Sociotechnical Scenarios (STSc)

Development and evaluation of a new methodology to explore transitions towards a sustainable energy supply

Report for NWO/NOVEM

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B. Elzen, F.W. Geels, P.S. Hofman

University of Twente: Centre for Studies of Science, Technology and Society

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1 Summary

This report describes the development and evaluation of a new methodology for exploration of a transition to a sustainable electricity supply: the sociotechnical scenario (STSc) method. Sociotechnical scenarios specifically take into account the complex and multifaceted nature of transitions (also called system innovations) which not only requires the development and use of new technologies, but also involves changes in user practices, policy and regulation, infrastructure, networks, and institutional change. The principal aim of this report is to demonstrate the promise of sociotechnical scenarios as a tool for transition policy by providing insight in the various complex processes at work in system change, in the driving forces and in the main elements of promising combinations of technological, societal and institutional change for transition paths.

The development of the new STSc scenario method is based on an analytical framework to describe and explain transitions. This framework is based recent insights in the dynamics of sociotechnical development, in particular the 'transition theory' co-developed by the Twente research group involved in this project. At the heart of the transition theory are three 'levels' and the interactions between them, the *socio-technical landscape*, the *socio-technical regime* and *technological niches.* Technological transitions are about major changes in socio-technical regimes that partly result from interactions with the other two levels. Innovation within a socio-technical regime is typically incremental. Under specific circumstances, however, development within the socio-technical landscape and/or in niches can get linked to the regime to induce developments that eventually lead to a drastic reform, i.e. a transition.

A sociotechnical scenario describes possible future developments in terms of this multi-level theory and makes use of patterns and mechanisms that have been identified in historical research on transitions. These include changing user patterns, links between technical development and political development, links between various regimes enabling certain niche developments, etc. The STSc-method can produce a wide variety of different outcomes, but, more importantly, since the scenarios describe development processes (and not just outcomes) it allows to explore *why* developments lead to certain outcomes. This feature enables use of the method as a stepping stone to inform policies aimed at the realisation of specific (e.g. sustainable) outcomes.

In this report, the method is used to develop two contrasting scenarios that describe possible transitions towards a sustainable electricity system. The first scenario features the large-scale integration of renewables in the electricity regime and is basically a transformation of the current national, fossil based regime to an international electricity regime where various renewable sources take up a significant part of electricity generation and the remaining fossil fuels are part of climate neutral generation routes. Crucial in this scenario are EU policies to develop an international grid and the changeover of security of supply issues from the national to the European level. The second scenario features distributed generation and illustrates the emergence of an alternative electricity regime where the design of the system matches regionally specific demand patterns and uses a variety of energy technologies. Moreover, electricity generation has become more integrated with other functions, especially housing and transport. This path evolves as specific energy technologies serve specific demands in the growing niche markets of the electricity regime.

The differences between the two scenarios are not so much the consequence of the 'simple' development and diffusion of different technologies but much more the result of different actor networks and drivers that become dominant. In the first scenario the traditional power producers utilise gasification technology on a large-scale driven by climate change pressure

and facilitated by EU convergence. Developments in the US initially provide strong stimulus for the development of the nich through its focus on coal gasification. In the second scenario especially energy distribution companies in coalition with gas utilities and other actors seek opportunities to increase their market share by the development of micro-CHP. In a sequence of steps and parallel learning processes this enables the further penetration of micropower based on renewable sources.

The two transition paths and the main factors that determine their course form the basis for policy recommendations. Presenting a number of contrasting STScs to policy makers can make them better aware of the strategic potential of new technologies, including their potential to link up with other technologies and their potential to induce change of user behaviour. In the initial phases of transitions, the emphasis for policy should be on learning how to deal with the complexity and uncertainty inherent in transitions by carefully monitoring developments at different levels, assessing their potential linkages, and adapting policies when required to exploit windows of opportunity. STSc can help to highlight especially those features of socio-technical change that may enable, obstruct or modulate change.

The main finding of this exploratory project is that is indeed possible to build a sociotechnical scenario method on transition theory and that the method can be used as a basis for policy recommendations. Feedback from scholars and policy-makers to our preliminary findings has encouraged us that we are on a promising track. The process of internal and external evaluation has yielded several relevant and constructive comments that can be used for the further development and improvement of the STSc methodology.

Sociotechnical scenarios are not predictions of the future but can help to design more robust transition oriented policies. The two examples of transition paths in this report illustrate that the methodology can indeed lead to scenarios in which a transition emerges, not as a *deus ex machina* but as the result of plausible new linkages under specific conditions. Specific innovations and changing user preferences have been identified that can form the seeds for a transition and thus are good candidates for further development and exploration in the near term. Very importantly, these options should not only be treated individually but possibilities to create links between them should also be explored. Processes of hybridisation and linkages between technologies and specific user preferences are core aspects of transition policy, not just a focus on single technologies. Thus the two scenarios illustrate that the construction of sociotechnical scenarios can not only help to create visions of a sustainable future, it can also help to identify potential transition paths that can lead to such futures.

Thus, this study constitutes the ‘proof of concept’ of the STSc methodology but our own experiences and the feedback collected also point to some difficulties and weak points in the ‘rough version’ of the approach described in this report. These need to be tackled through further research and development for example as defined in a follow-on project that has recently been submitted for funding to NWO/Novem.

2 Introduction

This report presents the results of the development and evaluation of a new methodology for exploration of a transition to a sustainable electricity supply. The project has been funded under the NWO/Novem program energy research. The main goal of this program is to stimulate research into the conditions under which a transition away from the fossil basis of the energy system can take place. This report aims to contribute to this by providing a tool for the exploration of potential transition paths.

The development of a sustainable electricity system not only requires the development and use of new technologies, but also involves changes in user practices, policy and regulation, infrastructure, networks, and institutional change. Processes with changes on all these dimensions are called transitions. Scenarios can be useful as a tool to explore future developments. The complexity and uncertainty of a possible transition to a sustainable electricity system, however, demands a scenario-methodology specifically designed to explore the sociotechnical and long-term nature of transitions. A sociotechnical scenario (STSc) describes a potential transition not only in terms of developing technologies but also by exploring potential links between various options and by analysing how these developments affect and are affected by the strategies (including policies) and behaviour of various stakeholders. A crucial distinction with other methods is that the focus is not on the outcomes but on how these outcomes emerge, i.e. on the transition path. Because of this focus on transition paths the STSc method provides interesting new opportunities to develop policy recommendations on how to induce and influence transitions.

This report develops the new STSc scenario method based on an analytical framework for understanding transitions. This analytical framework is based on recent insights in the dynamics of sociotechnical development, and particularly on ‘transition theory’ developed among others at the University of Twente. The method is subsequently used to develop various scenarios describing potential transitions towards a sustainable electricity system. The method is evaluated through feedback from energy experts (for feedback on the actual scenarios), scenario builders (for feedback on the method), and policy makers (for feedback on usefulness for policy-making). Their comments have been used to define requirements for the development of a next version of the methodology and for further exploration of transition paths.

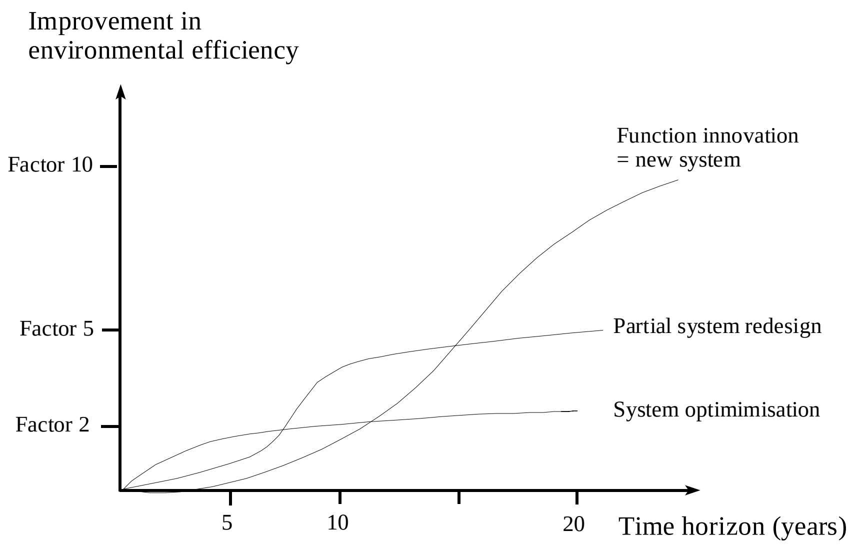
The report is structured as follows. The next chapter underlines the rationale for sociotechnical scenarios and depicts some of the limitations of existing scenario methods to explore transitions. Chapter 3 introduces the theoretical basis for the methodology of STSc followed by an elaboration on this methodology in chapter 4. Chapter 5 provides an example of the construction of sociotechnical scenarios for the electricity domain followed by a reflection and policy recommendations based on this. Chapter 8 evaluates the methodology, the usefulness of STSc for policy, and the usefulness of the method for constructing sociotechnical scenarios. This is followed by recommendations for further research directions and a concluding chapter.

3 Rationale for Sociotechnical Scenarios

3.1 The importance of systems change or transitions

This research starts from the observation that while in the past three decades we have witnessed a flood of energy-oriented innovations and improvements and a dramatic expansion of policies and regulations to reduce carbon emissions, we still are confronted with a potential environmental crisis due to global warming. The perception of the nature of this crisis seems to have changed in the course of decades (as is apparent in the successive national environmental policy plans and energy policy documents). The dominant view has long been that energy saving and increasing efficiency could pave a way out of the climate problem. However, there is now increasing awareness that the core of the climate problem is its fundamental link to established production and consumption patterns along with the use of fossil fuels (for transport, electricity, chemicals) as a core feature. In terms of solutions there is increasing recognition that paths out of the crisis not only involve innovations in current systems leading to system optimisation but that system innovation is required to achieve a drastic reduction of carbon emissions. This is illustrated in the following figure.

Figure 1: Systems optimisation versus systems change (Weterings et al, 1997)



System innovations or transitions not only involve new technologies but also changes in user practices, legislation, policy, infrastructure, networks, and institutions, i.e. they imply a combination of technical and social change. Transitions are complex processes characterised by uncertainty, because often multiple technologies compete and interact.

While transitions are interesting to realise major environmental gains, their complexity and uncertainty pose problems for policy makers. Transitions involve change of an integrated system of technologies and social practices and are characterised by processes of technological hybridisation and forking, for example triggered by changing user preferences or institutional change (e.g. liberalisation of energy markets). Insight in these processes is necessary to design transition policy that complements conventional policies with a long-term focus on promising transition paths. Conventional policies are biased towards the existing system such as technology policy predominantly supporting single technologies that are appraised on their fit with the existing technological system. There is a need to evaluate these short-term policies against the long-term perspective of fundamental change in production and consumption patterns, in order to prevent lock out of promising but yet immature or mismatching technologies or designs.

To assist policy makers with this they need anticipation tools. Traditional technological forecasting methods, however, are not very suited to explore transitions, because they pay virtually no attention to the interaction between technology and society and neglect the role of hybridisation and forking. To remedy these shortcomings our aim is to develop a new tool: Socio-technical scenarios (STSc). STSc are anticipation tools that can assist policy makers to design strategies that take into account the long-term, socio-technical and crooked nature of transitions.

3.2 The lack of appropriate foresighting or scenario methods

In the second half of the 20th century, a range of methods has been developed to formalise and structure anticipation efforts, e.g. trend extrapolation and curve fitting, computer modelling, cross impact analysis, Delphi methods, scenarios and foresight exercises. Each of these methods, however, has some fundamental problems, including:

- Too much attention for quantitative, reductionist methods, and a lack of attention to qualitative aspects. (Coates 1989, 17)
- Forecasting methods assume the future will be too much be like the past. Forecasts are too much based on extrapolations and the assumption of incremental change with too little attention for discontinuity and radical change. (Sapio 1995, 114)
- Forecasting methods focus too narrowly on specific topics, without looking at the broader system. (Coates et al. 1994, 24)
- Forecasting methods are based too narrowly on neo-classical economic approaches. Many technology-scenarios assume a set of technologies on the supply side, characterized by generic aspects such as price, performance and a historically calibrated ‘learning curve’. On the demand side, a homogeneous set of consumers is assumed with fixed preferences, sometimes complemented with government regulations as part of the selection environment. The development and diffusion of technologies is assumed to be economically driven: technologies with higher cost/performance ratios win higher market shares. This conceptualization is not wrong, but limited as it neglects the wider co-evolution aspects. (Leonard-Barton 1988; Nelson 1994 and 1995; Rosenkopf and Tushman 1994).
- Many technology-scenarios look at (emerging) technologies independently. Technical trajectories are analysed and characterised with learning curves as if they were independent. In reality, however, these trajectories influence each other. Interactions between technologies may be competitive, but also more complementary and symbiotic (Pistorius and Utterback 1997).
- Scenarios often have a ‘macro-bias’ (Geels 2002b). This means that the dynamic and outcome of the scenarios depend too much on such macro-aspects (e.g. econonomic growth, environmental awareness, oil price). The ‘logic’ of the scenarios is top-down in the sense that processes and actions at the meso and micro level are determined by macro-elements. The related problem is that the dynamic and outcome are unsurprising and somewhat tautological (Schoonenboom & Van Latensteijn, 1997).

These limitations are also apparent in scenarios focusing on the energy domain. For example Dammers (2000), in his Ph.D., provides an overview of the use of energy scenarios in energy planning in the Netherlands in 1973-1996. He concludes that most energy scenarios present themes that can be calculated with the help of energy models. These are variables and correlations that can be expressed in quantitative terms, such as economic growth, electricity use, needed production capacity, and the emission of harmful substances. Important shortcomings are the absence of contingencies and the lack of attention for societal and political developments (Dammers 2000: 190, 200). Thus, the scenarios are based on extrapolations from the existing economic order and are not based on change processes occurring throughout society that influence developments in energy demand and supply.

To cope with the aforementioned problems, there are several directions of improvement. The first improvement is to include more qualitative elements in the future explorations, even when this leads to methods that are 'looser' (cf. Huss 1988, 378; Simmonds 1989, 67). With regard to technological development this means that attention should not just be given to aggregate variables such as price and performance, but also to aspects like actor strategies, social networks and learning processes.

Secondly, a major direction for improvement is to focus more on radical technological change. A range of analysts identifies this as an important challenge, although they also signal some problems, particularly the lack of appropriate theories (cf. Amara 1988, 395-396; Ayres 1989, 49).

Thirdly, to explore radical technological changes, a broader systemic viewpoint is needed. The future exploration should not focus on individual technologies, but at the interactions between technologies, e.g. competition, complementary technologies, hybridizations. Furthermore, the exploration should not only look at technologies and markets, but also at possible changes in user preferences, policy, cultural changes, infrastructure. These changes do not occur independently, but in interaction. To analyse and explore the co-evolution of these dimensions, a systemic and socio-technical perspective is needed (Murdick and Georgoff 1993, 1; Porter et al. 1991, 17-19).

A fourth direction of improvement is to develop a futures methodology, which allows for meso and micro dynamic, next to macro dynamic. The dynamic and outcome of a futures methodology should not only depend on macro factors, but also on sectoral dynamic, where different actor groups (e.g. firms, users, public authorities, universities) are involved in learning processes and strategic games.

These directions for improvement are increasingly applied in more recent scenario exercises. In an IPCC special report on emissions scenarios (Nakicenovic et al, 2000) a formal approach with different models is combined with a qualitative, narrative apporach. Four storylines are developed to describe the relations between emission driving forces and their evolution and add context for scenario quantification. Each storyline represent different demographic, social, economic, technological and environmental developments (Nakicenovic et al, 2000: 3). While these storylines are clearly more qualititative and have a broader systemic viewpoint they depend largely on macro factors and lack attention for actor strategies, social networks and learning processes. In a more recent IPCC report (2001) this is to some extent acknowledged by reviewing literature that focuses on alternative development pathways that base the transition to balanced and sustainable resource flows on concomitant changes in technologies, institutions, lifestyles and worldviews (IPCC 2001: 96). Taking a certain future state of sustainability as its point of departure, a process of backcasting leads to several possible development paths allowing combinations of technological, social and cultural change. In the Netherlands this backcasting method has been applied and developed in the Sustainable Technology Development Programme (Weaver et al, 2000), in the Sushouse project (Green and Vergragt, 2002) , and in the COOL project (IVM, 2000; Andersson and Tuinstra (2000). Other efforts include a focus on the systems level (e.g. integrated assessment models (van der Sluijs, 1997, 2002; ICIS, 2001), technological roadmapping inititatives that include multiple technologies (such as from EPRI and KEMA), bringing in changing user preferences due to socio-cultural changes (e.g. Weterings et al. 1997); and focussing on bottom-up dynamics of strategies and interactions of actors (e.g. Van Hilten et al. 2000). Sociotechnical scenarios integrate the aforementioned directions for improvement and are grounded on a historical informed theory regarding the nature of transitions. With the development of sociotechnical scenarios our contribution to improve scenarios is specifically concerned with the interaction of processes of social and technological change that can create a sequence of steps towards a transition. These steps can be taken when certain windows of opportunities are exploited that occur through linkages of developments at three different levels: the sociotechnical landscape, regimes and niches (elaborated later in this report).

3.3 The potential multiple functions of STSc to contribute to transition thinking

In our view STSc can have multiple functions, which are also dependent on how the process of constructing sociotechnical scenarios is designed. In this project we have chosen to illustrate the promise of STSc with expert-based STSc mainly because of the limited scope of the project and because the project is concerned with the development of a methodology of the construction of STSc. However, some of the potential functions of STSc can better be realised through an interactive design. We present here some of the main functions we perceive although we will not be able to demonstrate the promise of STSc for all these functions in this report. In follow-up projects there is scope for further development and utilisation of sociotechnical scenarios and we will give some recommendations for this in the final section of this report. At this stage we think there are five potential functions that sociotechnical scenarios can fulfil in contributing to transition thinking.

The first possible function of sociotechnical scenarios is its use as a tool for transition policy. Transition policy or transition management as it has been labelled in the fourth National Environmental Policy Plan (NEPP) specifically aims to contribute to long-term transitory processes in order to solve problems that are persistent and fundamental and for which more traditional short-term policies have not been able to induce changes in systems of production or consumption. Climate change is one of those problems. According to the NEPP 4 "transitions demand a form of steering from government in which uncertainty, complexity, and coherence are key concepts. Long-term thinking should be the reference for short-term decisions." The NEPP 4 sees a specific role for scenarios as a tool for learning to deal with uncertainties (NEPP 4: 74).

The aim of this report is foremost to demonstrate the promise of sociotechnical scenarios as a tool for transition policy. The role of sociotechnical scenarios is not so much to point at what transition path needs to be followed but more to give insight in the various complex processes at work in system change, to give some sense regarding driving forces and main elements of promising combinations of technological, societal and institutional change in transition paths. Thus sociotechnical scenarios are not predictions of the future but can be useful in allowing policies and strategies to be designed in a more robust way. One of the main functions of this report is to demonstrate the promise of sociotechnical scenarios as tool to be better able to design short-term policies in the context of perceived potential long-term patterns of sociotechnical change. It especially should make policy makers more perceptive for policy types other than the most common of supply push through R&D programs and market pull through regulations and subsidies. These for example involve process related policies such as the stimulation of network formation and building, the focus on experimentation and learning, and ways to influence regime dynamics.

A second possible function of sociotechnical scenarios is its utilisation as a tool to stretch mental maps through the exploration of transition paths. One cause for the dominance of incremental innovation is that actors, especially those strongly embedded in the regime, do not seriously consider alternative developments because they do not fit their mental map of the way the respective function (transport, power, food, recreation, etc.) could be fulfilled. Sociotechnical scenarios and the construction of transition paths can then be part of a process to stretch those mental maps beyond the current regime in order to make actors aware of the potential of transition paths that were previously considered to be unlikely or impossible. Elements that may be part of this mental process are insight into links between technology and society that were previously not considered; and more insight in the unpredictable and crooked processes of technological and societal change. This is also a reflection of practice of historical transitions where during the initial change processes many actors disbelief their potential for creating a transition.

The third possible function of sociotechnical scenarios is that it can contribute to processes of vision building and development of shared visions on transition paths. This can especially be useful when there is some sort of consensus between actors/stakeholders that a transition is required but there is dissent on what kind of transition or on how the transition may be achieved. Especially the design of STSc in an interactive setting (with various actors, stakeholders) can potentially contribute to a process through which parties who see different aspects of potential solutions can constructively explore their differences and search for transition paths that go beyond their own limited vision of what is possible.

A fourth possible function of sociotechnical scenarios is its contribution to the societal basis for and commitment to potential transition paths. Sociotechnical scenarios can be useful to strengthen the societal basis for transitions, for example to reduce the idea that transition will involve large societal costs, will be painful for many actors, or will be almost impossible to realise, through the communication of possible transition paths.

A fifth possible function of sociotechnical scenarios is to make policy makers and scenario builders more perceptive for the potential of more qualitative explorative methods to explore transitions by the development of a method for the construction of sociotechnical scenarios. In this way STSc acts as a lever to reduce the fixation on quantitative anticipation tools which are often based on trend extrapolation and modelling and have too simplistic assumptions regarding the dynamics of technological development.

In this project we have chosen to do develop expert-based STSc mainly because of the limited scope of the project and because the project is concerned with the development of a methodology of the construction of STSc. Clearly some of the functions of STSc can better be realised through a more interactive design in which various actors together work on the construction of transition paths. This can be part of future work on the development of the STSc methodology.

4 Transition theory as a basis to construct STSc

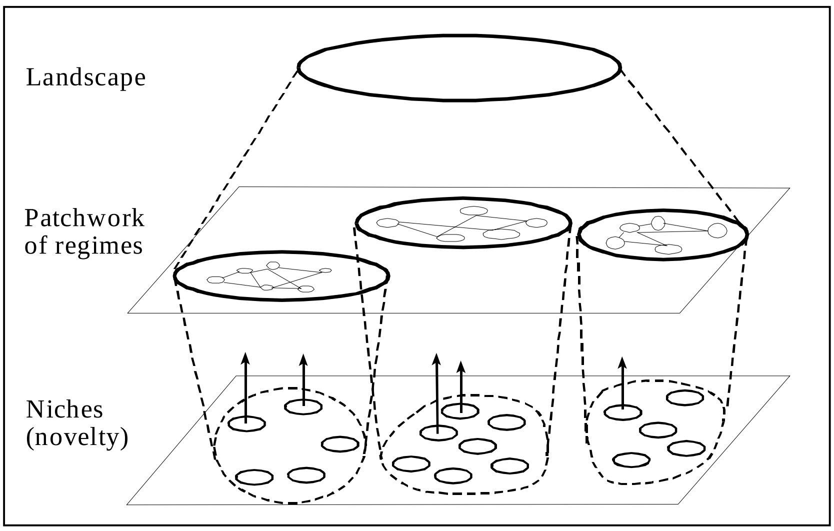
4.1 Dynamic of socio-technical change

To understand technological transitions we use a multi-level perspective that builds upon insights from the field of Science and Technology Studies (STS). STS emphasises the interrelatedness between technical and social change and analyses how technology is shaped by social, economic, cultural and political forces as well as how new technologies shape society and the interaction between various actors (e.g. Bijker et al, 1987; Bijker and Law, 1992; MacKenzie and Wajcman, 1999). At the heart of the transition theory are three 'levels' and the interactions between them. We will only briefly outline the multi-level framework, because it has been described more elaborately elsewhere (Kemp, Schot and Hoogma, 1998; Geels and Kemp, 2000; Kemp, Rip and Schot, 2001; Geels 2002a, 2002c). The three levels are the *socio-technical landscape*, the *socio-technical regime* and *technological niches:*

1. the *socio-technical landscape*: this describes broad processes and factors in society (e.g. cultural developments, climate policy) that affect a wide range of developments;
2. the *socio-technical regime*: a specific sector of society of interest to the analyst (in our case energy supply). Regimes describe the interrelation between technology, policy, user preferences, infrastructures, etc.
3. *Technological niches*: 'alternative' technologies that hold a promise to play a role in the regime but that cannot compete (yet) with existing technologies. This is partly an economic issue but it also requires tuning of a variety of technical and social factors including infrastructure requirements, user preferences, policy, etc. In niches, learning processes and interactions between actors are key.

The relation between the three concepts can be understood as a nested hierarchy or multi-level perspective (Figure 2). The meso-level of socio-technical regimes accounts for stability of existing technological development and the occurrence of trajectories. Technological transitions are about major changes in socio-technical regimes. This can involve change on many dimensions of the regime such as in technology, user practices, networks, regulation, infrastructure, required knowledge, and culture. The macro-level of landscape consists of mostly slowly changing external factors, providing gradients for the innovation trajectories within regimes. The micro-level of niches accounts for the generation of radical innovations.

Figure 2: Multiple levels as a nested hierarchy (Geels, 2002a)



The nested character of these levels, means that regimes are embedded within landscapes and niches within regimes. Novelties emerge in niches in the context of existing regimes and landscapes with their specific problems, rules and capabilities. New technologies are initially developed within the old framework, but often face a mismatch with the established economic, social and/or political dimensions (Freeman and Perez, 1988). Innovation within a socio-technical regime is typically incremental. Under specific circumstances, however, development within the socio-technical landscape and/or in niches can get linked to the regime to induce developments that eventually lead to a drastic reform, i.e. a transition.

4.2 Basic STSc features: patterns and mechanisms

Most innovation takes place within the regime, typically leading to gradual evolution or regime optimisation. This gradual pattern results because a regime consists of a wide variety of elements, including technical, behavioural, cultural, political that are *interconnected* and, therefore, cannot change easily. If a new opportunity emerges, parts of the regime typically seek to counter the threat.

Although gradual change is the common pattern, there are plenty historical examples of more radical transitions. Analysis of such transitions indicates that technological niches play a crucial role in their early phases. These niches may emerge and develop for two different sets of reasons. The first reason is that there are always people tinkering with novelties in a, from the perspective of existing regimes, arbitrary way. For example, the initial development of the early internal combustion engine in the late 19^{th} century, from the dominant horse-based regime, was not very significant in terms of satisfying people's transport needs. The second set of reasons comes from pressure on an existing regime. Such a pressure indicates that there are serious problems in a regime which can be either internal to the regime itself (such as power failure) or come from the socio-technical landscape (e.g. the current pressure to curb CO_2 emissions which affects more than just the electricity regime).

Given that there are always niches around it will depend upon the developments within these niches and the interaction between these niches and the regime whether they set things in motion that eventually lead to a transition. In such transitions, we can distinguish two general patterns, viz. (1) *technical substitution* and (2) *broad transformation*.

In the substitution route, socio-technical regimes are relatively stable until the wide diffusion of the new technologies. The diffusion and breakthrough of niches into main markets triggers all kinds of wider changes, and may cause established producers to fail (Schumpeter's 'gales of destruction'). On the level of regimes, this route can be described with punctuations between relatively stable socio-technical configurations. An example is the substitution of sailing ships by steam ships.

In the transformation route, much more is at stake than a technical substitution. There may also be changes in user behaviour, cultural change, policy changes, infrastructural change, etc. Furthermore, there are usually multiple technologies involved. The loosening up of the existing regime may create multiple windows of opportunity for novelties and stimulate actors to experiment with many technical options. Often, these novelties do not break through individually but first merge with each other or with parts of the regime. The typical pattern in an ensuing broad transformation is that regime (usually under pressure) first *opens up* and creates room for a wide variety of niches. Some of those may link up to the regime to create niche markets at the fringes of the regime. One or more of these may then start to grow at the expense of the existing regime until they become the new dominant regime. Then the regime tends to close in again, reducing the room for niches.

Under these general, longer term patterns some shorter term patterns and mechanisms can be distinguished. Some examples are:

- regime pressure creating room for niches (see above);
- regime trying to counter the threat of upcoming niches via various improvements; *sailing ship effect* after sailing ships countering the threat of upcoming steam ships;
- niche cumulation: the technology is developed further and diffuses via successive domains of application, e.g. the gas turbine moving from application military aircraft to civil aircraft, and to peak power generation;
- niche proliferation: niches spreading to other domains (other regimes or geographically);
- hybridisation: the merger of two options (either two niches or a niche with the regime) to create something new, e.g. the merger of the gas turbine and the steam turbine into combined cycles (Islas, 1999);
- forking: the opposite from hybridisation, i.e. the split of an option into to different concepts like the gas turbine development towards combined cycles and microturbines;
- new technical developments triggering new societal developments: a new technical option, for instance, may seize the interest of new user groups or make it easier to pursue certain policies;
- emerging new user patterns: some technologies may induce (initially small) groups of users to change their behaviour and these groups may grow under specific circumstances; this may be triggered by a variety of reasons like creating new opportunities, distinction, cost-performance considerations, etc. In transitions, often a combination of such reasons is at work while different reasons may appeal to different sets of users.

Based on this multi-level perspective we have developed a scenario methodology which we call ‘Socio Technical Scenarios’ (STSc). An STSc is a story that describes possible future developments, making use of the patterns and mechanisms described above.

In principle, everything is possible in an STSc but the developments described have to be plausible in terms of the multi-level theory and the patterns and mechanisms used should be likely to emerge under the given circumstances. Thus an STSc-method can lead to a wide variety of different outcomes, but, more importantly, since the developments have to match the multi-level theory it allows to explore *why* developments lead to certain outcomes. Thus, the method can also be a stepping stone to inform strategies that attempt to realise specific outcomes that are desired.

5 Methodology for constructing STSc

5.1 Introduction

The patterns and mechanisms in the previous section define the process elements that will be used to build an STSc. The next step is to identify various relevant characteristics of the domain of analysis that will be used in the scenario. These ‘empirical’ elements will have to be identified as preparatory work before making a scenario. It implies that the following tasks should be carried out:

- Characterise the current regime in terms of the embedded technologies, the main actors that constitute the regime, its dynamic and, based on this, the main trends in the recent past that are likely to carry on into the near future.
- Identify ‘potentially interesting’ niches and characterise them.
- Identify the main landscape factors that (could) influence the dynamic in the niches and regime.
- Design choices at various levels, notably:
  - ‘macro-level’ choices: choose landscape level factors that define the macro-environment in which the scenario-developments take place;
  - ‘micro-level’ choices: choose which niches will make a ‘breakthrough’ as a prelude to a transition.

These tasks can be carried out in a number of consecutive steps, notably:

- Step 1: Design choices and contours of the scenarios
- Step 2: Inventory of potential linkages as promising transition elements
- Step 3: Analysis of dynamic of the existing regime
  - Regime characteristics, problems, strategies and trends
  - Landscape factors and ‘enabling technologies’
  - Relevant niches: opportunities and barriers for transition
- Step 4: Develop scenario skeletons
- Step 5: Make the scenario
- Step 6: Reflect on the scenarios
- Step 7: Develop policy recommendations

These steps are elaborated in the sections below.

5.2 Step 1: Design choices and contours of the scenarios

As a first step, the analyst needs to make explicit what the purpose of building one or more scenarios is, e.g. to explore possible transition paths towards a sustainable energy supply under different, specified assumptions. This implies making some design choices, e.g. on the number of scenarios to make, the time-frame to be used (e.g. 30-50 years) and their main distinguishing features. This implies that this step should provide a general characterisation of the regime in question and needs to briefly indicate some ‘promising niches’. This step thus sets the stage for the steps to come in which these general characterisations are filled in in further detail.

Traditional scenario methods often work with a two dimensional matrix, e.g. with one dimension related to economic growth and the other to the urgency of environmental problems. This then defines four scenarios. From the perspective of STSc, however, the contrasts between scenarios thus defined is not very large in the sense that all scenarios typically are technology diffusion scenarios, not leading to any substantial change on social dimensions. As the main feature of STSc is that it does provide for a sociotechnical dynamic it seems appropriate to use the method to illustrate especially potential contrasts along the social as well as technical dimensions. To illustrate the method we have done this in the examples that will follow in the next chapters by developing two scenarios for the domain of electricity generation, distribution and consumption, notably one scenario that is basically an extension of the current design of the electricity system (the central station electricity model) based on large scale electricity generation with an extensive infrastructure for transmission and distribution towards users, and one scenario where the design becomes is much more local and decentralised (the distributed generation model) with some main changes on social and behavioural dimensions. This will help to illustrate the additional value of the STSc method.

In this step we will also need provide a general characterisation of the regime we are looking at and briefly identify some 'promising niches' to make plausible that a transition can occur. This will then be used to define the main contrasts between the two scenarios. This step thus sets the stage for the steps to come in which these general characterisations are filled in for each of the two scenarios in further detail.

The main contrasts between the two scenarios can take the form of describing the outcome at the end of the scenario in a page or so. Therefore, the usefulness of the STSc method is not this outcome, as that is predefined, but to analyse the factors that may lead to these outcomes by using plausible mechanisms and patterns from the transition theory. Contrasting a scenario with substantial social change with a 'high-tech' variant can then help to identify crucial factors (including policies and strategies by other actors) that stimulate the emergence of one variant rather than the other.

5.3 Step 2: Inventory of potential linkages as promising transition elements

One of the shortcomings of existing scenario methods is that they often leave the current basic features of technologies untouched as well as how they are used. STSc does allow this to change and to exploit this the analyst needs to make an inventory of possible new links such as:

- hybridisations: the merger of two options to create something new (e.g. hybridisation of gas turbine and steam turbine leading to combined cycle gas turbines;
- changing user patterns: some technologies may induce (initially small) groups of users to change their behaviour and these groups may grow under specific circumstances;
- links between technical development and political developments: for instance an electric vehicle with zero emissions (a technical element at the regime level) can get linked to strong determination to cut city pollution (a political element at the regime level).
- links between various regimes that enable certain niche developments. Multiple regime developments can create momentum for niches such as in the historical example of the gas turbine (military aircraft industry, aircraft industry, and power generation sector play important roles in the development of the niche, and in the current example of the fuel cell, which is both driven by opportunities for use in the transport and power sector.

The potential of such new links to occur is the main distinctive feature of STSc compared to other scenario methods. These linkage possibilities we call 'transition elements' which are defined as elements at each of the three levels (regime, niche, landscape) that could link up to create novelties as a potential prelude to a transition. For instance an electric vehicle with zero emissions (a technical element at the regime level) can get linked to strong determination to cut city pollution (a political element at the landscape level). The result could be a new type of 'city electric vehicle' that starts having noticeable effects at the regime level.

Transitions imply the breakthrough and take-up of new technologies along with a transformation of behaviour of various actors in relation to these. A starting point to identify them could be to identify a number (for example 5 to 10) novelties (technologies, concepts, new forms of societal embedding) that could be part of linkages between niche, regime and/or landscape level) with good 'sustainability performance'. Also potential 'enabling technologies' (e.g. generic technologies, like ICT, that could be taken up in a variety of regimes) could have a substantial impact on the dynamic of either one or both of our two domains.

Transition elements not only concern technologies. Transition theory distinguishes several articulation processes that play a role in the breakthrough of niches. Each of these processes defines a specific type of dimension that could play a role in a transition implying the following types of dimensions should be addressed:

- technical dimensions
- policy dimensions
- cultural and psychological dimensions
- market dimensions
- production dimensions
- infrastructure and maintenance dimensions
- societal and environmental (problems) dimensions
- financial dimensions[1]

The linkage opportunities identified in this step can be used when actually making the scenario. Whether they will indeed be used will be decided during the actual construction of the scenario when, based upon transition theory, it can be made plausible that such a new link will occur.

5.4 Step 3: Analysis of dynamic at regime, landscape and niche level.

5.4.1 Regime characteristics, problems, strategies and trends

The first step in our analysis is to focus on the existing electricity regime. According to the transition theory the chances for novelties to break through can be enhanced by 'windows of opportunity' and 'tensions' in the existing regime(s). Changing the electricity system is difficult because it has a large stability and inertia: it is in several ways locked-in (technologically, economically, institutionally and culturally). Initiating a transition process therefore demands not only a careful analysis of the existing system but also a thorough understanding of the factors that shaped these systems in the (recent) past. Not only is it very difficult to replace existing systems, but also do new promising, sustainable technologies often face enormous problems fulfilling their potential, because they encounter several barriers. The stability on the regime level however is a dynamic stability. There are periods of tensions, for example resulting from divergent developments due to differences of opinion within the regime on key issues (e.g. the shape and speed of the process of liberalisation), but also often occurring due to external pressure from slowly evolving landscape developments,

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[1] In earlier work, we have not explicitly distinguished this element in the list. We now think, however, it is useful to do so, especially since different forms of financing play a role in different stages of development, e.g. government (or EU) R&D support, market-launch subsidies or other incentives, exploitation subsidies (e.g. for public transport), venture capital, regular market capital. Distinguishing a specific articulation process on financing helps to analyse the linking of the appropriate financing structures to the niche at various stages, including how various forms of financing can induce each other. E.g. a venture capital funding of a specific project can make it 'prove itself' and open de door for more conventional sources of market funding.

e.g. the growing awareness of the climate change problem or the liberalization of the energy markets. When landscape or internal developments put pressure on the regime, this leads to ‘opening up’, and opportunities for radical innovations increase. If niches can take advantage of the resulting ‘windows of opportunity’ and when they have sufficient internal momentum (cost/performance improvements, increasing returns to adoption, bandwagon effects), they can break through. It is the alignment of developments (successful processes within the niche, reinforced by changes at regime level and at the level of the sociotechnical landscape) that determines if a shift in the existing regime will occur.

The task in this step is to identify major characteristics and current innovation trends in the regime. Partly, this will be an elaboration of some potential linkages identified in the previous step. The following issues should be addressed:

- Dynamic of the domain with the role of major actors; identify the main ‘drivers’ for the dynamic (leading to ‘innovation’, i.e. socio-technical change).
- Trends/patterns
- Tensions in the regime that could provide ‘hooks’ for linkages to niches (windows of opportunity).
- Attempts to guide/change the dynamic and their vicissitudes
- ‘Deeply entrenched’ characteristics (e.g. the role of the grid and grid connection in the electricity system)

This inventory should concentrate on those factors that determine the potential and direction of innovation, acknowledging that innovation has technical as well as social dimensions. The idea is not to already determine the concrete course of innovation (except for the near term when current trends are likely to continue for a while) but, rather, to identify the factors that determine what type of innovations have better chances than other and, in a general sense, to determine what room there is for innovations to hook on. A regime under pressure, for instance, (due to problems in the regime) is more open to innovation than a regime that functions more smoothly.

Some examples from the electricity domain of factors to be identified in this step:

1. There is increasing heterogeneity of actors involved in electricity supply and interactions of actors with different backgrounds. This is related to changes in market structures, e.g. new exchanges and the emergence of trading companies; in regulation due to the removal of entrance barriers; and to converging strategies of actors from different regimes, e.g. waste regime and its focus on closing material cycles and reduction of waste landfill and the use of the energy contents of (organic) waste for electricity generation.
2. The increasing importance of gas as a source for electricity generation. The combined cycle gas turbine has become the most efficient means of electricity generation, while also being flexible in terms of scale. In Europe investments in power plants were stagnating due to over capacity, and the only plans in relative large scale power plants were in CCGTs, such as Shell’s construction of a CCGT 600 MW power plant in the Botlek area for combined production of heat and power. In the US major investments in new power plants were planned at the turn of the century to satisfy demand and to replace obsolete power plants. Around 90% of these investments were expected to be in gas-fired power plants (combined cycles and gas turbines) because of their flexibility and relative low capital costs (compared to coal-fired and nuclear power plants).
3. There is a trend towards more segmentation of electricity based on economic aspects, market aspects, and societal aspects. Economic aspects relate to price differentiation for electricity in periods of peak demand, and off-peak demand, and different contracts that are being settled between producers and customers. Market aspects relate to specific requirements of electricity users, such as a level of reliability that is higher than average.

Societal aspects relate to the differentiation of electricity to energy source or production location, such as the demand for green electricity, or domestic green electricity, or electricity not produced by nuclear power.

5.4.2 Landscape factors and 'enabling technologies'

Developments at the level of the socio-technical landscape affect the dynamic at the regime level, the dynamic in various niches as well as the interaction between them. Therefore, we need to identify the relevant landscape factors that may affect these dynamics. Some examples of such factors are:

- Sustainability' dimensions, like the urge to tackle CO_2 emissions, air pollution, city liveability, etc.
- (Geo)-Political factors, like 'political culture' (e.g. strong hierarchical steering vs. 'laissez faire'); the issue of resource (in-)dependence; the role of public authorities at different levels and the actions between them, land development and urban planning policies, etc.
- Societal / Cultural factors, including demographic factors, values and perceptions, etc.
- Economic factors, like economic growth rate, globalisation trends, price of critical resources (e.g. oil or gas);
- Enabling technologies such as information technology, energy storage technologies (esp. of electricity or forms of energy that can be converted into electricity with very low emissions).

In conventional scenarios, these landscape factors are typically used to create contrast between the different scenarios, e.g. a high versus a low growth scenario or a strong hierarchical steering vs. a 'laissez faire' scenario. This could also be done for STSc but this not the best way to exploit the features of the method since these factors do not play the 'straightforward' role that they do in conventional scenarios. In a conventional scenario, these factors are modelled in a fixed way and using a different input variable immediately produces a different outcome. In STSc, these factors play a qualitative role, e.g. enabling a new link to create a new option that wil not develop under other conditions.

This implies that for STSc, the landscape factors are operationalised in a qualitative way in accordance with the design choices made in the first step. We have chosen five main landscape factors that impact the scenarios. The contrasts in the scenarios are to a certain extent related to the different way these landscape developments interact with regime and niche developments. Thus, in the scenario towards large scale integration the process of European integration has a much stronger impact than in the scenario on distributed generation. The following table summarises the impact of the various landscape factors on the two scenarios.

Table 1: Sociotechnical landscape factors and their impact on two scenarios

Landscape factor	Impact on scenario 1	Impact on scenario 2
	Large scale integration of renewables in the central station electricity system	Development of renewables in the distributed generation model
Liberalisation	+	++
ICT penetration	+	++
Climate change urgency	++	+
EU integration	++	+/-
Citizen green awareness	+	+

5.4.3 Relevant niches: opportunities and barriers for transition

The development of niches and their linking up with the regime is a distinctive feature of STSc and a crucial mechanism in inducing transitions. Identifying and characterising these niches is therefore critical for the method.

Step 1 (design choices) and Step 2 (identification of potential linkages) above should provide a list of the niches that are relevant for the scenario. Each of these niches will then have to be described and characterised. This description should indicate the recent dynamic, the current status as well as the future potential. More concretely, the following factors should be addressed:

1. Introduction through brief characterisation of the niche:
    - Are there many technical forms (e.g. many types of biomass conversion routes) or a relatively stable design (e.g. wind turbines)? The former situation creates much uncertainty for engineers (and the need for experimentation) while the latter provides stable search heuristics (an emerging dominant design?)
    - Are there many possible markets, functions and users or relatively clear markets/functions? The former situation gives uncertainty, but also many options for future linkages.
    - Is the niche national or international? Fuel cell developments seem to be dominated by large international players (e.g. Ballard, Daimler etc), while biomass gasification involves small networks of producers on a national scale.
2. Brief history of the niche (5-10 years). Issues to be dealt with are the following:
    - Which aspects have become clearer, further articulated? Has the niche grown or declined and what are the main factors explaining this?
    - What is the phase of development (R&D, experiments, demonstration projects)?
    - What has been learned in the last five years (about technology, market, policy)? Has this led to reformulation of search directions?
3. Analysis of current main promise and momentum by focussing on the following issues:
    - Which are the main actors carrying and driving the niche, e.g. policy makers, manufacturers involved in strategic games?
    - What are the expectations regarding the niche, for example regarding the potential contribution of several possible applications to sustainability? (e.g. PV has gained momentum because of very high expectations, possibly too high which has caused a backlash).
4. Analysis of the mismatch of the niche with regime on various dimensions that creates barriers for market introduction:
    - Costs: how much more expensive is niche-technology?
    - Technical barriers: e.g. how to deal with large scale integration of discontinuous renewable sources in the grid; the development of an infrastructure for hydrogen and the problem of hydrogen storage
    - Infrastructure: what are the new infrastructure needs? What about sunk investments?
    - User preferences/practices;
    - Policy, regulations: not yet adapted to new technology, no 'level playing field' for new technology, because established technology or design is favoured, etc.
5. Future possibilities and possible linkages/hooks. What are possibilities to 'get around' barriers? Supply logistics of biomass can become articulated if biomass is first used as an add-on in coal electric utilities (co-combustion).
6. The descriptions should make clear the (envisaged) role of three different sets of actors, notably:
    - developers / producers

- users
- public authorities (at different levels)

The required ‘depth’ of the description depends upon the ‘richness’ of the niche. The richness is basically exemplified in the variety of expectations in the niche on *how* the technology in question could hook on to the regime and eventually transform it. If this could lead to several qualitatively different forms of dynamic we need considerable detail in the niche-description to ‘play out’ these differences and let one (or more) of them ‘break through’ in the actual scenario. In such a case it is required to describe in considerable detail the actors involved, their expectations and their activities to try and make the niche break through.

Concerning ‘breakthrough’ we need to be aware that this does not have to follow from ‘linear growth’ of the niche but can also result from hybridisation, cascades, induced user preferences that subsequently make another niche break through, etc. It is therefore important to identify niches (technologies, resources or concepts) that have the potential of linking specific technologies and resources and can create a pathway in the changeover from a fossil to renewable based electricity system. Various characteristics can express linking capacity of technology. One is that technologies with linking capacity can adapt to the existing regime but also inhibit characteristics that enable other technologies to hook on to the pathway technology and the existing technological configuration. Another is that they can adapt to the existing regime but are able to change the way they are configured in that system. An example is the fuel cell because of its flexibility in terms of its energy resources (either gas, hydrogen or (m)ethanol), its potential role in energy storage, and its potential value to form hybrid systems with gas turbines, photovoltaic power (PV), wind power, and biomass. Moreover, the fuel cell could initially link up to the regime ‘relatively easy’ with the use of gas reformers but subsequently allows for a gradual transition with radically different outcome as a hydrogen infrastructure is built up. Another example is gas and gasification technology as potential pathway resource and technology.

5.5 Step 4: Combining landscape, regime, niche developments to initial paths: the scenario skeleton

Before writing the scenario in detail we will first sketch the ‘skeleton’ of each scenario, giving a broad sketch of the transition(s) to be included, the linking of the crucial elements that prelude the transition and support its eventual breakthrough, the time-path, etc. The scenario skeleton is a brief version (e.g. 2-3 pages) of the full scenario that indicates which major changes are going to take place when. The skeleton should use the vocabulary of patterns and mechanisms described above. It should indicate:

- Which niches are going to ‘break through’ in which period due to which main reason(s). Reasons could include niche-internal developments and a linking to regime and/or landscape developments. Beware that a breakthrough does not have to follow directly from the niche but can also result from hybridisation, cascades, induced user preferences that subsequently make another niche break through, etc.
- When relevant: cross-linking of niches
- When relevant: hybridisations
- The approximate ‘market share’ when the ‘breakthrough’ has stabilised or has become a trend-like further growth.

Making a scenario skeleton also helps to assess whether the necessary empirical building blocks have indeed been elaborated for each of the levels in the previous steps. This could lead to some additional work for steps 1-3.

To be able to actually make the skeleton it is assumed that on the basis of preparative work (e.g. the analysis carried out in step 3) the researcher has good knowledge of the dynamic of the domain in question, i.e. the regime under analysis, the important niches and the landscape factors that influence the dynamic. Also the researcher is supposed to be acquainted with the multi-level model and the main patterns and mechanisms that describe the interactions within and between these levels. Furthermore, clear design choices should have been made on relevant landscape level trends for the scenario-period that have an impact on the regime and niche dynamic. These should have been translated into:

- regime or landscape factors that put pressure on the regime for change or open it up for new developments
- factors that stimulate niche exploration

Under these assumptions, the following steps should be taken to develop an STSc-Skeleton:

1. Sketch the **contours of the regime at the end of the scenario time-frame** (an elaboration of the design choices made earlier), i.e. indicate:
   - Most important technologies
   - Most important social / behavioural characteristics, emphasising those that are different from the current situation
2. **Chronology per option**: knowing roughly the outcome by 2050 and the present starting point, sketch a rough development path for each of the new technologies/options (starting from the current niches and using linkage patterns) from the present to 2050. Start by describing the overall pattern of development in one or two sentences using the multi-level model. Also indicate new social / behavioural features. Subsequently make a bullet point list with a 'rough chronology', indicating:
   - phase of niche articulation; main outcome (including new behavioural, infrastructure or other aspects)
   - linking with the regime; the take-off phase (niche markets)
   - growth phase
   - levelling of phase
   - (when applicable): phase of hybridisation exploration and take-off
   - (when applicable): phasing out
   - main drivers for different phases
3. Guided by the previous step, distinguish some different **phases** for the scenario at the **regime level** with distinctive dynamics and try to catch that in a header clearly indicating the difference in dynamic for each period. For each phase, indicate the crucial developments in connection with the various options of the previous step (as a bullet point list); indicate hybridisations; indicate main drivers.
4. Overall **consistency check**.
   Are the previous steps consistent with each other? I.e. are the phasings of the different options congruent so that hybridisations or behavioural change patterns are indeed plausible in view of the 'overall regime situation' in each phase? Are the various drivers for the separate developments consistent with each other? In practice, it works as follows: initially, the steps 1-3 are carried out one after the other. Subsequently, to realise this consistency, the analyst will jump back and forth between these steps until a match is found that appears plausible.

5.6 Step 5: Writing the STSc

The STSc-skeleton provides the last step before the actual writing of the scenario. What remains to be done is to put flesh to the bones of the skeleton by adding a level of detail that makes the various new links plausible in view of the multi-level model and that thus helps to pinpoint various concrete factors crucial in inducing and supporting a transition.

If we would have the ambition to write a six page history of a transition (for instance the energy supply regime in the period 1900-1950) from a multi-level perspective, it would have to be rather superficial, i.e. we could only use a 'broad brush' to sketch the regime developments and could only treat a couple of niches in detail. Other niches we would have to let emerge and affect the regime in just a single paragraph.

In connection with an STSc we face exactly the same problem, implying we very much have to limit ourselves. This begs the question to what are 'minimal requirements' for an STSc to be 'convincing'. Some suggestions:

- Address all three levels to some extent. Use the regime-level as the thread through the story. Discuss a limited number of exemplary niches. Indicate how a limited number of landscape developments affected expectations and subsequent developments in the regime and the niches discussed.
- In the niches, pay attention to articulation processes. When a niche 'breaks through', make plausible all relevant 'articulation barriers' have been overcome. A niche is not only a technology but also a domain of use that should be described. Within a niche, an 'ordering principle' could either be specifc technologies or a specific domain of use.
- Watch out for (too) linear stories. Also introduce some cross-links, bifurcations, hybridisations, etc.
- Make the role of various actors clear (producers, users, government). Describe how they are guided by their expectations and how their expectations are influenced by developments and experiences at the three levels.
- Treat technical and social/behavioural issues 'symmetrically'; pay serious attention to co-evolution. Describe, e.g., how new technology leads to new experiences and then to new behaviour.
- Patterns and mechanisms; the theory provides a wide range; use them selectively and name them explicitly.

5.7 Step 6: Reflect on the scenarios

The final steps after the construction of the scenarios explicitly focus on the lessons that can be drawn from them. A first step is to reflect upon the two constrasting scenarios, by identifying main differences and similarities and trying to answer the following questions for each scenario in a couple of sentences:

- What are the main regime characteristics at the end of the scenario period:
  - In technical / system terms
  - In social / behavioural terms
  - In sustainability terms
- What were the main pathways from the present to the future situation in terms of:
  - Technologies / concepts (evolution; new linkages)
  - Profiles of use (changing and successive groups of users)
  - New links, hybridisations, etc.
- What were the main driving forces that induced and shaped the transition:
  - Landscape pressure
  - Regime dynamics
  - Regulation
  - 'Pushy' actors

This type of reflection could help to give some sense regarding driving forces and main elements of promising combinations of technological, societal and institutional change in transition paths. In a subsequent step this is translated into more specific policy recommendations.

5.8 Step 7: Develop policy recommendations

Making ‘useful’ and ‘well-supported’ policy suggestions on the basis of STSc is far from trivial because there is some risk of following a tautological reasoning because the design choices to some extent determine the outcomes. It should be stressed that the scenarios constitute an exploration of possible futures and the analysis of a limited number of factors that may (co-) determine these futures. Recommendations then should not only emphasise content but also have an ‘awareness raising’ focus and indicate options with ‘promising potential’.

We start with a brief characterisation of current policy or policies (if relevant, at various levels and/or by various departments). On the basis of an STSc analysis we subsequently develop recommendations for modifications of those policies. These modifications can take various forms, including:

- Suggestions for alternative policies;
- Suggestions for tuning of policies, either tuning different levels or tuning different policy strategies;
- Suggestions for using (combinations of) policy strategies in specific circumstances.
- Suggestions to stimulate learning
- Recommendations should be rooted to the original problem:
    - How to give focussing guidance in the range of promising transition elements that are present
    - Which technologies hold ‘better’ promise than others and why
    - How to loosen up the regime and create more room for alternatives to link up

5.9 Structure of STSc

The socio-technical scenario itself consists of a number of episodes with a recurring structure for each episode. In our experience, we found four episodes a useful choice for a scenario for the period 2000-2050 to be able to describe a dynamic that would include a transition towards a radically different regime. The scenario starts with a brief description of the dynamic in the past decade to make the scenario fluently evolve from the present. This description is based on the earlier analytical steps in the development of the STSc.

The basic structure of each episode is the successive description of developments at the landscape, regime and niche level. Each episode starts with a brief indication of the main ‘drivers’, i.e. those factors at either the landscape, regime or niche level that strongly determine the overall dynamic. In our case, they may include the pressure to curb CO_2 emissions and the process of liberalisation in the electricity sector. They may also include strong trends in a specific episode that are likely to continue into the next episode.

The second section describes developments at the regime level. The inputs for this are the drivers and main trends identified in the first section, assumptions made on the socio-technical landscape in the design choices for the scenario and the evolving niches described in the preceding period. Especially, the latter may lead to qualitative changes in the regime, e.g. by creating a new user segment with prospects for growth, a new transport system that may integrate some aspects from the existing regime with aspects from niches, etc. The focus is mostly on how the regime deals with the described impacts from the landscape and emerging niche developments. This can for example take the form of defending against niche developments by improving the regime, of incorporating some niche elements in the regime, or of becoming involved in certain niche developments.

The next section in each episode describes developments in a number of niches, partly under the influence of the drivers identified earlier, partly on the basis of plausible internal niche dynamic. In the niche descriptions, we should also be aware of the ‘cross-link’ opportunities identified earlier and assess whether overall scenario consistency (based on insights from the multi-level model) makes it plausible that specific cross-links will occur. Such a niche description may evolve to the point that it may link up to the regime, either as a niche market or by slightly transforming certain elements of the regime.

In the next paragraphs we present examples of sociotechnical scenarios. These scenarios are meant to illustrate the main features of the approach and its usefulness. The scenarios below are written as a ‘history of the future’, i.e. in the past tense. Using the past tense helps in writing as it stimulates the use of historical research standards to make a good story. It makes the writer sensitive in the case of ‘surprising developments’ to ask ‘why did this happen’ and then dig ‘a level deeper’ when needed. The past tense also helps to prevent reactions from the reader that ‘something else might also happen’ (which, of course, is always the case) and makes the reader focus on the plausibility of the stories. The latter is, after all, our objective: to make plausible stories, i.e. a story that might happen under the given circumstances.

6 Step 5: Example from the Electricity Domain

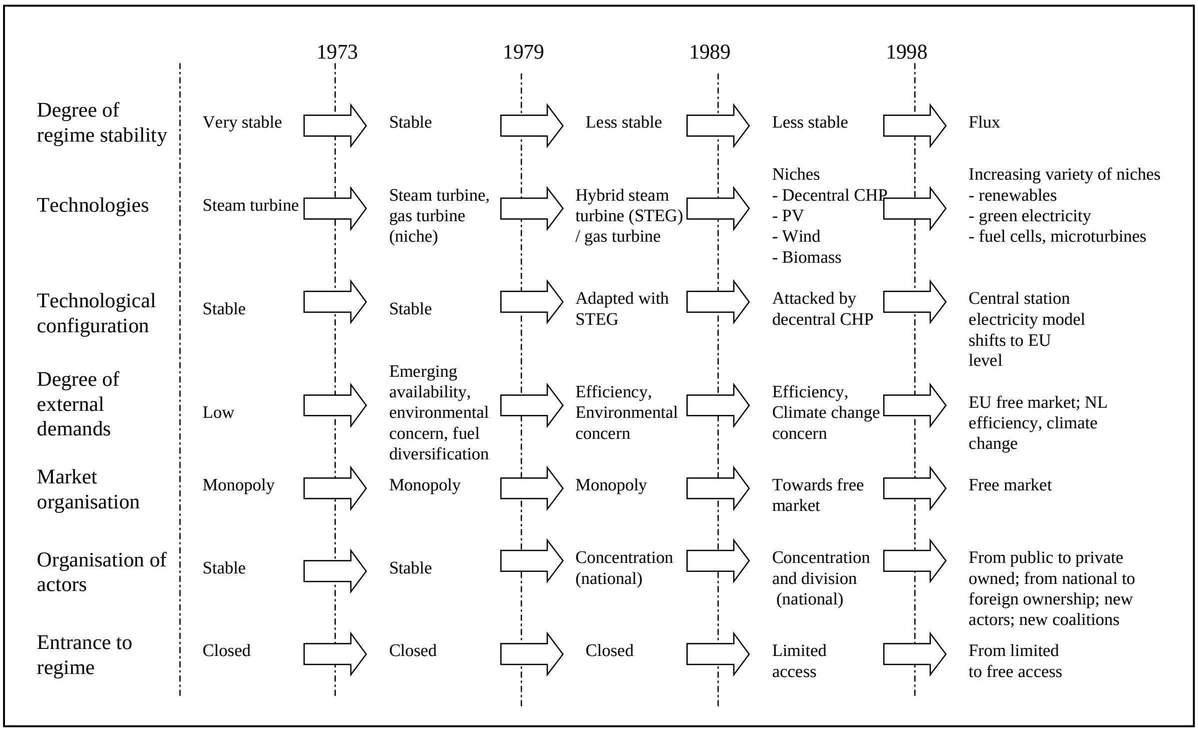
6.1 Introduction

This chapter presents two sociotechnical scenarios that illustrate how a transition towards a less carbon intensive electricity regime may take place. The choice for the electricity domain is foremost based on the fact that generation of electricity in the Netherlands and the rest of the world makes a major contribution to CO_2 emissions and thus to the climate problem. In the Netherlands it contributes 26% of CO_2 emissions, while the global figure for carbon emissions is 37.5% (ECN, Energieverslag Nederland 2000 [Netherlands Energy Report 2000], p. 112; IPCC, Climate Change 2001, Mitigation, section 3.8.1.). The challenge is therefore to initiate a transition away from the fossil base of the electricity system as is illustrated in the two sociotechnical scenarios in this section. The construction of the sociotechnical scenarios is based on the methodology offered in the earlier part of the report. This part of the report is in six sections. We start by focusing on dynamics in the electricity regime in the last decade in order to understand some of the trends that play out in the different scenarios. The next section introduces choices made regarding the basic design of the scenarios and the role of landscape factors. Section four presents the first scenario based on large-scale integration of renewable sources in the electricity system. A final section presents the second scenario where distributed generation becomes the dominant design. The next steps in the development of STSc are then provided in two subsequent chapters. First a reflection is given on the two scenarios in terms of dominant mechanisms and driving forces, and this is followed by policy recommendations that are drawn based on the two scenarios.

6.2 1990-2000: The Electricity Regime Opening Up

For more than a half century the electricity regime was rather stable, as a closed and stable network of actors had been able to control both the direction and speed of change in electricity generation, transmission and distribution, based on steady growth of electricity consumption. This process was similar in most industrialised countries (see for example Hughes, 1983; Hirsh, 1999; Unruh, 2000; Verbong, 2000). In the last decades the stable electricity regime has begun to open up. Its social network became unstable as national government aimed to exercise more control, and industrial and societal actors challenged guiding principles of the regime (Arentsen et al, 1997; Joskow, 1998; Hirsh, 1999, Patterson, 1999, Hofman & Marquart, 2001). The regime was long able to deal with increasing external demands such as efficiency and environmental emissions without fundamentally changing the sociotechnical configuration. In the Netherlands, the separation of electricity production and distribution companies in 1989 however led to increasing tension within the social network of regime actors. New coalitions were formed between electricity distributors and industrial actors for decentral cogeneration of heat and power at the expense of central electricity generation. The overcapacity that followed was already a sign of the loss of control by regime actors (Arentsen et al, 2000). The anticipation of further liberalisation and the increasing importance of the climate problem led also to new actor coalitions that developed and marketed the novel concept of green electricity (e.g. energy distribution companies and environmental NGOs). The phased introduction of free choice of electricity provider for consumers led to the end of fixed price developments based on monopoly organisation in the electricity regime. User preferences started to shift as consumers became aware of opportunities to settle different contracts and to buy electricity with specific characteristics that suited their demand, such as green electricity. With the emergence of new markets, exchanges and actors old social networks vanished and new networks emerged. With the landscape development of liberalisation, climate change and information technology increasingly penetrating the electricity regime, uncertainty over the future direction and speed of developments in electricity generation and use became high (e.g. van Hilten et al, 2000). Networks of actors were involved in different development paths and it was difficult to predict which group would become dominant. An example of the strategy of a powerful entrant in electricity generation is illuminating. Shell invested significantly in networks and R&D for the development of hydrogen production, storage and fuel cells, photovoltaic (PV) systems and offshore wind farms. Its investments in gas, such as production fields, pipelines and liquid transport, were even higher. Thus, it played the game of being party in all the potential energy sources and technologies that could determine the direction of future energy systems. In overview then, the nineties witnessed both significant institutional and technological changes in the electricity regime, as outcomes of processes that were already longer at work. Figure 3 presents an overview of the main developments in the Dutch electricity regime in the past decades. It is in this setting that the two sociotechnical scenarios illustrate paths towards a carbon-lean electricity system, initiated by some of the change processes in the electricity regime at the end of the twentieth century.

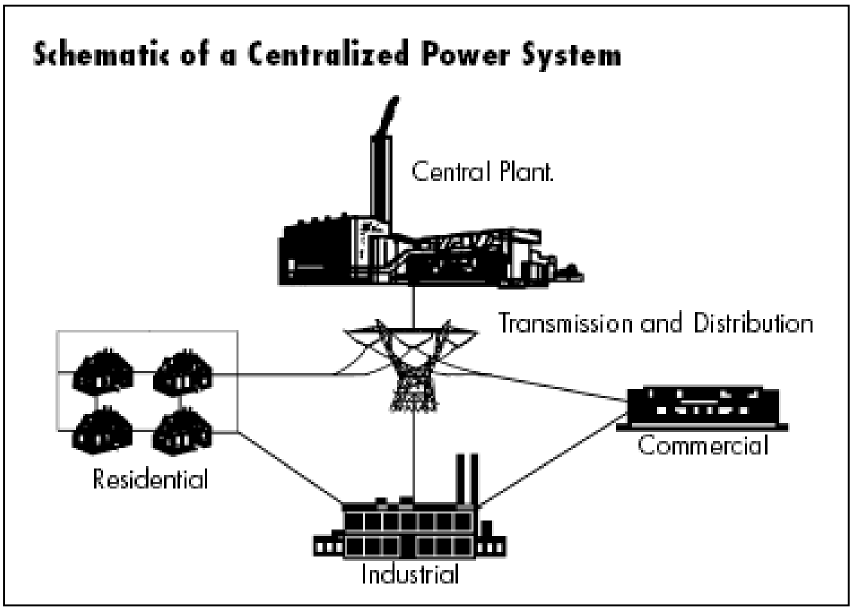
Figure 3: Overview of developments in the Dutch electricity regime 1970-2000 (adapted from Hofman & Marquart, 2000: 136)



6.3 Design of the scenarios

The traditional design of the electricity regime is based on large centralised power plants that produce bulk power and relies on an extensive infrastructure for transmission and distribution for transport of electricity to a range of consumers. This system is known as the central station electricity system and is illustrated in figure 4. Its dominance is still strong in most countries and particularly in those that employ energy resources that are most efficient at large scales such as Germany, France and the USA with its dependence on coal and nuclear energy (e.g. OECD 2001).

Figure 4: The central station electricity system (Dunn, 2000: 42)



In the Netherlands central generation has become less dominant with the advent of decentral combined heat and power production in the last decades facilitated by the extensive Dutch gas infrastructure. Yet, more than 50 %, and with imports more than 70%, of Dutch electricity is generated by central power plants in 2000 (EnergieNed, 2001). The process of liberalisation led to increasing crossborder electricity flows, particularly from 1998 on, and the Netherlands increasingly both imported conventional (fossil and nuclear based) generated electricity and electricity based on renewable sources. The first scenario particularly builds on this internationalisation of the electricity regime and the further extension of the central station electricity system to the European level. The carbon base of this system steadily drops as renewable energy is increasingly integrated into this system. Table 2 shows how landscape factors interact with developments in the regime and niches in this scenario.

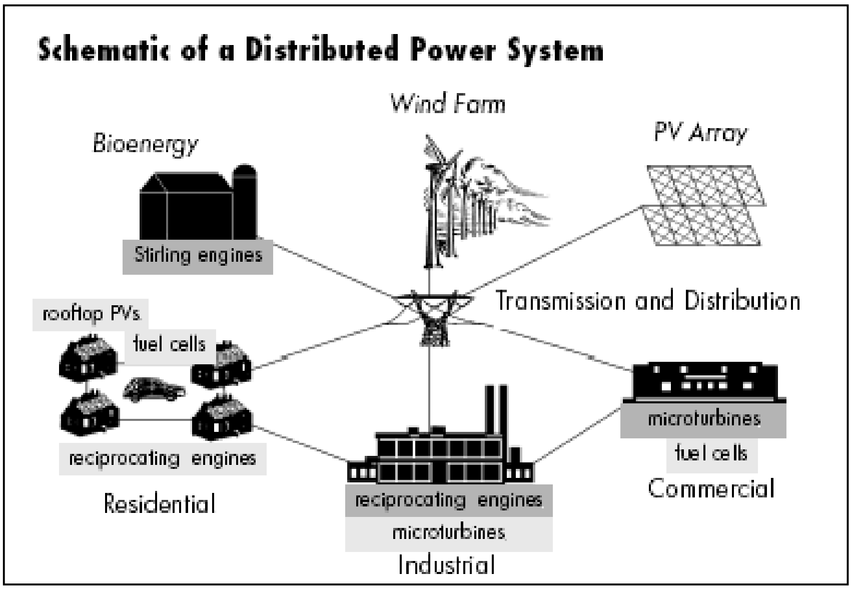
Table 2: Sociotechnical landscape factors and their impact on two scenarios

Landscape factor	Impact on scenario 1	Impact on scenario 2
	Large scale integration of renewables in the central station electricity system	Development of renewables in the distributed generation model
Liberalisation	+	++
ICT penetration	+	++
Climate change urgency	++	+
EU integration	++	+/-
Citizen green awareness	+	+

Various landscape factors interact with developments in the regime and at the niche level in the scenario of large-scale integration of renewables in the central station electricity system. In the long term the political development towards EU integration is of particular importance because it enables the exchange of electricity based on large-scale renewable sources between countries with different comparative advantages. The transition paths reflect driving forces that in the first scenario extend the current national electricity systems to the international European level, and in the second scenario lead to much more demand-oriented local and regional electricity systems. In the first scenario the process of liberalisation, European convergence and increasing concentration in the electricity sector facilitates the trend towards large scale centralised power stations that can supply electricity around Europe through electricity grid highways. Renewable energy in this system is supplied at large scale at the most optimal locations (for the technical potential see for example Meij, 1999).

In the second scenario liberalisation, increasing consumer power, and ICT developments have facilitated custom made electricity systems tailored to the specific needs of individual customers, be it households, neighbourhoods, SMEs or large firms. In this scenario the electricity system evolves towards a much more flexible and demand oriented system based on a variety of electricity generation technologies. This is known as the distributed generation model (Feinsteins et al, 1997; Smeloff & Asmus, 1997). The model is characterised by power systems that offer power close to the customers, rather than building transmission lines and distribution facilities to move electricity from central power plants to consumers (figure 5).

Figure 5: The distributed generation model (adapted from Dunn, 2000: 43)



The systems are designed on specific local or regional demand for electricity, sometimes connected to specific building or neighbourhoods. This technological path emerges because the conventional wisdom that large central stations are the most economical to provide power to customers is shaken by the advent of smaller, efficient gas turbines and the emergence of fuel cells that can secure reliability of electricity supply for individual users (see for example Flavin and Lenssen, 1994; Smeloff & Asmus, 1997; Budhraja, 1999; DOE, 1999; AD Little, 1999; Patterson, 1999; Dunn, 2000). The emergence of local based systems implies a development towards a much more diverse system, with the real-time fine-tuning of supply and demand within reach through developments in information and communication technologies.

The next paragraphs present the two sociotechnical scenarios, with the first scenario focussing on large scale integration of renewables in the electricity regime and the second scenario the transformation towards distributed generation.

6.4 Scenario 1: Large Scale Integration of Renewables in the Electricity Regime

6.4.1 2000-2010: Liberalisation creates tension in the regime

Five landscape trends were driving further change in the electricity regime with liberalisation as the most pervasive one. In combination with European integration, climate change, ICT and the new economy, and security threats it led to a totally different setting in which the electricity regime was operating.

Several patterns of change were visible in the electricity regime. Established power producers engaged in international price competition in order to realise full utilisation of their power plants and to satisfy customers' demand for low prices. A sharp increase in international trade in electricity was the consequence. To guarantee a European free market the EU intensified its role in harmonising the processes of liberalisation of national electricity sectors and in safeguarding sufficient capacity for crossborder electricity transport. The more volatile market conditions also demanded more flexible power plants that could produce efficiently at different loads and had short start up times[2]. This reinforced the shift towards gas within the fossil fuel mix because of the higher flexibility and efficiency of the gas turbine relative to the more capital intensive and rigid coal-fired and nuclear power plants[3] (see also Shell, 2001). Large oil and gas companies such as Shell were also able the enter the electricity generation market by investing in combined cycles (CCGTs) that produced electricity and heat fuelled by their own gas supply. This gave them an edge over other power companies with gas-fired power plants that had to cope with volatile market conditions for gas. Gas was also viewed as a strategic resource in the path towards a carbon free electricity supply based on hydrogen and for hydrogen production for other uses, such as mobile fuel cell applications. Production of hydrogen with gas was expected to precede other options of hydrogen production. In anticipation of an increasing role of gas in energy supply several oil & gas companies invested strategically in gas assets in Europe and Asia to assure their role in supply gas from example Russia to Europe and towards countries such as China.

The emancipation of the previous mostly passive electricity users led to various changing user preferences. In combination with the penetration of ICT and the new economy, for example, this led on the one hand to higher quality and reliability demands[4] while on the other hand it facilitated e-commerce in the electricity system. Also, industrial users settled one contract for the combined purchase of heat and power or different contracts for base-load and peak-load electricity delivery. Households with commitment to sustainability were keen on a green profile of electricity. Especially energy distributors and new entrants were developing innovative products and services that could meet the changing user preferences.

At the niche level, opening up of the electricity regime due to liberalisation and ongoing pressures due to the climate change problem spurred several niche developments. In order to

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[2] Flexible power plants could also reap benefits from the volatile market conditions. At the Amsterdam APX power exchange, for example, prices at peak periods soared during some hot days in August from the average of around € 35-40 per MWh to € 500 per MWh (Energeia, August 18th, 2002).

[3] In traditional thermal power stations coal, fuel oil or gas is burned in a boiler to generate steam, which is then expanded in a steam turbine to generate electricity. This type of power plants reached efficiencies just above 40% in 2000. Combined cycle gas turbines (CCGTs) were at that time installed with efficiencies of around 60% (IPCC, 2001: 237-238). CCGTs are more flexible than traditional power stations due to lower capital costs and shorter construction times, flexibility in plant size, and fast start-up (e.g. Islas, 1999; Colpier and Cornland, 2002).

[4] The new economy presented problems for power utilities because it required a much higher quality source of electricity than a traditional energy intensive industry. Much of the ICT sector required up to "nine nines" of reliability to prevent information being lost (Jones, 2000).

safeguard the continuing role of coal in power generation efforts were stepped up to improve the efficiency, and environmental and carbon profile of coal-fired power plants. This was done through various strategies. In the USA the main strategy employed by coal companies and government was to develop gasification technology that would enable higher efficiency and better emission control (see e.g. Soria and Russ 1996; McMullan et al. 2001) of coal based electricity generation by connecting it to the gas turbine technological trajectory and eventually to hydrogen based electricity generation with fuel cells[5]. Support for this strategy increased with the intensified focus on resource independence after the September 2001 terrorist attacks. While efficiency and resource independence mainly drove investments in clean coal technologies in the US, in Europe the Kyoto protocol was a prime driver. In the Netherlands, to relieve the strong political pressure in the Netherlands, Dutch coal power producers adopted strategies of co-firing coal fired power plants with biomass. In exchange political support was given through the exemption of the regulatory energy tax for the biomass-fired part of electricity generation[6].

In the Netherlands the concept of green electricity provided momentum for investments in renewable energy sources in the first decade of the century. Green electricity developed quickly as tax incentives[7] made it competitive to conventional electricity and households became more accustomed to it through extensive marketing campaigns of energy companies and environmental NGOs. As Dutch fiscal compensation for green electricity was relatively large in Europe, this led to significant imports of green electricity, sometimes based on already existent green power plants. Political and societal opposition increased against the perceived misuse of the exemption, and rules for exemption regulatory energy tax were sharpened to induce green electricity sales based on newly installed green power plants. Also a certificate system emerged to account for the renewable source of green electricity and to make green electricity flows more transparent. The different policy frameworks for green electricity in European countries began to converge with the introduction of a system of green electricity certificates in 2004 and the introduction of a European carbon tax by 2006. The amount of R&D in renewable energy at the European level also increased, and some large-scale projects were initiated to tap renewable sources.

While initially consumers were hesitant to buy green electricity, the marketing campaigns of energy companies and environmental NGOs, and its competitive price, increased consumer awareness of the product and sales. Increasing green electricity sales fuelled further investments in biomass and wind energy. Established producers of conventional power increasingly became involved in green electricity but had to compete with new actors that saw green electricity as a growth market. Constraints for wind energy on land (regulatory,

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[5] For example the Zero Emission Coal Alliance was formed in 1999 between 18 members from private industry and government in the USA and Canada to explore fossil fuel feedstock gasification. Part of the research efforts also focussed on options to separate and sequestrate CO_2 in anticipation of further regulation or carbon pricing to reduce carbon emissions (Nawaz & Ruby, 2000).

[6] These agreements were established in a covenant (Coal Power Plants and CO_2 Reduction) between six coal power producers (Electrabel, EPZ, Essent, E.ON, Reliant and NUON), the Dutch Ministries of Economic Affairs and Environmental Affairs, and the branch association EnergieNed. The electricity companies agreed to reduce their CO_2 emissions with 5.8 megaton in the period 2008-2012 relative to 1990. They were to realise this by 3.2 megaton through co-combustion of coal with biomass. The other part was to be achieved through efficiency measures also for their gas-fired power plants. Government agreed to continue the incentives for the use of biomass in a similar fashion as was taking place in 2002 through the exemption of the regulatory energy tax (Ministry of Economic Affairs, 2002).

[7] For example in 2001 the regulatory energy tax was 5.83 €ct/kWh for households and small consumers (annual consumption up to 10.000 kWh). The average electricity price in 2001for this consumer group was around 22 €ct/kWh. The tax is collected by the electricity provider and then transferred to the treasury. No regulatory tax is levied for the consumption of electricity generated by renewable sources (ECN, 2002).

societal) led to increased expectations and investments in off-shore wind farms where these constraints were less complex to deal with. Wind power continued its development toward offshore wind farms facilitated by further growing demand for green electricity, regulatory developments, and strengthening coalitions of offshore companies, utilities and oil companies. (see e.g. Beurskens 2000 and de Vries 2001)

The niche for biomass continued to grow with the increase of green electricity sales and increasing demand from especially coal producers. The number of actors involved in production, trade and infrastructure for biomass grew. This led to problems regarding regulation schemes for transport (initially only allowed for waste companies) and regarding emission standards. These problems were slowly solved on a case by case basis, and a clearer policy framework for biomass utilisation emerged. Actors such as forest organisations, agricultural companies and waste companies increasingly offered specific biomass flows to energy companies, and adapted their flows to specific categories and standards to increase its value. With an increase in companies commercially involved in biomass trading, handling etc., energy companies relied more on these actors for their supply while previously contracts were settled by energy companies with producers. An international market for biomass emerged and several (developing) countries became involved in biomass cropping[8].

6.4.2 2010-2020: Increasingly adoption of climate friendly energy technologies

Climate change concern became a more significant driver of regime change as carbon emissions were priced through policies of emission trading and carbon taxes. Pilot projects in emission trading in the Netherlands, UK, and Denmark served as examples for the design of a European trading scheme. The EU also reinforced its role in international electricity trade to secure to reliability of the emerging European electricity system. ICT technologies became more pervasive throughout the electricity system as it enabled online energy resources and electricity markets and fine-tuning of power plant utilisation.

In the electricity regime coal power plants started to reach the end of their life-time and new investments occurred in energy technologies that suited power and environmental demands better. The strategy of co-firing with biomass reached its limit as the rising share of biomass in the fuel mix led to high capital costs to clean exhaust gases. Coal gasification increased in several coal dependent countries. Especially the US was a frontrunner as part of their strategy towards more resource independence. In Europe, with stronger climate pressure, the higher efficiencies that could be reached with coal gasification in combined cycles were accompanied by strategies to reduce the carbon content. This involved projects with carbon removal and sequestration and co-gasification with biomass. Gasification processes were in some pilot projects integrated into existing refineries and chemical plants, as syngas was utilised as raw material for a variety of products.

While co-combustion and co-gasification stimulated early demand for biomass, later biomass gasification technology became more prominent. Regulations regarding emissions of CO_2, NO_x and other substances became based on the performance of the integrated gasification combined cycles (IGCCs), making further installation of traditional coal-fired power plants difficult. Moreover, biomass gasification became more attractive as costs of carbon removal were becoming a heavier burden for coal power plants.

[8] The potential and profitability of this was already shown by van den Broek (2000) who, in his PhD thesis, estimated in 2000 that biomass cropped in Nicaragua could compete cost-effectively, including transport costs, with local Dutch biomass crops.

In the Netherlands the number of households purchasing green electricity steadily grew from 10% in 2000 to 30% in 2015 [9]. Its price level remained competitive as cost reduction of biomass and wind energy offset the reduction of tax benefits. The introduction of the regulatory energy tax for industries, later replaced by the carbon tax, increased the number of companies using green electricity. This also provided momentum for industries to invest in and buy renewable energy. Green electricity from foreign sources grew as Dutch growth of renewable energy was insufficient. This gap closed as more wind farms and IGCC power plants were constructed to replace power plants from the 1980s.

A relatively new niche development involved hydrogen production from gas, with hydrogen mixed in the gas network and CO_2 removed and either used in horticulture or sequestrated. Also conversion from gas to hydrogen and carbon black was initiated in demonstration projects, with the carbon reused in the tire industry, as it was thus able to improve its carbon profile. Hydrogen was also used for first mobile applications of hydrogen fuel cells. Another niche for hydrogen powered fuel cells concerned data processing stations that needed very reliable power that could be served by fuel cells that additionally are quiet, clean without the need for a strong grid. The growth potential of these niche market led power equipment sector to further develop and market the combined fuel cell and microturbine that with its very high electric efficiency and low emissions was very attractive in several fast growing niche markets such as back-up systems and ICT concentrated demand. The system was especially suited for power supply to areas where power demand was high and heat demand low.

6.4.3 2020-2035: Disintegration of the fossil based regime

At the landscape level, the European Union continued to reinforce its role in the electricity system. Moreover, reducing the carbon content of the energy system became a high priority as extreme weather events and global warming were now generally accepted to be related to human induced increases in carbon emissions.

At the regime level, investments in IGCCs started to outrun those in CCGTs as they combined high efficiency with an ability to deploy various feedstocks and produce multiple products. The significant price on carbon emissions were also a factor that made CCGTs economically less viable. Coalitions between energy companies and agricultural and chemical companies emerged to bundle expertise regarding biomass utilisation, electricity marketing and chemical production and marketing. Hydrogen, as one of its products, was utilised increasingly for mobile applications. Global use of biomass as an electricity generation source increased rapidly and spurred trade in various waste and biomass products. Several developing countries shifted part of their commodity production towards biomass crops that guaranteed better income than traditional crops. ICT played a role in facilitating on-line exchanges of electricity and of resources for electricity generation such as biomass, hydrogen.

After production of several thousand units of hybrid microturbine/fuel cell systems lowered the costs of the system, power equipment producers started to produce larger scale units in the MW range because the enabled them to reduce costs even further and to tap other than niche markets. Some large power equipment producers bought up fuel cell companies to produce these larger systems. The systems began to compete effectively with CCGTs especially for peak and medium loads also because gas prices were steadily increasing as rising gas demand had led to reduction of gas reserves, especially in Europe. While initially the hybrid fuel cell/gas turbine systems were powered by hydrogen through gas reforming, they increasingly used direct hydrogen as both the production and infrastructure for hydrogen developed.

[9] In 2000 this corresponded with around 2% of total electricity consumption, in 2015 with 6%.

One source for hydrogen were the offshore wind farms that produced surplus electricity at low demand, especially night, and were connected with electrolysis system to produce hydrogen. This also enabled better integration of the wind farms into the grid. The increasing share of wind power in the grid and its intermittent character drove the search for solutions that could decrease its discontinuous character and improve its integration in the grid. Combined production of power and hydrogen gained momentum as it solved both the problems of discontinuity and storage. Hydrogen and fuel cells turned out to be a strong solution because of its durability, reliability, flexibility and modularity. Also solar power was implemented at large-scale in pilot projects in southern Europe under support of the EU. Utilisation of ICT also enabled better anticipation of discontinuous resources such as PV and wind, and thus enabled better overall control of the international electricity regime. Expectations regarding large-scale solar power increased because with the further strengthening of the grid, long distance transport at higher voltage, and improvement of cable and conduction technologies, led to reduction of transport losses and made transport at longer distances possible.

As climate change and sustainability became even stronger issues in this period, both in housing and in mobility several initiatives were taken by environmental NGOs in collaboration with progressive energy companies and municipalities to develop zero-emission communities. The worldwide fund for nature (WWF) had already been involved in low energy housing and now aimed for housing districts that were emission free and with several renewable sources for hydrogen production. The fuel cells in the cars that used hydrogen both served as a source for mobile power and for stationary power in the districts. Especially Greenpeace had been involved in getting these cars to the market in collaboration with car companies. As hydrogen production and application for electricity generation other resources increasingly converted to hydrogen as the final energy source through the emergence of hybrid energy technologies, such as wind-hydrogen and solar-hydrogen systems.

6.4.4 2035-2050: Regime shift to international renewable electricity generation

The process of European unification continues and political power increasingly shifts to the European level, for example authority over the grid shifted to a European operator authority over national high voltage grids. With political stability in Europe there is less concern regarding national under capacity as the reliability of electricity supply is guaranteed through European law, rules and agreements. The development of various renewable sources at large scale across Europe also led to increasing transport of electricity to tap the most suitable sources at all times. Various large-scale projects for wind energy, PV, tidal energy were developed as they could be connected to this European grid. In the Netherlands coal was only utilised as a power resource in a coal gasification plant in the Rijnmond area, with the CO_2 re-used in other processes, such as in horticulture. In Europe the number of coal power plants was dropping because of the costs of CO_2 removal and the difficulty, also due to societal opposition, of finding proper locations for carbon sequestration.

The installation of a combination of wind turbines and farms with hydrogen powered fuel cells became a standard option. However the growth of investments in wind farms flattened out as the most suitable locations had been utilised and resistance to more wind farms grew. Various renewable resources and energy technologies increasingly started to compete with gas and gas turbine technology on the basis of costs. Solar hydrogen systems were developed in Southern regions (Europe and Africa) as they served local hydrogen need and produced power for the international grid**.** Wind hydrogen systems were developed that combine the production of power, hydrogen and water at offshore locations and competed based on their different functionalities. Production and international trade in biomass fuels continued to blossom as it both provided input for the production of hydrogen and for the IGCC power plants. In 2050 electricity demand in the Netherlands was met half by national power production with several highly efficient combined cycles based on inputs of gas, biomass and coal (with CO_2 removal) and offshore wind-hydrogen systems, leading to a halving of CO_2 emissions compared to the 1990 level. The other half was met by import of electricity based on combined cycles, offshore wind farms, solar hydrogen systems and hydropower.

6.5 Scenario 2: Towards Distributed Generation

6.5.1 2000-2010: Diverging actor strategies in the electricity regime

Several landscape trends were driving further change in the electricity regime with liberalisation as the most pervasive one. In combination with climate change and the further penetration of ICT and the new economy, it led to a totally different setting in which the electricity regime was operating.

At the regime level, changing user preferences facilitated by liberalisation induced increasing divergence in strategies of mainly international operating electricity producers and more national focussed energy distribution companies. They redefined their strategy in order to survive in the changed setting, while new actors saw chances to penetrate the electricity regime. Producers that previously operated on domestic markets with monopolistic organisation and fixed prices became involved in international price competition. Their strategy was to supply cheap base load electricity by full utilisation of their large-scale power plants based on coal, oil, gas or nuclear energy[10]. They were mainly focussed on industrial actors with a relatively high electricity demand. However they were increasingly faced with problems to gain enough demand as the European market was characterised by over capacity at the onset the 21st century. Distributors were more focussed on customers with smaller electricity demand, such as households and small firms. They were attracting customers mainly by highlighting the specificity of the products and services they could deliver[11]. Examples were the joint delivery of heat, power, water and telecom, with reduced administrative burdens for customers, and the provision of green electricity with its environment friendly image. It also included the provision of tailor made heat and power supply based on the specific demand profiles of customers, such as levels of reliability higher than could be delivered through the grid. On the one hand distributors aimed to further expand market niches such as industrial CHP, in collaboration with industrial actors, and on the other hand they further explored technological niches such as micropower[12] in coalition with gas utilities and electric equipment producers. In various projects the potential of microturbines was demonstrated for relatively efficient heat and power generation. Gas utilities were involved in order to expand the market of gas relative to central produced electricity and to prevent the substitution of gas in heating and cooking for electricity. Several industries were involved because they needed electricity in combination with high quality heat that could be provided by microturbines. Support by R&D programs, given because of the higher efficiency of these systems and associated CO_2 reduction, made these projects attractive for industries,

[10] The efficiency of these, steam turbine based, power plants, decreased significantly when they were not operated at full load. With the dominance of gas-fired power plants in the Netherlands, and relative high gas prices in the first decade of the 21st century, opening up of international electricity trade led to an influx from electricity based on coal (e.g. from Germany) and nuclear energy (e.g. from Belgium, France).

[11] For example the Dutch energy distributor Essent said its strategy was to provide convenience to customers and in a similar strategy NUON marketed the homecare concept (Intermediair, December 13th, 2001; Berkhout (2000); ECN (2002).

[12] Micropower is the production of electricity by systems in the range of kilowatts, for example with gas/stirling engines, microturbines or fuel cells, enough to serve one or several households.

while in the longer term these systems were expected to be able to compete with central power delivery and steam delivery from gas. Projects with micropower for several households were also supported by coalitions involved in the development of energy-efficient housing districts. The Dutch branch of the worldwide fund for nature (WWF) was already involved in projects to increase the energy performance of housing districts, and had developed a set of design criteria that were used in several housing projects by project developers, construction companies and municipalities. They explored the potential of further improving energy efficiency in houses by installing these micropower systems. Additional costs of these houses were only small relative to total costs of construction and land, while some subsidies were granted through R&D programs. Potential buyers were not scared away by these additional costs also because of the continuing housing scarcity, while some leading edge buyers were specifically attracted by the green profile of the houses.

The projects induced further experiments with local generation systems because several problems were encountered. Distributors had to solve problems of increasing two-way electricity flows in the local low voltage network as these networks had always been designed to carry flows from central production units to users. In follow-up projects they placed more efforts in designing the network more specifically for two-way flows. Also the projects did not discern the different heat and power demand profiles of various users, and this led to surplus heat production that needed to be stored. To reduce this problem, power equipment producers began to work on designs for micropower systems with different heat-power ratios, while distributors in collaboration with producers of domestic appliances began to focus on the development of smart systems in which appliances could be switched on and off at the most feasible periods. Also construction companies and engineering companies learned through the projects that traditional designs of electricity and gas networks at the house level needed to be reconfigured.

Apart from these technical issues, the coalition of actors also aimed to make micropower economically more attractive. They increased lobbying to reduce the tax on the gas used for micropower, through partial exemption of the regulatory energy tax, because they argued that this concept also significantly reduced CO_2 emissions. The economic conditions for CHP began to improve in the second half of the decade partly because of these government measures but also because the effects of the liberalisation of the gas market started to impact gas price developments. Increasing trade in gas and the release of the link of the gas price to oil price development led to lower gas prices. Moreover, in the electricity regime over capacity began to wither away with increasing electricity demand and limited investment in large-scale power plants, leading to small hikes in electricity prices. As growth of electricity demand was rather concentrated, such as in areas with many ICT companies, the capacity of the grid was insufficient to serve this power demand. This led to collaboration of ICT companies and energy distributors to develop local systems that were able to serve high electricity demand and a high level of reliability.

6.5.2 2010-2020: Decentral CHP gains momentum

At the landscape level, climate change gained priority as the Netherlands had been unable to realise the Kyoto targets and Dutch government aimed to intensify its climate policy. The strong development of the new economy led to further demand for high quality electricity by companies involved in ICT, banking and online exchanges.

In the electricity regime central producers were faced with increasingly obsolete power plants that needed replacement. Due to stagnating demand for centrally produced electricity only a small amount of the closed traditional power plants were replaced by new combined cycles gas turbines (CCGTs). The relative share of central power generation continued to fall as various energy technologies provided opportunities to produce power efficiently locally. Climate change started to get a higher priority as the Netherlands had been unable to realise the Kyoto targets and Dutch government was looking for ways to intensify its climate policy. The policy to exempt CHP partly from the regulatory energy tax became into operation, while the regulatory energy tax was now also applicable for large energy users.

Several users developed specific demand characteristics with regard to the reliability of power delivery due to the nature of their business. This involved on-line financial transactions, exchanges, ICT operations, that needed reliable power. These companies were increasingly installing local power back up that could handle short fall out periods, especially since the trend in the electricity regime was of declining quality of infrastructure and a decreasing reserve capacity which increases the risk of fall out. Increasing power shortages led leading edge companies to install fuel cell stacks to secure their electricity supply. Also increasingly electricity contracts were settled between ICT, financial companies and energy companies that combine high reliability with high liability, and energy companies installed very reliable local capacity with fuel cells for these types of companies.

At the niche level, microturbines became more widespread with as the coalition of energy distributors and gas utilities continue to spread the application of CHP systems to smaller companies, neighbourhoods and households. Project developers and municipalities adopted the design criteria by the WWF in several new housing districts that were developed and installed micro CHP systems. In several projects users were involved in the design phase of these houses in order to improve the balance between individual demand and the micropower system installed. Also smart electrical equipment was used to improve the utilisation of the micropower system. The leading edge users that were involved in this project turned out to be able to more efficiently use the micropower system, effectively reducing their energy costs. This led to more users in other projects that wanted to be involved in the early stage of the housing project development. The high energy efficiency of these houses also led to sharpened energy performance standards in energy and housing policy.

The rise of micropower for neighbourhoods and the rise of very reliable local power supply for specific companies led energy distributors to increasingly focus on the design and management of local electricity networks. In these market niches the role of energy distributors shifted towards managing local electricity flows. Energy distributors established closer relationships with online sellers of appliances for domestic and business use, and with local electrical engineering companies in order to be able to provide advice to customers regarding their use of electric equipment. Much of these advices took place in a virtual setting, with customers such as companies and households getting online advice whether the sale they were considering would fit into their power and heat system.

6.5.3 2020-2035: Stagnation of central electricity generation

Reducing the carbon content of the energy system became a high priority as extreme weather events and global warming were generally accepted to be related to human induced increases in carbon emissions. ICT further penetrated society with for example an increasing in the use of smart equipment, where users could control and program equipment from a distance.

At the regime level, most traditional power plants that originated from the period 1985-2000 were dismantled. Only highly efficient and flexible CCGTs remained competitive. This led to an increasing demand for local electricity generation capacity. Carbon trading also led to a search for ways to reduce environmental impacts of gas-fired CCGTs and central systems. The share of decentral CHP further increased (40%) and distributed generation systems started to make up a significant part of the Dutch electricity regime (10%).

While until then the rise in micropower was mainly based on the development of new housing districts, micropower now started to replace the conventional heating systems in existing houses as installation companies increasingly adopted it as an option for heat and power production in houses. Several of these installation companies had gained experience with the design and installation of these systems in new housing districts and became convinced of its potential in existing houses. Also users became increasingly accustomed to the use of micropower as it slowly became available in companies that provided household equipment and marketing campaigns were started to convince customers of the economic and environmental benefits of micropower.

The development of PV and wind had been relatively independent of the development toward micro CHP. This started to change also because of the realisation that further progress needs to be made to tackle the climate problem. Energy distributors played a central role in the emergence of local CHP systems that make combined use of fuel cells, PV in urban areas and wind plus PV in rural areas. In their coalition with the WWF and various project developers new housing districts were designed with zero emission in several demonstration projects, supported by subsidies. As climate change and sustainability became even stronger issues in this period, both in housing and in mobility several initiatives were taken by environmental NGOs in collaboration with progressive energy companies and municipalities to develop zero-emission communities. The worldwide fund for nature had already been involved in low energy housing and now aimed for housing districts that were emission free and with several renewable sources for hydrogen production. The fuel cells in the cars that used hydrogen both served as a source for mobile power and for stationary power in the districts. Especially Greenpeace had been involved in getting these cars to the market in collaboration with car companies. The systems make balanced use of renewable energy production from PV, wind and biomass, and use hydrogen as an important intermediary resource. PV and wind can either produce electricity for the households, or, in periods that power demand is low, hydrogen through electrolysis for the fuel cell.

6.5.4 2035-2050: Regime transformation towards distributed generation

Gas was still exploited as a resource for the production of hydrogen but its share in power generation was falling. Alternative options for the production of hydrogen steadily increased their share, such as hydrogen from biomass sources, wind energy and solar energy. Investments in power generation virtually all took place in flexible power systems that offered power close to the customers and were based on sources varying from wind and sun, to biomass and hydrogen. The systems were designed for specific local or regional demand for electricity, with connections to specific industrial users, commercial users and neighbourhoods. Also micropower systems continued to take a significant share of the power market. Investment in central capacity was absent in this period, although some larger power plants were installed related to specific electricity and heat demand of industrial users.

In 2050 around 25% of electricity generation capacity was handled by relatively autonomous distributed generation systems, also fuelled by zero-emission zones. This emerged through the connection of previously independent small scale power generating technologies in local systems, facilitated by on-line monitoring and power management. Newly built neighbourhoods became self supportive for power generation while existing neighbourhoods increase share of local produced power. This process was stimulated by new legislation was enacted that prohibits the construction of houses and housing areas that draw external power or generate any harmful emissions with power generation. Moreover standards were developed to increase the share local produced power in existing houses. Apart from wind and PV also locally produced biomass was becoming part of a local cycle of power and hydrogen production. Another 50 % of electricity generation was provided by decentral CHP systems with a connection to the central grid. Around 25% was provided by central power plants that were not connected to specific users. Regulations were developed that made further investments in fossil based power plants more unattractive as it became only possible under specific conditions to enact power plants that were not part of a zero-carbon-emission scheme.

7 Step 6: Reflection upon the scenarios

The two scenarios have quite contrasting outcomes. The scenario of large-scale integration of renewables in the electricity regime is basically an example of modification of the current national, fossil based regime to an international electricity regime where various renewable sources take up a significant part of electricity generation and fossil fuels have developed climate neutral generation routes. Crucial is here the development of EU policies to develop an international grid and the changeover of security of supply issues from the national to the European level.

The scenario of distributed generation illustrates the emergence of an alternative electricity regime where the design of the system is regionally dependent on the match of specific demand patterns to a variety of energy technologies. Moreover, electricity generation has become more integrated with other functions, especially housing and transport. This path evolves as specific energy technologies serve specific demands in the growing niche markets of the electricity regime.

Important to note is that the differences in the two scenarios are not so much the consequence of different technologies being developed and used but much more the result of different actor networks and drivers that become dominant. In the first scenario the traditional power producers utilise gasification technology on a large-scale driven by climate change pressure and facilitated by EU convergence. Developments in the US provide important initial development of the niche through its focus on coal gasification. In the second scenario especially energy distribution companies in coalition with gas utilities seek opportunities to increase their market share by the development of micro-CHP in coalition with other actors.

Table 3 provides an overview of some of the main characteristics, drivers, networks and differences and similarities of the two scenarios.

Table 3: Characterisation of the two scenarios and transition paths

	Large scale integration	Distributed generation
Initial Niches	• Biomass co-combustion in coal-fired power plants • Offshore wind power farms • Coal/Biomass gasification; based on international niche proliferation • Fossil generation with CO_2 separation, storage.	• Combined heat and power production with small scale electricity generation technologies • Local power generation because of overburdened grid • ICT demand for reliable power • New housing districts with low energy impact
Main differences	Large scale power plants at international level, based on biomass gasification, wind power, pv and hydrogen facilities; international electricity highway; international coordination of electricity flows	Dominance of local based networks with electricity generation units dimensioned to local demand; high voltage grid serves as back up; integration of number of energy technologies/sources such as pv, wind, biomass, fuel cells, turbines
Main similarities	Gas and hydrogen important bridging resources, fuel cells important energy technology also in hybrid combination	Gas and hydrogen important bridging resources, fuel cells important energy technology also in hybrid combination
Drivers		
Landscape	Liberalisation, EU integration, Climate change	Liberalisation, ICT, Sustainability/climate change
Regime	Increasing international character of regime, uptake of renewables by regime	Battle between electricity producers, multi-utilities and gas companies; changing position of consumer
Niches	Hybridisation of niches with regime; niches adapt to dominant design of central station electricity	First niches because of differentiation in regime; niches slowly built new power system design of distributed generation
Barriers	Mismatch of renewables with regime, problems of integration into existing regime	Design, regulation, routines based on central station electricity regime, not on local generation with local grid
Dominant networks	Networks with traditional electricity producers, distributors and government actors; oil and chemical sector becomes part of electricity regime	Networks of energy distributors, engineering firms, construction companies, housing associations and municipalities
Policy	Strengthening of international grid, EU policies, support for green electricity, and labelling of electricity flows	Local energy policy, stimulation of alternative infrastructures, integration of energy in built environment

8 Step 7: Policy recommendations

We started this report arguing that there is a need for transition policy in order to place short-term policies into a more long-term perspective of transition thinking. Sociotechnical scenarios can contribute to create visions on promising transition paths. The question then arises whether existing policies enable or constrain certain promising routes and can be improved to promote them. Sociotechnical scenarios help to answer this question. Ongoing dynamics in the electricity system offer starting points for two diverging transition paths that both are plausible. Policies need to be robust in a way that they allow these transition paths to unfold and support the main underlying dynamics. Based on the constructed sociotechnical scenarios we draw several policy recommendations to support a transition to a sustainable electricity system.

8.1 Short description of current policies related to the electricity regime

Energy policy related to liberalization has a strong impact on the electricity regime. They have been and are influencing the rules and routines under which regime actors devise and revise their strategy. The policy motivation behind liberalization is to increase efficiency of the electricity supply through increased competition at the international level. In the situation of liberalisation furthermore various regulations are developed to safeguard two other priorities in energy policy: reliability of electricity provision and security of supply. Within this context and *separate from liberalization* also climate policies are formulated. Climate related policies until the end of the nineties had a dominant orientation towards optimisation of the current electricity system. Policies initiated out of diversification of energy resources and efficiency concerns have been extended. With economic sectors agreements have been concluded to increase energy efficiency and with the energy sector to increase the efficiency of electricity generation and reduce the carbon content. The agreement with the energy distribution sector ended in 2000, with the sector successful in reaching its target for CO2 reduction. In the changed context of the energy sector a new agreement is not pursued, and strategies now mainly run through *fiscal routes* (energy tax and exemptions) and *economic routes* (subsidies for R&D in renewable energy). The aforementioned policies have played a role in the increase of combined heat and power production and green electricity and have consequently accelerated the introduction of relatively mature energy technologies in the existing electricity regime. The limitations to this success, however, mainly lie in the *relatively narrow focus of energy and R&D policy.* Thus, national targets for wind energy were developed but not translated to the local level, and energy policy has been unable to deal with the spatial implications of wind energy development. R&D strategies have been focussed on economic and technological dimensions, and not sufficiently on the societal dimension where interaction between technology push and market pull, processes of network building on the local level, learning processes, and experiments between various actor groups are important mechanisms. Priorities within government R&D have shifted from nuclear energy and coal energy to energy conservation and renewable energy (especially wind energy and biomass), but the fixation on single technologies and actors remained dominant. Also *the lack of integration between various policies leads to barriers* for the development of biomass (conflicts between waste regime and electricity regime), wind energy (conflict between energy policy, spatial policy, and national and local policy), and energy technologies in the built environment (conflict between housing policy, environmental policy and energy policy). Recent policy documents *aim to develop a transition agenda towards a sustainable energy supply,* such as the National Environmental Policy Plan 4 (VROM, 2001) and the Energy Report (EZ, 2002) but still inhibit most of the aforementioned limitations.

8.2 Design of policies to support transition paths

Based on the constructed transition paths and the assessment of current policies we focus on five main aspects for the support of transition paths. They are:

1. Adapting and directing wider institutional changes
2. Exploit linking (or pathway) potential of technologies, resources
3. Support interplay of pressures and network formation from various regimes
4. Facilitate enabling technologies
5. Avoid lock in to existing design and support the built up of alternative infrastructures

8.2.1 Adapting and directing wider institutional changes

The electricity regime has already *opened up due to changes in institutional organisation* that have led to changing strategies of regime actors and the uptake of alternative technologies and concepts to serve specific user preferences. These changing strategies have in the past fuelled the fast rise of combined heat and power generation and the emergence of green electricity. They were accompanied by institutional changes that facilitated further investments in CHP and green electricity. While these examples show that certain developments can gain momentum when they align with dynamics in the electricity regime and the sociotechnical landscape, they also make clear that appropriate wider institutional changes are crucial to keep momentum going and to make it part of a process of regime change. Thus, CHP lost momentum as deteriorating economic conditions were not balanced by policy and institutional changes that translated the contribution of CHP to CO_2 reduction in economic terms. While the prime mover acquired legitimacy for the green electricity concept by investing in new facilities for renewable energy, the attractive fiscal compensation increasingly led following companies to offer green electricity that was not based on newly installed capacity. Moreover, the difficulty of developing new renewable energy projects in the Netherlands resulted in a sharp increase of import of green electricity. Although there was considerable support for measures to constrain the import of green electricity or to cancel fiscal support for green electricity based on already installed capacity, these were difficult to implement as they would require either an elaborate verification system or would conflict with the intended level playing field in the European energy sector.

In the scenarios processes of institutional change are key to facilitate transition paths. In scenario 1, where renewables become integrated into the central station electricity system, key processes are the way EU policies to support renewables and to price carbon emissions unfold. Other processes involve schemes for green electricity and the labelling of electricity flows. Important institutional developments also will take place in areas not directly related to energy. Spatial planning policy and the way decision making processes for large-scale projects influence the development of new energy projects. Institutional change may smoothen these processes to facilitate these large-scale projects, for example by reducing the procedural constraints at the local level (e.g. specific areas for renewable energy projects in zoning schemes[13], which is already the case in Germany). Or the shortage of space in the Netherlands and the difficulty to develop new projects increases the likelihood of further integration of relatively small scale modules for electricity generation within houses and offices, such as sketched in scenario 2. From this perspective it becomes sensible to invest in those energy technologies that are less associated with spatial problems and to develop institutional frameworks where there is more incentive to engage in these projects at the local level. Opportunities exist in areas where electricity demand is growing and can not immediately be met by the traditional electricity producers, e.g. growth areas of ICT clusters,

[13] In Dutch: bestemmingsplannen.

demand for green electricity, demand for combined heat and power in industry and households. These can be used to experiment with alternative systems of energy technologies, infrastructure and use. As traditional electricity producers and distributors with vested interests in production capacity and networks may be less inclined to engage in such experiments, policy makers should be open for *new actors or actor networks* that may consider investing in these experiments.

8.2.2 Exploit linking potential of technologies, resources

The construction of the STSc indicates that transition paths involve hybridisation of technologies and concepts. This leads to the recommendation to change the dominant focus of policies on individual technologies towards a focus on systems and hybrid forms of technologies. Current policies mainly promote individual technologies that run the risk of being unable to break out of individual paths with its specific constraints (such as wind, PV and their intermittent character). Developing hybrid forms with other technologies and/or resources is a way to overcome these constraints for example by introducing other functionalities that are useful and make it easier to integrate the hybrid form within the existing technological configuration. STSc can be a tool in the identification and exploitation of linking potential of specific technologies and resources. Various characteristics can express linking capacity of technology. One is that technologies with linking capacity can adapt to the existing regime but also inhibit characteristics that enable other technologies to hook on to the bridging technology and the existing technological configuration. Another is that they can adapt to the existing regime but are able to change the way they are configured in that system. The scenarios point at the importance of fuel cells as a technology with linking potential, because it is flexible in terms of its energy resources (either gas, hydrogen or (m)ethanol), can play a role in energy storage, and has potential value as a complementary technology in the development of hybrid forms with gas turbines, pv, wind power, and biomass. Moreover it has certain characteristics that coincide with certain landscape developments, such as its modular, noiseless, and zero-emission character and therefore it creates no problems of spatial planning and pollution, and its ability to provide reliable electricity without the need of costly transmission and distribution. The fuel cell combines several domains and concerns not a single industry, such as wind, but one that can penetrate several industries, and is being driven by various industries such as automobile industry, power industry, gas industry, space industry. The number, scale and diversity of actors involved in fuel cell development is large. There is a variety of applications for fuel cells, from power generation to power and heat production in buildings to powering cars, and these can also involve hybridisation of fuel cells with other energy technologies and fuel sources. In power generation there is a variety of potential consumers with current market niches for highly reliable power and potential market niches for combined heat and power production for hotels, small neighbourhoods and industries.

Both scenarios also indicate the importance of gas as an energy source that can link development paths of traditional technologies with emerging niche technologies and can create linkages between alternative designs. For example the gas turbine has become dominant in the electricity regime with the advent of combined cycles. However its development to smaller scale and the emergence of CHP and micro-CHP can open up a path towards distributed generation where local heat, cold and electricity demand is being matched by specific energy technologies. CHP and micro-CHP are first steps in this process and engage actors such as households, industries, energy companies, construction companies, municipalities, and housing corporations in a learning process can provide stepping stone for experiments with fuel cells. Gasification technology is in the first scenario developed because it fits the existing regime by connecting coal to efficient combined cycles based on gas. It also can provide a stepping stone for further integration of the biomass niche into the regime. Moreover after initial use of gas as a power resource in a subsequent step it has the potential of shifting towards production of hydrogen.

8.2.3 Support interplay of pressures and network formation from various regimes

The scenarios suggest that various configurations, concepts, technologies will emerge in the coming decades that cut across several regimes and lead to involvement of actors from other regimes in the electricity regime. Transition paths are likely to be shaped through *the interplay of pressures from various regimes* that create momentum for change of the electricity regime. The successful examples of decentral CHP and green electricity show how alignment between different actors can create momentum for more environment friendly concepts. Also the development of PV has shown the importance of collaborative networks. Social networks are key elements in the stabilisation of present technologies but also in the creation of new ones. These networks often cross borders of policy fields, sectors and regimes and may initiate new niche developments that have potential to escape carbon lock-in. Actors in the waste regime (and also agricultural regime) are involved in technological development (e.g. biomass fermentation, gasification, pyrolysis) in order to serve various goals: closing material streams and reducing CO_2 emissions. Gas utilities that used to provide heating services to households and now are developing micro CHP systems that provide electricity and heating, based on gas input. Both networks can benefit from stronger local and user participation. Incentives could be developed to stimulate closing of material cycles at the local level, and to develop local based energy systems. Oil and gas companies are becoming increasingly involved in electricity generation due to the opportunities created by opening up of electricity and gas regimes. They increase momentum for the changeover to gas and CCGTs as dominant resource and technology but also are involved in experiments with micro CHP that involve alternative technologies and change of user behaviour. Other examples are the development of fuel cells that is relevant for both transport and electricity, the production of hydrogen both for mobile and stationary power, and the conversion of biomass both for chemical and energy purposes.

8.2.4 Facilitate ICT as enabling technology

Both scenarios point at the importance of landscape developments on the way regimes and niches evolve. The development in information and communication technologies (ICT) is relevant for the electricity system because on the one hand facilitates more flexible control of supply and demand, and on the other hand it is an important factor in the ongoing process of electrification of society. In the scenario towards large-scale integration ICT plays a role in facilitating on-line exchanges of electricity and of resources for electricity generation such as biomass, hydrogen. It also holds promises for consumer based real time monitoring of energy use, e.g. facilitating the switching on and off of systems at moments when electricity is relatively expensive or cheap can play an important role in the operation of a system of distributed generation. Moreover, ICT also enables better anticipation of discontinuous resources such as PV and wind, and thus enables better overall control of the international electricity regime. In the distributed generation scenario ICT enables the development towards local networks where a variety of electricity generation technologies is connected to demand, while demand is under distance control. The potential of modular, flexible decentral energy technologies is more efficiently utilised with the use of intelligent electronic monitoring, metering, and operation systems. All involve shifting actor strategies that can come together in actor networks that focus on the development of decentral micropower systems that provide comfort for the user, and some level of distance control for energy companies. *ICT can play an enabling role* in either the integration of more sustainable energy alternatives in the large-scale system or the development of alternative systems. Apart from identifying these developments one possible suggestion for policy is therefore direct part of the large investments that take place in ICT into this specific area. One option is to use the fast emergence of ICT companies as an opportunity for experiments with distributed generation. Due to the fast growing concentration of ICT companies in the Southeast of Amsterdam, at the end of 1999 the capacity of the grid became insufficient to be able to distribute electricity to new companies. Electricity demand had risen sharply and unexpectedly as ICT firms have chosen Amsterdam as favourable location for new investments and they use substantial more electricity compared to other types of firms. ICT firms choose Amsterdam because of the interchange of the transatlantic glass fibre cable located there and because they wish to settle down close to each other. The firms and distributor try to solve the problems by expanding the grid but this will take six months to three years. ICT firms are now hesitant to settle in Amsterdam, because they need guaranteed electricity services, and are depending on the extension of the grid. This specific example provides opportunities to experiment with decentral energy technologies in order to overcome the infrastructure bottleneck.

8.2.5 Avoid lock in to existing design and support the build up of alternative infrastructures

A significant part of Dutch government efforts is focussed on the path of large-scale renewable energy development, especially large-scale wind energy and the development of biomass applications. While the first scenario shows the promise of this path, sole focus on large-scale integration has the risk of locking out other promising routes while there is significant uncertainty whether large-scale integration will succeed. Factors that contribute to uncertainty are the shaky path of European convergence, the difficulty to integrate large-scale power plants into the landscape also due to societal opposition, and the difficulty to integrate the various technologies into a reliable system. It is therefore sensible to invest in other promising routes that are not hampered by the same threats in its development path and derive potential from other drivers that may gain force. An example is the development towards distributed generation. This route is especially hampered by the fact that it can not easily adapt to the current technological configuration and needs the built up of a new technological and social constituency. Too much reliance on market conform measures will bias developments towards large-scale renewable energy technologies. They especially promote options such as offshore wind and biomass co-combustion that are currently most competitive and fit the current electricity system. This needs to be accompanied by investments in alternative technological trajectories such as micro CHP. In the short term this trajectory will yield less environmental gain but in the longer term this trajectory has potential for a transition to a carbon free electricity system because other technologies (fuel cells) and resources (hydrogen) may hook on to it. Certain developments that can have importance for the transition path do not have to be motivated by the actual target of sustainability or reduction of CO_2. They can, however, provide an important stepping stone in the transition path because they can initiate the emergence of certain actor coalitions, lead to learning processes on aspects relevant for the transition, or provide a starting point for the development of different designs/design principles. An example is the use of reliable, decentral electricity generation systems for ICT companies. This niche development is driven by the need for reliable electricity and the constraints of the current electricity network and may be beneficial for growth possibilities of ICT companies concentrated in certain areas, such as Southeast Amsterdam, and induce learning on integrating urban decentral systems in the grid, and on the feasibility of fuel cell systems.

Both scenarios have shown that potentially promising paths especially require *more experience with alternative infrastructures*, such as those for biomass, hydrogen, and local microgrids. There is uncertainty regarding the way the electricity regime will evolve, regarding the technologies that will be dominant in the medium to long term and regarding the whole design of how electricity is delivered to the consumer. Also consumers are increasingly taking up new roles in this situation of flux. The design of policies can play a role in directing this flux on a path towards a low carbon future such as has been the case in the support of green electricity through tax relief and public procurement. Several regulations based on the fossil-based regime hamper experiments with microgrids and hydrogen, while waste policy raises several barriers for biomass utilisation. The scenarios make apparent that most of the promising niches do not easily adapt to the central station electricity model and have other kinds of systems and infrastructure requirements. It often involves a two-way flow of electricity with a larger number of relatively small units, discontinuity plays an important role, etc. Moreover at the user side also the development towards smarter (metering) equipment can be witnessed. In order to facilitate these developments and enhance their chances of establishing environmental friendly development paths and systems this asks for a stronger focus on systems instead of on individual technologies. Both fundamental as well as practical knowledge regarding systems integration needs to expand at for example universities and research institutes and through specific experiments.

9 Evaluation

Through the development of a methodology for the construction of sociotechnical scenarios, and through the illustration of transition paths towards a sustainable electricity supply, we have demonstrated the principle of sociotechnical scenarios. One of the main objectives of this project was to gain insight in the potential of developing and using sociotechnical scenarios. Therefore an important part of the project was to receive feedback on the process of constructing STSc, on the transition pahts, and on its usefulness for policy. Internal feedback was generated through intensive rounds of discussion on various versions of the methodology and on the scenarios. Apart from the project team we received specific comments from Ken Green (who participated in several sessions), Rene Kemp and Geert Verbong and other colleague researchers (such as from ECN and RIVM). Further feedback was received through presentations at conferences (Greening of Industry Network conference, June 23-26, 2002) and through an international workshop organised by the project leader on "Transition to Sustainability through System Innovation" (Enschede, 4-6 juli 2002), in which researchers and policy makers participated. The main points of comment are presented in the following sections.

9.1 Methodological issues

In the process of developing a methodology for and constructing sociotechnical scenarios there were several problems that were encountered and need to be resolved.

1. One issue is that the **amount of time available** for constructing the scenarios impacts the methodology. As the research team could tap from previous research based on the analytical framework we use for the construction of sociotechnical scenarios we could save time in the analytical phase. But for potential users of the methodology there is a need to develop more strict guidelines for the analysis and the amount of time spent on it as part of the whole project.
   Recommendation: develop guidelines for time distribution over the project.
2. The project team spent considerable time discussing what should be **the actual steps and their sequence** in the construction of the scenarios. While there was agreement on the need for a thorough analysis of the different levels to gain insight in potential linkages and transition paths the question arose when choices could be made regarding the demarcation of the research domain (which regime developments, landscape developments, actors, niches) and regarding the design of the STSc. In our methodology some choices are made at the onset of the project, but for users that start with less expertise regarding the research domain it may be necessary to start with a first analytical step.
   Recommendation: Tune methodological steps with the characteristics of users.
3. In the analytical step it was recognised that here already **historical analysis needs to be combined with interpretation of possible future developments**. In the process the project team learned that the analysis of developments at the different levels in the past was to some extent inefficient due to a lack of focus on how these development could impact the regime and niche development in the future.
   Recommendation: Extend historical analysis from the start with a focus on future developments.
4. **Design choices and the role of landscape developments**. An important methodological issue was how the landscape was to play a role in the scenarios. Often scenarios are developed through a 2 by 2 matrix were there is contrast on two main landscape developments, e.g. high/low economic growth; high/low social cohesion. In our scenarios we use more landscape developments with more variety. Moreover landscape

developments impact have different impact on the scenarios. The actual contrast between the scenarios is the way interactions between landscape, regime and niche play out. Initially the project team invested significant time in developing patterns of landscape developments for the period 2000-2050. However in the actual writing of the scenarios it turned out that not that much detail was required, plus that some landscape development became more specified as the scenario evolved.
Recommendation: from a list of potential landscape developments choose up to 5, 6 main landscape developments that provide interaction with regime and niches. Try to characterise these landscape developments in terms of likeliness that they will continue in the future and importance in terms of impact on the specific domain.

5. **Patterns and mechanisms.** The patterns and mechanisms need more structuring and further elaboration under which conditions which patterns and mechanisms are likely to occur. These can then be labelled as so-called formative moments under which change processes may be set in motion, and where interventions may be effective.
Recommendations bring further order in the list of patterns and mechanims, distinguishing between them and within these categories make some further distinctions; focus on formative moments.
6. **Length of the scenarios**. While initially the idea was to develop scenarios of up to 20 pages there was realisation that this might not altogether serve the purpose of the scenarios. Thus it was decided to develop smaller versions of the scenarios that were likely to be more accessible for users.
Recommendation: Tune depth and size of the scenarios with the actual function and user.
7. **Visualisations**. In order for the reader to capture the main elements of transition paths it can be useful to visualise them. This will give the reader a quick overview of the main dynamics on which the paths are based, and prevents the reader from being lost in the details given in the textual descriptions. While first drafts of figures were made by the project team this turned out to be more difficult than expected. There is a need for visualisation tools that are able to capture the dynamics of transition paths and this requires time and some extent of expertise.
Recommendation: Reserve time and expertise for the development of visualisations.
8. *Transparency, data*. While the actual output of the methodology are the scenarios there is a need for information on how the step from methodology to scenario takes place. This requires for example information on what has come out of the analysis, what have been the data sources, etc. Thus the presentation of the scenarios needs to go hand in hand with presentation of the outcomes of the various steps.
Recommendation: Do not solely present the scenarios but present also the inputs and outcomes of the process steps.

9.2 Usefulness of method for construction of STSc

In interaction with energy experts and scenario builders the following issues were raised:

- Make clear what is exactly new for the STSc method compared to other methods that also increasingly deal with the interaction of societal and technological change (e.g. backcasting scenarios)
- The scenarios should be transparent as to how the scenarios are based on the earlier analytical steps
- Some level of quantification is necessary even for qualitative scenarios, for example to underpin the carbon free characteristics of the transition paths

- Some of the concepts that are used should be clearly defined:
  - what exactly is a niche? Is it a technology, or the way a technology is configured and adapted in a user setting?
  - When defining problems in the regime the question is: whose problem? For example climate change is foremost a governmental problem, but is this problem also part of the regime?
  - What is the relation niche – future state – sustainability; if you want to develop a path towards a sustainable future state you already need some kind of indication on what role specific niches can play in making these future states sustainable. Our exercise lacked a kind of vision regarding a future state;
- In an interactive session where participants were given the task to sketch some kind of transition path based on the STSc guidelines some problems were encountered:
  - what is the role of policy in the scenario's, especially when barriers seem to hamper a further route, it seems (too) convenient to have policy incentives relieve this barrier.
  - Generally the constructed path was little bit too simplistic and only too a limited extent explored interaction, coupling between the different levels and the way they could facilitate niche cumulation, hybridisation etc.
  - Choice of niche very strongly determines the path, too little insight in possible patterns of technological hybridisation, specific niches etc. (the number of energy technology experts was quite limited, most were policy experts)
- In a more general discussion on the methodology several issues were highlighted:
  - maybe it is more fruitful to first construct a future state in order to be able to assess the barriers to reach this future state;
  - niche is some kind of seed that can grow to something big, but you need to have some idea regarding the future promise of the seed;
  - where do we aim to create the niche? Some niches may be more realistic in other countries' settings; this refers to the geographical dimension of the scenario exercise, something that should be made explicit in the design choices.
  - better to start from current mechanisms, patterns and interactions between landscape, regime and niche; first niche needs to be rooted in current structures and should have potential to couple towards a transition
  - what is a good way to gather information, maybe including the various actors (niche, regime) may prove to be fruitful;
  - actor strategies are dynamic, in the course of path development these strategies may change; some actors are more fixed than others in their strategies, some are more likely to push certain niche developments and hamper other; important to describe these patterns
  - links between various regimes are often key for the emergence of certain niche developments. Thus multiple regime developments are important for the creation of (momentum for) niches; historical example: gas turbines (military aircraft, aircraft, power generation); current example: fuel cell (driven by transport and power sector opportunities; biomass/fuels: potential for transport, chemical and electricity regime.

9.3 Usefulness of STSc as a policy tool

In interaction with policy makers (through the workshops and bilateral talks) the project team evaluated the usefulness of STSc as a policy tool. This led to several aspects that were considered to be useful for policy-makers:

- problems of current scenarios with regard to technological transitions were recognised.
- STSc create insight regarding transitions as a process of transformation through interaction between the old and new regime

- the concept of meta-stability was seen as important (this refers to regime characteristics), the nature of this stability also defines when and which policy options are available to exploit ‘windows of opportunity’;
- developing a database with various paths and their patterns and mechanisms will be useful;
- STSc can give more insight in how and why technological transitions occur and can occur; based on notions such as stability of regime, problems in regime, developments in landscape, and niche patterns.

Several issues needed also further clarification according to the policy makers:

- Issues of definition: what defines a transition?; when is it possible to realise targets through optimisation, when is a transition required?;
- when can sociotechnical scenarios be useful, e.g. when regime is in flux, when problems can not be solved by optimisation etc. When can optimisation pave the way for transition?

And several aspects needed to be dealt with in further versions of the STSc methodology and construction:

- transparancy of scenarios (in general and also for STSc) was considered vital by policy makers, it is often not clear what the assumptions in scenarios and models are and on what they are based;
- elements of quantification were considered essential (especially by economic affairs), because it structures and increases discipline
- it was argued that the value of for policy should be made more specific, e.g. set of guidelines regarding the construction of sociotechnical scenarios; a number of illustrations; an indication what kind of learning can be derived for various actors (scenario-builders, policy-makers).
- how can they play a role in policy making (how to integrate them into the decision making framework / should policy makers develop them themselves, interactively, or use expert based scenarios
- what is the role of policy in the scenarios: identify patterns/mechanisms in which certain policies may be useful, e.g. at niche level; identify how regime developments may constrain or enable certain policies; this should be made more explicit;
- Develop contrasting scenarios based on differences in institutional change, policy developments;
- There should be more clarity regarding the sustainability aspects of a future state, planning bureaus already calculating these kind of things, some quantitative elements are considered vital, yet unclear how to integrate them;
- The policy recommendations were considered useful but need further elaboration in terms of how to actually intervene in the dynamics. Are new policy instruments needed or can this be realised through the tuning of existing policies and instruments. What should be the timing of those interventions? How can we assess whether a ‘window of opportunity’ is there or when a formative moment is occurring?

10 Exploitation and further elaboration of the findings

The feedback presented in the previous paragraph gives extensive clues to further improve the STSc methodology and to improve its usefulness for policy. Several of these points are integrated in a new proposal for the further development of Sociotechnical Scenarios which is submitted for the NWO/NOVEM energy research program. The proposal is part of a larger research program on transitions and transition paths led by the TU Eindhoven. Aspects that come back in this proposal based on the feedback are:

- further development of the methodology with a focus on how to convert the preparatory steps into the scenarios;
- transparency by providing more information on data, data sources and by including more quantitative elements;
- focus on drivers for transition paths from multiple regimes;
- further structuring of patterns and mechanism and their conditions as a basis for the methodology;
- explicit focus on formative moments when intervention may be most effective;
- more specification of the patterns and mechanisms that are used in the scenarios;
- development of more specific policy recommendations based on more elaborate analysis of existing policies and instruments and potential new ones.

Early versions of the methodology and the scenarios are published or under publication through various fora, and further feedback is expected on these publications:

- Elzen, B., F.W. Geels, P.S. Hofman and K. Green, Sociotechnical Scenarios as a Tool for Transition Policy, Paper for 10th International Conference of the Greening of Industry Network, Gothenburg, Sweden, 23-26 June 2002.
- Boelie Elzen, Frank Geels, Peter Hofman (University of Twente) and Ken Green (UMIST), Socio-Technical Scenarios as a tool for Transition Policy, Paper for Workshop "Transitions to Sustainability through System Innovations", Enschede, University of Twente, 4-6 July 2002.
- Hofman, P.S. Governance and Sociotechnical Change in the Electricity System, Paper for the 10th Greening of Industry Network Conference, Göteborg, 23-26 June, 2002
- Hofman, PS, B. Elzen, F.W Geels, and K. Green, Sociotechnical scenarios as a tool for transition policy: An illustration from the electricity domain, Chapter for book on "Foresighting and Innovative Approaches to Sustainable Development Planning" edited by W. Wehrmeyer a.o. expected 2003

11 Conclusion

The main tasks of this study were to develop a new method to explore possible transition paths towards a sustainable energy supply, to use the method to develop recommendations on how to stimulate achieving sustainability and to evaluate the usefulness of the method. The major finding of this exploratory project is that this is possible in principle and that the method can indeed be used as a basis for policy recommendations. Feedback from scholars and policy-makers to our priliminary findings has encouraged us that we are on a promising track. The process of internal and extern evaluation has yielded several relevant and constructive comments that are valuable in the process of further development and improvement of the STSc methodology.

More concretely, the primary aim of this study was to explore the promise of sociotechnical scenarios as a reflexive tool for transition policy and to develop a methodology for their construction. Sociotechnical scenarios are not predictions of the future but can help to design more robust transition oriented policies. They can give insight in the various complex processes at work in systems change, in driving forces and promising combinations of technological, societal and institutional change.

The two examples of transition paths in this report illustrate that the methodology can indeed lead to scenarios in which a transition emerges, not as a *deus ex machina* but as the result of plausible new linkages under specific conditions. Specific innovations and changing user preferences have been identified that can form the seeds for a transition and thus are good options for further development and exploration in the near term. Very importantly, these options should not only be treated separately but possibilities to create links between them should also be explored. Processes of hybridisation and linkages between technologies and specific user preferences are core aspects of transition policy, not just single technologies. Thus the two scenarios illustrate that the construction of sociotechnical scenarios can not only help to create visions of a sustainable future, it can also help to identify potential transition paths that can lead to such futures.

These paths and the factors that stimulated their occurrence form the basis for policy recommendations. Presenting a number of contrasting STScs to policy makers can make them more reflexive on strategic considerations related to promising technologies and their potential to link up with other technologies and their potential to affect user preferences. In the initial phases of such change processes, the emphasis for policy should especially be on learning how to deal with the complexity and uncertainty inherent in transitions, by carefully monitoring developments at different levels, assess their potential linkages, and adapt policies when required to exploit windows of opportunity. STSc can help to highlight features of socio-technical change, including linking potential between various technologies, flexibility, reversibility, and robustness, and on institutional settings to enable, obstruct or modulate change.

Despite the ‘proof of concept’ demonstrated in this study our own experiences and the feedback collected also pointed to various difficulties and weak points in ‘rough version’ of the approach as it is described in this report. It seems to us, however, that none of these is fatal and could not be adequately tackled through further research and development. This has inspired us to define a follow-on project that has been submitted for funding to NWO/Novem as part as a more encompassing program in co-operation with colleagues from the Technical University of Eindhoven.

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