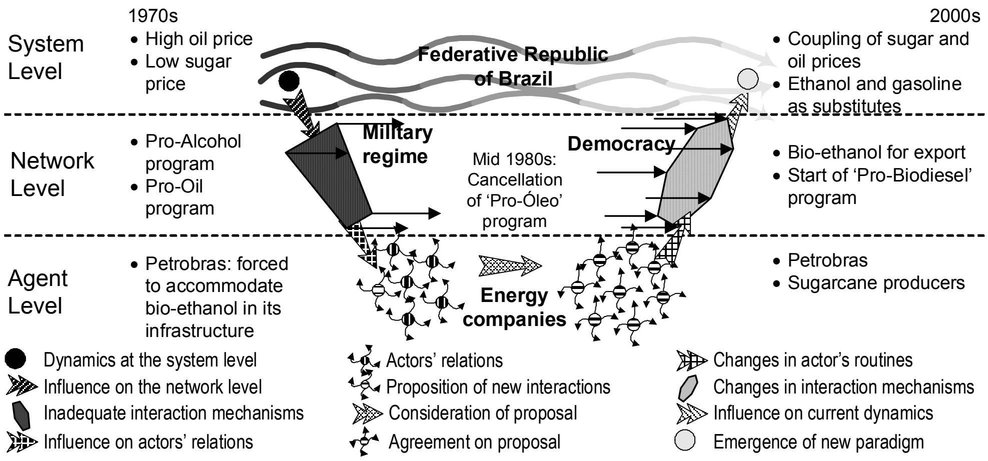

Figure 4.14: The main information feedback of the Brazilian case (Adapted from (Chiong Meza & Dijkema, 2009))

4.4.2. *Evolution to the current dynamic Brazilian equilibrium*

More than thirty year has passed since the first official attempt to introduce a new energy carrier for transportation purposes in Brazil. The two variants of Bio-ethanol, anhydrous ethanol and hydrated ethanol, have had a particular role in this transition.

In the case of the anhydrous ethanol, it has stayed in use from the beginning of the Pro-Alcohol programme with a slight increment in the last decade (See Figure 4.15), not only due to the compulsory mix with gasoline, but also due to the positive side-effect on air pollution, reducing lead concentrations in the air.

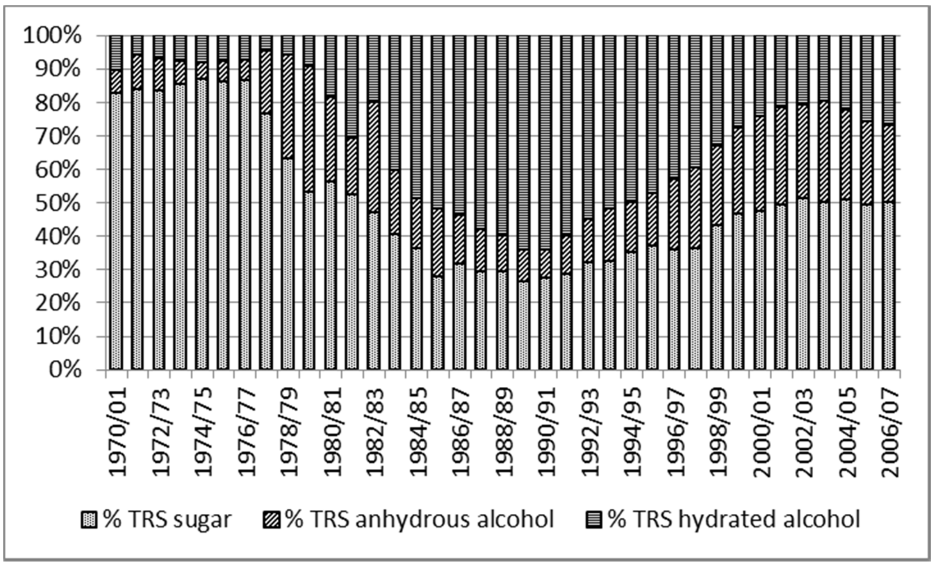

Figure 4.15: Distribution of sugar and alcohol production (Departamento da Cana-de-açúcar e agroenergia, 2007)

The use of the hydrated ethanol has been very sensitive to the market conditions. If with the introduction of the bio-ethanol car at the beginning of the 1980s the population used it intensively, when the shortage occurred, together with low oil prices, bio-ethanol was less consumed (See Figure 4.15) and new cars sales were refused totally by consumers and they went back to the gasoline cars (See Figure 4.16). Only the emergence of a reliable car could give back consumers the confidence in the hydrated ethanol.

The creation of a flexible and reliable car was only possible by making use of the lessons learnt by the car producers during the years of the production of bio-ethanol cars and consumption of hydrated ethanol. The expertise of the Brazilian car industry put on a new generation of cars gave birth to the Flex-Fuel cars, which is able to use gasoline (mixed with anhydrous ethanol) and hydrated ethanol in any proportion.

This flexible car has opened a new horizon for consumers of light vehicles. As it can be seen in Figure 4.16, Flex-Fuel car sales are replacing gasoline car sales because in the eyes of the consumers, they are no longer obliged to make decision up front and incur in large sunk costs when buying a car. The choice is now made at the service station, where consumers can see which fuel is cheaper in real time.

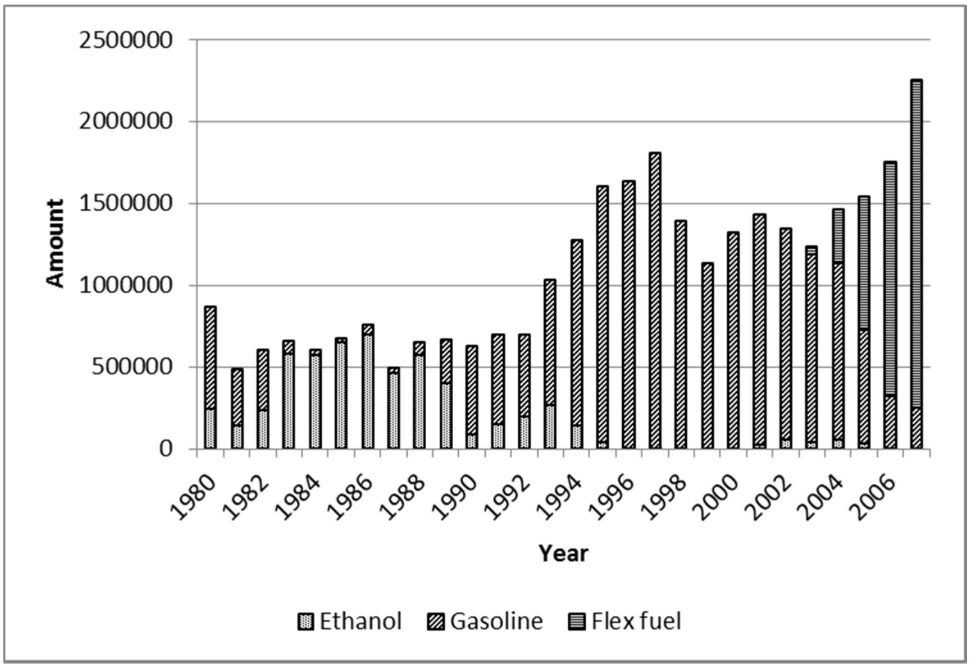

Figure 4.16: Sales of light vehicles (Associação Nacional dos Fabricantes de Veículos Automotores (ANFAVEA), 2008)

All in all, bio-ethanol in any of its two types has come to stay in the Brazilian market. Although the proportion is not big when compared with other energy sources, bio-ethanol is showing a stable market share (See Figure 4.17)

As regards to the discussion of fuel versus food, it is possible to say that the sugar production has suffered little from the ethanol production. As it can be seen in Figure 4.18, the sugar production has increased over time, as well as the ethanol production. However, little information has been obtained regarding to the details of the sugarcane producers' decision-making in a liberalized market with respect to the rate sugar – ethanol to be produced.

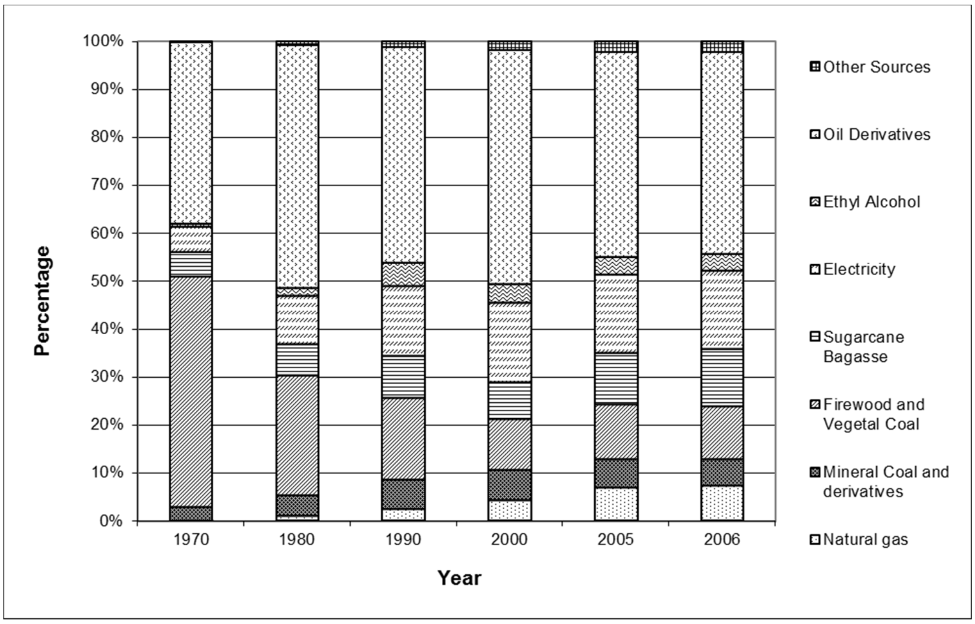

Figure 4.17: End consumption patterns per source (Ministério de Minas e Energia (MME) & Empresa de Pesquisa Energética (EPE), 2007)

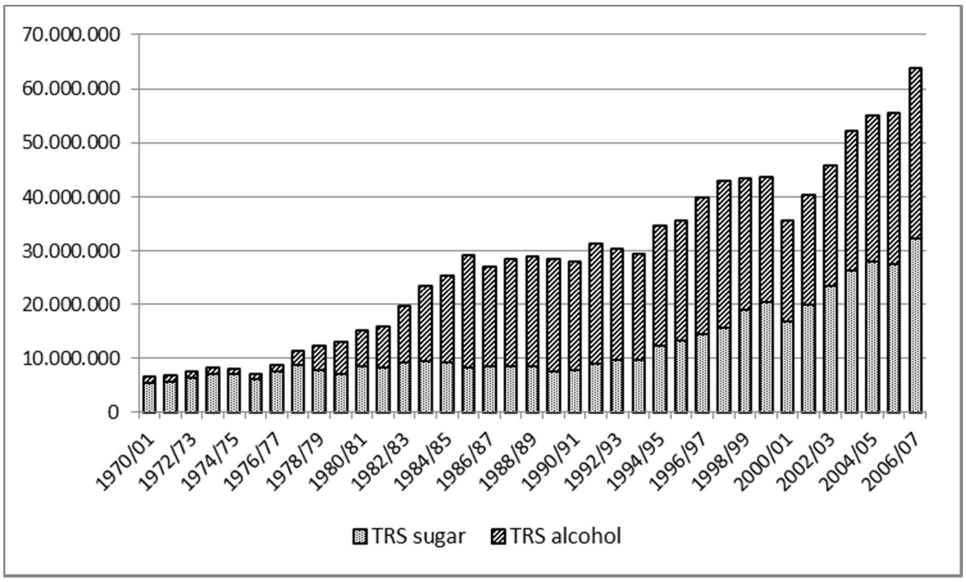

Figure 4.18: Evolution of sugar and alcohol production (Departamento da Cana-de-açúcar e agroenergia, 2007)

Regarding land use, it can be seen that almost all cultivated area is also harvested and the yield per hectare cultivated has increased over time (See Figure 4.19).

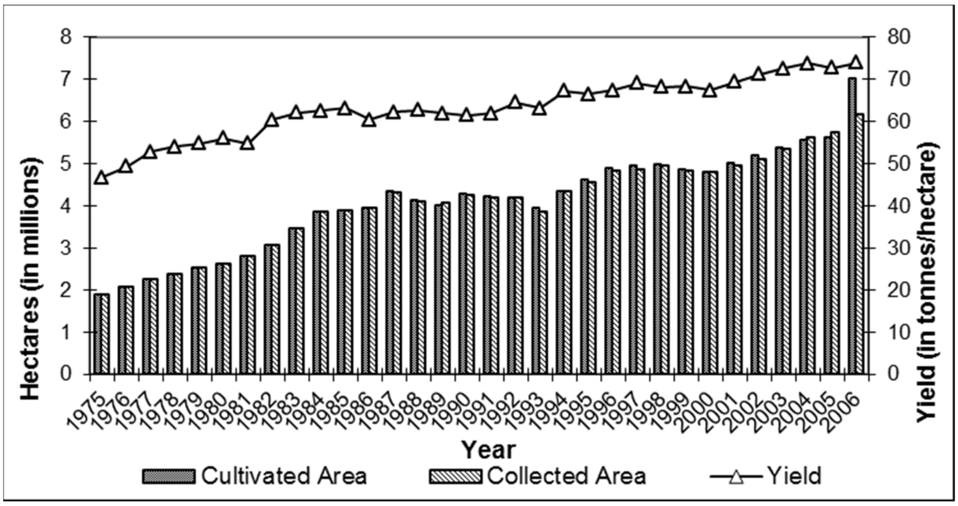

Figure 4.19: Evolution of production and productivity of sugarcane plantations (Departamento da Cana-de-açúcar e agroenergia, 2007)

Additionally, the current land use for sugarcane production is concentrated in two zones: the north east and the centre south. These two zones behave complementary to each other because the centre south area cultivation period is between January and March, while the north east area cultivation period is between May and June. This means that the harvest periods of both areas can guarantee a continuous supply of sugarcane for sugar and ethanol production.

Although there is some land use for sugarcane production in the state Mato Grosso (where Pantanal is), it is officially considered that rain forest is preserved from agricultural activities, as it can be seen in Figure 4.20 and 4.21.

Figure 4.20: Brazil's sugarcane production intensity (Adapted from (United States Department of Agriculture, 2006))

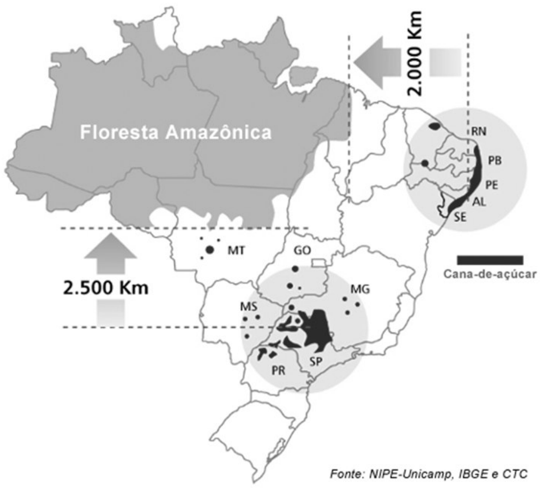

Figure 4.21: Current sugarcane land use (Adapted from (União da Indústria de Cana-de-Açúcar (UNICA), 2008))

4.5. Learning opportunities and learning risks of the Brazilian case

This study of the Brazilian transition from an oil-dependent country to a bio-ethanol exporter has brought us several lessons to learn, which are grouped in the four following topics.

A. The role of government as initiator of a transition process

In this particular combination of cultural dimensions, a strong government was able to enact, through legislation, the necessary mechanisms to open an entrance in the market to new energy sources for transportation purposes. By owning the incumbent firm in the energy carriers market, government could alter the original supply chain under the fossil fuel paradigm to accommodate a new product, bio-ethanol, in its storage and distribution scheme.

Additionally, it created incentives for most relevant parties of our typology of actors, while taking into account different transaction costs that could prevent actors to switch to the new energy carrier and can encourage them to stay there (e.g. high taxed gasoline prices vs. subsidised bio-ethanol prices; lobbying power of sugarcane producers vs. thousands of unemployed people in the sugar industry). However, all these effort came at a certain price: scarcity of financial resources, which lead to the decay of the ethanol programme in the early 1990s, especially due to the fall of oil prices.

B. The relevance of an objective-oriented transition using perceivable instruments for actors

At the network level it becomes clear that the Brazilian government had to concentrate its efforts on few alternatives due to the critical economic and financial situation of the country in the 1970s.

The difference in the development and the speed of innovation and production of the energy carriers mentioned determined which programme would continue to exist and, later on, which raw material would dominate the supply of the production – path-dependency. Bio-ethanol from sugarcane became a reliable combination due to the volume of sugarcane produced in Brazil and the availability of a proven bio-ethanol production technology. Path-dependency on the choice of raw material is also perceived at the early stages of the bio-diesel program, as reported by Campos and Moraes (2008).

The associated reduction of uncertainty helped actors at the agent level focus on their core business and work on the local optimisation of their functions and costs. Other incentives were created by means of:

* Subsidies, lowering the cost of bio-ethanol, and were combined with high taxes on gasoline, as a way of cross-subsidy
* Facilitation of loans and fixation of interest rates and terms for producers

The success of these incentives suggests that actors use Neo-Classical economic theory in their decision-making processes once uncertainty is reduced.

C. Dealing with the risks of a direct institutional transplantation (de Jong & Mamadouh, 2002)

The Brazilian transition towards less dependence on oil products has only been possible due to the conjunction of (1) a suitable cultural background and a disruptive incident such as the 'drastic' event (2) which trigger the top-down development of programmes that helped reduce the uncertainty of key actors in this new energy market design, and (3) the acceptance of these programmes by the key actors. Coordination among the three different levels was necessary in order to minimise the friction in the transition. The main pitfalls to be avoided when taking this transition to other countries or regions and apply the same strategies are (1) the availability of raw material for bio-ethanol production, which is scarce (e.g. sugarcane in countries with different climate conditions), (2) the possibility to adapt the current infrastructure to accommodate new energy sources (e.g. mixing ethanol and diesel), (3) the nature of governance mechanisms, which should be tuned in to the cultural background of the actors involved. Underestimating these factors could diminish the speed of a transition or prevent it from occurring.

D. Revisiting the SyNeA framework for analysis and modelling

The case study of Brazil has served to test the applicability of the SyNeA framework for analysis and modelling with what has happened in reality. From this application to a case, the findings related to the role of 'drastic' events, the typology of actors, and the qualitative modelling of agent will be discussed next.

In relation to the 'drastic' event, this case has showed that such kind of events can produce a disruption of the state-of-affairs in a system. These 'drastic' events attract the attention of actors within a system towards a particular topic and help coordinate the efforts of individual actors to achieve common objectives. 'Drastic' events present windows of opportunity for the creation of a sense of urgency. This can speed up or block transitions.

Concerning the typology of actors, the case study of Brazil has yielded some insight into the role of actors in a transition. From the seven actors of the original SyNeA framework, five have retained a direct role during the transition in Brazil, namely Government, Producers of bio-ethanol, Infrastructure Intermediaries, Facilitator of light vehicles, and Consumers. The other two roles, namely the Interest Groups and the Research Organisations, attain different performance during the transition.

About the Research Organisations, they have had and indirect role by improving the existing devices and machinery (e.g. accommodate gasoline blended with bio-ethanol as additive) or innovating to cover other needs (e.g. bio-ethanol motor and Flex-Fuel motor).

Improvement and innovation was done as a commission of one of the direct actors (e.g. as a research institute of Government) or a co-joint work with one of the active actors (e.g. a research institute of Government and the Facilitator of light vehicles to develop the bio-ethanol motor), because the latter was able to introduce the technological change in the system.

In the case of the Interest Groups, their presence in the most part of the transition has not been officially acknowledged. Furthermore, it has been recognized the presence of international organisations as interest groups in the system only in the current century, when the danger of the bio-ethanol production in Brazil was pointed out (Rodrigues & Ortiz, 2006) based on the increase of bio-fuels production to cope with the spike of oil prices, happening parallel to the unrest in the Middle East (WTRG Economics, 2007).

Therefore, our typology of actors has been modified as we now identify five direct roles, namely Government, Producers of bio-ethanol, Infrastructure Intermediaries, Facilitators of light vehicles, and Consumers, and two indirect roles, namely Research Organisations and Interest Groups (See Figure 4.22).

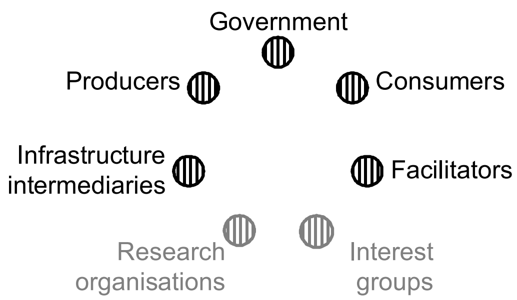

Figure 4.22: Revisited typology of actors at agent level

Regarding the modelling of agents, the case study of Brazil has yielded some insight into the modelling of agents, as introduced Van Dam. Although Van Dam (2009) only distinguishes two kinds of edges, for our particular application we will distinguish three types of edges:

* Social edges: These are social relations, normally expressed in contracts or agreements between social agents if it is a two-way relation or regulation if it is a one-way relation.
* Physical edges: These are technical relations expressed in a connection (way in which material is transported) and a flow (the actual material being transported).
* Socio-technical edges: These are connections between the social and the technical sub-system, expressed in ownership of the physical node (technology) by the social node (agent)

In a graphical way, the socio-technical edges are separately portrayed as a one-way arrow coming out of an actor in the social sub-system and reaching a technology in the technical sub-system. The three above-mentioned relations are portrayed in Figure 4.23.

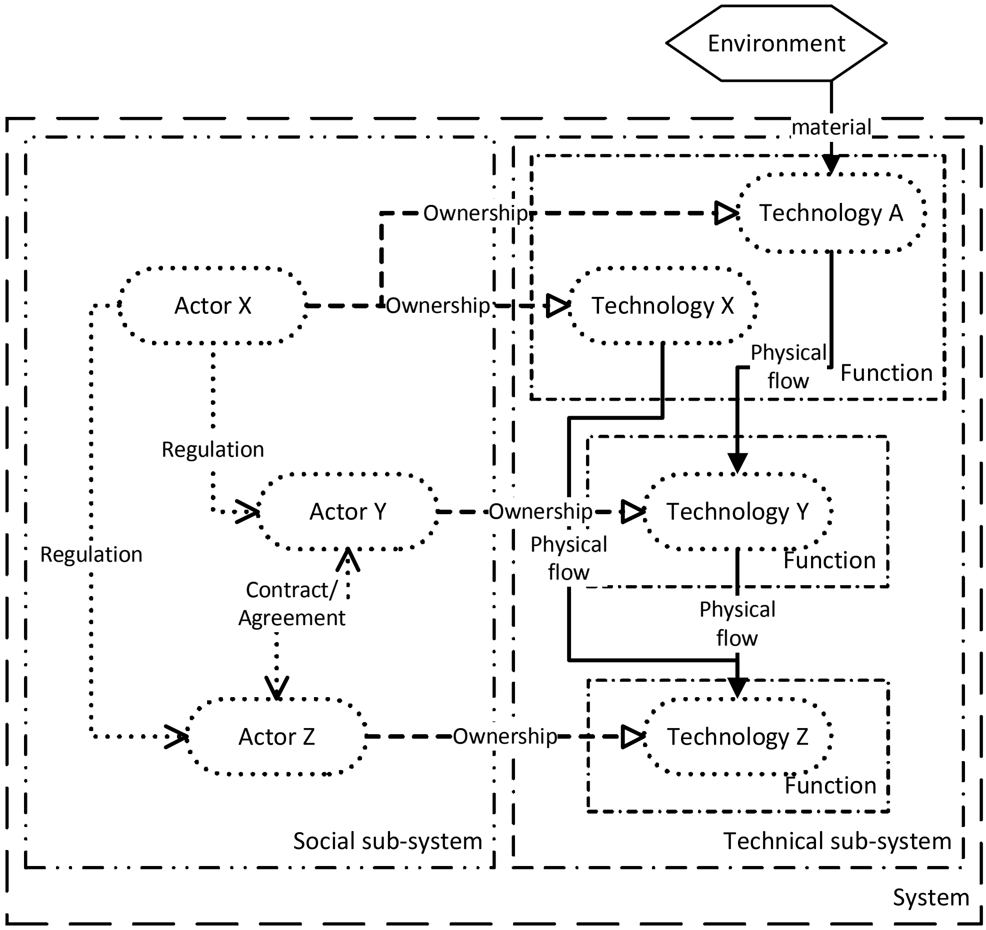

Figure 4.23: Improved display of agents in a system

In this way, it is made explicit that the relation between the social and the technical sub-systems has a different character from those within each sub-system.

Chapter 5
Case Study II: the Netherlands and the transition to a supply-chain approach for household waste treatment

The Netherlands has been struggling to improve its household waste treatment practices for a long time, first to avoid health problems, later to reduce the environmental impact and ultimately to close material cycles. In the last thirty years, a large regulatory reform has brought to light a new order of preference for waste treatment alternatives. A long process of negotiation with different stakeholders in society was necessary in order to achieve several agreements between government and the business community, with the collaboration of consumers, environmentalists and research organisations.

The social, economic and geographical situation of the Netherlands has played a role in the effort of changing the structure of activities to handle waste from a distributed to a centralised system for waste disposal management. Because of an increasing population density an hence a decreasing available space per inhabitant, in connection to an increase in wealth, government had to find alternatives to the landfilling of waste, which was originally the dominant waste treatment method. As a consequence it was tried to produce more added value from waste through the increase of energy production from waste incineration and the separation of material (waste) flows in order to reuse or recycle these materials.

The way in which waste is handled in the Netherlands has witnessed a significant change, especially over the last three decades, which includes changes in various aspects, from the infrastructure used to the formal institutions about waste disposal management.

5.1. Introduction to the Dutch case

The transition of household solid waste treatment in the Netherlands is a relevant case for the study of transitions of socio-technical systems: with a view to hygiene, the guarantee of the social health, and economic considerations, the introduction of a new order of preference for activities to handle waste has tipped the existing waste disposal management system to restructuring in such a way that separate waste flows are identified and the reuse and recycle of products and materials is encouraged in the first place, and the disposal by means of incineration with energy production or landfilling (when no added value could be created) is used as a last resort.

This transition would only have been possible with the active participation of the business communities of different branches, the consumers' association, the environmental groups and the research organisations together with the government, to agree on common goals, targets, processes and standards.

The case of the Netherlands fulfils the selection criteria of our case study because it was a country that came close to saturation (as proposed by Daly (1990)) regarding waste handling, where different parties in society started their own initiatives to deal with the shortage of waste processing capacity but where the government's intervention was necessary to canalise and synthesise society's expectations and current practices. Additionally, the waste disposal system in the Netherlands was organised by the municipalities.

This case study aims to use the three-level approach to develop some insight about the way the waste disposal system evolved over time towards a supply-chain system, and try to explain the dynamic behaviour in terms of the way the system elements were interacting. We will decompose the system in its important elements and their interactions to observe the drastic events that triggered the Dutch transition and the cultural background on which this transition rests. At the network level, the polity, the policy change and the technology change will be put on the spotlight to study the mechanisms' change that set in motion this transition process. At the agent level, we want to investigate to what extent the role of the government could be consider as coordinator of this transition process among all other actors involved. The insights to be developed using the three-level framework about the underlying mechanisms of the system behaviour in the Dutch case are important because they have the potential to be transferred to other transition contexts with different cultural backgrounds.

In the next section we present a historical overview of the transition to a solid-waste supply-chain management. Section three presents a description of the different elements of the Dutch transition at each of the three levels of our approach. In section four, the evaluation of the Dutch transition process is put forward as regards the actors' interactions, the current situation as compared with the initial objectives and the lessons learnt from this transition. Finally, conclusions of the case study and in relation to the research methodology and approach are elucidated in section five.

5.2. Observing the Dutch historical developments

While being an agrarian society two centuries ago, the Dutch household organic waste – such as vegetable and fruit skin and peel – was used for feeding the cattle or making compost, leaves and straw was used for insulation, wood was used as natural fuel for heating: in summary, waste was dealt locally and decentralized. With the arrival of industrialisation, there were some initiatives that form the basis for the current centralized recycling system in the Netherlands, which are reported in an account of the modernisation of the Netherlands during the XIX century. Before wood fibres were used for paper production, rags were an important source of fibres for the paper industry. Rags were traded by merchants at local, regional and national level but, when the export duty was stopped and coincided with a scarcity of rags in the Netherlands, new fibres – such as straw and esparto grass – replaced rags fibres in the paper production (De Wit, 1993).

In particular, the urbanisation of towns and the growth of cities represented a challenge for the preservation of populations' health. Air pollution as a result of putrefaction of waste matter was an indication of where waste was dumped and it was expected that the daily collection of household and gutter waste, among other organisational measures, would improve the hygiene of the neighbourhood (De Wit, 1993).

In order to guarantee social health, the need of government to adequately manage waste, at least at household level, has been already acknowledge since the end of the XIX century and, although there was a decline in waste production during World War I, the increasing amount of produced waste at household level, in particular in the cities, has required the execution of a country-level study to exchange experiences and find suitable ways to cope with household waste disposal and collection, and introduce a certain level of hygiene at household level (Nederlandsche Vereeniging van Reinigingsdirecteuren, 1932). An example of this is the amount of waste produced in the city of Amsterdam, which has an increasing trend (See Figure 5.1). Furthermore, it was socially and institutionally assumed that local government (municipalities) were responsible for the collection, transportation and transformation of waste (van Zon, 1986).

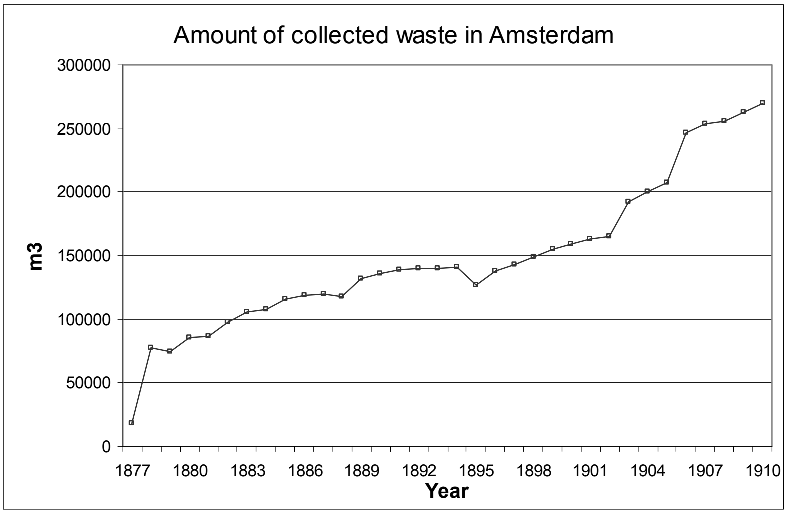

Figure 5.1: Collected waste in Amsterdam at the beginning of the 20th century (van Zon, 1986)

5.2.1. Exploration of waste disposal choices

Cities like Amsterdam needed a faster way to deal with the produced household waste. Due to the experience of England and Germany, incineration was made available by the Amsterdam cleaning service (Stadsreiniging Amsterdam) on the north side of the city in 1918; however, the expectations put on this new alternative were not satisfied (Buijs, Kaars, & Trommelen, 2005). Opposite to the reaction of the population with the choice of Naardermeer, the choice of the Volgermeerpolder did not caused any reaction and the Amsterdam cleaning service took up an old practice in 1927: dumping household waste (Haijtema, 2009), this time in holes left from peat extraction in the Volgermeerpolder (See Box [α]), (Buijs, et al., 2005).

Box [α]

Volgermeerpolder

This is an area located at the north-east of Amsterdam, which is not a polder or a lake as the name might suggest. It has around 100 hectares (van Goethem, 2006) and lies between Belmermeer, Zunderdorp and Broekermeer. The company Veenderij Maatschappij started to extract peat in 1920 (Peat was sold as fuel to cover the shortage of coal after World War I) but in 1927 this company had financial problems due to the low peat price: the financial problems were worked out with the municipality of Broek in Waterland and a new loan, but it was necessary to find new sources of income; the latter was provided by NV Siccatio, a subsidiary company of the peat company which got a license to dump household waste in the peat wells (Buijs, et al., 2005), until 1933 probably because it was cheaper to dump the waste of Amsterdam households elsewhere. The Volgermeerpolder dump, now property of NV Scheepsexploitatiemaatschappij Bavo, was again used as dump area from 1948, as part of a ten-year contract (with an extension of ten more years) with the Amsterdam cleaning service (Stadsreiniging Amsterdam): the latter took over the company in 1968 (Buijs, et al., 2005).

Figure 5.2 shows the evolution of household waste in three big cities in the Netherlands, namely Amsterdam, Rotterdam and The Hague in parallel with population growth in the west of the Netherlands. Except for the period of World War I (Between 1914 and 1918), where it shows a slight decreasing trend, household waste had an increasing trend after World War I, and this increase is greater than the population growth of the area. Also, World War II had a similar impact on waste production. Based on a 1944 report of the Dutch Association of Cleaning Directors, Oldenziel (2001) mentioned a reduction of waste production of 25% in the first weeks of the German occupation and this reduction went on down to 47% in 1943. This waste reduction was first related to the precaution of households to save materials in case of future scarcity because the Dutch municipalities did not have experience on how to recover materials from waste streams, besides Amsterdam.

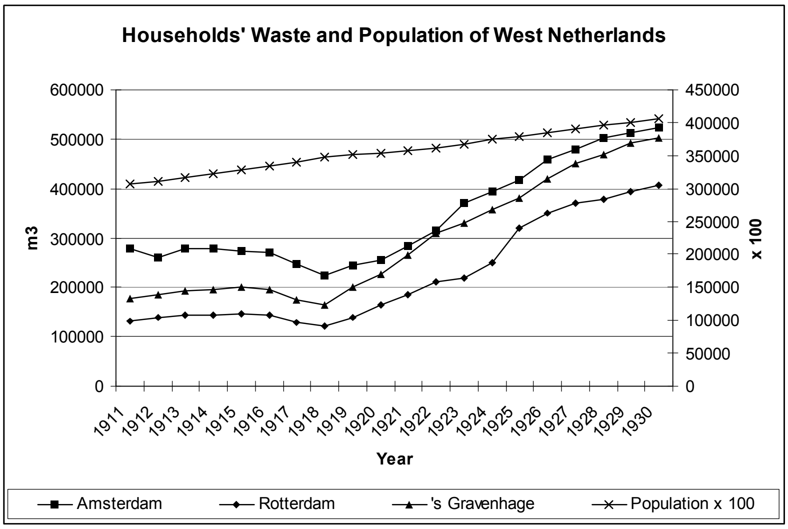

Figure 5.2: Household waste progression in three cities of the Netherlands with the population of West Netherlands (Based on (Nederlandsche Vereeniging van Reinigingsdirecteuren, 1932) and (Centraal Bureau voor de Statistiek, 2009))

Between 1940 and 1945, the German administration in the Netherlands set up a central body to take care of the recovery of rags, paper and metals at the source – a new concept for the Dutch municipalities – and housewives played an important role in it because they were made responsible for the sorting, though it was a difficult task to carry out in the cities due to the little space available at home; parallel, rag pickers were formalised and each was assigned to a neighbourhood to collect old usable material in a centralized way (Oldenziel, 2001). Around this system, housewives were approached to collect fruit and vegetable skin and peel for cattle feed in exchange for dairy and animal products, as well as bones in return for soap. Later on, these materials were also covered by the neighbourhood collector (Oldenziel, 2001).

In the period of the reconstruction, material scarcity impelled people to keep practices introduced right before or during World War II: these initiatives have already been reported (Oldenziel, 2001) and here they are complemented with common knowledge of Dutch people, as described below.

Glass bottles were embedded in a deposit money system: the suppliers of a liquid or fluid motivated their customers to return glass bottles to save in this way some packaging costs. Especially in the Netherlands, milk bottles were the source of two monetary streams: the deposit money for glass bottles and the compensation of aluminium caps for recycling aluminium.

Paper provided another recovery cycle. Associations of diverse types made campaigns to collect paper and raise money for their own purposes given the large amount of paper to be recovered in order to get back a significant amount of money (Stuurgroep en Werkgroepen voor Milieuzorg van het Koninklijk Instituut van Ingenieurs, 1973).

With the reduction of small scale agriculture and vegetable gardens, the urbanisation of small towns, and the appearance of ornamental gardens, vegetable and fruit skin and peel were collected door to door for composting at a larger scale than households, keeping a war-time practice.

The second half of the 20th century can be characterized by a significantly growing amount of waste in the Netherlands, as a direct consequence of the new lifestyle and economic system, promoting increased consumption. In line with this, it was noticed in the 1950s that the waste composition and amount dumped in the Volgermeerpolder had changed: there was an increased amount of synthetics in the form of packaging materials and disposable products, and possibly poisonous or toxic substances, increasing nuisance – in the form of smell, vermin, fire and smoke – in the villages located around the dump (Buijs, et al., 2005).

To prevent the production of danger, damage and nuisance of constructions, the government adopted the Nuisance Act ("Wet van 15 Mei 1952, houdende nieuwe regelen ter voorkoming van het veroorzaken van gevaar, schade of hinder door inrichtingen (Hinderwet)," 1952), which includes dumping sites in the definition of constructions.

The nuisance caused by the enormous amount of waste dumped in the Volgermeerpolder, reached such a level in 1962, that an interest group was established with the intention to shutdown of waste dump in the Volgermeerpolder; after the dump in the Volgermeerpolder got its operating license on waste dumping and the dump was adapted to comply somehow with the existing regulation of the Nuisance Act (Hinderwet), the interest group stopped in 1967; however, the toxicity and the hazard of the substances transported from several industrial facilities to the Volgermeerpolder come to raise the concern of the owner of the dump site (Buijs, et al., 2005).

An almost exponential growth of waste to be handled and the preferred choice for waste disposal – landfilling – were exerting serious pressure on the existing waste disposal system around the big cities. As landfilling has an important effect on the available space, the surroundings of the site and the landscape of the area, it was necessary to take them into account when assessing waste disposal alternatives (Gemeente Groningen, 1976).

5.2.2. Formalisation of new preferences for waste disposal

The idea that technology on its own would not solve the increasing amount of waste produced was already acknowledge at the end of the 1960s (Buekens, 1975). Buekens (1975) pointed out that the issue with waste disposal also required a transition from a consumption mentality to a sense of responsibility culture in which each actor – individual or collective – is accountable for the creation of waste and its adequate disposal. In this sense, some changes were noted. In 1972, two women, Wilhelmina Kuijper-Verkuyl and Babs Riemen-Jagerman, got the permission of the municipality of Zeist and supermarket Albert Heijn to place a container of the transport company Maltha to collect glass bottles for recycling, and, given the success of this initiative and with the support of the Ministry of Health and Environmental Protection, other municipalities were encouraged to place containers for the collection of glass bottles for recycling (Oldenziel, 2001). Additionally, municipalities put themselves as a supporting role of the central government, to help provide information and support a mentality change on the citizens towards waste prevention and recycling (as a method under development), and the way in which waste is dealt with once it has been originated (Gemeente Groningen, 1976). This change of mentality also was reflected in the slight change in preferences of waste disposal choices: incineration started to seem a better alternative than landfilling according to environmental and hygienic perspectives but the current cost was still high enough for not having it as a first choice, while recycling was still an incipient alternative that needed to be tested and well-balanced at large scale before any consideration is done (Gemeente Groningen, 1976).

At the European level, the change of mentality was reflected on the efforts of the Council done to align the differences in legislation of Member States on waste. On July 15th, 1975, the Council passed a directive on waste ("Council Directive of 15 July 1975 on waste," 1975) having in mind:

- The protection of human health and the environment
- The recovery and reuse of discarded materials
- The harmonisation of legislation of Member States on environmental issues
- The avoidance of obstacles for the trade in a common market
- The introduction of the "polluter pays" principle

With this directive, the Council formalized the promotion of waste reuse, recycling as a source of raw material for other processes, and the utilisation of waste as an energy source.

The environmental concerns being raised at a global and European scale and the high volume of waste being landfilled triggered the change in the social awareness during 1970's regarding the environmental consequences of the landfilling practice. Meanwhile in the Netherlands, some significant changes in the policy arena were also taking place parallel to the changes in public opinion.

The Waste Product Act was adopted ("Wet van 23 juni 1977, houdende regelen inzake huishoudelijke afvalstoffen, autowrakken en andere categorieën van afvalstoffen (Afvalstoffenwet)," 1977). The introduction of this act, and especially its Chapter 5 dedicated to the protection of the environment by the limitation of the waste stream, forced the public acceptance of a separate waste collection system by waste handlers. Again, recycling and re-use emerged in the form of alternative circuits for glass, paper, clothes and metals. Because of this act, incineration also became a method promoted by the government for waste disposal, which increased the investments in this kind of facilities. By the end of the 1970s waste collection and transportation were organized as a municipal service.

In the Second Chamber of the Parliament, a method for ranking different ways of waste disposal - better known as "Lansink's Ladder" (See Box [β]) - was proposed and later discussed as part of the budget for the year 1980 of the Ministry of Health and Environmental Hygiene. In the assembly of November 22nd, 1979, Lansink's motion was adopted by the Second Chamber of the Netherlands.

Box [β]

Lansink's ladder (Lansink, 1979)

1. Prevention policy on waste production
2. Reuse of raw material from waste recovered at the source
3. Reuse of raw material from waste recovered at waste separation facilities
4. Energy recovery from adequate waste
5. Controlled dump of non-processable waste

An overarching rule became necessary in order to bring into the same line several laws with regards to the topic of environmental hygiene and the coordination regarding the preparation and handling of request or applications for constructions or work. The act on General Provisions on Environmental Hygiene was adopted ("Wet van 13 juni 1979, houdende regelen met betrekking tot een aantal algemene onderwerpen op het gebied van de milieuhygiëne (Wet Milieubeheer)," 1979) and it was applicable to the Nuisance Act and the Waste Product Act. The act on general provisions on environmental hygiene later on became the Environmental Act after several modifications of this law and the laws under its influence.

5.2.3. Dealing with the legacy of the previous policy on waste

Suddenly on September 15th, 1979, the Netherlands was confronted with its first waste scandal. A water pipeline snapped in the town Lekkerkerk and barrels with toluene and xylene were discovered in the ground corroding the water pipelines and probably affecting the water quality itself (van Liempt, 2004). To allow a cleaning operation of 225 000 square metres of ground, the neighbours had to leave their house to live in camps before they could return to their homes, which happened around five months later (Schreuder, 2005). The cleaning costs were first covered by the government and, after 27 years of negotiations, the companies involved in the preparation of the ground for housing construction – covering peat holes with waste – agreed on a settlement by which they will pay two million Euros to cover the cleaning operation of the ground ("Schikking in gifzaak Lekkerkerk," 2008). Unfortunately, it took few months before another waste scandal will appear.

Twenty years after the owner of the dump in the Volgermeerpolder made explicit his concern to the Amsterdam cleaning service about the nature of the waste being brought to the dump, this concern was legitimated: while doing some work to facilitate the traffic of boats with waste to the south part of the dump, workers got in touch with barrels full with unknown substances, coming from the chemical industry of the province North Holland in March, 1980 (Buijs, et al., 2005). Apparently, toxic chemicals in high concentrations illegally became part of the waste stream to the dump in the Volgermeerpolder in the 1960s (Haijtema, 2009), including harmful substances such as dioxin and chlorobenzene (van Goethem, 2006). Sadly, Volgermeerpolder did not enjoy the same luck of Lekkerkerk: the execution of the decontamination operation started almost 25 years after the discovery of the first toxic barrels (Buijs, et al., 2005) and it is estimated to be concluded in five years given that the choice is not to remove the contaminated ground but rather first isolate it with ground and film and cover it with clean ground (van Goethem, 2006) while using the self-cleaning capacity of the ground (Trommelen, 1999). Although the government hold some chemical industries responsible for the pollution of the Volgermeerpolder and took one of them to court, a court of justice in Amsterdam pronounced against the request of the government ("Rijk betaalt sanering Volgermeer," 1992) and this decision was confirmed by the Supreme Court of the Netherlands in 1994 ("Staat moet kosten sanering betalen," 1994).

Some months after the discovery of barrels with toxics at the Volgermeerpolder, there was found sulphuric acid in a barrel at the location currently known as Griftpark in Utrecht (Determeijer, 1992). It took several years to decide the way in which the decontamination operation would be done. It was finally chosen to isolate the area with a concrete wall covering the top part with clay and to pump out the water inside the walls and the underground water around the walls to clean it and the works were rounded up in 1997 (Determeijer, 1997).

More cases of ground contamination were found and, eventually, an inventory was done, identifying hundreds of locations spread over the Netherlands (van Liempt, 2004). Not only public areas, such as Coupépolder in Alphen aan de Rijn, but also private company premises – such as Philips Duphar in Naarden – were included in this list (van den Berg, 1997)

Although previous waste scandals were related to the existence of dumps, another incident happened at the end of the 1980s, exposing the risks of the currently preferred way of waste disposal: incineration.

In July, 1989, dioxin was found in milk coming from cows grazing in the Lickebaert area, which is close to the incineration facility Afvalverwerking Rijnmond (de Ruiter, 1994). Research has confirmed higher levels of dioxins in dairy product that come from areas in the vicinity of incineration facilities and policy was developed to prevent the cow's milk consumption coming from the Lickebaert area (Lien, Hoogerbrugge, & Koostra, 1991).

After the adaptation of the incineration facility Afvalverwerking Rijnmond and the confirmation of the dioxin values in the emissions under the standard, the Ministry of Agriculture withdrew the restrictive measures on processing cow's milk and sheep's' meat in the Lickebaert area ("Minder dioxine Einde 'Lickebaert-affaire' en vervuiling AVI," 1994); however, the Food and Goods Authority (Voedsel en Waren Autoriteit – VWA) reported ten years after the first discovery that dioxins' concentration in grass in the same area were again high (ANP, 2005).

To cope with increasing consumption and waste production patterns and the increasing difficulty of waste disposal, some research initiatives were undertaken with the believe that a proper design of products and production processes would have influence in the way the environment is affected (Eekels & Weenen, 1987), and in this way prevent waste production at the beginning of the life cycle of a product and make use of produced waste as raw material for other products through process re-engineering.

5.2.4. Towards a national harmonisation and the European Union's policy influence

To make agreements regarding the waste processing capacity and to execute the country waste policy, the central government, the provinces and the municipalities created the Consultation Body on Waste (Afval Overleg Orgaan – AOO) in 1990, having as members representatives of the Ministry of Housing, Spacial Planning and the Environment (Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer – VROM), the interprovincial consultation body (Interprovinciaal Overleg – IPO) and the Association of Dutch Municipalities (Vereniging van Nederlandse Gemeenten – VNG), supported by representatives of the business community and environmental organisations (Oosterhuis & Grijp, 2003).

Box [γ]

Waste flows (Randstad Afval Overleg, 1993):

1. Domestic waste
2. Coarse domestic waste
3. Offices, stores and services waste
4. Hospital waste
5. Industrial container waste
6. Construction and demolition waste
7. Shredder waste
8. Cleaning service waste
9. Purification sludge
10. Contaminated ground

This consultation body was meant to design a coherent and coordinated approach for waste disposal: for this, the Ten-year program for Waste (Tienjarenprogramma Afval) was set up – with a release every three years – and ten waste streams were presented (See Box [γ]), to steer the waste flows to its adequate processing form and avoid as much as possible landfilling practices while stimulating prevention and reuse or recycling (Afval Overleg Orgaan, 1995). The administration office of this consultation body had the task to monitor and evaluate the waste disposal performance, stimulate the waste prevention and separation and take care of up-to-date information for the parties involved (Oosterhuis & Grijp, 2003).

Coordination on how to reduce waste production and disposal was not only done between governmental bodies but also between the government and the business community. Specially on the topic of packaging materials, the government, represented by the Ministry of Housing, Spatial Planning and the Environment (Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer – VROM) and the ministry of Agriculture, Nature and Food Quality (Ministerie van Landbouw, Natuurbeheer en Visserij – LNV) together with the Council of Packaging and Environment (Stichting Verpakking en Milieu – SVM) signed a covenant to agree on how to deal with packaging and packaging waste on June 6th, 1991 (in 't Veld, de Bruijn, & ten Heuvelhof, 1992).

The Netherlands was as well sensible to the effects of the common European policy in different topics: packaging was not different. The European Union also started to consider packaging and packaging waste as a topic for harmonisation among Members States, taking the following into consideration:

- Reduction of the environmental impact by dealing with packaging waste
- Facilitation of a European waste market
- Promotion of a shared responsibility attitude and a behavioural shift of consumers

On December 20th, 1994, the European Parliament and Council released a guideline on packaging and packaging waste ("Directive 94/62/EC of 20 December 1994 on packaging and packaging waste," 1994).

Given the amount of changes in the legislation on environmental hygiene, an integral version of the Environmental Act was enforced at the beginning of 1994 ("Wet milieubeheer," 1994). This recently published version included changes such as enforcement of Lansink's ladder to protect the environment. The application of Lansink's ladder implied the responsibility of the municipalities on waste collection: in particular, household organic waste – such as vegetable and fruit skin and peel – should be separately collected for further recycling.

5.2.5. A new vision of the national waste disposal policy

The Ten-year program of Waste and other programs were replaced by the first National Waste Management Plan (Landelijk Afvalbeheer Plan) in 2002. The Ministry of Environment determined a four-year national plan – with the possibility of revision at the end of the period but with a horizon of ten years – to deal with the type of waste matter indicated in the Environmental Management Act and its amendments[4], which includes a policy outline for waste prevention and disposal, the sector plans per waste flow and two capacity plans for incineration and dump (Afval Overleg Orgaan, 2002). It was already taken in to account the dynamics around the liberalisation of the waste market in the European Union for the incineration and dump capacity planning (Afval Overleg Orgaan, 2002).

Another step towards the separation of waste flows is the Resolution regarding rules for packaging, packaging waste, paper and cardboard ("Besluit van 24 maart 2005, houdend regels voor verpakkingen, verpakkingsafval, papier en karton," 2005). This resolution includes glass, paper and cardboard, metal, wood and plastics as materials for packaging and puts the responsibility and the cost of keeping the packaging materials separated on the producer or importer. Additionally, producers and importers are responsible the innovation in packaging such that the amount and the harmfulness of the material are reduced. Furthermore, producers and importers should at least 70% usefully applied and 65% recycled.

[4] The Environmental Management Act and its amendments excludes radioactive waste, dredging, manure, demolition waste and sewage (Afval Overleg Orgaan, 2002).

After 15 years of existence, the Consultation Body on Waste (Afval Overleg Orgaan – AOO) was deactivated on January 26th, 2006, and SenterNovem – an agency of the Ministry of Economic Affairs – took over the administrative functions while the consultation functions were transferred to the Directorship Environment (Directoraat Milieu), which is a joint work of the district water boards and outlet sluices (Unie van Waterschappen en uitwaterende sluizen), the interprovincial consultation body (Inter Provinciaal Overleg - IPO) and the Association of Dutch Municipalities (Vereniging van Nederlandse Gemeenten – VNG) (SenterNovem, 2006).

In December of 2009, the second National Waste Management Plan came into force: in this case, it is a six-year program with a view through 2021, where the material supply chain perspective – from raw material extraction until waste disposal – has been taken in order to reduce environmental pressure, from product design, throughout the production process and clients consumption, until waste disposal (Directie Duurzaam Produceren, 2009).

The differentiation of waste streams has turned waste into a market sensitive product. In the case of paper, the foundation of the Netherland's Paper Recycling (Papier Recycling Nederland - PRN) had to establish a fund to pay the collection cost of waste paper when it cannot be covered by the sales of waste paper (ANP, 2010b).

The last development in the differentiation of waste streams is the separate collection of plastics from 2010 on. Like glass or paper, plastic can also be reused for producing new plastic products (Stichting Nedvang). However, there are indications that separation of plastics before collection is more costly than separation in sorting facilities (ANP, 2010a; ANP Video, 2010; "Limburg: nascheiden afval effectiever en goedkoper," 2010).

5.3. A SyNeA characterisation of the Dutch Case

The three-level approach, as explained in Chapter 2 will help us unravel the complexity of the Dutch transition to a solid-waste supply-chain management. Dynamics occur at three different levels: system, interaction and agent level, and the elements of each level will be described in the next sections.

5.3.1. Description of the Dutch system conditions

At system level, it is possible to identify the "drastic events" and the underlying cultural background that play a role in this transition.

A. Drastic events

In the case of the Netherlands, the combination of two sets of triggers has become the "drastic event" that started this transition process. The first set occurred with the wars, especially with World War II acting as an external drastic event, and German administration during World War II as an internal drastic event. The second set of drastic events composed by the prognosis on scarcity of materials done by the Club of Rome as an external drastic event and the series of "waste scandals" about pollution of ground and its consequences for food production and living standards as an internal drastic event.

Regarding the first set of drastic events, the World Wars were external drastic events for the Netherlands. From World War I, thrift in consumption was socially encouraged in the lower social classes even in the period between wars due to the necessary reconstruction after the war, e.g. government promoted electricity consumption as a way to save coal (Oldenziel, 2001). World War II changed the scope of thrift: saving materials was meant for the whole society.

The external event became an internal event when the German administration took over the Dutch government: this administration saw the necessity to ration households access to products in order to keep businesses with enough resources for goods production for German use (Oldenziel, 2001). Households needed to be inventive to save resources for themselves and to reuse old products and materials, even for personal use. The German administration also brought a new perspective on waste usage: a systematic waste collection system based on the existing rag pickers collection with sorting at the source (households), but this time for industrial use (Oldenziel, 2001)

Regarding the second set of drastic events, and specifically the external drastic event, one year before the oil crisis of 1973, the Club of Rome published a report called "Limits to Growth" (Meadows, et al., 1972), which was translated to Dutch and influenced the realisation of the relevance of environment pollution (Oldenziel, 2001). This report emphasized on the ecological limit of the earth to bear the effects of human development. The team lead by Donella H. Meadows focused on the planet's physical limits by analysing five issues and assuming some tendencies for each, as follows: accelerating industrialisation, rapid population growth, widespread malnutrition, depletion of non-renewable resources, and a deteriorating environment. This report warned about a decline of population and human welfare unless policy at global level is developed in order to prevent the irrational use of non-renewable resources and the excess of the planet's ecological limits. This report received criticism, one of them from Herman Kahn, who argued that the planet has the possibility to bear five times the population of that time (Kahn, et al., 1977), being this a conservative statement. The material scarcity, together with the waste abundance and the increasing difficulty to deal with it, started a shift from health prevention to benefit from materials being idled away in waste. Waste reuse and recycling slowly became a sustainable way to benefit from wasted material while diminishing the amount of waste to be dealt with.

Concerning the internal drastic event, the occurrence of waste scandals shook living standards and preferences of people. From the government, the high costs of different cleaning operations as well as the economic losses caused by ground, water and air pollution triggered several policy changes in order to make polluters responsible for their deeds. This was supported by the introduction of the "polluter pays" principle at EU level. In this way remediation of waste pollution was slowly encouraged by waste prevention, especially with the introduction of changes in the Environmental Act. This also signified a change in perspective about waste: it was no longer only an issue of health and health care coming from solid waste but also a matter of environment conservation and scarcity of materials later on.

B. Cultural background

Cultural background is a relevant aspect to consider when dealing with transitions. The way a new paradigm is introduced could succeed or fail depending on the state of mind of the relevant actors involved. Based on Hofstede's (1991) cultural dimensions, it is possible to currently describe the Netherlands as a country where power is perceived as equally distributed, the sense of belonging to a group is relatively weak when compared with developing countries, gender roles are relatively balanced, uncertain or unknown situations are lightly experienced as threats, and where a relatively middle-term orientation prevails (Hofstede, 1991). This particular combination of cultural dimensions allows the country to work as a "well-oiled machine" as interpreted by Owen James Steven (Hofstede, 1991), in which rules take care of the common problems and intervention is necessary to address special circumstances.

In the evolution of the waste treatment in the Netherlands, it is possible to observe this behavioural trend, in which the status-quo reigns over the day-to-day circumstances until critical situations, such as wars in the 1910s and 1940s, waste scandals in the 1980s or physical limits like land scarcity for landfilling, appear and strike the existing interaction mechanisms, making them no longer suitable for the sustainability of the system. Also, the creation and extinction of consultations bodies relates to this "well-oiled" behaviour: once the interaction mechanism is known and most parties have embraced their new function, there is no longer need for a special institution to deal with daily situations. However, women in society did play an important role in the introduction of sorting at source, recycling and reuse, especially during war time and the German administration. Housewives were the ones who dealt with the rationing system and found out way outs to get extra provision for their household (E.g. getting soap for animal bones), were held responsible for the separation of waste in different categories, should be creative with the reuse of materials (E.g. children clothing from old grown-up suits) or the use of material for other purposes (E.g. curtains cloth for making dresses) (Oldenziel, 2001).

The reliance on rules and agreements is probably a reflection of the high living standards and quality of life in the Netherlands, which is capture in the Human Development Index (Watkins, 2007) (See Figure 5.3).

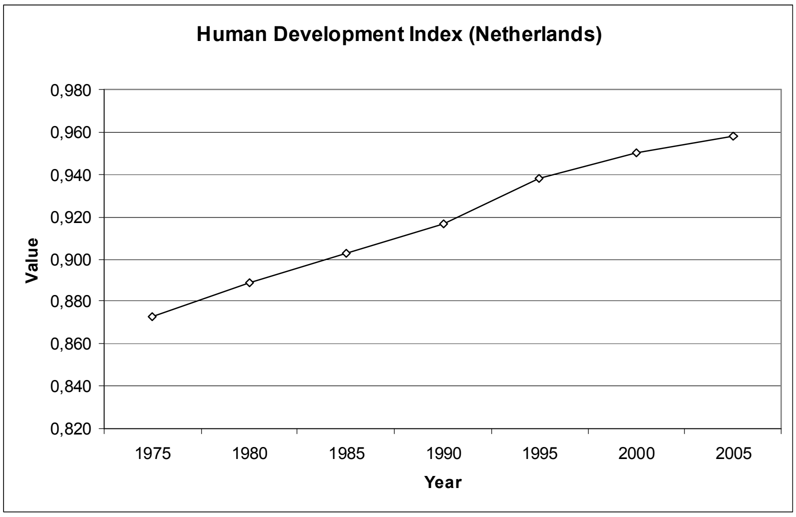

Figure 5.3: Evolution of the Human Development Index of the Netherlands (Based on (Watkins, 2007))

5.3.2. Description of the Dutch network conditions

In the Dutch waste disposal case, two main governance mechanisms can be recognised. One is related to the way the waste disposal system was organised. The other is related to the way the formal interaction mechanism was done.

<u>A. Polity</u>

The Netherlands

The revision of the constitution in 1848 set the basis of the current government structure of the Kingdom of the Netherlands: a parliamentary constitutional monarchy. The government (*'regering'*) comprises of the head of state (the king or queen) and all the ministers. The ministers, individually or as a group, are responsible for policy-making and for the political deeds of the head of state (Europees Parlement Bureau Nederland). The ministers are nominated by the Prime Minister and together they form the cabinet (Ministerie van Algemene Zaken). Cabinets need to be supported by the majority of Parliament. The government together with both chambers of Parliament form the legislature. Members of the Second Chamber of Parliament, as well as the members of the Municipality council and the Provincial States, are directly elected by the population, while members of the First Chamber of Parliament are indirectly elected (Europees Parlement Bureau Nederland).

The first cabinet was formed in 1848 and since then, the Netherlands has known 65 cabinets. The political nature of these cabinets has lingered around the centre of the political spectrum most of the times (As it can be seen in Figure 5.4); however, the Netherlands has had governments with members of left and right parties in the same cabinet from time to time. Remarkable is the creation of a Ministry of Health and Environmental Hygiene in 1971. This is the first time that environmental affairs are explicitly part of a ministry; in 1982, environmental affairs became part of the Ministry of Housing, Spatial Planning and the Environment (Ministerie van Algemene Zaken).

Europe

Since 1951, the evolution of the Netherlands has been linked to the development of a supra national organisation in Europe. With the signature of the European Coal and Steel Community Treaty on April 18th, 1951, France, Germany, Italy, Belgium, Luxembourg and the Netherlands embarked in a common project to improve the social and economic conditions in Europe by means of a common market of coal and steel initially (European Union). The signature of the treaty establishing the European Coal and Steel Community ("Treaty establishing the European Coal and Steel Community ", 1951) had as basis:

- A common market: to contribute to economic growth, increasing employment and improved living standard of Member States
- Common objectives: to ensure favourable market conditions for Member States, and to promote improved working conditions and living standard, international trade growth and quality, and expansion and modernisation of production
- Common institutions: namely a high authority, a common assembly, a special council of Ministers and a court of justice, to provide guidance and assistance, to place financial resources, to ensure normal competitive conditions, and to make public the reasons for its actions

The work on a common market was later extended to a customs union and the development of common policy on agriculture, trade, and transportation with the Treaty establishing the European Economic Community ("Treaty establishing the European Economic Community," 1957) among the six countries of the Coal and Steel Community. Another topic for common work is the utilisation of nuclear energy: with the signature of the treaty establishing the European Atomic Energy Community ("Treaty establishing the European Atomic Energy Community (EURATOM)," 1957), the six countries of the Coal and Steel Community tried to do joint efforts to utilise nuclear energy in an expanding nuclear industry.

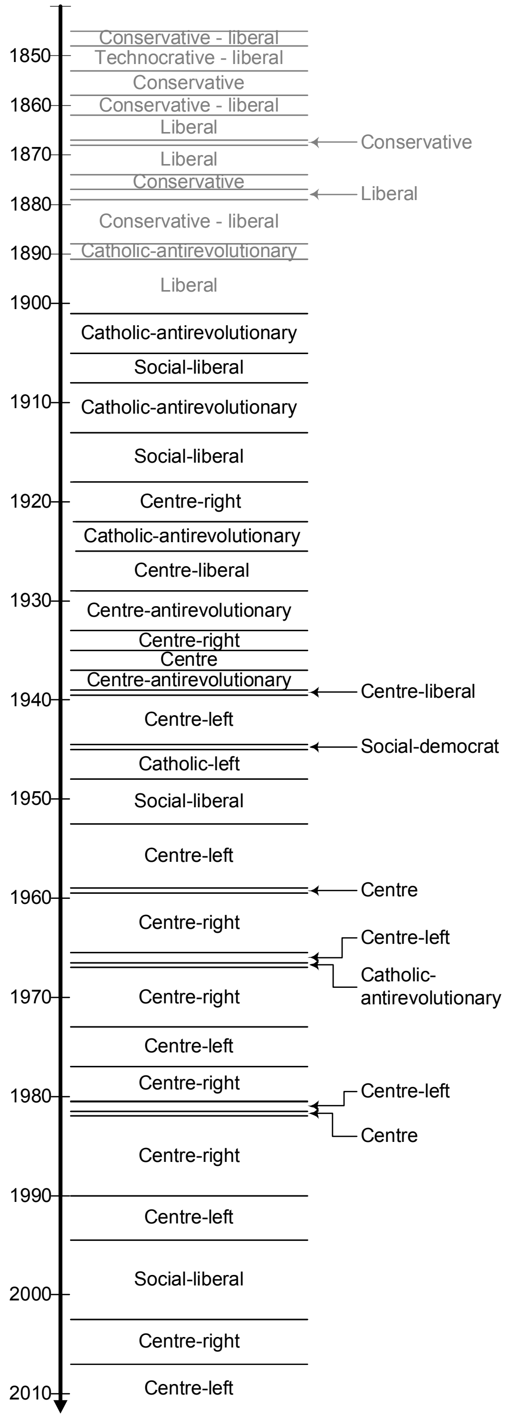

Figure 5.4: Cabinets in the Netherlands since the revision of the Constitution

In the course of the years, there were continuous efforts on more integration in different topics, such as administrative, budgetary, financial, and the improvements done by the Community encouraged other countries to access to the Community, such as Denmark, Ireland and the United Kingdom. By the end of1980, the number of members increased to twelve with the accession of Greece (1979), Portugal and Spain (1985). With more members and more topics to coordinate, the integration process received a new élan with the fall of communism.

With the signature of the treaty on European Union ("Treaty on European Union," 1992) on February 7th, 1992, the Member States went further with the integration process, having as main objectives:

- Free traffic of people and goods
- Economic and monetary union with a single currency
- A common foreign and security policy, and the basis for a common defence policy
- A unified citizenship for the national of the Member States
- Cooperation on justice and home affairs
- Efficient mechanisms and institutions

This treaty has been amended by the Treaty of Amsterdam (1997), mainly on the topics of employment, justice, home affairs, and the Treaty of Nice (2001), mainly on the topics of cooperation, justice, and voting (European Union).

Also, more countries have acceded to the European Union: in 1994, Austria, Finland and Sweden; in 2003, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, the Czech Republic, Slovakia and Slovenia; and in 2005, Bulgaria and Romania (European Union).

B. Policy change

Acts were one of the ways to orchestrate the change in the waste disposal system. With the introduction of the Waste Products Act, a period of uncertainty arose due to the lack of standards for waste collection and the inclusion of incineration as another method for waste disposal. Lansink's motion in the Second Chamber of the Parliament of the Netherlands shed some light on the preference for waste disposal. This preference was later materialized in the revised version of the Environmental Act of 1994.

Besides acts and Parliamentary motions, programs were another instrument of the government to advance the new preference structure for dealing with waste. The Ten-year program for Waste was the first country-level instrument to deal separately with different types of waste matter and to try to recover as much material as possible in order to reduce landfilling practices.

With several programs for dealing with different groups of waste matter existing in parallel, a new plan was seen to be necessary to carry on with the achievements. The National Waste Management Plan (Landelijk Afvalbeheerplan – LAP) was presented by the Ministry of VROM to replace Ten-year program for Waste and other programs and to deal with types of waste matter included in the Environmental Management Act. As instrument of the government, the National Waste Management Plan reflects the perspective taken when dealing with waste matter. Here, prevention and management are the key concepts, keeping incineration and landfilling as last resorts. The progression of government's perspective, from waste treatment to waste management, is also reflected on the design of a Second National Waste Management Plan. The current viewpoint adopted is a supply chain approach, where waste is separately collected as much as possible at the source to improve the reuse as raw material or product, the recycling with some transformation, the energy winning with incineration and leaving landfilling as a last resort. With the intensification of separate waste flows, waste handlers can carry on with the adoption of new practices supported by technological developments, facilitating collection and separation processes.

The existence of the Consultation Body on Waste became a key element in the coordination of the different layers of government (National, Provincial, Municipal) regarding competencies and responsibilities to achieve progress in the implementation of the revised version of the Environmental Act, to measure the progress of the programmes and to distribute the information to all parties involved. As a specialized body fulfilling a particular role in the creation of a new waste system, its existence was relevant until most of the new interaction mechanisms were in place: from then on its functions could be incorporated to an existing organisation with similar functions.

A pioneer move of the Netherlands regarding waste matter treatment was the inclusion of the business community in the design process of the future waste supply chain. The agreements between government and parties involved in the production, transformation, use, and reuse of package and packaging material were collected in the First Covenant Packaging. In this covenant, measures for prevention, use and recycling as well as the responsibilities of the signing parties were made explicit.

The European Union supported the existing practices in the Netherlands with the emission of the Directive 94/62/EC of 20 December 1994 on packaging and packaging waste because this directive collected front-runner countries' practices, such as:

- Promotion of waste prevention
- Exploitation of packaging waste as raw material for the same purpose or energy production
- Specialisation of waste flows, and to guarantee a high rate of collection, return and recovery
- Voluntary agreements between the governments and the economic sectors involved
- Preparation of standards for identification, composition, processing and analysis of packaging waste
- Implementation of targets and deadlines – and exemptions when necessary – for recovery and recycling of packaging material
- Creation of an information system for monitoring the progress of Member States
- Use of economic instruments to pursue this directive's objectives

The European Union also forced to change the existing waste structure of the country. In accordance with the principle of free traffic and unified market, the system of waste concessions – useful for the design of processing capacity because of the reduction of uncertainty for waste companies – was no longer possible.

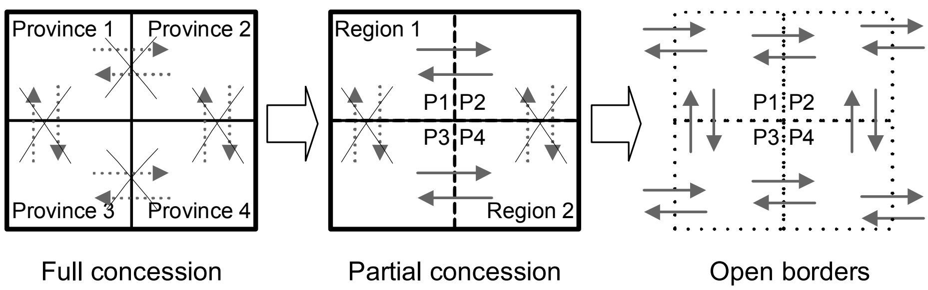

Figure 5.5: Schematic evolution of concessions and their borders in the Netherlands

Although the Netherlands already started to open up its internal borders due to the cooperation between provinces, the influence of the European Union in the national government was effective enough to eliminate the internal concessions in 2000. A schematic evolution of concessions in the Netherlands can be seen in Figure 5.5.

C. Technological change

In the course of time, there have been several changes regarding scale, technical improvement and appreciation of waste as usable raw material.

In general and regarding scale, it is possible to speak about a shift in the magnitude to which waste is collected. What once was done by individuals as breadwinning (Rag pickers) or cost-saving (Farmers), was later on done by groups or associations as a way to raise funds (Soccer clubs or charity), and is currently done by companies collecting large amounts of different types of waste to benefit from scale economies (SITA or Van Gansewinkel BV).

About the technical improvement, three basic processes have been used to process or dispose waste. The evolution of the use of these processes in the last 15 years (due to availability of data) of these three methods is explained below.

Dumping / Landfilling

Dumping has been one of the easiest methods for waste disposal because waste could be buried in the ground or sunk in water. In time, dumping turned into landfilling when it was done on ground and in a controlled way, taking into account the location and the surroundings of the chosen area, the hydrology and composition of the ground, and the amount of waste to be dumped (Buekens, 1975).

Lately, there has been improvement in the usage of landfill gas for energy production; however, the process itself has stayed the same. Landfilling as a way of waste disposal was initially a cheap option, but its cost increased with the mechanisation of the landfilling process and the measures that are required to protect the ground and the surroundings from leachate.

Incineration

It is the conversion of waste into primarily CO2, water and ashes. Two major cities of the Netherlands – Rotterdam and Amsterdam – started with incineration of waste in 1908 and 1912 respectively (Buekens, 1975).

If incineration was in principle a way to reduce and dispose waste by means of combustion, in the course of the years there are more attempts to improve the use of by-products (steam for electricity production or ashes for pavement of roads) or improve the material (e.g. ashes and metals) recovery.

Composting

It is the breaking down of organic (vegetable) material (such as vegetable peel and skin, plants, leaves) to obtain substrate for agriculture and horticulture. Composting has been practiced in cities of the Netherlands until the introduction of incineration facilities in big cities like Amsterdam (1912) and Rotterdam (1908) and the appearance of artificial fertilizers, which meant the displacement of composting practices to rural areas, like Wijster (Drenthe) or Mierlo (Noord-Brabant) (Buekens, 1975). Still, there is a large amount of municipalities collecting organic material in a separate stream to produce compost.

Several new streams for improving the use of waste have been developed, as it can be seen in Figure 5.6.

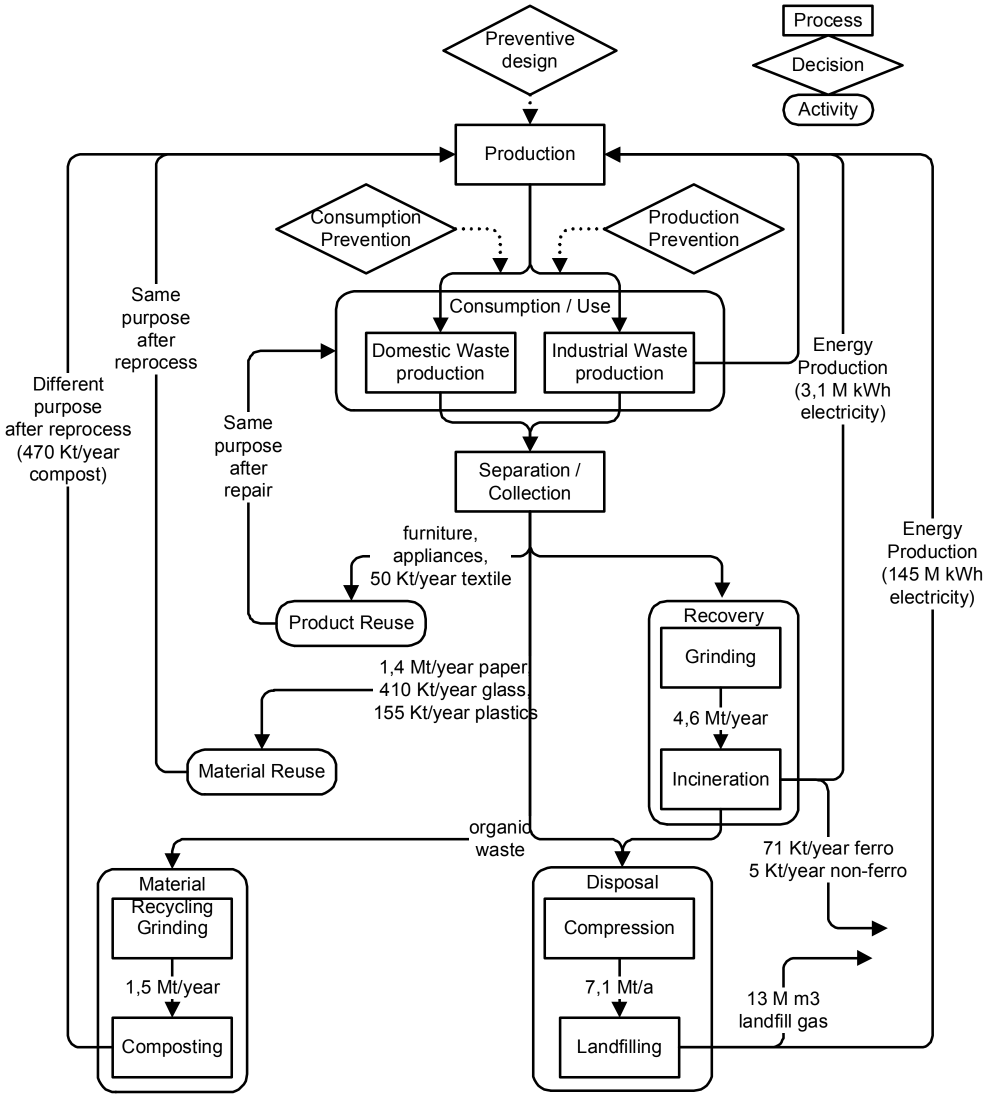

Figure 5.6: Waste flow in the Netherlands (Based on (Dijkema, 2009))

Product reuse has been professionalised: items are being picked up for repair and later re-sold as second-hand articles or shipped to foreign countries as charity. Material reuse is applicable to plastic and paper, the latter with much better reuse rate than the former once outside the production facilities.

Landfilling is currently used as reserve capacity for residues that have no further use until now and landfill gas is won to be used for energy production. Incineration is used more often to separate materials with heat and for electricity production.

5.3.3. Description of the Dutch agents conditions

At the agent level, it is possible to observe the relevant actors of the system – as proposed in our typology – which are the source of change at the interaction and system layer. While being heterogeneous in terms of the nature and impact of their decisions, actors naturally have differing objectives, which is also highlighted as the multi-actor nature of the transitions (Rotmans, 2005a).

In the Dutch waste transition case, seven actors of our framework can be identified in the transition process, each of them with an active role:

A. Government

In this case, the central government has functioned more as a coordinator of existing social initiatives rather than an initiator of a transition, in accordance with the cultural characteristics of the Dutch society. In this context, government intervenes under specific and acute circumstances, such as health problems related to waste abundance in urban areas, or waste scandals. Holding the function of policy maker, government works on the formalisation of local and regional initiatives by means of local and regional government's organisational and budgetary support and spreading them to the entire society by standardisation of procedures and practices, such as the case of the bottle banks and separate waste collection. The acknowledgement of preferences of households and the general society has been instrumented not only through regulation (e.g. acts) but also parliamentary motions and covenants with different business sectors (e.g. covenant packaging).

An exemption to this "business as usual" behaviour was the occupation of the Netherlands by the German administration, which disrupted the existing course of business. The German administration brought practices related to waste that were unknown to most of the Dutch local and regional government, such as sorting several materials at the source (e.g. vegetable skin and peel) or separating waste streams for material recovery due to the low pay off of the collected materials (e.g. paper collection). Furthermore, this administration formalized existing practices (rag pickers collecting materials) to embed them in a system in which materials could be won with fewer complications due to the pre-work on sorting done by household.

B. Producers

Households have here become the producer in the waste treatment chain. If in the past they were the source of waste and were affected by the health problems uncollected waste can produce, households are nowadays the source of relevant raw material for the production of different goods (e.g. paper or glass) or services (e.g. electricity or heat). In particular, women played an important role in the creation of separate waste flows. During the occupation of the Netherlands by the German administration, women at each household were held responsible for the sorting and the delivery of the "right" type of waste to the proper destination. Later on, the initiative of the bottle bank was first introduced by women, although it meant more work for themselves by adding the transportation to the sorting of glass at home.

Citizens have also exerted power to prevent of allow the creation or installation of new facilities for waste treatment. Naardermeer was saved from being transformed into a waste dump while Volgermeerpolder became not only the waste dump of Amsterdam but also the focus of the second waste scandal in the Netherlands due to the pollution level in water and ground. A decisive factor for this difference might be the fact that the Volgermeerpolder was property of a business extracting peat and it needed to keep the business alive and the citizens around this area were the ones affected by the nuisance of the waste dump. Naardermeer received another treatment because nature enthusiasts demonstrated against the plans of the municipality of Amsterdam of turning this area into a waste dump (Buijs, et al., 2005) and the founders of the association Nature Reserve (Natuurmonumenten) bought the whole area to keep it under their protection and supervision (Natuurmonumenten).

Community action against the construction of new landfill sites after the leakages of landfills in Amsterdam and Lekkerkerk, and public concern on environmental issues after the found of dioxin in milk, show the active role of the households as producers, supported by Interest Groups.

At business level, several industrial branches are currently bounded by covenants with the government to work on the prevention of waste from the production process. Remarkably, there has been little households' information for the reduction of waste produced, which might be an indication of a lock-in effect of the waste consumers (companies reprocessing waste) in order to keep sufficient material to produce their own products to be sold.

C. Facilitators / Infrastructure Intermediaries

The local municipalities are responsible for managing the waste collection at households' level. If in the past, municipalities had to organize their own collection system and disposal alternatives (e.g. like in the case of Amsterdam hiring the dump in Volgermeerpolder or investing in the incineration facility in Amsterdam north), they nowadays perform their collecting function by issuing permits or hiring waste contractors of the advised alternative for waste handling depending on the waste flow (Personal Communication with Herman Huisman). Still, municipalities hold some stakes at companies providing facilities for landfill, collection and composting (Personal Communication with Han van Rijssen). Even government keep some stakes at companies specialized in waste incineration and energy production (Personal Communication with Herman Huisman).

At households' level, municipalities currently organise the first part of the collection (offering waste to collectors) by providing conditions on how waste should be offered (e.g. type of container, time of placement, location of placement (Gemeente Delft, 2010)) in order to avoid nuisance and other inconveniences. The collection itself could still be done by a municipality service but more and more there are companies contracted for that purpose, which also provides the containers for the offering of waste.

D. Consumers / Infrastructure Intermediaries

Companies providing for waste treatment alternatives are contracted by local government to deal with the last part of the waste treatment chain. Available alternatives are incineration of waste matter, landfilling of waste matter, or composting of vegetable matter and sometimes transportation is also included in the contract. In the case of landfilling and incineration, (local) government still holds stakes in these companies, while composting and transportation is almost in private hands.

There has been a matter of professionalisation of waste treatment companies in order to improve their (processing) capacity and their compliance with increasing regulation to diminish the impact on the environment. For improving their capacity, waste treatment companies should provide for the maintenance the existing infrastructure, supply of the means for collection, investment in new alternatives. For the purpose of complying with regulation, these companies are somehow dependent on the research and development of providers of equipment, machinery or appliances for the execution of their tasks.

E. Interest Groups

They work on the public perception of means and legislation, canalising people's interests and concerns about specific topic and providing support to innovative ideas that correspond to their perspectives about what is more or less favourable for the community. In the Dutch waste disposal case, NGOs play this role and are assumed to have an opinion about the convenience of each alternative for waste disposal. Additionally, there have been initiatives for recycling, with the rag pickers collecting rags to earn a living, associations of different types collecting paper for charity or to cover a monetary need, or individual initiatives recovering glass in bottle banks to take care of the environment.

F Research Organisations

Their presence has been limited to the improvement of existing techniques and technologies supporting the actual way to deal with waste and to cope with higher environmental standards. In this sense, improvement has been reached in the reduction of emissions, the recovery of materials and energy, and the recovery of exhaustion gases from landfilling and incineration practices.

5.4. Evaluation of the Dutch transition process

In this section, we will sketch the transition process of the Netherlands when adopting a new perspective on the handling of household waste. It is important to note that the Dutch waste transition case is peculiar because there is a matter of inversion of (intuitive) roles: households are waste producers while waste treatment companies are waste consumers. Additionally, goods, services and money flow parallel and in the same direction:

- Households, as waste producers, have to pay a levy to get their waste taken away and to comply with particular rules regarding sorting, offering, placement, and time, among others
- Local government, as facilitators, offers the collection service to households and receive a levy, which allows them to do provide the collection service themselves or contract waste companies to do this service
- Waste companies, as consumers and infrastructure intermediaries, have a contract with local government to collect waste and recover or recycle material which can be later sold to the producing industry

With this in mind, we will delineate the system's situation before the transition and address the main information feedback that gave shape to this transition in the next section. In section two, we will portray the current dynamic situation of the system. In section three, we focus on the opportunities and risks of the lessons learned from this transition.

5.4.1. Triggers and supporting conditions for the Dutch transition

At the beginning of the twentieth century, there were two parallel structures for dealing with waste in the Dutch society. One of them was the formal waste collection, which was (and still is) a responsibility of local government due to a higher level responsibility of government to preserve society's good health. Levies from households were collected in order to support the collection system and to take care of disposal facilities. A schematic representation of this formal structure is shown in Figure 5.7. Here, the elements of the social and the technical sub-system are shown separately. In the social sub-system, agents relate to each other by means of agreements, while in the technical sub-system agent relates by physical flows. Still, the social and the technical sub-systems relate to each other by ownership.

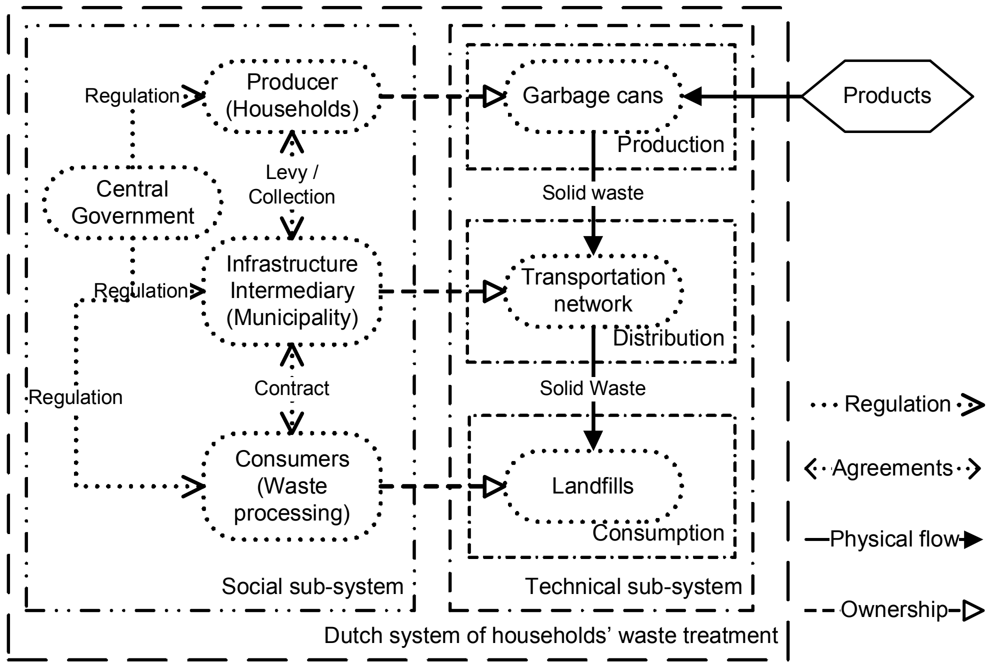

Figure 5.7: Formal waste treatment system before the transition in the Netherlands

The other (parallel) system is an informal way of material recycling. Rag pickers are central to this informal system, because they collected materials from the disposed waste to bring them to the production acilities (e.g. paper factories). These rag pickers received a monetary compensation for the collected material and make a living from this activity. As these rag pickers were not subject to any regulation, they only needed to comply with the requirement of the producing companies. A schematic representation of this informal structure is shown in Figure 5.8. Again, agents relate to each other by means of agreements in the social sub-system, while agent relates by physical flows in the technical sub-system. Furthermore, the social and the technical sub-systems relate to each other by ownership.

The formal and the informal waste treatment structures co-existed in the Netherlands for several years, with households as waste producers, and two types of consumers, namely the landfill owners receiving the municipality waste and the companies recycling products obtained by rag pickers. Government regulated the activities of all actors by making policy about nuisance. The schematic representation of the system before the transition is presented in Figure 5.9.

From the system level to the agent level, there are two elements that were sufficient to support the introduction of a new perspective in the household waste treatment. One is the cultural background of the Netherlands, where intervention is necessary to face special situations, such as war and, coupled with it, shortage of materials. These "drastic" events – World War II and shortage of material –affected the network level, making possible the existence of a German administration in the Netherlands, which focused on the recovery of materials from waste.

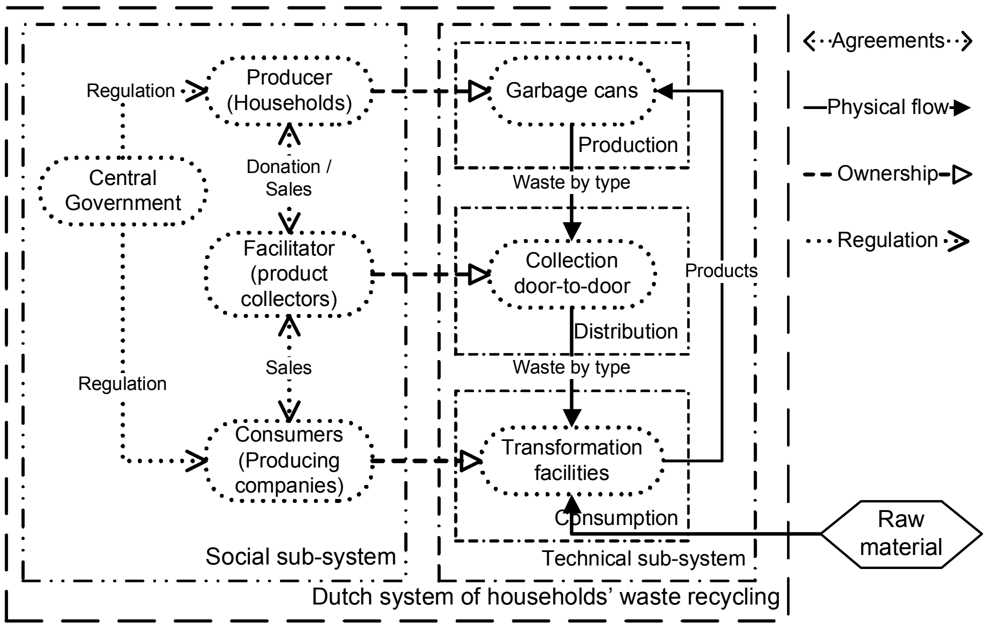

Figure 5.8: Informal waste recycling system before the transition in the Netherlands

At network level, the German administration introduced new measures for waste collection, such as the separation of waste at the source, and formalised existing practices, such as the separate collection done by rag pickers.

At the agent level, rag pickers became part of the organised system in order to canalize the different waste streams and households became responsible for the adequate offer of waste to the collection system. Here, the role of the housewife was central to the execution of the policy of sorting at the source.

As the shortage of raw materials vanished, waste production increased in the Dutch society. As a result, government has to intervene with an act to keep under control the nuisance caused by dumps existing in the 1950s. Figure 5.10 portrays how a higher level affected a lower level.

With the formalisation of rag pickers and their inclusion in the waste treatment system, the formal and informal waste treatment system integrated to form one complex system with more actors in the social sub-system. In this new system, the social and the technical sub-system reconfigured in order to accommodate elements of the two original systems.

In the social sub-system, there has been an increasing professionalisation of tasks supported by the development of new technology to fulfil the legal requirements. Professionalisation of the waste sector also meant for facilitators, e.g. municipalities, the outsourcing of the execution of some of their responsibilities, such as collection and transportation; even though, they keep stake in the ownership of incineration and landfill facilities. Between facilitators and infrastructure intermediaries, interaction is formalised by contracts, while government provides the boundaries and conditions to other actors for the execution of their tasks.

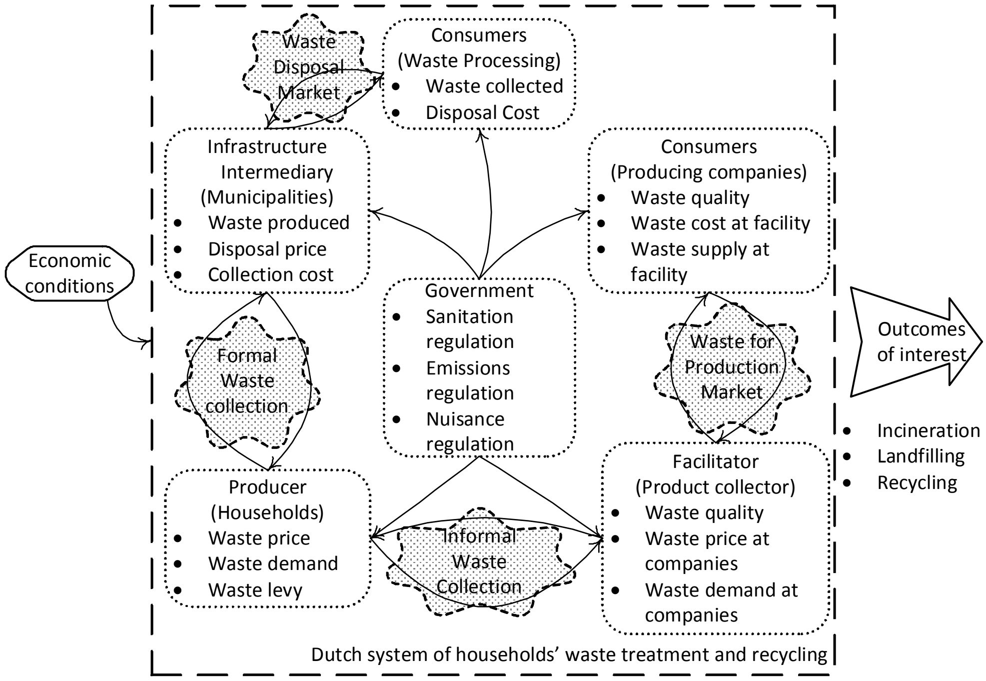

Figure 5.9: System diagram before the transition in the Netherlands

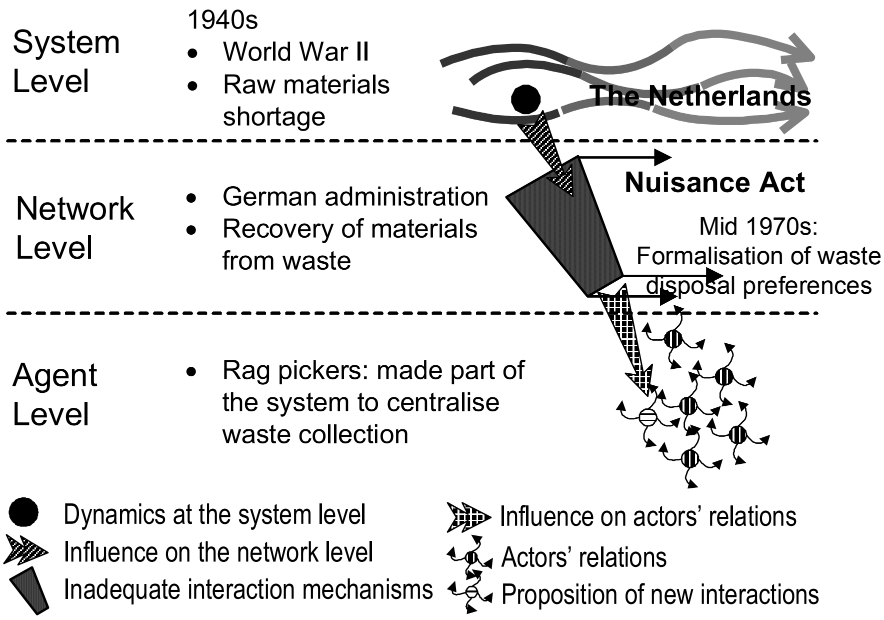

Figure 5.10: Downward impact of drastic events on the Dutch system, network and agent level

There exist different parallel tracks in the technical sub-system to treat waste: on the one hand, old recycling practices were professionalised by infrastructure intermediaries collecting and also processing waste to make it suitable as raw material for the consumers, i.e. producing companies; on the other hand, and with more support for incineration, not sortable waste is transported to incinerators as a way to reduce waste matter and later on to recover material, e.g. metals, or to produce energy. A schematic representation of the agent level is shown in Figure 5.11.

When zooming out to the system level, it is possible to observe a reduction of the number of networks due to the inclusion of the informal structure in the formal structure for waste treatment. Additionally, it is possible to speak of an embedded actor, namely one that acts as an infrastructure intermediary and consumer at the same time. This portrays the vertical integration of actors that collects, sorts, do some recovery and finally dispose the unrecoverable part of the waste. Still, the outcomes of interest are based on the existing ways to finally dispose household waste. Figure 5.12 portrays a schematic representation of the system.

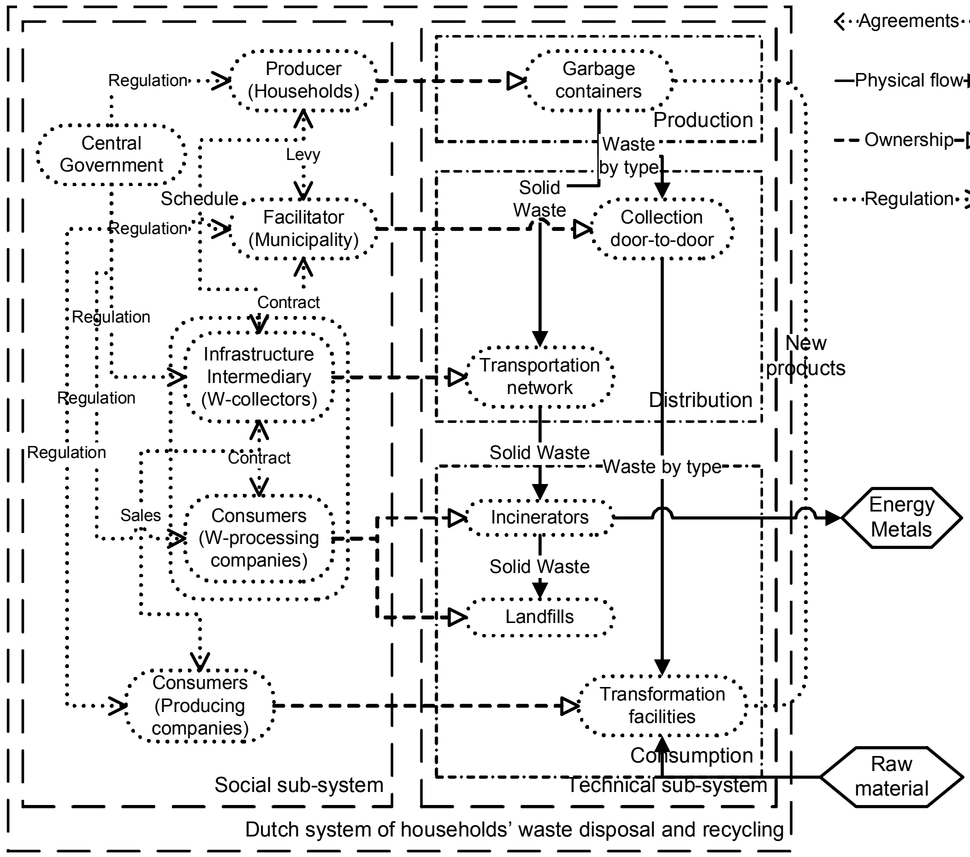

Figure 5.11: Current waste treatment system

The 1970s was a time of consolidation of existing practices, such as the separate collection of glass and paper, development of new disposal preferences, such as prevention over disposal or recycling over incineration, and the formalisation of rules by means of acts to protect the environment by restraining waste stream.

This on-going process of codification of existing procedures was reinforced with a wave of waste scandals related with former dumps or existing incineration facilities, with possible repercussion on human health and surely impact on ground, water or air. Together with internal events, the influence of the European Union on the Dutch policy-making reinforced the existing trend of events and a new consolidated version of the Environmental Act was presented in the mid-1990s. These resulted in a change of the institutional and market structure, the physical infrastructure, the practices and culture in order to improve efficiency and economic benefit from the waste disposal. Not only the waste practices in households but also the waste disposal system itself diversified, making possible an intensive use of the different waste flows and a shift from landfilling practices to incineration and reuse at the waste disposal level, and recycling at household level at the end of the 1990s. This situation did not impede the growth of total waste production.

At the beginning of the 21st century, the Dutch waste disposal system can be characterized by an intensive re-use and recycling, in which landfilling is the least utilized option (actually as a back-up option). At the same time, market developments, organisational aspects, policies and individual practices reached a temporal equilibrium, all of them with a supply chain perspective as background and the European Union legislation as outline law. Figure 5.13 shows how a lower level affected an upper level.

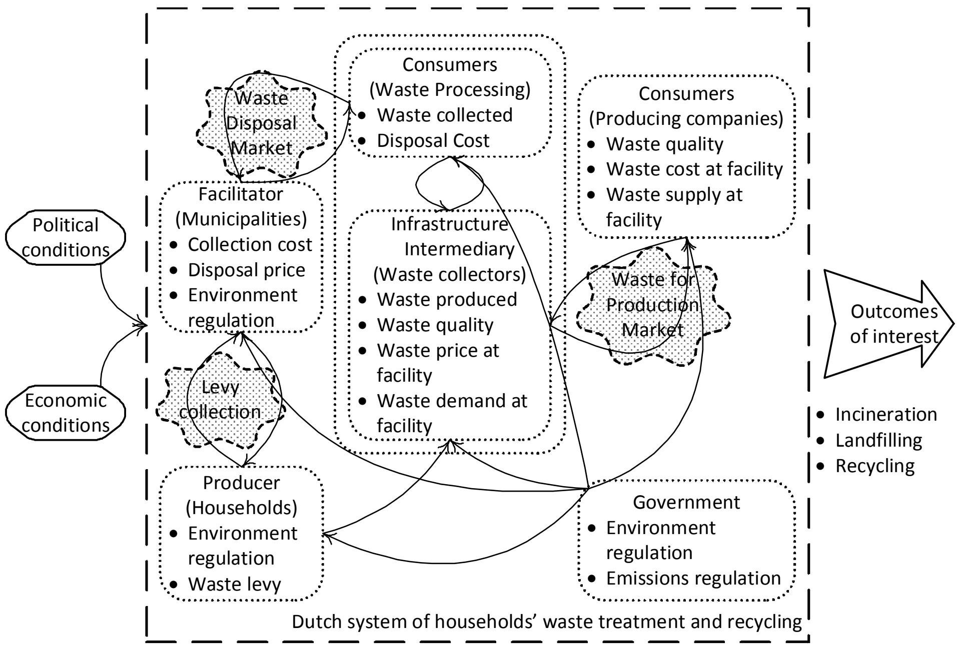

Figure 5.12: System diagram after the transition in the Netherlands

Figure 5.14 portrays the complete but simplified information feedback from the system level towards the agent level and vice versa, with a reference to the time when the events took place. As explained before, there was another wave of "drastic" events affecting the Dutch system, which were necessary to create some intervention in such a way that more emphasis was put on the elaboration of rules to go back to the common routines.

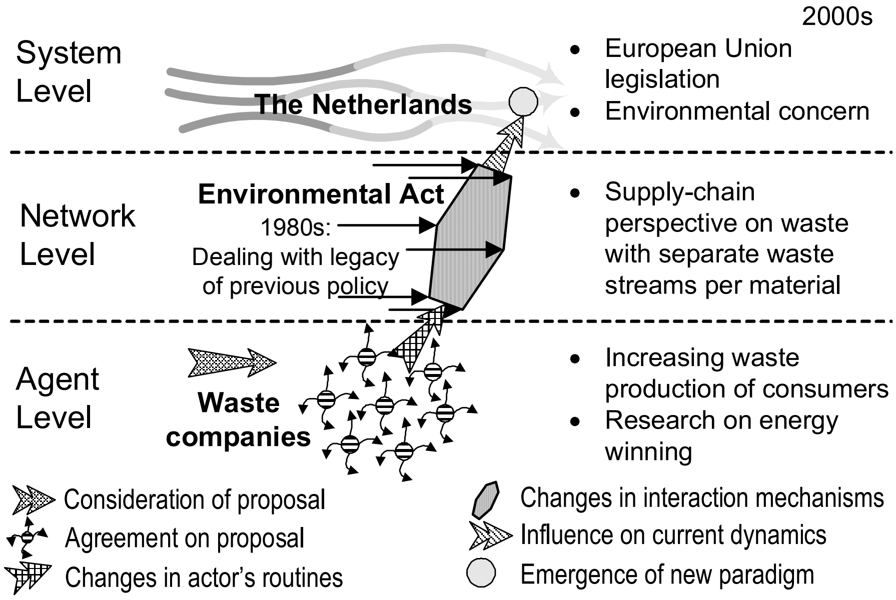

Figure 5.13: Upward impact of drastic events on the Dutch agent, network and system level

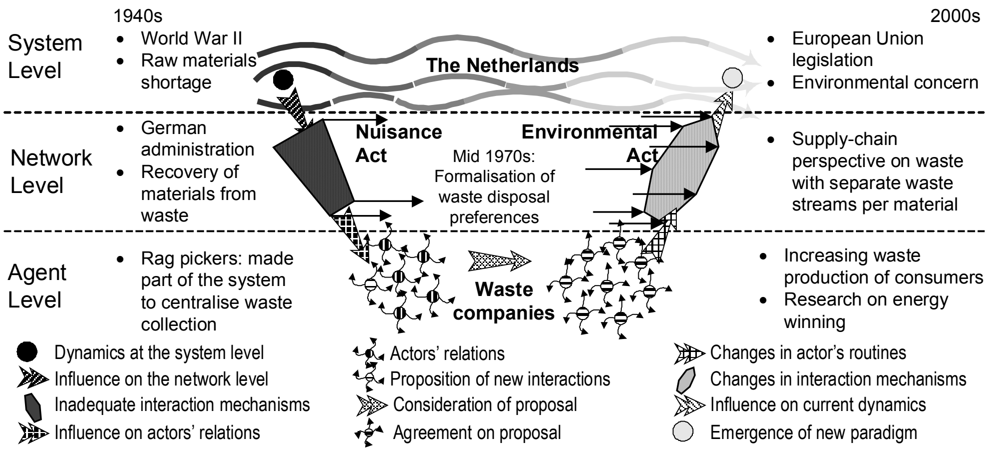

Figure 5.14: The main information feedback of the Dutch case

5.4.2. Evolution to the current dynamic Dutch equilibrium

It has taken the Dutch society more than sixty years to transition from disposal of waste towards a supply-chain approach, in which waste is more as a raw material for other products or as a source for energy production. The three alternatives to process waste have evolved, not only in technological advancement, but also in society's preferences.

With improvement in the process equipment and techniques, these three processes have been subject to changes in preferences of society due to their environmental performance, land occupation and compliance with regulation and public opinion, as it has been modelled by Yücel and Chiong Meza (2008) using the System Dynamics methodology.

Figure 5.15 and 5.16 show the evolution of preferences of four actors, namely Infrastructure Intermediary (municipalities), Producers (households), Government and Consumers (waste processing companies), regarding landfilling, incineration and reuse. As it can be seen, public's preference was the first to shift to reuse, followed by government with a softer shift to reuse targets. The infrastructure intermediary and consumers took more than a decade to realize society's new preferences and act accordingly.

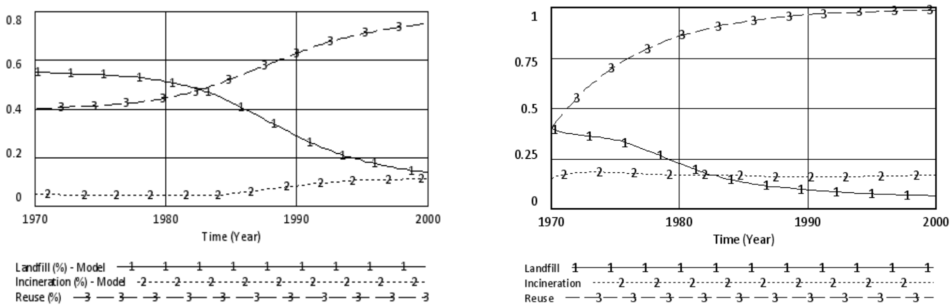

Figure 5.15: Infrastructure Intermediary's allocation and the Public's preference (Yücel & Chiong Meza, 2008)

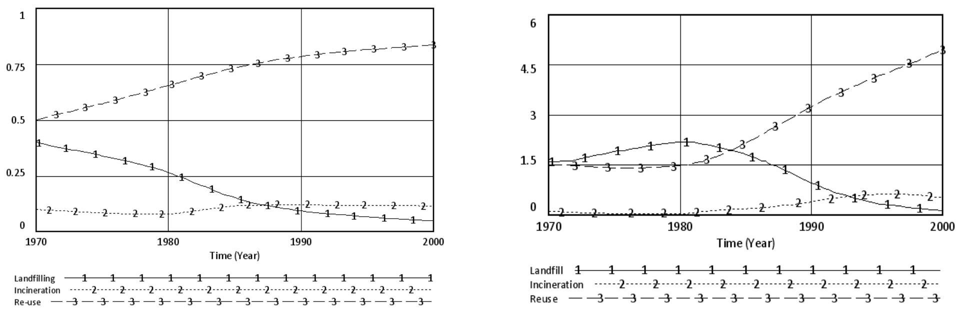

Figure 5.16: Government's percentage targets and Consumers' investment preference (Yücel & Chiong Meza, 2008)

Another side-effect of preferences in relation with public opinion is the appreciation of waste as usable raw material. It can be seen from the shift in process use and increase in installed capacity that reuse, recycling and recovery have taken a better position in the last couple of decades. All of these preferences are reflected on the shifts in number and available capacity of these three alternatives.

In the Netherlands, the number of landfills has reduced dramatically from 90 in 1991 (Compendium voor de Leefomgeving, 2009c) to 22 in operation in 2008, representing almost 53 million m^3 landfilling remaining capacity, more than 105 million kWh electricity delivered to the network and 12 million m^3 natural gas (SenterNovem, 2009), as it can be seen in Figure 5.17.

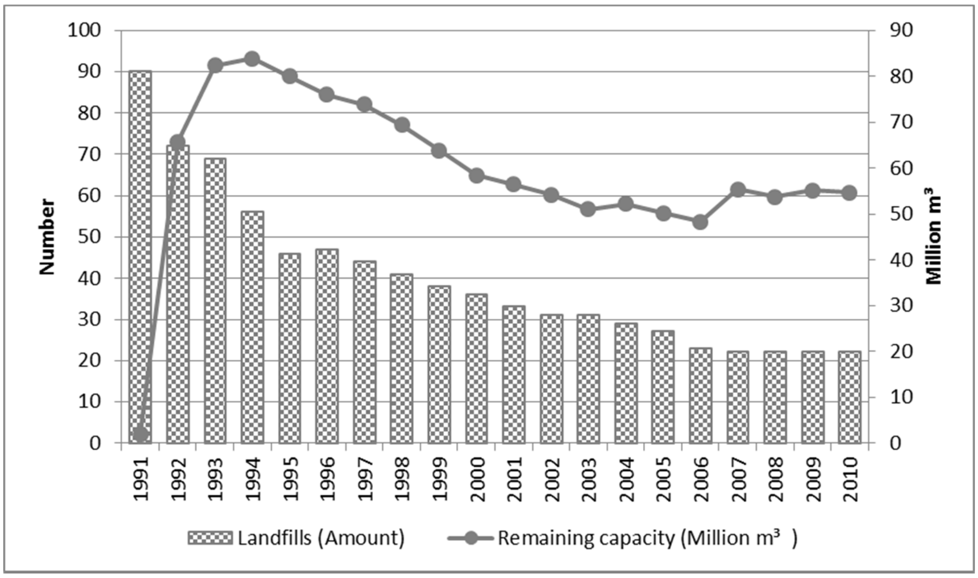

Figure 5.17: Amount of landfills and their capacity in million m^3 (Compendium voor de Leefomgeving, 2009c). The capacity in 1991 is unknown.

The number of incinerators first grew to a peak of 13 in 1990, then dropped to 8 in 1995, but recovered later to remain at 11 for several years. In all those years, the total capacity of the incinerators has been increasing, as it can be seen in Figure 5.18, while also the amount of actually burnt waste has increased (Compendium voor de Leefomgeving, 2009a).

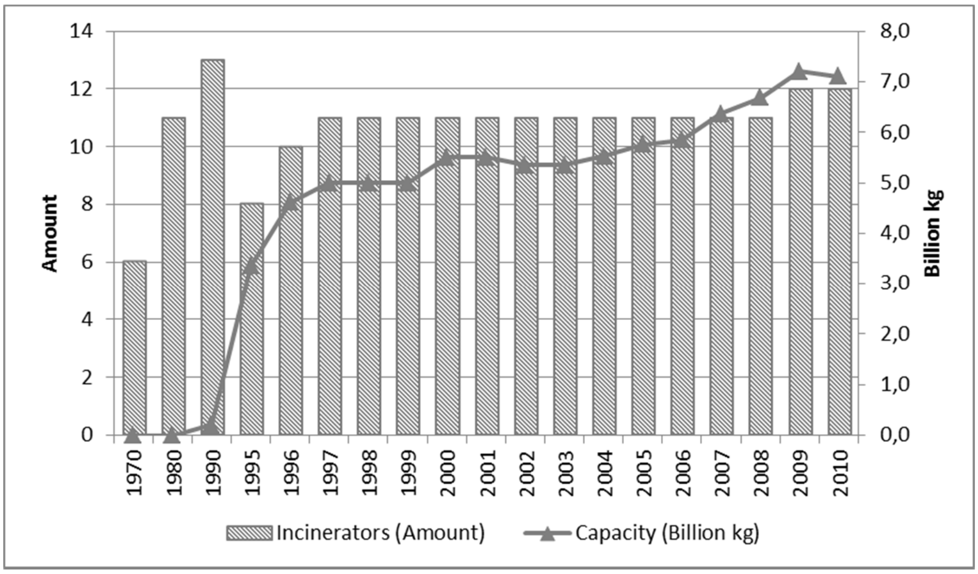

Figure 5.18: Number of incinerators and their capacity in billion kg (Compendium voor de Leefomgeving, 2009a). The capacities in 1970 and 1980 are unknown.

Composting has experienced an increase in the number of facilities since the late 1980s, but this number has become relatively stable after 1994 though the composting capacity has increased year after year, as it can be seen in Figure 5.19, whereas the composted amount has remained almost stable during the last 15 years (Compendium voor de Leefomgeving, 2009b). Additional efforts are being made to produce electricity, which implies a change in the process: fermentation replaces composting to produce biogas (For electricity production) and compost (For agricultural use) (van Ewijk, 2008).

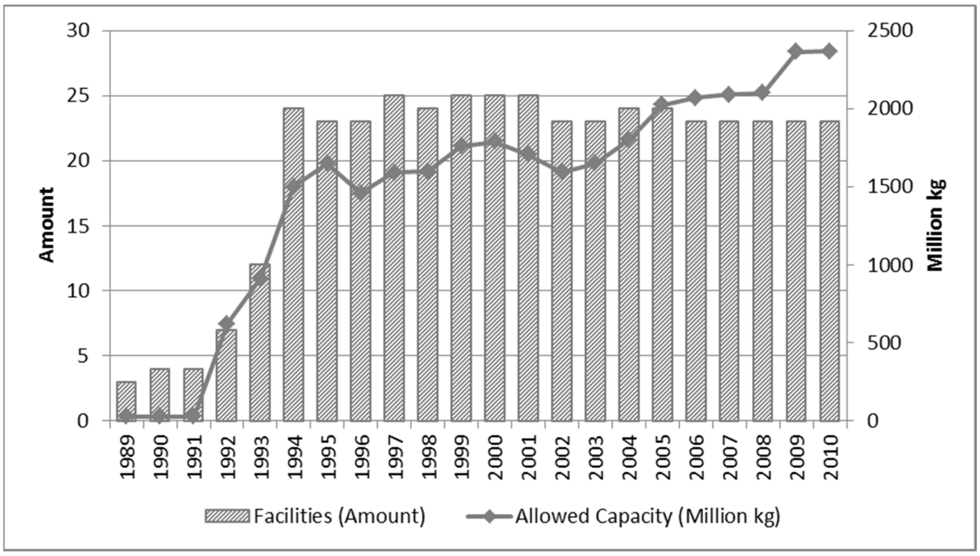

Figure 5.19: Number of composting facilities and their capacities in million kg (Compendium voor de Leefomgeving, 2009b). The capacities in 1989, 1990 and 1991 are unknown.

5.5. Learning opportunities and learning risks of the Dutch case

The study of the Dutch transition towards a supply-chain approach for household waste treatment has brought new insight to the way in which new technologies and procedures could be introduced in the Dutch society. They are grouped in the following topics.

<u>A. The role of "drastic" events to break the current state of affairs</u>
In this case study, it is possible to appreciate the impact of "drastic" events along almost one century recap of the events in the transition of the Netherlands to a supply-chain approach for households' waste treatment.

At an early stage, wars had played a relevant role in the change of the perception of people regarding raw material. With World War I, people became aware of the need of being frugal in the consumption of goods. The combination of World War II – as a special circumstance – and the German administration in the Netherlands – as an intervention – precipitate the formalisation of existing recycling practices at household level, especially in cities due to a higher population density, and diffusion of these practices in society.

At a later stage, waste scandals became "drastic" events that signalled the need of improved rules to prevent, not only serious damage to people's health, but also the occurrence of more waste scandals. New rules were also necessary to improve the management of the existing waste system in order to minimize the environmental impact.

These example of the role of "drastic" events as a way to identify windows of opportunity for speeding up transitions also corresponds with the description of the cultural background, where intervention is necessary to deal special circumstances. Not recognising these windows of opportunity may delay any transition because an inadequate sense of urgency is created in society.

B. The relevance of common social needs and formulation of common social objectives

Common social needs also play a role when concentrating effort of different parties in society. For example, the scarcity of material, especially during World War II, was experienced by the whole population. Additionally, the urge to keep recycling practices even several years after the war is a sign that that the need to keep society away from system collapse was a greater need than the inconveniences of having at home different types of waste. Here, we recognize the relevance of the creation of an adequate sense of urgency in society to facilitate the identification of common social needs and the formulation of common social objectives.

The counterpart of the above-mentioned is the lack of common social needs, or failing to recognize them. In the last decades, the waste production has increased with the years and, even with more recycling, this trend is far to be reduced. Early studies have already indicated that society will increase their waste production until another shock makes its appearance. This could be prevented if there is a re-education of people to create the sense of responsibility on the waste produced. Here, environmental awareness is still too far from most peoples' minds to have a significant impact on their behaviour, and therefore even less to reduce the consumption mentality in society.

C. The value of individual initiatives and the recognition of those

In the case of the Netherlands, individual initiatives have played an important role in society, no matter the reason behind. This is the case of the original recycling system carried out by rag pickers, or the bottle banks introduced by ladies of a community. This is a representative example of emergence in this system, which is possible because, culturally speaking, every individual counts and everyone has the power to create alternatives to deal with social matters.

At this point it is relevant to indicate that the endurance and diffusion of these individual initiatives in society are dependent on the existence of common social needs and the benefits that could be obtained from them. For example, the rag pickers' recycling system could only be embedded in society because of the lack of raw material to produce goods for society. In this way, by handing in useful waste the supply chain of the whole society was guaranteed. Something similar happens with the introduction of bottle banks: glass could be reused to produce more glass with less purchase of new raw material.

D. Revisiting the SyNeA framework for analysis and modelling

The case study of the Netherlands has served to validate the SyNeA framework for analysis and modelling with a different case, namely one at the back-end of a supply chain. From this application to a case, the following lessons have been identified.

Concerning the typology of actors, the case study of the Netherlands has yielded some insight into the role of actors in a transition. From the seven actors of the original SyNeA framework, five have retained a direct role during the transition in Brazil, namely Government, Producers of bio-ethanol, Infrastructure Intermediaries, Facilitator of light vehicles, and Consumers. The other two roles, namely the Interest Groups and the Research Organisations, attain different performance during the transition.

Contrary to what happened in the case study of Brazil, the presence of Research Organisations has not been officially acknowledged in the most part of the transition. Technological innovation has happened as a way to deal with higher environmental standards while improving the existing ways to deal with waste. Only direct actors like Infrastructure Intermediaries are the ones able to introduce the technological change in the system.

Also, the role of Interest Groups differs from the performance in the case study of Brazil. Interest groups have been present in the transition but with different interests. One group is the rag pickers with economic interest. Another group is the different associations that collected paper for charity or to cover a special need within the association. A different group is the one concerned about the environmental impact of waste. In all cases, Interest Groups have been present to support recycling in the system following different interests. As their initiatives were absorbed by the system, it is considered that they have a supporting role in a transition, and therefore an indirect impact.

Regarding the modelling of agents, the case study of the Netherlands has confirmed the use of the distinction of the socio-technical edge when modelling agents. It facilitates the identification of this kind of relations and makes explicit the different nature of this kind of relation.

Conclusion

The need to better understand the dynamics of transitions of large socio-technical systems has been the driving force of this research project. Embedded in the study of the evolution of socio-technical systems, this research project was established to contribute to the improvement of the current understanding of transitions in three aspects: (1) the design of a framework and a method for the analysis of socio-technical transitions that cover the social, technical, economic and political dimensions in a systematic way, (2) the exploration of ways to translate qualitative knowledge into models suitable for simulation, and (3) gaining more insight in the dynamics of (actual) transitions (in systems with different cultural backgrounds), which may help in the identification of possible leverage points suitable for intervention strategies for transitions.

For this purpose, several perspectives dealing with (processes of) change in different kinds of systems were reviewed and a framework for the analysis and modelling of transitions was constructed. Parallel to this, a strategy for the execution of case studies was designed to test the method and the framework with a reference case and then apply it to another transition.

Several lessons have been obtained from the framework construction, the case study design and the modelling process, and each of the executed case studies. These lessons will be used to answer the research sub-questions (See Section 4 of the Introduction chapter) and finally provide an answer to the main research question:

> *Is it possible to design a method and a conceptual framework which are suitable for the systematic analysis of socio-technical transitions (covering the relevant social, technical, economic and policy dimensions) and which could help explain the dynamics of such transitions?*

In this chapter, we will provide answers to the sub-questions related to the construction of the framework and the method (sub-questions 1 and 2) in Section 1. In Section 2, the implications of this framework for quantitative modelling are considered (which relates to sub-question 3). Subsequently, the insights obtained from the case studies are discussed in Section 3. This concerns the sub-questions 4 and 5. An answer to the main research question is presented in Section 4.

6.1. Consolidation of different perspectives on transitions

Concerning the sub-question:

> 1. *Which levels of aggregation should be taken into account in a conceptual framework to describe large-scale socio-technical systems in transition, and what are the relevant elements at each level?*

The literature review already portrays four perspectives to describe transitions: the perspectives of

(a) *technological transition* in socio-technical regimes
(b) *individual relations* in social systems
(c) *governance mechanisms* in institutional economics, and
(d) *interactions* in actor-network analysis

From our literature review we had to conclude that any single of the reviewed perspectives comes short when trying to explain the (broad) complexity of (socio-technical) transitions and its multiple facets. For a thorough understanding of the dynamics of such transitions, which involve the interplay of the technical sub-system and the actors' decision-making, these multiple facets must be taken into account. As the reviewed perspectives address transitions following the conventions of their own discipline, they have blind spots. In the technological perspective, technology is considered the answer to problems concerning environmental sustainability; however, sustainable schemes can also be achieved by changes in belief systems or regulations. In the social perspective, the interaction of actors in networks is hidden in the description of society. In the perspective of institutional economics, (information) feedback is mostly disregarded (but such feedback does play an important role in actual transitions). In the actor-network perspective, the impact of networks is mostly evaluated against the realisation of agreed objectives, disregarding the effect of networks at society (or: system) level.

Nevertheless, these perspectives present some similarities in their structure (they distinguish different levels within their unit of analysis), but each perspective uses different terminology to refer to (parts of) the phenomenon of transition itself and to the elements that are part of a system in transition. By focusing on a particular aspect, each of the presented perspectives can be understood as not being derived from the other perspectives. This allowed us to use the principle of multiple formalisms (Mikulecky, 2001) of the field of Complex Adaptive Systems, which provides the theoretical basis for incorporating the significant features of the four perspectives in (the development of) a *new* conceptualisation of socio-technical systems in transition, for which we define and describe the relevant aggregation levels, their elements and the relevant interactions of a system in transition.

The first issue we had to tackle in the framework design was finding an adequate definition for 'transitions' of socio-technical systems (we refer to these transitions as 'socio-technical transitions'). It turned out to be necessary to design a stipulative definition (Verschuren & Doorewaard, 1999) of transitions because each of the reviewed perspectives has its own way of describing processes of change: there is no common definition. We stipulated the following definition:

> Socio-technical transitions are long-term processes of social and technological transformation from one dynamic equilibrium state to another.

Here, we have strived to reach a balanced definition of transitions from a systemic point of view. A balance between breadth and depth has been sought, with a preference for breadth, under the assumption that systems in transition can be considered as complex adaptive systems, with multiple interconnected agents (Waldrop, 1992). The result is an interdisciplinary academic work, where different disciplines receive a particular place in the framework in order to explain a specific dimension of desired transitions.

We have sought as neutral a definition for transitions as possible. One issue that was thought to give a bias is the concept of sustainability, which is included as the direction of a transition in several definitions of transitions, e.g. within the field of 'transition management'. If the concept of sustainability is interpreted in a broad sense, meaning the 'survival' of the system, it is an obvious but meaningless characteristic of a transition as a process in which a system adapts to changing circumstances. However, in practice, the interpretation of the concept of sustainability is much more specific and differs significantly between, for example, industrialised and non-industrialised countries. In industrialised countries, sustainability is generally looked at from an abstract level, mostly aiming at environmental objectives (which is also the main interpretation used in the field of 'transition management'). On the contrary, in non-industrialised countries people are occupied with survival at a tangible level and would therefore sooner relate sustainability to securing the provision of basic needs for the society than to (only) environmental issues. To avoid this discrepancy, we decided to exclude the concept of sustainability from the definition of (socio-technical) transitions, as we also did not find any other reasons as to why this element would be necessary to describe transitions. In this respect, our definition of socio-technical transitions is 'neutral'; several cases around the world could be potential subjects of study, preventing researchers' prejudice against using those cases.

An additional issue to consider in a definition for transitions is related to time. It can be said that transitions are processes of change that span several years. However, this does not necessarily imply fixed periods of years, because it is difficult to define the beginning and end points of transition processes, when considering historical cases. Such processes can also not be 'run as a project' with a clear start and finish in the case of on-going transitions. We find that the restriction to a particular (pre-defined) time frame may hinder the search of relevant drivers of transitions, especially in the past. As an example of this, we want to make a contrast between the Brazilian case presented in this thesis and the introduction of cell phones. While in the former one may speak of a transition of almost half a century, the latter is a particular example of transitions that required less than a couple of decades to pervade society in its entirety. In this sense, we consider that just the realisation of transitions as long-term processes of change without a specific time frame, especially in the case of large-scale socio-technical systems, will be sufficient to start the search in the past or in the present and to project efforts to the future.

Although the above-mentioned definition of socio-technical transitions is generic, covering for instance both transitions that occur spontaneously and ones that society consciously strives for, we will put, in this research, emphasis on what we call 'desired transitions'. These are transition processes for which the direction has officially been established by government and where one could expect that the government(s) involved would try to influence the transition process. This type of transitions forms a distinct category due to the special position of government (such as its authority to enact laws and its financial resources) and a relevant object of study for this research in the field of technology and *policy.*

After establishing a definition for socio-technical transitions, we have identified the levels of aggregation that in our view should be taken into account in the conceptualisation of socio-technical systems in transition. This was based on the reviewed perspectives on transitions. We distinguish three different levels of aggregation that are needed to describe (the dynamics of) socio-technical transitions:

* System level: this concerns the (socio-technical) system as a whole, which is formed by the aggregation of several networks. At this 'system level' one can observe the behaviour of the (socio-technical) system in transition within its environment.
* Network level: this level concerns the 'networks' of relations, interactions and connections that exist among the individual elements at the lowest aggregation level (we call these 'agents'). At the 'network level', one can, for example, observe the existing arrangements available to actors for their interaction with each other and for resources exchange.
* Agent level: this is the lowest level of aggregation and concerns the individual 'elements' within the socio-technical system, such as the actors in the social subsystem and the components in the technical subsystem. At this level one can observe, for example, how the different actors are active in a transition (whose decisions cause changes at higher levels of aggregation).

These levels are needed, as (a) the transition takes place at the system level, (b) the 'behaviour' of the individual actors and components (or technologies) needs to be represented (the 'agent level') as they impact the transition process, while (c) the patterns of interaction and interrelations play a significant role as well, because a transition manifests itself in changes in these patterns (and therefore the framework needs a 'network level'). Figure 6.1 shows an abstract representation of the levels.

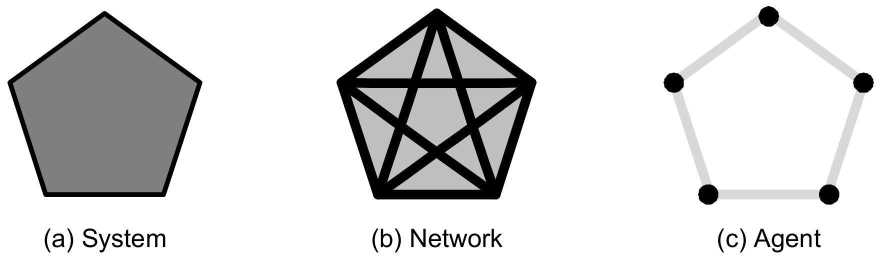

Figure 6.1: Abstract representation of (a) system, (b) network and (c) agent

Subsequently, we considered the three levels of aggregation in more detail in order to determine the relevant 'elements' at each level, which led to the following result.

At the system level we identified the relevant elements to be:

- Drastic event(s), as a force affecting the current state-of-affairs of the system, which could either work in favour of or against a transition; under certain circumstances, a drastic event could be considered as a signal of a window of opportunity to develop sense-of-urgency in society.
- Cultural background, as an inherent characteristic of a society, working in favour of or against new arrangements at the network and agent levels.

As the network level deals with the (patterns of) interaction among the 'agents' (actors and components), the relevant elements are such patterns. We have identified at least the following (types of) networks that are most relevant:

- Polity: this refers to the institutional organisation of government and gives an indication of what the institutional capability is to introduce country reforms.
- Policy: this refers to the policy arrangements in the system; for transitions, policy change is important, and relates to the process of the introduction of a new set of rules for actors in society and the dynamic equilibrium to which this introduction leads.
- Technology: this refers to the technological paradigm(s) in the system; for transitions, a technology change is important, which relates to the process of the introduction of a new technological development for actors in society and the dynamic equilibrium this introduction leads to.

The agent level deals with the individual elements of the social and technical subsystems, which are actors and (technical) components, respectively. The actors have an impact on the transition process through their behaviour and are therefore relevant for understanding the dynamics of a transition. The technical components are mostly of interest in the context of modelling (and simulation) of socio-technical systems (See Section 3 of this chapter). We have classified the actors by their role and, based upon our research, we have identified the most relevant actors to be:

- Government, as a possible catalyst of the transition process with the capability of making policy, specifically by conveying urge, attaining authority, expending treasure or providing organisation (Hood, 1986).

- Producers, as actors with the capability of transformation of raw materials into products.
- Consumers, as actors with the capability of using products or services as end-users.
- Facilitators, as actors with the capability of the provision of supplementary products or services to facilitate the consumption of end-users.
- Infrastructure intermediaries, as actors with the capability of transportation, distribution and commercialisation of products or services.

In addition to the above-mentioned actors, two other types of actors play a role in transitions. However, from our research we concluded that these two types of actors have a secondary role in transitions because they affect the social and technical sub-system indirectly, causing a softer impact at higher levels of aggregation. These actors are:

- Interest groups: these are actors with the capability of influencing opinions and they have an active role by delivering opinions or instigating protest actions to affect society's preferences.
- Research organisations: these are actors with the capability to innovate, and they play their role in transitions by delivering product or process innovation.

The compound behaviour of the above-mentioned actors around a particular transition can be compared to the model and mechanism of a series of cog-wheels, which represent a system of systems, as described by Shove (Shove, 2004). If each actor performs as a system within a system and each of them is dependent on each other to get through a transition, the final direction of the transition is uncertain. This means that the potential of policy intervention remains unclear, as its effect depends on how the different actors are connected with each other. If one wants to steer the process, the difficulty lies on how to identify the 'right' actor so that the system can be transformed (Shove, 2004). In this research the first five actors of the proposed typology proved to be the necessary 'cog-wheels' to put forward a transition, or at least the capabilities they possess are required to introduce changes in a system.

Figure 6.2 summarises the elements of the framework for the analysis of transitions.

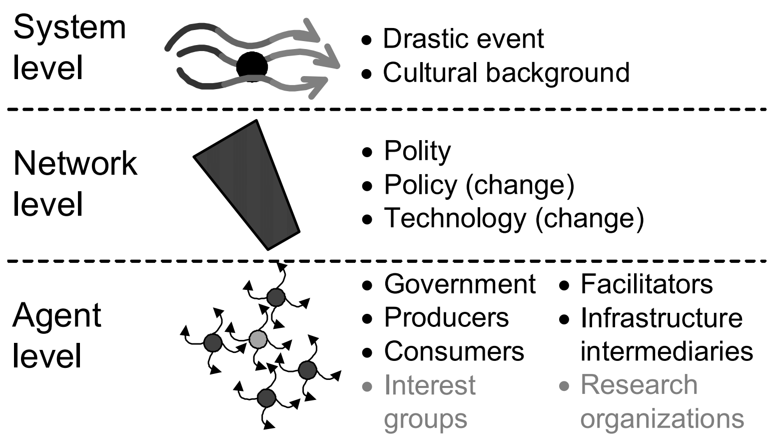

Figure 6.2: The **Sy**stem-**Ne**twork-**A**gent (SyNeA) framework for the analysis of transitions

Regarding the sub-question:

2. Can we find (and if not, propose) a method that can be used to systematically analyse transitions?

Our literature review showed that several types of socio-technical analyses about transitions have been performed in the past with different tools and purposes. One of those analyses focuses on the emergence of technological novelties and the diffusion of those by analysing transitions at three parallel levels: system, regime and niche (Geels, 2002). Another approach focuses on the solution to sustainability issues, by analysing the transitions of so-called constellations (as sub-systems of a societal system) with regard to the conditions for the occurrence, patterns of evolution and paths the transition has followed (de Haan, 2010). Other analyses focus on the *ad hoc* simulation of actors in a particular case, either by means of causal relations (Yücel, 2010) or agents (Chappin, 2011), while reducing the choices of actors to a ranking of preferences of existing alternatives and the observation of the evolution of those choices in time. However, based on our literature review we had to conclude that a method for studying transitions in a systematic way which can cover the relevant social, technical, economic and policy dimensions in a balanced manner and which is capable of transforming the richness of any transition into cases for comparison or even more for modelling, is still lacking.

In this research we have tried to fill this gap, by proposing both a conceptual framework for describing socio-technical systems in transition and a method for the study of actual transition processes (including the possibility to model them). We have proposed a generic framework that captures the nature of transitions by analysing relevant features at three aggregation levels: system, network, and agent (see above). By considering the development at these three levels as well as the interactions between the levels, we think that an analyst may be able to provide an explanation for the occurrence of transitions, while that framework also offers a basis for comparison among studied cases.

Furthermore, a method is presented for the systematic approach to the study of socio-technical transitions. This method helps transition researchers deal with the information about transitions and capture them in a modular way: the first step is to go from reality to case studies, the next step concerns qualitative modelling of causal relations, while the last step relates to the qualitative modelling of agents with nodes and edges (these last steps are discussed below). This method presents:

* The criteria for the selection of cases that reflect a transition,
* The basic topical issues that guide the collection of information to describe the case (Stake, 1995),
* The way to apply the designed framework to study the system in transition and its elements, and
* A way to model the selected cases to make them suitable for computer simulation.

The framework and the method were first verified by applying them to the transition to the sugarcane ethanol as fuel for light vehicles in Brazil. Based on the experience with the application of the method in that Brazilian case study, we made some small adaptations to the framework and method. The improved framework and method were then validated by applying them to the transition to a supply-chain approach for household waste treatment in the Netherlands. A discussion about the validation of the framework and method can be found in Section 3 of this chapter.

As this generic framework and method combine the significant features of four mono-disciplinary perspectives that deal with change plus two modelling paradigms, it allows cross-discipline learning because each discipline can be related to the framework and back to its own discipline. Due to the modularity of the proposed methodology, it can integrate some of the above-mentioned socio-technical analyses, such as that of De Haan (de Haan, 2010) for the patterns of evolution, Yücel (Yücel, 2010) for the simulation modelling of causal relations by actor, or Chappin (Chappin, 2011) for the simulation modelling of actors and technologies as agents. In this way, this generic framework also fosters cross-discipline learning.

6.2. Implications for quantitative modelling

In relation to the sub-question:

> 3. *To what extent can the selected conceptual framework and method for studying transitions support modelling with a view to simulation?*

The study of socio-technical systems in transition required different perspectives and aggregation levels. The difficulty with modelling lies in the fact that any modelling attempt requires a balanced choice of aggregation levels and elements representing the real system in such a way that even with this reduction the model still reflects the behaviour of the real system.

To make possible the modelling of systems in transitions, we have applied the knowledge application cycle of the Action-Oriented Industrial Ecology (AOIE) modelling approach of Nikolić, Dijkema and van Dam (2009) to transform information from a case study to models suitable for simulation. However, since the purpose of this AOIE modelling approach is to model industrial clusters, we propose an extension to the AOIE modelling approach specifically designed for decomposing socio-technical systems in transition, without including the simulation cycle, as carrying out the simulation itself has not been the purpose of this study.

As it can be understood from Section 1 of this chapter, the use of multiple formalisms to describe parts of a socio-technical system in transition (as considered in complex adaptive systems) reduced the possibilities of applying any particular modelling approach in an exclusive way. Considering the numerous elements in large-scale socio-technical systems (and the corresponding amount of variables) and the different levels of aggregation (system, network, and agent), it was established that one modelling approach was not enough to provide sufficient insight at different aggregation levels.

Instead of perceiving top-down and bottom-up approaches as rivals (Yücel & Chiong Meza, 2007), it was recognised that there is a need to combine both approaches to cope with the challenge of transforming qualitative analysis into information suitable for quantitative modelling and computer simulation. Top-down approaches are good at dealing with changes at the system level and the link(s) with the network level. Bottom-up approaches can take into account the behaviour of individual actors and their effects on the network level (and, possibly, the system level).

The visualisation of the dynamics of a transition process is only possible with a hybrid modelling approach. In our method, synergy was created between, on the one hand, causal loop diagrams, as a top-down approach that maps causality of variables at system level, and, on the other hand, the socio-technical ontology for the definition of agents, as introduced by Van Dam (2009), as a bottom-up approach that identifies properties and decision rules of agents.

We proposed a strategy to combine these approaches in a step-by-step fashion: first, the case study is expressed in the form of causal loops (which relates to 'continuous systems'), arranged by actor; in the next step, this is used as a basis for an agent-based model of the socio-technical system concerned. We found that this approach facilitated (1) the simplification of information from the richness of the case studies to the specificity of qualitative modelling, and (2) the integration of information flows (as continuous processes) on the one hand, with discrete decisions per actor involved on the other hand, as well as the quantification of these. Moreover, our approach allows for modularity, which is relevant when one wishes to model one actor at a time and then integrate them in an existing simulation engine as introduced by Nikolić (2009). The step-by-step modelling approach proposed here also allows the simulation of actors with a particular modelling approach (see (Chappin, 2011) for an example of simulation of energy infrastructures with agent-based models and (Yücel, 2010) for an example of simulation of actors with causal relations).

All this is carried out using a representation of the socio-technical system concerned that builds upon the SyNeA framework. The large-scale socio-technical system is considered to consist of a social sub-system and a technical sub-system. The relevant elements in the social sub-system are the actors that we identified at the agent level in the SyNeA framework. In the technical sub-system artefacts are connected (production facilities, infrastructure, consumption devices) and 'materials' (or energy) flow. Raw materials are assumed to come from the environment or from the recovery of materials from the end-users. Consumption produces emissions and/or residues, which in turn affect the social sub-system hindering it through pollution, as well as the environment, affecting the availability of raw materials. This representation is illustrated in Figure 6.3.

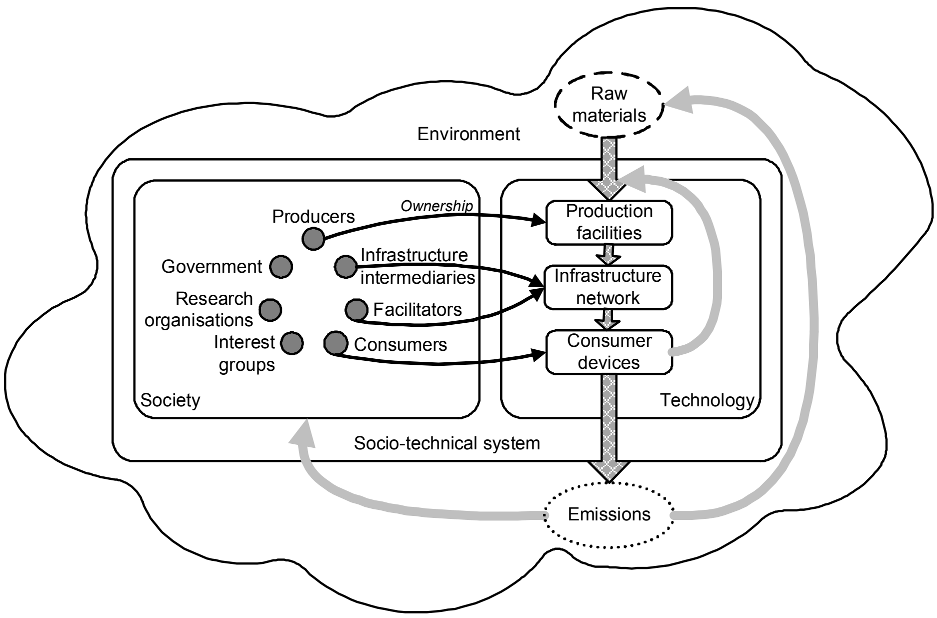

Figure 6.3: Socio-technical system, conceptualised with the SyNeA framework

Relations exist between the elements of the socio-technical system. Based on the definition of actors at the lowest aggregation level of the conceptual framework, we have used the classification of relations of Van Dam (2009) to categorise the relations of actors in a functional way for simulation purposes. The typology of actors of the framework and the results of the case studies gave as a result the following typology of relations , also called 'edges' by Van Dam (2009), which were re-arranged in three categories, as follows:

* Social relations: regulation, contract, agreement
* Technical relations: connection, flow
* Socio-technical relations: ownership

Social relations (or 'social *edges*') involve relations between actors in the social sub-system. We identified three relevant types: 'regulation' refers to a unilateral possibility of one actor to influence the behaviour of another actor; a 'contract' concerns a bilateral (or multilateral) economic agreement affecting both (or all) actors involved; 'agreement' is used for a bilateral (or multilateral) agreement that is *not* economic. From all theoretical possibilities we selected the most prevalent relations, based upon our case studies. These are listed in Table 6.1 below, which shows the details of the type of relation each actor has within the social sub-system. By the way, in Figure 6.3 we have left out the lines representing these social relations to avoid an unintelligible mesh of interactions, although these (networks of) interactions do exist.

Table 6.1: Relations between agents in the social sub-system

Agent	Social Edge	To	Social Edge	From
Government	Regulation	Producer	-o-o-o-	-o-o-o-
		Consumer		
		Facilitator		
		Infrastructure Intermediary		
		Interest group		
		Research organisation		
Producer	(Mostly) Contract	Infrastructure Intermediary	Regulation	Government
		Research Organisation	Contract	Infrastructure Intermediary
				Research organisation
Consumer	Contract	Facilitator	Regulation	Government
	Contract	Infrastructure Intermediary	Contract	Facilitator
	Agreement	Interest group	Contract	Infrastructure Intermediary
			Agreement	Interest group
Facilitator	Contract	Consumer	Regulation	Government
	Contract	Infrastructure Intermediary	Contract	Consumer
			Contract	Infrastructure Intermediary
Infrastructure Intermediary	Contract	Consumer	Regulation	Government
		Facilitator	Contract	Consumer
			Contract	Facilitator
Interest group	Agreement	Consumer	Regulation	Government
			Agreement	Consumer
Research organisation	Contract	Producer	Regulation	Government
			Contract	Producer

Within the technical subsystem two types of relations (or 'edges') are distinguished. A 'connection' refers to the link between two artefacts, for example a production facility (such as a power plant) and the infrastructure it is linked to (such as a power network). A 'flow' involves the flow of materials or energy within the technical sub-system (such as a power flow from the production facility through the network towards the devices of the consumer that finally use the electricity). Based upon our case studies we list the relevant technical relations in Table 6.2 They are also depicted in Figure 6.3.

Table 6.2: Relations between elements in the technical sub-system

Element	Physical Edge	To	Physical Edge	From
Production Facility	Connection	Transportation network	Connection	World
	Flow	Product	Flow	Raw material
			Connection	Consumption device*
			Flow	Raw material
Transportation Network	Connection	Consumption device	Connection	Production facility
	Flow	Product	Flow	Product
Consumption Device	Connection	World	Connection	Transportation network
	Flow	Emissions/Rests	Flow	Product
	Connection	Production facility*		
	Flow	Raw material		

Finally, there is an important link ('edge') between the social and technical sub-system: ownership. This relates the actors in the social sub-system to the artefacts in the technical sub-system. Based upon our case studies we identified ownership relations listed in Table 6.3 as relevant.

Table 6.3: Relations between the social and technical sub-systems

Agent	S-T Edge	To
Producer	Ownership	Production facility
Consumer	Ownership	Consumption device
Facilitator	Ownership	Transportation network
Infrastructure Intermediary	Ownership	Transportation network

6.3. Lessons from the case studies

Regarding the sub-question:

4. *What lessons can be learned from the studied transition cases*
   a) *with regard to the utility of the conceptual framework and method, and*
   b) *regarding the dynamics of (desired) transitions of socio-technical systems?*

The first half of this secondary research question (4a) relates to the validation of the method and framework: are they practicable in actual research and are they useful for their purpose? Concerning the latter it is important to note that the purpose has been two-fold in this research: first, can the method and framework help researchers gain a better understanding of the dynamics of a transition process and, second, could the method and framework provide a suitable basis for the modelling (and, possibly, simulation) of socio-technical systems in transition?

In this research, the proposed method and framework have been applied to two case studies. From this experience we conclude that the method and framework are workable in practice. Moreover, after having learned how to apply the method and framework in the first (Brazilian) case study, we found it relatively easy to use the method in the second (Dutch) case study. This suggests that the method and framework are practicable for a wide range of transitions (as our case studies were quite different). However, it should be noted that in these case studies the method and framework were applied by the same researcher that has developed them. Thorough validation of the method and framework would require that others also apply the method and framework. This would be a topic for further research.

With respect to the issue whether the method and framework are useful for their purpose we already presented three relevant (validation) questions at the end of Chapter three: could the elements of the SyNeA framework (a) be identified in the case study, (b) be connected with causal relations, and (c) are the conceptualised relations of the 'agents' sufficient to describe the connections of the different roles of actors, their technologies, and between both sub-systems. These questions were considered in the case studies.

First, we were able to identify the levels of the SyNeA framework and their elements in the case studies. However, in the first (Brazilian) case we concluded that the impact of the actors 'interest groups' and 'research organisations' upon the course of the transition had only been indirect. This finding was confirmed in the second (Dutch) case study. As we found that these two (types of) actors do add some value to a transition with their particular resources (i.e. interest groups with promotion resources and research organisations with innovation resources), they have kept their place in the SyNeA framework, but as actors with *indirect* influence. Moreover, the case studies showed that a researcher must bear in mind that the SyNeA framework classifies the actors for the *roles* they perform in a particular context. This could mean that a single organisation has multiple roles. But it can also occur that an organisation that we usually refer to as (part of) 'government' (e.g. a municipality) plays a role as an infrastructure intermediary (e.g. when the municipality itself collects household waste) or as a facilitator (e.g. when a municipality provides collection facilities for waste collection by other parties). When applying the SyNeA framework, a researcher should be attentive to this issue.

Furthermore, it was possible to determine causal relations for the system and here we found that it was quite helpful to start with identifying the physical flows in the system. Building upon that analysis it turned out to be not very difficult to describe all the relevant causal relations.

With respect to the utility of the conceptualisation of agents, technologies and their interplay in our framework (and method) the case studies did yield important insights, which led us to alter the initially proposed framework (see Chapter three) a little bit. First, we found that it would be more adequate to consider the relation 'ownership' as a link between the social sub-system (i.e. the owner) and the technical sub-system (i.e. the owned object) rather than as a relation *within* the social sub-system ('social edge'), which was done by Van Dam (2009), whose work we have used as our starting-point. Second, for the type of cases we looked at, we needed to define two additional types of relations within the social sub-system (in addition to the 'social edges' identified by Van Dam (2009)), namely 'regulation' and 'agreement' (the latter being a *non-economic* agreement as opposed to the 'economic' relation of contract).

Did the method and framework help us gain a better understanding of the dynamics of a transition, in particular with a view to the interplay of the different dimensions (social, technical, economic, and policy) and the interaction between the different levels (of the system, the actors and the intermediate level)? Below we shall discuss the main findings as to the dynamics of the studied transitions, but here we can say that the method and (SyNeA) framework present a structure to portray the interaction between the different levels that are relevant in a transition including the feedback loops, which play an important role. The method and framework helped us systematically unravel the (complex) transitions in the case studies.

Another point is the question of to what extent the proposed method and framework do support *simulation* based on the modelling in accordance with our framework. Although carrying out (quantitative) simulations was not part of this research project, the model of the Dutch case study has been used as the basis for a quantitative simulation of certain aspects of that case, using a system dynamics approach (See Yücel & Chiong Meza (2008)). We suggest that more of such simulations are done as part of a thorough validation of the method and framework in this respect.

A last validation issue is the scope of applicability of the proposed method and framework. In this research, the method and framework have been applied to two cases of a socio-technical transition. These cases differ in many respects: one concerns the front-end of a supply chain, the other the back-end, the cultural backgrounds of Brazil and the Netherlands are quite different as is the 'polity', but also the technical systems concerned have different characteristics ('waste' is a peculiar case since both the material flows and the money flows go in the same direction). The fact that our method and framework could be employed in both cases without problems, suggests that the method and framework are applicable in a wide range of socio-technical transitions in different systems (countries).

Our two case studies concerned 'desired transitions', which means that we did not directly validate the method and framework for other types of transitions. However, considering the generic structure of our method and framework, we do not see any reason why they could *not* be applied to other types of socio-technical transitions. Actually, we think that such a study would be very interesting. Probably, one would find that in transitions of the other types the importance of the actors must be valued differently. For example, in a transition where the desired direction is advocated by non-governmental organisations (but not an officially established government goal) we would expect to find that in those cases interest groups do play a *direct* role in the transition. And it may turn out that in spontaneous (socio-technical) transitions research organisations can play a direct role, since they may be the source of a technological novelty that eventually leads to the transition.

The second half of the secondary research question (4b) concerns the issue of what lessons could be learned from the case studies about the dynamics of (desired) transitions of socio-technical systems. In other words: did we learn anything about how transitions develop? In the case study chapters we already gave an elaborate assessment of each case separately. Here, we want to focus on the lessons that follow from a comparison of the cases. Before we arrive at these lessons, the dynamics of both cases is briefly described in the terms of the SyNeA framework.

The first case study concerned the (partial) substitution of gasoline as fuel for light vehicles by ethanol made from sugarcane in Brazil. This transition process started in the early 20th century with the policy requiring the addition of 5% bio-ethanol to the gasoline (which gives bio-ethanol its place at the 'network level'). When in the 1970s Brazil is confronted with high oil prices and the overproduction of sugarcane (two 'drastic events'), the government set up programmes to support alternative fuels based on ethanol, diesel or coal. Soon, the support was concentrated on bio-ethanol from sugarcane because of the overproduction of sugarcane and the availability of cars that can be driven by bio-ethanol. These support programmes are changes at the network level, influenced by 'drastic events' and the availability of technology. However, after more than a decade these support schemes were cancelled (change at network level) due to lack of (government) funds, lower oil prices and a drop in sugarcane production due to climatic circumstances (events at system level). As a result, the number of bio-ethanol cars declined, but bio-ethanol continued to have a role as a substitute for lead in the gasoline. At the start of the 21st century the advent of the flex fuel vehicle, a car that can use both gasoline and ethanol, (a technological innovation) caused a revival of bio-ethanol as fuel for light vehicles in Brazil. Consumers started to buy these flex fuel vehicles, which provide them with the flexibility to decide whether they use gasoline or ethanol at the moment they fill their tank, for instance depending on the actual prices. Here, it is the 'collective' behaviour of actors ('agents' in the SyNeA framework) that leads to the change at network and system level, but the development is path dependent because the success of flex fuel vehicles is specific to Brazil. The SyNeA framework helped to portray the evolution of this transition, which is shown in Figure 6.4.

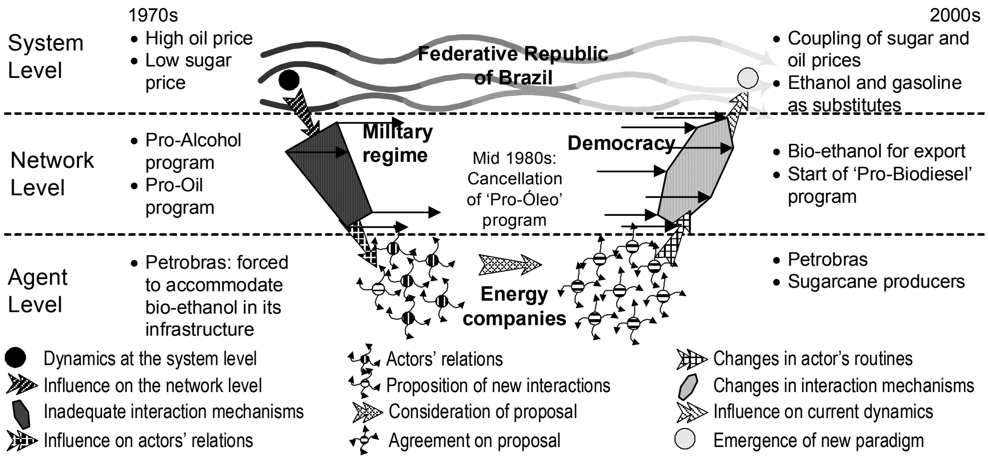

Figure 6.4: The main information feedback of the Brazilian case (Adapted from (Chiong Meza & Dijkema, 2009))

The second case study is about the transition in the Netherlands to a supply-chain approach for household waste treatment. It concerns a long term development that combines two 'traditions' (that existed at the 'network level'). First, the tradition of rag pickers that collected specific types of material (such as rags or organic waste) in order to reuse it. Second, the tradition of municipalities (especially cities) collecting general household waste for hygienic reasons, which they initially disposed of by dumping. During the German occupation of the Netherlands (1940-1945) in World War II the German administration introduced a landmark change: government became involved with the reuse of materials and a central body was established to take care of the recovery of certain materials, such as rags, paper or metals, while the system of rag pickers became publicly formalised. This change at the 'network level' was triggered by a change of polity (the German occupation) and the scarcity of raw materials during World War II (a 'drastic event'). As this scarcity remained after World War II, the 'German' system of recovery was kept in place, which has resulted in various material-specific Dutch collection schemes. On the other hand, the amount of general household waste that municipalities collected continued to grow after World War II so that municipalities got more difficulty finding sufficient landfill capacity. However, it lasted until the 1970s before alternatives to the dumping of waste, such as recycling or incineration, were seriously considered not only because of capacity problems, but also because of growing environmental concerns. Scandals about toxic waste at dumping sites and toxic substances that were emitted by a waste incinerator that occurred between 1979 and 1989 were triggers to finally change legislation and the practice of waste treatment – another example of the impact of 'drastic events'. Interestingly, however, the process of waste treatment did not get centrally organised in a single way, but, in line with the Dutch consensus tradition, a consultation body was created, in which all stakeholders were represented. Moreover, also under influence of legislation from the European Union more emphasis was being put on prevention of waste and reuse, which eventually has led to the adoption of the material supply chain perspective. This perspective fits in well with the other (Dutch) tradition of the recycling of specific materials (such as glass or, more recently, plastics) so that both traditions finally got linked. This transition is portrayed in Figure 6.5, using the SyNeA framework.

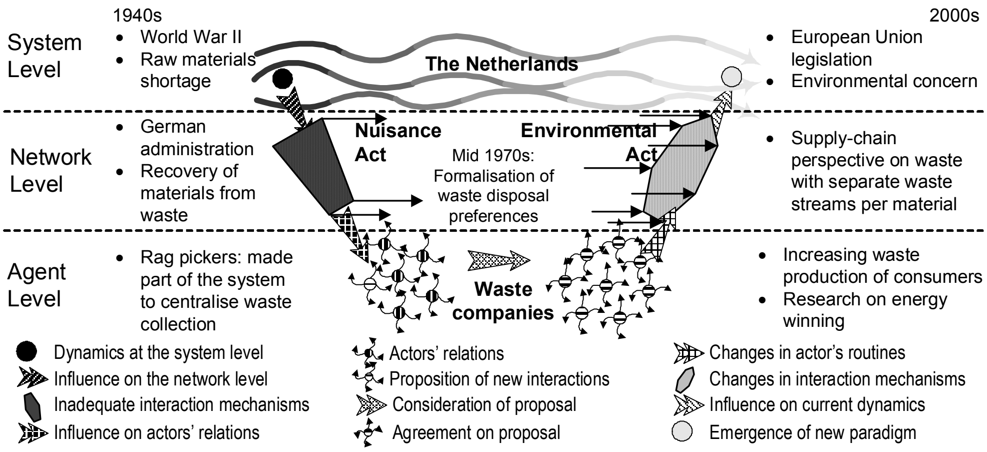

Figure 6.5: The main information feedback of the Dutch case

If we consider these two cases, we can see the crucial role that drastic events play as a trigger for change. Drastic events are capable of breaking the current state of affairs in society and play an important role as an external force affecting the functioning of the system, such as high oil prices in the case of Brazil or the World War and the waste scandals in the case of the Netherlands. The specific nature (e.g. economic collapse, wars, social upheaval, or inventions) of the drastic event seems not to matter. It is the impact on the system and the spread which seems to matter: a drastic event plays a role as long as the impact is high and it pervades all instances of society. Especially in desired transitions, drastic events can be taken as signs that identify windows of opportunity and can be used for developing a sense of urgency in society in such a way that the interests of all parties converge – at least temporarily.

As both transitions are examples of 'desired transitions' (for which government has officially established the desired direction), it is important to look at the role of government.

Government has a special role in society because it gathers the needs and interests of its citizens in accordance with the political system of the country. Additionally, government is expected to safeguard the rights and obligations of all parties in society. Due to its four-fold capability ("convey urge, attain authority, expend treasure or make organisation" (Hood, 1986)), government is able to dimension the playing field of other actors in society with policy. Government can create incentives for and limit (or even prohibit) the execution of deeds. This means that the production of goods and services can be affected in such a way that some alternatives are encouraged above other less desirable alternatives. Additionally, government is able to reduce uncertainty for other actors by the coordination of their responsibilities. This allows other actors in society to work on the optimisation of their own production and cost functions. In addition to being a co-ordinator, government can also be an initiator of transitions (Rotmans, 2005b) under special circumstances. This was seen in both case studies, where government officially decreed the use of alternative ways of dealing with existing problems: the use of bio-ethanol for transportation purposes in the case of Brazil and the introduction of recycling loops under the German administration in the case of the Netherlands. Interestingly, these two effective policy changes were in both countries carried out under military rule. As a contrast, when later, after the waste scandals in the Netherlands, the (then: democratic) Dutch government wants to implement a new policy, the policy change is much less effective, probably because they choose for the noncommittal instrument of a consultation body. Concluding, it can be seen that government attains a certain power and can influence transitions towards particular objectives when it is able to perform top-down control, such as in a hierarchical culture. However, government is not able to completely steer a transition because there are always externalities that government cannot control, such as oil prices.

Moreover, the case studies show that social acceptance is also vital, which underlines the need to consider both the social and technical side of socio-technical transitions in a balanced manner. The success of the use of bio-ethanol as a fuel in the Brazilian case depended on the acceptance by consumers. At first a reasonable share of consumers followed the government's choice for bio-ethanol as car fuel, probably because of the hierarchical culture, whereas later the attractiveness of the flexibility of the flex fuel car led many consumers to buying such cars, which in turn led to an increase of the use of bio-ethanol as a fuel for light vehicles. In the Dutch case the success of the collection schemes for different materials relates to a large extent to the generally high willingness of the Dutch citizens to collect and turn in such materials. This willingness does not only cover 'traditional' collection schemes, such as for paper, but it was recently also manifested in the context of the new collection scheme for plastics, which is quite successful.

Another lesson is related to the relevance of common social needs and the formulation of common social objectives. Common social objectives are important because they make known to all actors in society what is important for society at large. The role of common social objectives is that it urges all individual efforts towards a particular goal and concentrates individual efforts on particular alternatives, given the room (economic, political, social, technological) each society has. Depending on the level of wealth of each society, this room will allow some countries to keep "all options open" while others will be forced to concentrate on the few options they can afford, as happened in Brazil: only the Pro-Alcohol Program survived to encourage the production of bio-ethanol, mainly from sugarcane. The trade-off here is that the more options there are available, the higher the level of uncertainty each actor within each specific system will have. This happens, for example, with the energy transition in the Netherlands and the different types of energy sources for transportation, such as bio-diesel, electricity, hydrogen, or natural gas. Until now, none of these alternatives has achieved a level that it has any sizeable impact.

In connection with the previous lesson, this one is related to concentration of efforts on a handful of alternatives based on already agreed upon common social objectives. If there are only a few alternatives to concentrate on, actors can more easily focus on a smaller set of decisions to take and issues to deal with. This allows them to work on the optimisation of their own production and cost functions with less uncertainty. Here, the role of government is relevant for the dimensioning of other actors' playing fields with policy (with or without economic consequences) because it helps actors to concentrate on their own core business.

Furthermore, individual initiatives, coming from persons or organisations, can be relevant for the introduction of new alternatives in society: if these initiatives attract attention they can become a focal point for other smaller parties in society with similar interests, ideas or values that individually are missing enough critical mass to pervade society. From a scientific perspective, these individual initiatives reflect the emergent characteristic of agents in a system of bottom-up influence. A nice example of a successful individual initiative occurred in the Dutch case study: the first bottle bank was an initiative of two Dutch women and, after its success this system was soon adopted by many municipalities, well supported by the central government. By the way, common social objectives also have influence on the success of individual initiatives because they allow the diffusion and endurance of new alternatives in society, so that they can become part of the new paradigm.

A final lesson is related to the risks of direct institutional transplantations (de Jong & Mamadouh, 2002). At each conceptual level (system, network, and agent) and in each sub-system there are particular characteristics that are not transferable to other contexts because these characteristics only work within the logic of a particular system. The way in which actors take decisions, the arrangement of interaction patterns and the cultural characteristics are all unique to each society and change in their own particular way. For example, the flex fuel vehicles are a success in Brazil, but – as it appears – nowhere else. This relates to the specific situation of Brazil as a country with a 'history' of the use of bio-ethanol as a car fuel and the availability of an infrastructure to supply that type of fuel. The same holds for the physical environment in which each society develops: it affects the way in which technology develops over time due to the specific set of resources available and the specific environment with which technology has to hold account. If one plans to apply successful or failed experiences elsewhere in another system, it is necessary to deal with these differences and try to find the equivalences so that the desired transitions can be achieved.

Concerning the sub-question:

5. *Based on the studied cases, to what extent does it appear possible to design intervention strategies to steer and/or speed up desired transitions?*

In the field of Complex Adaptive Systems, the control of systems is considered to be highly dispersed and decentralised, as expressed by John Henry Holland (Waldrop, 1992). This indicates that a large number of agents are present in the system, each of them with its own decision rules and relations within the system. While agents might have farsightedness in their own playing ground and anticipate the results of their own decisions, this is not the case when agents interact: decisions of agents and interactions among multiple agents may create unexpected results of taken measures because of the non-linear characteristic of those decisions and interactions. This means that any attempt to steer the whole system is intractable.

However, if the evolution of the transitions presented in the case studies is taken into account, it is possible to acknowledge, to some extent, a degree of influence. Government can influence transitions, but it is very difficult to truly steer a transition. There are circumstances that are beyond the control of government, such as fluctuations of oil prices. Also, the degree of influence of the government is culturally dependent. In the case of Brazil, a country that works as a (hierarchical) 'pyramid of people' (Hofstede, 1991), government was able to introduce reforms and convey social commitment towards particular objectives. In the case of the Netherlands, a country that works as a 'well-oiled machine' – but less hierarchical - (Hofstede, 1991), drastic events (such as the waste scandals) were necessary to introduce regulatory reforms that counted with the support of society at large; in the period between drastic events, government was only capable of introducing a few minor reforms which had little impact in the system.

Other actors in society can influence the transition with their own power and resources, but they need to have critical mass in society to achieve this influence. An example of this is the initiative of two women to introduce bottle banks for the recycling of glass in the Netherlands, which was followed in other municipalities due to its success; another example is the introduction of the Flex-Fuel cars in Brazil by car producers, which was accepted by the consumers and allowed a second life for the bio-ethanol programme. It is, however, difficult to predict which actions will have a significant impact.

As can be seen, policy measures, economic incentives, social stimuli or technological developments, all of them nourished by the existing cultural background and possibly catalysed by drastic events can influence transitions but not steer them. This means that agents can create conditions within their range of influence in order to encourage particular preferred options and the dissemination of those options in society, but this does not guarantee control over a transition.

With regard to intervention strategies, more than co-ordination of objectives, it is necessary to achieve the co-ordination of deeds towards the achievement of the agreed objectives. The question here is whether voluntary co-operation of the actors involved is sufficient to achieve this coordination of deeds. In the case studies it was found that drastic events can temporarily help focus on the same objectives and act accordingly. However, it is by no means guaranteed that actors will keep that focus in the long run.

Even though it remains difficult to reconcile the concept of emergent system behaviour and the management of transitions, our proposal is to use modelling to carry out experiments that would be too complicated to execute in real-life systems. Simulation offers the possibility of discovering (the working of) relations simplified from real systems and experiment with those relations for educational purposes (Axelrod, 1997). Although optimal solutions are not guaranteed, it allows performing thought experiments without affecting the real system.

6.4. The SyNeA framework as the cornerstone of our method for the analysis and modelling of transitions

With respect to the main research question:

> *Is it possible to design a method and a conceptual framework which are suitable for the systematic analysis of socio-technical transitions (covering the relevant social, technical, economic and policy dimensions) and which could help explain the dynamics of such transitions?*

The literature study presented in Chapter 2 has reviewed four perspectives that analyse transitions: the technological, the social, the institutional economics and the network perspective. Although each of them elaborates on the details of each topic, they present knowledge gaps that make them – individually – insufficient to cover all relevant aspects of socio-technical transitions. However, it turned out to be possible to reconcile the differences of all perspectives based on the principle of multiple formalisms (Mikulecky, 2001) of Complex Adaptive Systems.

By using the significant features of each above-mentioned perspective, this research presents a generic conceptual framework to describe and analyse socio-technical systems in transition, embracing the dual nature of systems: the social and the technological aspects. Its main characteristic is that it distinguishes three levels (system, network, and agent) which are considered to be three aggregation levels of the same reality. Because of this feature we called the framework the System-Network-Agent framework, or short: the SyNeA-framework. This framework offers the possibility to zoom in when necessary to observe and identify the elements behind transitions and the interactions between elements in the form of information feedbacks that are relevant for the decision making process.

The SyNeA-framework we propose differs from the Multi-Level Perspective of Geels (2002), in which the 'landscape' represents boundary conditions for a 'regime' to change and where 'niches' refer to emergent changes that alter the existing regime. In that Multi-Level Perspective, all three levels (landscape, regime and niche) are considered to exist in parallel although they are thought to be embedded in one another. Specifically, the Multi-Level Perspective focuses on the emergence of technological novelties and their diffusion, which is less broad than the topic of this thesis.

The three levels in our conceptual framework form the main structure to systematically approach the information of a certain case for explanatory and communication purposes. As such, the framework plays a central role in the method we propose in order to study socio-technical transitions in a systematic way. Basically, the method suggests to use *case studies* to analyse the phenomenon of socio-technical transitions and gives some criteria for the case study selection; it further indicates the basic topical issues that guide the collection of information to describe the case; then it helps the analyst to capture the studied transition in a modular way: first, from the 'real case' to the description in terms of the SyNeA-framework, then to the qualitative modelling of causal relations, while the last step relates to the qualitative modelling of agents with nodes and edges. These last two steps make the case suitable for (different types of) computer simulation. The method works as a kind of protocol for conducting the case studies.

Modelling plays an important role in this method because it helps structure information, e.g. in a graphical way, which facilitates the communication of information at a glance. Modelling also helps simplify the amount of information from case studies and prepares the information for quantitative modelling and simulation.

The phenomenology of (desired) socio-technical transitions is such that there is a large amount of information to be gathered and processed. This large amount of information is necessary to describe the system, the transition itself and the transformation of the information for quantitative modelling. Because the large amount of information comes from different sources and in various ways, it becomes a downside of the application of the SyNeA framework.

The second part of the main research question relates to the issue of whether the method and framework could help explain the dynamics of socio-technical decisions. Based on our research we dare to answer this question with 'yes', although it remains a fact that transitions are complex processes that we probably shall never *fully* understand.

The method and the framework help to improve our understanding of the dynamics of socio-technical transitions, as they allow for the analysis of transitions through two different research methods: case studies and the modelling of socio-technical systems (with the possibility of simulation: 'thought experiments'). With both methods, the framework and the method help display the role of actors, their networks and the system properties and take the interaction and feedback between the different levels into account. This is important for disclosing the mechanisms behind the transition.

Moreover, the structuring that the method and framework compel makes it a good basis for comparison: first, the comparison between transitions in systems with different cultural backgrounds. But it also allows a comparison between different types of transitions (there is no 'conceptual' need to restrict the study of transitions to desired transitions); one could for example compare (a) spontaneous transitions, (b) transitions that are advocated by non-governmental organisations (not yet endorsed by government) and (c) 'desired transitions' as defined in this research. Finally, the method and the framework also provide a structure to link different research methods, such as a case study about an actual transition and the modelling and simulation of aspects of that type of transition.

The case studies that were carried out in the course of this research show that the application of the method and the framework actually did yield insights about the dynamics of both studied socio-technical transitions: *inter alia* about triggers, about the effectiveness of government policy, about the issue under what conditions actors in society would align their actions, and about the role of culture.

Finally, some words on the relation between our proposed method and framework and the other (reviewed) perspectives and approaches. As the proposed generic conceptual framework is the result of combining the features of four mono-disciplinary perspectives to understand transitions, it broadens the insight about socio-technical transitions and allows cross-discipline learning. The main reason is that this generic framework is designed in such a way that each discipline can be related to the framework and, due to the similarities in their structure, each discipline can be related to the other disciplines included in the study. In this way, further cross-discipline learning is being fostered.

While trying to reconcile the principles of the theory of Complex Adaptive Systems with the management of transitions, it can be concluded that our contribution is related to the expansion of the understanding of transitions while contributing to the effort of modelling socio-technical systems for further exploration of different alternatives under different settings. From these efforts, some strategies could be designed in such a way that they may influence desired transitions towards the desired common social objectives. However, there is no guarantee of success because of the distributed nature of decision making in this kind of system.

Reflection

Nowadays, transitions of large-scale infrastructures, specifically energy infrastructures, have captured the interest of different parties because each of them wants to steer the process of change towards their particular set of solutions, in the hope that the problems of existing paradigms can be eliminated, reduced or kept under control while providing the same or comparable comfort, products or services. While taking the above-mentioned into account, this research project was set up to address transitions of socio-technical systems at three different aggregation levels (system, network and agent).

During the execution of this research project, we encountered several issues that in our eyes require special consideration. Looking back to the research process and project, we will, in this chapter, take a closer look at and reflect upon the following: in Section 1 the definition for transitions in relation to existing definitions in different fields of study, in Section 2 the developed perspective to analyse transitions and its applicability in different fields, and in Section 3 the case study as a method to study transitions. In Section 4 we make suggestions for further research.

7.1. A definition of transitions

Transitions, as processes of change, have been addressed by different fields of studies. In the literature review (Chapter 2) we provide an overview of the multiple possibilities for defining transitions, which are much more specific to a particular field of study.

In the course of the literature review, it was found that the task to reach a balanced definition of transitions from a systemic point of view is complicated. One can include several characteristics as part of the definition, but the inclusion of all features – coming from different fields of studies – helps little when trying to identify elements that are relevant for the explanation of transitions. A balance between breadth and depth was sought, but the preference was given to breadth under the assumption that socio–technical systems in transition can be considered as complex adaptive systems, and since this field of study embraces an interdisciplinary academic work.

During the literature review we tried to be as thorough as possible when reviewing the different perspectives; however, the limits of this research project required the concentration of our effort on aspects that were considered to have a direct impact on socio-technical transitions and for which previous knowledge of the topic was available. Considering that this research project has been realised with the patronage of the Next Generation Infrastructures Foundation and within the framework of the faculty of Technology, Policy and Management and its body of knowledge, we have addressed the role of technology (in the form of technological replacement and not fundamental technological change), policy (in the form of institutions, including economic arrangements), and management. We have added the social component to address a system in a holistic way, as people and their interactions are an important part of any socio-technical system.

Two other issues to reflect upon are (i) the consideration of both small and large changes as transitions, and (ii) calling both the resulting change and the process of change transitions, as it is done in the context of Transition Management. Considering everything as a transition without determining what is included in the transition, makes it unclear what a transition is. If one also contemplates the collection of small changes in the same direction as a transition, it remains unclear as to what the boundaries of the system under study are. It has been difficult to define when a transition starts and when one can talk about a full transition. In general, the systems concerned are not in a static equilibrium but rather in a dynamic equilibrium. Therefore, the description of an initial or end state of a system will be an approximation: even a description of a system at a certain point in time will only capture the stable mechanisms in the system but not the differential changes already occurring at the edges. Instead of cataloguing everything as a transition, we decided on the use of an initial and a final dynamic equilibrium to define transitions because small changes will be included in this way in a transition, as part of the large process of change.

A final issue we would like to address is the difference between spontaneous transitions and desired transitions. An example of a spontaneous transition would be the introduction of cell phones. There was no government intervention or higher social goal to be achieved with this: there was a need for sufficient communication when there were no fixed lines available or for people with high mobility. The development and innovation in the mobile telephony have been such that more and more services are being coupled to the cell phone: what once was simply a matter of communication is now an instrument for remaining connected to the broader world. Although these spontaneous transitions may be a rich source of information, the focus in this research project was on desired transitions, i.e., transition in which a conscious orientation was taken in order to tilt the system toward a certain direction. This 'desire' is normally made public and addresses a preferred social objective to achieve. In both spontaneous and desired transitions, a matter of emergence is observed in the way actors deal with the existing interaction mechanisms they receive from policy, technology or economic constraints, which determine their playing field, and the decisions and actions they take or execute within this playing field. Interestingly, it seems that spontaneous transitions, such as that of cell phones, have generally occurred more smoothly than desired transitions, such as the introduction of the chip card for public transport in the Netherlands.

7.2. A perspective from which to analyse transitions

During the design phase of the analytical framework, there were several considerations in favour of and against the use of a particular definition of transitions coming from a specific field of study. The main argument in favour of the use a particular perspective of transitions is that it clearly facilitates the study of a system: one perspective facilitates the focus on particular aspects of a system, provides existing terminology to describe a system, and uses a standard set of assumptions and heuristics to analyse a system.

However, these features are also an argument against the use of a particular perspective of transitions. The use of just one perspective to deal with transitions provides too limited a scope when dealing with large-scale systems, such as an infrastructure system in which not only technology and economics are involved but also people fulfilling different activities. For example, technological development is a desirable output of functional domain transition in the Technological Perspective (Section 1.1 of Chapter 2). However, technology cannot be analysed independently from its environment since several factors influence it, including market changes and social adjustment. Technological development and technological paths are the result of different and multiple causal relations. The emergence of a new paradigm is the result of different interactions, not only of technology, but also between technology and the actors' network, institutions and policies. A new socio-technical paradigm also influences the system by affecting the social principles and values.

The use of one perspective also limits the scientific dissemination, as this targets only a limited research community. Additionally, the possibility of cross-fertilisation among different research communities and disciplines is also restricted because of little contact with other disciplines that may also study transitions as processes of change.

Considering the above-mentioned arguments, our choice was to search for similarities among different fields of study. Naturally this made the dissemination process much slower because a neutral (as possible) language had to be used to address different audiences; however, it allowed cross-fertilisation and made it possible to create synergy in our framework, combining the strengths of different fields.

Regarding the type of design of the analytical framework, several considerations had to be made in relation to the level of aggregation and whether the image of the system we wanted to achieve was a static or a dynamic one.

In the case of the aggregation level, we could choose between a high or low level of aggregation, with the corresponding trade-offs: a black-box image of the system at a high aggregation level or something like a white-box image of the systems at a low aggregation level. On the one hand, the advantage of choosing a high aggregation level of analysis was that the most evident causal relations would be included in a model of the system under study, which facilitated dealing with long-term decision-making with few variables; however, this situation would possibly impede the visualisation of non-linear effects while at the same time sacrificing the detailed handling of specific drivers behind transitions. On the other hand, the advantage of choosing a low aggregation level was that it would allow the study of individual behaviour and the observation of emergent structures; the downside of this was that the level of detail would provide such an amount of variables that any model would become intractable. Each choice would have certain repercussions in the use of modelling and simulation techniques, which would need to suit the proper level of aggregation.

Here we tried to find a balance between breadth and depth, trading off scope and detail. In this sense, we prefer to consider our framework for analysing transitions as a set of adjustable lenses, which allows us to zoom in and out on large-scale socio-technical systems. This allows us to observe changes at the system level (the interaction of the system with the environment) at a high aggregation level, and when zooming in, to observe changes at network level (relations to cope with changes in technology, economics or policy) or changes in the heuristics of individual agents to find new ways to adapt to new conditions. The use of proxies to deal with elements in the background of a transition (e.g. Hofstede's research to characterise countries) is an example of the trade-off between scope and detail.

Concerning the type of conceptualisations of the system we would like to obtain, there were some considerations to be made around the objective of the project "Institutions, Industrial Infrastructure and Transition Management" of the Next Generation Infrastructures Foundation. The objective of this research project has been "to establish a multi-disciplinary framework for analysing and shaping transitions", especially of the energy infrastructure, in which "simulation and modelling will underpin a method to establish to what extent one can effectively manage a transition".

This objective asks for an analytical framework that can cope with dynamic behaviour of a system in transition in order to translate the insights of the system into a model of this systemic behaviour, which could later be programmed in a simulation model. This objective also points toward the exploration of the effect of different decisions by actors in the system and to determining whether those decisions have the desired effect on the system. Although this main objective may call for a dynamic representation of the system (to establish the main mechanisms that should be designed and modelled for a simulation model), it was also considered necessary to find points in time at which a start and an end could be signalled: this in order to generate opportunities for comparison with other transitions as well as information for a possible simulation model.

Considering the above-mentioned, the proposed analytical framework and method to study transitions try to provide an image of a starting point, the developments over time, and an image of an end point (or the current status) of a studied transition. All three mentioned elements fulfil a role in the analysis and modelling phase, not only for comparison matters (between start and end states as well as among other transitions) when doing static studies, but also for design matters (modelling actors' behaviour and interaction mechanisms to portray (emergent) system behaviour) when specifying the basis for a simulation model and a reference mode for comparison between simulation runs.

7.3. The use of case study in transition research

The study of transitions of large socio-technical systems has been a task that, due to our definition of what a system in transition is, implied the research of several variables at the same time. Case Study as a research methodology fulfilled the demands of such a task, but there were still several issues to be dealt with. In Section 3.1 we will explain the considerations of the design of the case study as a method to study transitions, in which the criteria for the case selection were defined in order to make the cases suitable for comparison. In Section 3.2 we will elaborate on the execution of the case study, with emphasis on the accessibility of possible information sources and possible strategies to acquire information and the attainment of different perspectives of actors of the system in transition.

7.3.1. Case study design

The definition of the criteria for the selection of cases was based on two objectives: first, the expansion of the understanding of transitions of large socio-technical systems by identifying characteristics that influence and portray the extent of transitions; and second, the tuning and validation of the analytical framework to make it suitable for the exploration of incipient transitions.

To make those objectives operational, we focused on the question of how a transition begins. Here, the challenge was to identify signs that indicate the start of a transition in a particular society. Based on the literature analysis and using the developed analytical framework, we chose to find signs at each level of aggregation in order to allow the differentiation between spontaneous and desired transitions (i.e., as a reaction to some external and intentional influence).

The first case study (the introduction of sugarcane ethanol as a fuel for light vehicles in Brazil) provided a learning opportunity for the fine-tuning of the case study design. What started as a set of criteria ended up as one combined criterion in which the public declaration to pursue a particular objective was combined with the choice and introduction of new technology or methods to cover a particular need in society.

This combined criterion proved to facilitate the choice of other cases because it allowed the selection of desired transitions and retained the neutrality in the choice of any large-scale system. That happened with the choice of the second case study: the transition of the Netherlands to a supply-chain approach for household waste treatment, which was used for the validation of the usability of the framework and the case study design as a method with which to study transitions.

7.3.2. Case study execution

Once the case study design was ready, the next issue to deal with was the available information sources and possible strategies to acquire information for the case studies, so that all elements of the analytical framework were represented.

At this point, the typology of actors, defined in the analytical framework, facilitated the selection of information sources because each actor in real life has its counterpart in the typology. In this sense, institutions, databases or libraries related to these actors were simple to identify; however, the sensitivity of the information, the lack of verifiability of the information with other sources and the time elapsed from the start of a transition until the moment of the execution of the case study were obstacles difficult to overcome in the acquisition of information. Especially in the case of contacting government representatives or government employees, it was difficult to find a doorway that allowed us to directly acquire information from this source. Yet the degree of difficulty diminished with the degree of influence that our contacts in the system had and the type of society we were dealing with.

An example of this was our ability to reach Dutch government representatives while Brazilian ones excused themselves due to problems with their agendas. The opposite occurred with other actors in the system: In the Brazilian context it was possible to make contact with producers – of bio-ethanol and cars – associations, while in the Dutch context we could only secure a phone interview with a waste processing association and gain access to the archives of a waste processing company after several attempts and under the condition to return it as soon as possible. An interesting type of interaction has been that with researchers at universities: no matter what their position in the hierarchy, they are willing to provide their knowledge of the topic.

Although the use of the framework as a reference for the identification of actors proved useful when targeting actors and their information sources, we acknowledge that there are several actors that may be involved in the studies of transitions, but they perform a less active role or they fall outside of the scope or boundaries of the system in transition.

It is worth mentioning that in all three kinds of sources – institutions, databases, and libraries –the ability of the researcher to understand the original language in which the information was manifested was key. Especially in the case of interviews, the respondents showed more willingness to share their experience and knowledge when the interviews could be held in their native language.

7.3.3. Case study conclusions

Now that the case study has been executed, the analysis performed and conclusions obtained, two issues still remain that we would like to reflect upon.

One topic is the inclusion of cultural background as contextual information on how to interpret the interaction mechanisms and the actors' heuristics for decision-making. During the execution of the case study, it became evident that cultural background has some influence in the style of the decision-making process, the construction of regulatory frameworks, and the participation of actors in the transition process. As we had already chosen for a combination of breadth and depth in the context of complex adaptive systems, it became relevant to find some indication of the kind of cultural background in which the transition was taking place. To point out what characteristics of cultural background are involved, we have used Hofstede's indicators as proxies for comparison. In this way, cultural background is taken into consideration to complete the system's picture when mapping the different elements of a system in transition, at least in an indirect way. However, it also raises questions about the endurance of system to change by lacking a thorough study on how cultural background influences decision-making processes.

Another topic is the determination of a time frame to study transitions. Unfortunately, this remains a difficult task to determine and may have unexpected results. For example, in the case of the Netherlands one can assume that the scandals in the 1980s were triggers of the transition to the extended use of recycling, placing incineration and landfilling second and third in the ranking. Or that the change in legislation and environmental awareness in the 1970s were the actual reason behind the encouragement of recycling and the discontinuation of landfilling as a way to deal with household waste. However, a longer time frame showed that an important turning point occurred during World War II: the introduction of recycling to recover from household waste as much material as possible in order to reduce the raw material shortage laid the basis for the different recycling circuits – for paper, glass, and plastic – to appear in different social circles of the Dutch society. Here, our suggestion is to go as far into the past as to when there was no significant change in the state of the system under study.

7.4. Recommendation for further study

During the execution of this research project, care was taken to conclude the study as much as possible within the allowed time and budget while guaranteeing the quality of the research. To accomplish that, choices were made which resulted in the current focus of this dissertation, while several topics were set aside. The following issues would be considered to improve the span of this research.

R1. The multiple manifestations of technology in transitions: This thesis has addressed a particular type of transitions in which the technological replacement of existing paradigms play a role, such as the use of bio-ethanol in light vehicles instead of gasoline in Brazil. These kinds of transitions are characterised by 'small' adaptations of the existing products or services and infrastructure, and are therefore to some extent path-dependent on the existing paradigm. However, it seems relevant to expand the current knowledge towards the role of inventions in transitions, as they might provide profound metamorphosis of the existing systems. They may even make new products, services or infrastructure necessary, as the old paradigm might no longer serve the basic function in society.

R2. The value of spontaneous transitions: The central issue of this thesis has been transitions that are desired by a particular society. This type of transitions rests on the achievement of common social objectives to preserve the functioning of the society. Additionally, the interest of this research lies in understanding how this kind of transition can be activated and sustained in such a way that the desired change is achieved and maintained. As desired transitions are just a sub-set, it is estimated that spontaneous transitions (i.e., transitions that occur without a social agreement of common objectives), such as the use of smart phones in the telecom market, can be an important source of knowledge regarding how transitions may also occur.

R3. The influence of social constructions in transitions: During the execution of this research project, it was observed noticed that culture has a relevant influence on the formation of objectives, rules, and decisions in society. To a certain extent, the influence of culture has been included in the analytical framework and expressed by means of proxies based on the cultural indicators of Hofstede (Hofstede, 1991). Still, it seems important to deepen the knowledge about the role of culture in relation to transitions as culture pervades all activities in any society and therefore the way in which transitions occur.

R4. The extension of the modelling process towards simulation: The case studies presented in this thesis show that a large amount of information is necessary simply to describe how a transition has happened. To analyse transitions, and, later, to obtain lessons from the case studies, it was necessary to arrange the case study information in orderly manner and then model the case study in such a way that the relevant elements of the system remained in place. This was done in two steps: from case study to causal relations to agent-based relations. The result of these two steps is a functional analysis of actors in the system. Yet, it seems significant to specify the functional definition of actors with appropriate formulations for computer simulation and add them to the simulation engine as introduced by Nikolić (2009) to allow the exploration of alternative transitions of a particular system.

To better understand transitions, it is necessary to help close the knowledge gaps of transition analysts, decision makers and transition managers. Eventually, the closure of these knowledge gaps will support the 'management' of transitions.

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Summary

Transitions are processes of change that have always occurred in societies. Man changed from nomads to settlers, the production of goods changed from handcraft to machine-made, long-distance communication changed from delayed to almost instantaneous. Some of these changes gave rise to our current infrastructures, such as railways or telecom. Traditionally, these changes in society developed throughout long periods of time, without a specific common objective leading the transition. However, in recent times, societies want to *manage* their change(s) necessary to safeguard their functioning and survival: they desire to secure supplies for covering their citizens' basic needs, to promote employment, to secure a well-functioning health care system and to improve the well-being of their people, as well as to address the effects of the human ecological footprint. Achieving such a *desired* transition is not a simple task; several questions can be raised as to how to achieve such changes. Fundamental questions are: what exactly is a transition? How can we unravel it? To what extent can a transition be influenced or even steered?

In this research, we have tried to address these questions with a focus on transitions that involve *(inter alia)* technological aspects and, more in particular, in which infrastructures play a role. Suited for these types of cases, we have developed a conceptual framework as well as a method to unravel the complexity of transitions of societies, here conceptualised as socio-technical systems. These systems are seen as a combination of society (individuals or organisations) and technology (artefacts with techniques produced and used), and they influence each other which results in a certain evolution of the infrastructure (and society).

In order to understand what transitions are, we first performed a literature review (see Chapter 2). We reviewed four different perspectives on transitions: (1) the technological perspective which focusses on the role of technology in transitions, (2) the social perspective which looks at the adaptation of societies to different situations, (3) the actor-network perspective that studies the relation among actors in societies, and (4) the perspective of institutional economics that focusses on institutions linking society and technology. As these perspectives address transitions in accordance with the conventions of their own discipline, they have blind spots. In the technological perspective, technology is the answer to problems concerning environmental sustainability. However, sustainable schemes can also be achieved by changes in belief systems or regulation. In the social perspective, the interaction of actors in networks is hidden in the description of the society. In the actor-network perspective, the impact of networks is mostly evaluated against the realisation of agreed objectives, disregarding the effect of networks at society level. In institutional economics, (information) feedback is mostly disregarded: in this view, a transition approximates to a top-down process from the (in-)formal rules towards the individual actor. Although each of these perspective is not derivable from the others, they have several commonalities: they (1) use a multi-level perspective for analysing transitions, comprising at least a system and an actor level, (2) acknowledge that there is some interaction among actors, networks and the system, (3) identify 'actors', that can be a 'motor' of transitions, and (4) they use a higher level of aggregation to observe the results of the introduced changes.

To unravel transitions, we have used the significant features of these perspectives to develop an overarching explanation of transitions of socio-technical systems. In this way we address the multi-disciplinary character of transitions. In Chapter 3 we first determine the levels of aggregation that are needed to describe (the dynamics of) transitions well and we define a basic set of elements for each level. This forms our conceptual framework for analysis. In addition, we propose a method to capture the richness of a transition in a case

study design, and the qualitative modelling of causal relations and agents. In this research, 'transitions' are long-term processes of social and technological transformation from one dynamic equilibrium state to another. A special class of transitions are 'desired transitions', in which the government has officially established the preferred direction of the transition process concerned. Such transitions aim at reaching established common social objectives to facilitate the endurance of society and occur when the function of a (part of) a society is considered to be at risk.

We propose an analytical framework, which distinguishes three conceptual levels (see Figure a):

a. System level: this refers to the system as a whole, seen as the aggregation of several networks of connected agents and their technologies. The system is characterised by cultural features. External forces, here called 'drastic event(s)', may induce, speed up or slow down a transition of the system.
b. Network level: this refers to the aggregation of actors and their technologies by patterns of interactions. These patterns are the rules actors use to interact with each other. While interacting, actors create networks in order to exchange resources and knowledge for the transition to occur. At this level. We pay attention to the policy and technological aspects, as well as the polity of a system.
c. Agent level: this level is composed of the individual elements of the system. Actors, which are here conceptualised as agents, can be the source of change. The identified relevant actors are: government, producers, facilitators, consumers, and infrastructure intermediaries. The actors 'interest groups' and 'research organisations' only have an indirect impact on transitions.

We have called this conceptual framework called the System-Network-Agent framework, or in short: the SyNeA framework.

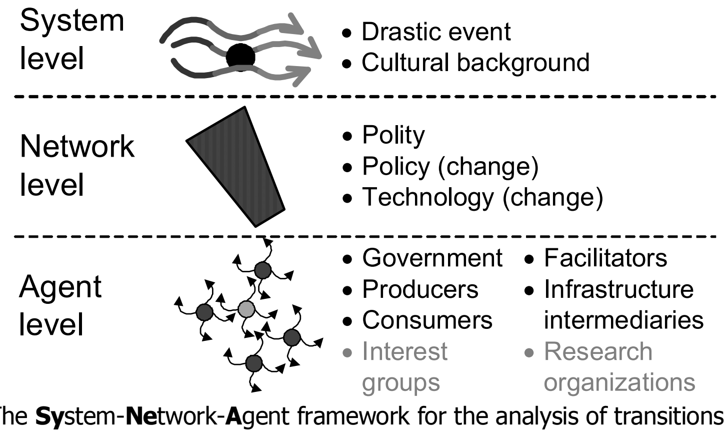


Figure a: The **Sy**stem-**Ne**twork-**A**gent framework for the analysis of transitions

Within this framework, it is assumed that a transition is accelerated by the occurrence of a drastic event, affecting the current state of affairs. In this way, the existing interaction mechanisms become inadequate. As a reaction, actors introduce changes in their routines. If actors agree on these new ways of interaction, changes occur in the existing networks, with new policy, new technology or new economic arrangements within the existing polity. These changes at agent and network level would, in turn, lead to a new state of affairs at system level, 'completing' the transition.

The complexity of a (socio-technical) system in transition appeals to use case studies, which is justified by the need to understand how and why transitions happen. We propose a case study design that indicates what kind of information should be gathered and how to analyse it with the analytical framework. The analysed case serves as basis for qualitative modelling, which allows for comparison, evaluation and communication, and helps to set the basis for quantitative modelling. We propose the use of a step-by-step approach that first transforms the richness of a particular case into causes and effects, using the principles of System Dynamics. Then, these causes and effects are detailed on the level of networks and agents, using the principles of Agent-Based modelling.

In Chapter 4, the proposed method and framework are applied to a case related to the consumption of natural resources. The first case is one at the front-end of a supply chain (the use of a different raw material to produce fuel for transportation): the transition to sugarcane ethanol as a fuel for light vehicles in Brazil. This transition process started in the early 20th century with the policy requiring the addition of 5% bio-ethanol to the gasoline. When in the 1970s Brazil is confronted with high oil prices and the overproduction of sugarcane (two 'drastic events'), the government set up programmes to support alternative fuels based on ethanol, diesel or coal. Soon, support was concentrated on bio-ethanol from sugarcane because of the overproduction of sugarcane and the availability of cars that can be driven by bio-ethanol. However, after more than a decade these support schemes were cancelled due to lack of (government) funds, lower oil prices and a drop in sugarcane production due to climatic circumstances. As a result, the number of bio-ethanol cars declined, but bio-ethanol continued to have a role as a substitute for lead in the gasoline. At the start of the 21st century the advent of the flex fuel vehicle, a car that can use both gasoline and ethanol, caused a revival of bio-ethanol as fuel for light vehicles in Brazil, as many consumers started to buy these flex fuel vehicles. The SyNeA framework helped to portray the evolution of this transition.

One lesson of this case is that the concentration of all efforts in a handful of alternatives together with economic instruments like subsidies, loans or taxes helped reduce uncertainty. Actors can in this way better concentrate on their core business. The experience of the introduction of bio-ethanol in Brazil is an example of how transitions can evolve as a result of drastic events (high oil price and low sugar price). But the success of the flex fuel car shows that also bottom-up change is feasible, although we must admit that the development is path dependent since the success of flex fuel cars is specific to Brazil. In general, if any of these lessons would be applied elsewhere, attention must be paid to the differences with the Brazilian situation, to overcome the pitfalls of the transplantation of lessons without any adaptation. Moreover, based on the experience with the application of the method to this case study, we slightly altered the originally proposed framework.

In Chapter 5 the revisited framework is validated for its usability by applying it to a case related to the disposal of used materials. This case is at the back-end of a supply chain (the transformation of garbage into raw material or new products): the transition to a supply-chain approach for household waste treatment in the Netherlands. It concerns a long term development that combines two 'traditions': first, the tradition of the rag pickers that collected specific types of material (such as rags or organic waste) in order to reuse it, and, second, the tradition of municipalities (especially cities) collecting general household waste for hygienic reasons, which they initially disposed of by dumping. During the German occupation of the Netherlands in World War II the German administration introduced a landmark change: government became involved with the reuse of materials and a central body was established to take care of the recovery of certain materials, such as rags, paper or metals, while the system of rag pickers became publicly formalised. As the scarcity of (raw) materials remained after World War II, the 'German' system of recovery was kept in place, which has resulted in various material-specific Dutch collection schemes. On the other hand, the amount of general household waste that municipalities collected continued to grow after World War II so that municipalities got more difficulty finding sufficient landfill capacity. However, it lasted until the 1970s before alternatives to the dumping of waste, such as recycling or incineration, were seriously considered, not only because of capacity problems, but also because of growing environmental concerns. Scandals about toxic waste that occurred between 1979 and 1989 were triggers to finally change legislation and the practice of waste treatment. The process of waste treatment did not get centrally organised, but a consultation body was created, in which all stakeholders were represented. Moreover, influenced by legislation from the European Union more emphasis was being put on prevention of waste and reuse, which eventually has led to the adoption of the material supply chain perspective. This perspective fits in well with the other (Dutch) tradition of the recycling of specific materials so that both traditions finally got linked.

One lesson of this case is that 'drastic' events present windows of opportunity for creating a sense of urgency to speed up transitions. Another lesson is that common social needs help people prioritise necessities to keep the system functioning. A different lesson is that individual initiatives can have an impact at the network and system levels, which is an example of emergence in this system. In the Netherlands, such an impact from private initiatives can be large and it shows the Dutch 'culture', in which there is strong practice of creating private initiatives for dealing with social matters.

Our main conclusion is that it is possible to design a method and a framework for analysing transitions of socio-technical systems. This framework covers four basic aspects: the role of technology in transitions, the adaptation of societies to different situations, the interaction between actors, and the institutions linking society and technology. Furthermore, this framework has been designed in such a way that it offers the possibility of being extended with other perspectives dealing with transitions. As this framework, the case study design and the step-by-step modelling have been verified and validated with two different case studies, we believe these research tools will enable the study of transitions at large in a structured and systematic way. While the ambition is to foster cross-discipline learning among the studied perspectives which deal with processes of change, this attempt tries to open up the discussion about other disciplines also dealing with processes of change.

We further conclude as to the dynamics of transitions. It appears that all three levels that we have distinguished are needed in a transition. Drastic events only are not sufficient for a transition, neither are actions taken by individual actors, as both need to be incorporated at the network level. Moreover, a technological change does not lead to a transition if social acceptance lacks. In 'desired transitions' the government plays a pivotal role, but from our analysis we conclude that government may be capable of influencing such a transition, but not of steering it. An intractable 'problem' is that in such transitions the goals of the social actors are generally different from the government's objectives.

We recommend further study on (1) the role of disruptive technologies (inventions) in transitions, (2) the relevance of spontaneous transitions (new products or services in the market), (3) the influence of social constructions ('culture') in transitions, and (4) the extension of the modelling process towards the actual carrying out of simulation.

Finally, to better understand transitions, it is necessary to close the knowledge gaps of transition analysts, decision makers and transition managers. Hopefully, this thesis contributes to that goal with the consolidation of four different perspectives into a single method and framework. Eventually, with the closure of all knowledge gaps it could be possible to influence transitions.

Resumen

Las transiciones son procesos de cambio que siempre han ocurrido en todas las sociedades. El hombre dejó de ser nómade para volverse sedentario, la producción de bienes pasó de la artesanía a la producción en masa, la comunicación a distancia ha pasado de esperar meses por una respuesta para volverse casi instantánea. Algunos de estos cambios han dado lugar a nuestra actual infraestructura, como el ferrocarril o las telecomunicaciones. Estos cambios en la sociedad se han desarrollado tradicionalmente a lo largo de largos períodos de tiempo, sin un objetivo específico común que lidere estas transiciones. Sin embargo, en los últimos tiempos, las sociedades quieren manejar los cambios necesarios para salvaguardar su funcionamiento y su supervivencia: ellas desean asegurar los suministros para cubrir las necesidades básicas, cuidar el nivel de empleo, los servicios de salud y el bienestar de sus pueblos, así como hacer frente a los efectos de la huella ecológica humana. Lograr una transición tan deseada no es una tarea sencilla, por lo que se plantean varias preguntas sobre cómo lograr esos cambios. Preguntas fundamentales son: ¿Qué es una transición? ¿Cómo podemos descifrarlas? ¿Hasta qué punto se pueden influenciar las transiciones?

En este trabajo de investigación hemos tratado de abordar estas cuestiones con un enfoque en las transiciones que implican (entre otras cosas) los aspectos tecnológicos, en particular en el que las infraestructuras juegan un papel importante. Para ello, hemos desarrollado un marco conceptual adecuado para este tipo de casos, así como un método para desentrañar la complejidad de las transiciones de estas sociedades, conceptualizadas en esta tesis como sistemas socio-técnicos. Estos sistemas combinan la sociedad (constituida por individuos u organizaciones) y la tecnología (conformada por los artefactos con las técnicas producidas y utilizadas), las cuales se influyen mutuamente y dan forma a la futura infraestructura.

Para empezar a entender lo que son las transiciones, se realizó una revisión de la literatura (Ver capítulo dos) que se centró en (1) el papel de la tecnología en las transiciones (punto de vista tecnológico), (2) la adaptación de las sociedades a situaciones diferentes (perspectiva social), (3) la relación entre los actores dentro de las sociedades (la perspectiva del actor-red), y (4) las instituciones de vincular la sociedad y la tecnología (la economía institucional). Como estas perspectivas abordan las transiciones según las convenciones de sus propias disciplinas (y por lo tanto se enfocan sólo en esos puntos), estas no son derivables las unas de las otras. Sin embargo, tienen en común: (1) la perspectiva multi-nivel para analizar las transiciones, que comprende al menos un nivel de sistema y otro de agente, (2) la interacción entre actores, redes y el sistema, (3) los actores, que pueden ser un "motor" de las transiciones, y (4) el uso de un mayor nivel de agregación para observar los resultados de los cambios introducidos.

Para desentrañar las transiciones, hemos utilizado las importantes características de las perspectivas anteriormente nombradas para desarrollar una explicación general de las transiciones de los sistemas socio-técnicos. De esta manera se aborda el carácter multidisciplinario de las transiciones. El capítulo 3 introduce la definición de lo que son las transiciones de los sistemas socio-técnicos, define un conjunto básico de niveles de agregación y elementos necesarios para describir las transiciones dispuestas en un marco de análisis, presenta un método para capturar la riqueza de una transición en un diseño de caso de estudio y el modelado cualitativo de las relaciones causales y de los agentes. En esta investigación, transiciones son procesos a largo plazo de transformación social y tecnológica de un estado de equilibrio dinámico a otro. Las "transiciones deseadas" en específico pretenden alcanzar ciertos objetivos sociales comunes, los cuales son establecidos para facilitar la supervivencia de la sociedad y se producen cuando la función de una (parte

de) una sociedad se considera en situación de riesgo. Se propone primero un marco analítico, que distingue tres niveles conceptuales (Ver figura b):

a. Sistema: como la resultante de varias redes de agentes conectados y sus tecnologías. El sistema se caracteriza por los rasgos culturales. Las fuerzas apremiantes, aquí llamadas 'acontecimientos drásticos', pueden inducir o acelerar la transición del sistema.
b. Red: como el agregado de los actores y sus tecnologías conectados por patrones de interacción. Estos patrones son reglas que los actores utilizan para interactuar entre sí. Al interactuar, se crean redes de actores con el fin de intercambiar recursos para la transición que se produzca. Aquí se presta atención a los aspectos regulatorios y tecnológicos, así como la organización político-administrativa dentro del sistema.
c. Agente: como el elemento más pequeño del sistema. Los actores, aquí conceptualizados como agentes, son la fuente del cambio. Los actores juegan un papel particular en las transiciones (especialmente en las deseadas) en función de sus intereses, prioridades y capacidades. Los actores identificados como relevantes son: el gobierno, los productores, los facilitadores, los consumidores y los intermediarios de la infraestructura. Las organizaciones sociales y los institutos de investigación juegan un rol secundario en las transiciones.

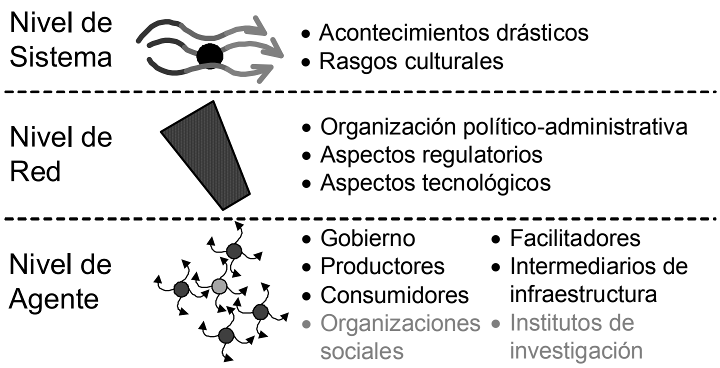


Figura b: El marco teórico de sistema-red-agentes para el análisis de las transiciones

Dentro de este marco teórico, una transición se puede originar en cualquiera de los niveles anteriormente mencionados. En el caso de una transición deseada, esta es acelerada por la aparición de un acontecimiento drástico, afectando a la situación actual del sistema. De esta manera, los mecanismos de interacción existentes llegan a ser inadecuados. Los actores reaccionan introduciendo cambios en sus rutinas. Si los actores están de acuerdo en estas nuevas formas de interacción, se producen cambios en las redes existentes, con nuevas reglamentaciones, nuevas tecnologías o nuevos acuerdos económicos dentro del sistema político-administrativo existente. A su vez, un nuevo estado a nivel de sistema se origina basado en los cambios en los niveles de agente y de red.

La complejidad de un sistema de transición apela al uso de casos de estudios, el cual se justifica por la necesidad de comprender cómo y por qué las transiciones suceden. Se propone un diseño de caso de estudio que indica qué tipo de información debe ser recopilada y la manera de analizarla con el marco teórico diseñado. El caso analizado sirve de base para el modelado cualitativo, que se utiliza con fines de comparación, evaluación y comunicación, y ayuda a sentar las bases para la elaboración de modelos cuantitativos.

Proponemos el uso de un enfoque progresivo que primero transforma la riqueza de un caso particular en causas y efectos, utilizando los principios de la Dinámica de Sistemas. Luego, estas causas y efectos se detallan al nivel de agentes, utilizando los principios del modelado basado en agentes.

En el capítulo 4, el marco teórico y el método de estudio diseñados se aplican a un caso relacionado con el consumo de recursos naturales. Este primer caso es uno al inicio de una cadena de suministro (distinta materia prima para producir combustible para el transporte): la transición hacia el etanol de caña de azúcar como combustible para vehículos ligeros en Brasil. Esta transición, que tiene sus orígenes a inicios del siglo XX con la adición de cinco por ciento de bio-etanol en la gasolina, recibió el impacto de la crisis del petróleo y la caída del precio del azúcar en los años setenta como acontecimientos drásticos. Estos eventos produjeron la creación de programas gubernamentales para la elaboración de los combustibles alternativos basados en el alcohol, gasóleo y carbón. Rápidamente los esfuerzos se centraron en la producción de bio-etanol por la sobreproducción de caña de azúcar, a lo que se añadió la adaptación de los vehículos ligeros para funcionar en base a bio-etanol. Luego de más de una década del funcionamiento, el programa Pro-Alcohol fue cancelado debido a la falta de fondos sumado a la caída de los precios del petróleo y la sequía que afectó la producción de caña de azúcar. Sin embargo, el bio-etanol continuó siendo mezclado con la gasolina porque pasó a reemplazar el plomo utilizado para adecuar el octanaje de la gasolina. La aparición del vehículo Flex-Fuel a inicios del siglo XXI permitió un resurgimiento del uso del bio-etanol de forma espontánea, porque se hizo posible que los consumidores eligieran en la estación de servicio el tipo de combustible a utilizar, y no más qué tipo de vehículo comprar.

Una de las lecciones de este caso es que la concentración de todos los esfuerzos en un puñado de alternativas junto a los instrumentos económicos como subsidios, préstamos o impuestos, ayudó a reducir la incertidumbre de los diferentes actores. Los actores pueden de esta manera concentrarse mejor en sus funciones principales. La experiencia de la introducción del bio-etanol en Brasil es un ejemplo de cómo puede evolucionar la transición como resultado de acontecimientos drásticos y también luego de acciones individuales de los actores. Sin embargo, si cualquiera de estas lecciones se aplica en otros lugares, se debe prestar atención a las diferencias con la situación brasileña, para superar las dificultades del trasplante institucional de las lecciones aquí obtenidas. La aplicación del marco teórico y el método a este caso ha permitido verificar la identificación de los elementos necesarios para describir las transiciones. El resultado de esta verificación ha resultado en la expansión del tipo de las relaciones sociales entre los actores dentro del marco teórico.

En el capítulo 5, el marco teórico modificado y el método de estudio se validan para su facilidad de uso mediante la aplicación a un caso relacionado con la eliminación de los materiales utilizados. Este caso se encuentra al final de una cadena de suministro (la transformación de la basura en materia prima o productos nuevos): la transición hacia un enfoque de cadena de suministro en el tratamiento de los residuos de los hogares en los Países Bajos. Esta transición tiene sus bases en las dos trayectorias paralelas para el tratamiento de los residuos: la colección hecha por la municipalidad para ser dispuesta en botaderos y la recolección hecha por los ropavejeros para su posterior uso o reventa. La segunda guerra mundial en particular trajo consigo la formalización del reciclaje hecho por los ropavejeros y su ampliación a diversos materiales, como metales, cáscaras y huesos. Esta formalización fue realizada durante la ocupación alemana con el fin de obtener suficiente materia prima para sus procesos productivos. La escasez de materia prima en el periodo de la reconstrucción hizo que el reciclaje se mantuviera. Esto no impidió el aumento de la producción de residuos, lo cual puso presión en el sistema de tratamiento de residuos ya que el limitado espacio disponible no permitía la expansión de los botaderos. No fue hasta los años setenta en que la legislación fue cambiada para estimular el concepto de la protección del medio ambiente por medio de la reducción de residuos y el uso de tratamientos alternativos antes de la disposición final de desechos. Los efectos del uso de prácticas (uso de botaderos o incineración de residuos) sin la suficiente supervisión pasaron la factura a través de escándalos que destaparon la gravedad de la polución ocasionada. Las medidas para remediar los daños han sido variables en tiempo pero todas han tratado de descontaminar el área afectada de un modo u otro. A fin de homologar las diferentes prácticas a nivel nacional, se creó un órgano consultivo para estimular las nuevas prácticas, monitorear el progreso de los programas y evaluar los resultados alcanzados. Asimismo, el gobierno y los empresarios lograron acuerdos para tratar el uso de empaques y su desecho. La política a nivel europeo no fue ajena a este problema y emitió normas que apoyaron la legislación hecha en los Países Bajos. En el nuevo milenio, la perspectiva sobre el tratamiento de residuos cambió para ser más proactiva: se tratarían los desechos como una cadena de suministros, tratando de aprovechar al máximo los materiales existentes como materia prima o para la producción de energía y minimizando el desecho irreducible.

Una de las lecciones de este caso es que los acontecimientos drásticos son ventanas de oportunidad para la creación de un sentido de urgencia para acelerar la transición. Otra lección es que las necesidades comunes ayudan a la gente priorizar las necesidades sociales para mantener el funcionamiento del sistema. Una lección distinta es que el éxito de las iniciativas individuales, como la introducción del *'glasbak'* (contenedor público de vidrio), es un ejemplo de la capacidad de surgimiento de los actores en este sistema: esto es posible porque dentro de la cultura de los Países Bajos cada individuo tiene la oportunidad de crear y realizar alternativas para tratar los asuntos sociales.

Nuestra principal conclusión es que es posible diseñar un marco teórico para el análisis de las transiciones de los sistemas socio-técnicos. Este marco teórico abarca cuatro aspectos básicos: el papel de la tecnología en las transiciones, la adaptación de las sociedades a las diferentes situaciones, la interacción entre los actores del sistema y las instituciones que enlazan la sociedad y la tecnología. Además, este marco ha sido diseñado de tal manera que ofrece la posibilidad de ser ampliado con otras perspectivas que se ocupan de las transiciones. Este marco teórico, el diseño del caso de estudio y el modelado paso a paso se han verificado y validado con dos casos de estudio, por lo cual creemos que estas herramientas de investigación permitirán el estudio de las transiciones en general, y las deseadas en particular, de una manera estructurada y sistemática. Mientras que el objetivo es fomentar el aprendizaje trans-disciplinario entre las perspectivas aquí estudiadas que se ocupan de los procesos de cambio, este intento trata de abrir la discusión acerca de qué otras disciplinas también se ocupan de los procesos de cambio.

Se recomienda continuar el estudio realizado en esta tesis con respecto a (1) el papel de las tecnologías de punta (invenciones) en las transiciones, (2) la relevancia de las transiciones espontáneas (nuevos productos o servicios en el mercado) o de gobernabilidad (cambios legislativos), (3) la influencia de las construcciones sociales (cultura) en las transiciones y (4) la extensión del proceso de modelado para efectuar la simulación.

Para comprender mejor las transiciones, sobre todo las deseadas, es necesario cerrar las brechas de conocimiento de los analistas de la transición, para que ellos puedan ayudar a los tomadores de decisiones y gestores de la transición. Esperemos que esta tesis contribuya con el posicionamiento de cuatro puntos de vista estudiados en un marco teórico para la comprensión de las transiciones. Finalmente, con el cierre de las brechas de conocimiento, será posible comprender las transiciones y obtener lecciones para ejercer alguna influencia en ellas.

Samenvatting

Transities zijn veranderingsprocessen die zich door de geschiedenis heen hebben voltrokken in alle samenlevingen. Mensen waren eerst jagers en verzamelaars om vervolgens sedentair te gaan leven, de productie van goederen gebeurde eerst ambachtelijk maar inmiddels veelal in massaproductie, en waar men vroeger bij de communicatie over langere afstand misschien wel maanden moest wachten op een antwoord, komt dat nu vaak onmiddellijk. Een aantal van zulke veranderingen heeft geleid tot onze huidige infrastructuren, zoals de spoorwegen of de telecommunicatie. Dit soort maatschappelijke veranderingsprocessen kosten meestal een lange tijdsperiode en voltrekken zich in het algemeen 'spontaan', zonder een bewust vastgesteld doel. In de laatste jaren echter proberen samenlevingen steeds vaker zulke maatschappelijke veranderingen te sturen om zo hun functioneren en voortbestaan te verzekeren. Ze richten zich dan op het verzekeren van de voorziening in de basisbehoeften van hun bevolking, het behoud van werkgelegenheid, gezondheidszorg, het welzijn van de bevolking, of op het beheersbaar houden van de effecten op het milieu. Hoe sterk de wens ook is om zo'n veranderingsproces ('transitie') te ondergaan, het blijkt niet eenvoudig om dat ook echt te realiseren. Rond zulke transities dienen zich meteen enkele fundamentele vragen aan, zoals: wat zijn 'transities' precies, hoe ontwikkelen die processen van verandering zich, en in hoeverre kan men zo'n proces beïnvloeden of zelfs sturen?

In dit onderzoek zijn we ingegaan op deze vragen, waarbij de focus lag op transities waarbij technologische aspecten een belangrijke rol spelen. Voor dit soort transities hebben we een conceptueel raamwerk ontwikkeld om zo'n transitie goed te kunnen beschrijven en ook een methode om zulke complexe veranderingsprocessen systematisch te kunnen onderzoeken. In ons raamwerk beschouwen we de systemen die een transitie doormaken als een socio-technisch systeem: dit is combinatie van een sociaal deelsysteem (bestaande uit personen en organisaties) en een technisch deelsysteem (bestaande uit fysieke componenten en de technieken waarmee we die gebruiken), die onderling wisselwerken en die wisselwerking bepaalt uiteindelijk hoe het systeem zich ontwikkelt.

Om een idee te krijgen wat transities eigenlijk zijn hebben we een literatuurstudie gedaan (zie hoofdstuk 2). Daarbij hebben we gekeken naar verschillende perspectieven op transities die in de wetenschappelijke literatuur bestaan: (1) het technologische perspectief richt zich op de rol van technologie in transities; (2) het sociologische perspectief kijkt naar sociale verandering; (3) het actor-netwerk perspectief beschouwt de relaties tussen actoren binnen de maatschappij; (4) in het perspectief van de institutionele economie focust men op de instituties die de maatschappij en de technologie verbinden. Deze perspectieven komen voort uit verschillende wetenschappelijke disciplines en kennen dan ook ieder een eigen terminologie, focus en benaderingswijze. Ondanks de verschillen hebben ze toch kenmerken gemeenschappelijk: de perspectieven (1) onderscheiden meerdere niveaus binnen het bestudeerde systeem, in ieder geval een systeemniveau en een actorniveau, (2) houden rekening met wisselwerking tussen actoren, hun netwerken en het systeem, (3) erkennen dat actoren een motor kunnen vormen voor transitieprocessen, en (4) spreken van een transitie als op het systeemniveau een wezenlijke verandering is opgetreden.

Om socio-technische transities goed te kunnen begrijpen hebben we een conceptueel raamwerk ontwikkeld, gebaseerd op de gemeenschappelijke kenmerken van de bestudeerde perspectieven. Op deze manier kunnen we recht doen aan het multidisciplinaire karakter van zulke transities. In hoofdstuk 3 geven we eerst onze definitie van 'socio-technische transities'. Vervolgens geven we aan welke niveaus nodig zijn bij de beschrijving van een socio-technisch systeem in transitie en wat de relevante 'elementen'

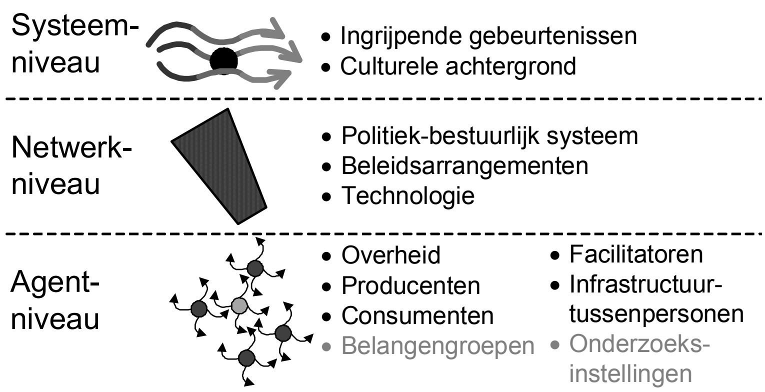
zijn op elk niveau. Met dit conceptuele raamwerk in ons achterhoofd stellen we daarna een methode voor om transities te bestuderen door middel van *case studies*.

In ons onderzoek verstaan wij onder 'socio-technische transities' processen van een technologische en sociale verandering op lange termijn waarbij een systeem van de ene dynamische evenwichtstoestand overgaat naar een ander evenwicht. Een bijzondere categorie vormen de 'gewenste transities': hieronder verstaan we transities waarbij de overheid heel duidelijk de gewenste richting heeft aangegeven en waarbij verwacht kan worden dat de overheid ook zal proberen het transitieproces te beïnvloeden.

In het door ons voorgestelde conceptuele raamwerk onderscheiden we drie niveaus, met elk zijn relevante 'elementen' (zie ook Figuur c):

a. Systeemniveau: dit betreft het hele socio-technische systeem, dat gezien kan worden als opgebouwd uit verschillende netwerken; een belangrijk kenmerk van dit niveau vormt de culturele achtergrond; verder is relevant dat een systeem geconfronteerd kan worden met 'ingrijpende gebeurtenissen' (zoals een crisis, schandaal of oorlog), die een transitie op gang kunnen brengen, kunnen versnellen of vertragen.
b. Netwerkniveau: dit niveau bestaat uit de 'netwerken' van relaties, verbindingen en interacties tussen de elementen op het laagste aggregatieniveau (van de 'agenten'); de meest relevante netwerken betreffen de beleidsarrangementen, technologie en ook het politiek-bestuurlijke systeem.
c. Agentniveau: dit is het laagste aggregatieniveau en bestaat uit de individuele 'elementen' van het socio-technische systeem, zoals de 'actoren' binnen het sociale deelsysteem en de fysieke componenten in het technische deelsysteem. Binnen dit niveau worden de activiteiten van actoren zichtbaar en de invloed die ze (kunnen) hebben op het netwerk- en eventueel het systeemniveau. De meest relevante actoren in een 'gewenste transitie' blijken te zijn: de overheid, producenten, consumenten, partijen die zorgen voor een infrastructuur tussen producenten en consumenten, en 'facilitatoren'. De actoren 'belangengroepen' en 'onderzoeksinstituten' lijken vooral een indirecte invloed te hebben in een socio-technisch transitieproces.

Naar de drie onderscheiden niveaus hebben we dit conceptuele raamwerk het Systeem-Netwerk-Agent-raamwerk genoemd (in het kort: SyNeA-raamwerk).



Figuur c: Het conceptuele **Sy**steem-**Ne**twerk-**A**gent-raamwerk voor de analyse van transities

Een transitie kan 'beginnen' op elk van de niveaus van het SyNeA-raamwerk. Bij 'gewenste transities' (waar we in dit proefschrift vooral naar gekeken hebben) werkt een ingrijpende gebeurtenis vaak als aanjager van een transitie, omdat het de bestaande orde op een of andere manier verstoort. De bestaande 'netwerken' voldoen niet meer helemaal en de actoren reageren door hun gedrag en relaties te wijzigen. Dit kan tot nieuwe patronen van interactie en relaties leiden, wat betekent dat netwerken veranderen: er komt nieuw beleid, nieuwe technologie, andere contractuele relaties of een andere inrichting van het politiek-bestuurlijke systeem. Dit kan uiteindelijk weer resulteren in een verandering van de kenmerken van het systeem: de transitie is 'compleet'.

Vanwege de complexiteit van socio-technische systemen in transitie ligt het voor de hand om *case studies* te gebruiken om bestuderen hoe en waarom zulke transities gebeuren. Om dit systematisch aan te (kunnen) pakken hebben we een methode voorgesteld die helpt bij de keuze van de *case study*, het verzamelen van informatie en de wijze waarop de *case* geanalyseerd kan worden met behulp van het SyNeA-raamwerk. Bovendien geeft de methode aan hoe de bestudeerde *case* vertaald kan worden naar een (simpeler) 'model', dat gebruikt kan worden voor evaluatie, communicatieve doeleinden of een vergelijking met andere *cases*. Ook kan dit model als basis dienen voor een kwantitatief model, bijvoorbeeld met het oog op computersimulaties. Dit bereiken we door een stapsgewijze aanpak: eerst vertalen we de beschikbare informatie over de *case* in de belangrijkste causale relaties voor die *case*, daarbij gebruik makend van de benadering van *System Dynamics*; vervolgens verbinden we die causale relaties met de 'agenten' op het agentniveau, daarbij gebruik makend van de traditie van agent-gebaseerd modelleren.

Om een beter begrip te krijgen van transities hebben we twee uitgebreide *case studies* uitgevoerd. De eerste *case study* betreft de transitie naar de gedeeltelijke vervanging van benzine door bio-ethanol (alcohol) als autobrandstof in Brazilië. Deze *case study* is behandeld in hoofdstuk 4 en vormt de eerste praktische test van de methode en het SyNeA-raamwerk.

Dit transitieproces begint in de eerste helft van de 20e eeuw toen Brazilië een verplichting invoerde om 5% ethanol toe te voegen aan benzine. Wanneer in de jaren '70 de olieprijs stijgt en er sprake is van overproductie van suikerriet, zet de Braziliaanse overheid programma's op om het gebruik van alternatieve brandstoffen (bio-ethanol, diesel, of kolen) te stimuleren. Al snel concentreert men de steun op de productie van bio-ethanol uit suikerriet vanwege het overschot aan suikerriet en de beschikbaarheid van auto's die op bio-ethanol kunnen rijden. Na ruim tien jaar zet de Braziliaanse overheid het steun-programma echter stop omdat de overheid te weinig geld heeft, de olieprijs inmiddels is gezakt en de suikerrietproductie gedaald is door een periode van droogte. Hierdoor begint het aandeel bio-ethanol te dalen, hoewel bio-ethanol een rol houdt als de vervanger van lood in benzine. Met de komst van de *'flex fuel'* auto's aan het begin van de 21e eeuw krijgt het gebruik van bio-ethanol een tweede leven. Deze auto's kunnen zowel op ethanol als op benzine rijden, zodat de eigenaar de flexibiliteit heeft om aan de pomp te beslissen welke brandstof hij tankt, bijvoorbeeld afhankelijk van de prijzen van het moment. Doordat steeds meer consumenten in Brazilië zulke *flex fuel* auto's kopen, stijgt het aandeel bio-ethanol de laatste jaren weer flink.

Een van de lessen uit deze casus is dat de concentratie van de steunmaatregelen op slechts een paar alternatieven succesvol was omdat het de onzekerheid van maatschappelijke partijen verkleint: zij kunnen zich op die alternatieven concentreren. Daarnaast laat deze casus zien dat ingrijpende gebeurtenissen (hoge olieprijs en overproductie van suikerriet) een transitie kunnen aanjagen, maar ook dat een verandering het gevolg kan zijn van acties van bedrijven (de introductie van de *flex fuel* auto) in combinatie met het gedrag van de consumenten (die massaal zulke auto's kopen).

Overigens moet men voorzichtig zijn om de ervaringen uit Brazilië te 'verplaatsen' naar andere landen, gezien de verschillen tussen landen (systemen). De *case study* vormde ook een test ('verificatie') van het model en het SyNeA-raamwerk. Op basis van de ervaringen met deze *case study* hebben we het oorspronkelijk voorgestelde SyNeA-raamwerk iets bijgesteld: we maken nu onderscheid tussen actoren met directe en indirecte invloed op een transitie en hebben de typen relaties op het agentniveau uitgebreid.

Dit licht aangepaste conceptuele raamwerk en onze methode hebben we vervolgens toegepast op een tweede *case study*, die beschreven is in hoofdstuk 5. Dit vormt een (nieuwe) test van de bruikbaarheid van de methode en het raamwerk (een 'validatie'). Deze casus gaat over het afvalbeheer in Nederland en beschrijft de transitie naar een 'materiaalketenbeleid' voor afval, waarbij onze focus ligt op huishoudelijk afval. In deze transitie komen uiteindelijk twee parallelle 'tradities' samen: aan de ene kant de traditie van het inzamelen van bepaalde materialen, zoals vodden of organisch afval, voor hergebruik, oorspronkelijk door de voddenboer of schillenboer; aan de andere kant de traditie dat gemeenten (in het bijzonder de steden) huisvuil ophaalden om hygiënische redenen, dat ze oorspronkelijk overigens gewoon dumpten op de vuilstort. Tijdens de bezetting van Nederland door Duitsland in de Tweede Wereldoorlog (1940-1945) vindt een belangrijke verandering plaats: voor het eerst gaat de (centrale) overheid zich bemoeien met afval, in het bijzonder het hergebruik van materialen. De aanleiding hiervoor is de schaarste aan materialen tijdens de oorlog. De overheid gaat de inzameling van verschillende materialen (zoals metalen of beenderen van dieren) coördineren en zet daar (onder andere) de voddenboeren voor in. Omdat de schaarste aan materialen ook na de oorlog aanhoudt, blijft het systeem van inzameling en hergebruik ook na de Duitse bezetting in tact. In de loop der jaren ontwikkelen zich zo voor verschillende materialen (zoals papier en glas) goedwerkende systemen van recycling. Overigens stijgt – met de groei van de welvaart – de hoeveelheid 'algemeen' huisvuil in de decennia na de oorlog sterk, waardoor de gemeenten op een gegeven moment tegen de grenzen van de capaciteit van hun vuilstort aanlopen. Daarbij komt dat men in de jaren '70 ook aandacht krijgt voor de effecten van vuilstort op het leefmilieu. Er wordt dan gepleit voor het verminderen van afval en alternatieven voor vuilstort (zoals vuilverbranding en recycling). Echte veranderingen komen er echter pas na enkele schandalen in de jaren '80 (vervuilde vuilstortlocaties en ook schadelijke stoffen in de uitstoot van vuilverbrandingsinstallaties), hoewel de overheid dan niet kiest voor centralisatie van afvalbeheer, maar (slechts) voor het instellen van een adviesorgaan waarin alle relevante organisaties betrokken zijn. Ook regelgeving van de Europese Unie dwingt Nederland om meer aandacht te geven aan het verminderen van afval en hergebruik. Dit zorgt ervoor dat de Nederlandse overheid ook voor het 'restafval' meer gaat kijken naar de daarin aanwezige materialen om vervolgens de hele 'keten' van dat materiaal aan te pakken, gericht op maximaal hergebruik. Dit sluit goed aan bij de beschreven traditie van het hergebruik van materialen als papier en glas in Nederland. Inmiddels is er ook voor plastic een – succesvol – systeem van inzameling (en hergebruik) ingevoerd.

Een van de lessen uit deze casus is dat ingrijpende gebeurtenissen sleutel-momenten (kunnen) vormen in een transitie, zoals de omstandigheden van de Tweede Wereldoorlog en later de gifschandalen rond afval. Die schandalen zorgden voor een gevoel van urgentie waardoor de bestaande routines doorbroken konden worden. Ook laat deze casus zien dat (kleine) initiatieven een groot effect kunnen hebben: de eerste glasbak was een idee van twee dames en, na het succes ervan, verspreidde het fenomeen zich over heel het land. Zoiets past bij de cultuur van Nederland, waar een rijke traditie bestaat van 'maatschappelijk initiatief'.

Onze belangrijkste conclusie aan het eind van het proefschrift is dat het mogelijk is gebleken om zowel een onderzoeksmethode als een conceptueel raamwerk te ontwerpen voor socio-technische transities, die toepasbaar en bruikbaar zijn. De voorgestelde methode en raamwerk houden rekening met de verschillende relevante aspecten van zulke transities (technologie, sociale ontwikkelingen, de interactie tussen actoren, en de 'instituties' in het systeem). Bovendien zijn methode en raamwerk zodanig ontworpen dat ze als basis kunnen dienen voor modelleren en computersimulatie.

Uit de bestudeerde literatuur en de twee gedane *case studies* kunnen we ook enkele conclusies trekken over (het verloop van) transities. Zo blijkt dat de verschillende onderscheiden niveaus 'nodig' zijn voor een transitie: een ingrijpende gebeurtenis alleen is niet voldoende, net zo min als acties van actoren, want deze moeten wel op netwerkniveau 'overgenomen' worden. Bovendien is een technologische verandering alleen niet genoeg om daadwerkelijk tot een transitie te leiden, omdat sociale acceptatie ook steeds nodig is. Bij 'gewenste transities' speelt de overheid een belangrijke rol omdat ze een bepaalde (richting van de) transitie als beleidsdoel heeft gesteld. Op basis van ons onderzoek concluderen we echter dat de overheid zo'n transitie weliswaar kan beïnvloeden, maar het proces zeker niet kan controleren. Een 'probleem' bij zulke gewenste transities is dat de verschillende maatschappelijke actoren zich niet per se op dezelfde doelen als de overheid richten.

Op basis van dit proefschrift bevelen we aan om voor de volgende onderwerpen verder onderzoek te doen: (1) de rol van uitvindingen die tot een radicaal ander systeem zouden leiden; (2) het verloop van *spontane* transities (dit zijn transities die niet bewust 'gepland' zijn, zoals de opkomst van mobiele telecommunicatie); (3) de invloed van 'cultuur' en de daarmee samenhangende manier waarop actoren met elkaar omgaan; (4) het uitvoeren van verschillende (typen) simulaties op basis van de door ons voorgestelde methode en raamwerk.

Om een beter begrip te krijgen van transities, in het bijzonder gewenste transities, is het nodig om bestaande lacunes in kennis te vullen en daarmee de hiaten tussen onderzoekers van transities, beleidsmakers en degenen die een transitie willen sturen, aan te pakken. Het is onze hoop dat dit proefschrift daaraan kan bijdragen doordat we de verschillende bestaande perspectieven op transities in één raamwerk hebben geïntegreerd.

Curriculum Vitae

Catherine M. Chiong Meza was born to the family of Victoria Meza de Chiong and Francisco Chiong, on September 19th, 1975, in Lima, Peru.

She attended her primary and secondary school at the private girls school *San Jorge de Miraflores*, between 1982 and 1992, in Lima, Peru.

She studied at the *Universidad de Lima* (Peru) and obtained her BSc degree in Industrial Engineering in December 1997, which focused on the organisation and optimisation of production processes and services, logistics, and management of quality systems. She graduated at the eighth place of the class of 1997-II.

After her graduation, she worked in Peru for the *Santander Central Hispano-Perú* Bank of the Santander Group for more than four years. During this period, she ran and was involved in several projects focusing on process redesign and information systems design for internal and external clients, especially the government. In 2000, she also obtained her Professional License as Engineer, granted by the Peruvian government.

In 2005, she obtained her MSc degree *(cum laude)* in "Engineering and Policy Analysis", at Delft University of Technology in the Netherlands. Her graduate research project addressed the consequences of investment decisions on the production capacity of the Dutch Paper and Board Industry, using System Dynamics as the research methodology.

In 2006 she joined Delft University of Technology as a PhD candidate at the Faculty of Technology, Policy and Management to study the transition of socio-technical systems. In addition to doing her research, she was during that time lecturer of the Master's course "Research Methods and Data Processing" (in English), supervised various working groups within the Master's courses "Multivariate Modelling" and "Research Methods and Data Processing" (both in English), the Bachelor's courses "Project research and data processing in the EWI domain" and "Continuous Modelling Project" (both in Dutch), and supervised Master's and Bachelor's theses.

In 2009 she married Hamilcar Knops, and their son Enrique was born in 2010.

Since September 2011, she has joined the Rathenau Institute in the Hague, the Netherlands, as a senior researcher of quantitative research information.

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