



Crossing the Energy Valley of Death

*Financing of low-carbon electricity production
technologies in the demonstration phase*

Silvia de Vaan

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Silvia de Vaan

Student number 1152203

Committee:

Chair: Prof. J. Groenewegen/R.W. Künneke

Delft University of Technology, Faculty of Technology, Policy and Management

Section of Economics of Infrastructures

1st supervisor: A. Correljé

Delft University of Technology, Faculty of Technology, Policy and Management

Section of Economics of Infrastructures

2nd supervisor: I. Bouwmans

Delft University of Technology, Faculty of Technology, Policy and Management

Section of Energy and Industry

External supervisor: H. de Coninck

Energy research Centre of the Netherlands, Unit Policy Studies

International Energy and Climate Issues



Preface

This thesis is the end result of my graduation project for the study Systems Engineering, Policy Analysis and Management (SEPAM) at the Delft University of Technology. It is performed in close cooperation with the Energy research Centre of the Netherlands (ECN).

My interest in sustainable energy technologies has been settled a long time ago. Financing though, I knew almost nothing about at the start of this research, which increased the challenge. Hearing how important topics of technology development and financing are, also in the climate change negotiations, made the choice for this subject an easy one. I was going to solve the financing problems of energy demonstration technologies through closing the “Valley of Death”.

This turned out to be quite a voyage passing by many scientific disciplines and great thinkers, which all provide useful insights for this multi-disciplinary topic, with the difficult task of choosing one theoretical framework. Luckily enough the research also involved case studies to distract me from theory to direct contact with practice. The interviews with experts have provided me with a treasure of information. Learning about all the (entrepreneurial) activities taking place in sustainable energy makes me eager to take part in these activities myself. I would like to thank all the respondents for spending some of their valuable time to share their insights, expertise and personal experiences. The end result of this study led to a typical SEPAM conclusion: technology matters – but only focussing on technology is not enough to drive our society.

There are a lot of people that somehow contributed to my research. I am very grateful that I have gotten the opportunity to work at ECN policy studies, providing me with a pleasant environment with nice colleagues who were always willing to help me. I would like to thank my supervisors for their time, comments and motivating attitude: Andrew Higham for his guidance in the first months in finding the right direction in a labyrinth of theories and insights; Heleen for making time in her busy schedule to take over the stick from Andrew, providing me with extensive, critical, and very useful comments; Aad for his positive and supportive guidance filled with new ideas, including phone calls during week-ends and holidays; Ivo for his sharp and out-of-the-box comments and good ideas; John for his theoretical reflections and ability to incite me for the theoretical aspects of the research and Rolf for making time for what is hopefully going to be a nice graduation.

Silvia de Vaan

Delft, 20 August 2009.

Executive Summary

Financing problems in the demonstration phase

A broad portfolio of new energy production technologies is needed to cope with challenges of climate change and sustainability while addressing the world's growing energy needs, including technologies which still have to be commercialised. The development of these new low-carbon energy technologies encounters serious problems. One of the most prominent problems is a financing problem when leaving the R&D phase to be demonstrated in real-life conditions. This financing problem is often characterised by the concept of a "cash-flow Valley of Death", which is a combination of rising cash demands and a low ability to raise it. For a demonstration project on a real-life scale, the cash demands are significantly higher than in the preceding R&D phase. Unit costs are high and only expected to go down through development of the technology and economies of scale. It is difficult to raise cash at that stage because public funding is more focussed on early phase R&D and the uncertainties and pay-back times are still too large for private investors. Therefore, the following main research question is formulated:

How can the financing problems in the demonstration phase of low-carbon electricity production technologies be understood and addressed?

Research method

Financial and economic issues are not the only causes of the financing problems. Influences at different levels of the socio-technical system surrounding the technology affect investment decisions, like political, institutional, social, cultural, ecological and technical issues. Therefore, the concept of the Valley of Death is too limited to understand the financing problems of low-carbon electricity production technologies: a multi-disciplinary and multi-level approach is needed. The Technological Innovation Systems (TIS) framework is chosen for this study because it offers a multi-disciplinary and multi-level approach to study the circumstances that foster growth of emerging technologies. It identifies structural and functional components of the innovation system around the technology which together shape the development of the technology. The structural components of the TIS framework are the actors, institutions and technology and the relations and networks between them. Activities and interactions of the structural components lead to dynamics in the system. For successful development of a technology, these dynamics should result in certain "key activities" taking place, which are described by functional components:

1. Knowledge development and diffusion;
2. Influence on the direction of the search;
3. Entrepreneurial experimentation;
4. Market formation;
5. Legitimation;
6. Mobilisation of resources.

For this study offshore wind and solar photovoltaics (PV) are researched as case-studies to acquire understanding in the financing problems for different technologies in the demonstration phase. They represent reasonably polar examples in scale and they have a large variation in difficulties and important stakeholders. The offshore wind case is a historical case focusing on the first demonstrations of offshore wind parks in the different North-Western European countries. The solar PV case focuses on new solar PV technologies of which the application or production are currently (about to be) demonstrated at a real-life scale, like certain thin film PV and concentrating PV technologies. The case studies are based on interviews with more than 30 actors from the offshore wind and solar PV sector, including researchers, technology

developers (private and public), debt and equity providers, suppliers, contractors, policy makers and policy executors. The set-up of the interviews was open and unstructured to acquire an image of the problem which is as open and objective as possible, asking for the respondent's opinion on the financing problems of the technologies in the demonstration phase. The information from the interviews is cross-checked and supplemented with existing research on both technologies.

Results: the financing problems of offshore wind and solar PV

The case studies show that the financing problems are directly influenced by the scale and uncertainties of a technology and the entity developing the technology. In general, the financing problems are smaller for solar PV than for offshore wind. The scale of solar PV is much smaller which makes experimentation easier to finance and the modularity of the technology offers flexibility in experimentation scales. Also, the technical and regulatory uncertainties are larger for offshore wind than for solar PV. The harsh environmental conditions offshore and the moving parts in the turbine lead to a higher chance of defects, while maintenance and construction offshore is difficult. Regulatory uncertainties are larger because offshore regulation and spatial planning are not as well developed as onshore. For separate projects or technologies, the entity developing the technology or project is important: large companies have more financial strength than small companies.

Next to these direct financing issues, there are also indirect issues from the socio-technical system affecting the financing problems. An analysis of the factors affecting the problems of offshore wind and solar PV has resulted in "inducement and blocking mechanisms" for the technologies in the demonstration phase. Both technologies have two important drivers in common: a high need for low-carbon technologies and high expectations of future cost reductions. This is enforced by stimulating policy frameworks in several countries and growing income and advocacy of the emerging industries. On the other hand, they both have relatively high costs and high investment costs and many uncertainties. They face inertness through the role of incumbents, which are investing in new technologies but may react slowly because of their vested interests in currently leading technologies. Negative economic developments, like the current financial crisis, increase the financing problems. The two technologies also have specific barriers and drivers, displayed in Table 0-1.

Table 0-1. Inducement and blocking mechanisms for offshore wind and solar PV

	Inducement mechanisms	Blocking mechanisms
Offshore wind	<ul style="list-style-type: none"> - Lack of space for wind turbines onshore 	<ul style="list-style-type: none"> - Lack of knowledge of wind technology offshore - Lack of knowledge of environmental effects of the technology - Missing connection between the offshore and wind sectors - Changing incentive schemes in some countries - Sluggish and changing licensing and spatial planning - Problems of grid connection and capacity - Scarcity of turbines, offshore sector capacity and vessels - Opposition of actor groups (nature and horizon conservation)
Solar PV Developed countries	<ul style="list-style-type: none"> - International competition/market pull - Technological niches 	<ul style="list-style-type: none"> - Complexity of the technology/lack of fundamental knowledge - Passive consumers, administrative barriers for consumers - Financial weakness of small PV companies
Solar PV Developing countries	<ul style="list-style-type: none"> - Lack of stable electricity supply 	<ul style="list-style-type: none"> - High risks (crime, corruption, political instability, etc.) - Lack of educated people, bad infrastructure - Lack of financial strength of consumers and entrepreneurs

Conclusions: addressing the financing problems

The financing problems and their causes vary for different low-carbon electricity production technologies. This indicates that next to general policy to stimulate low-carbon energy technologies, technology-specific analysis and technology-specific policy is needed to address the problems and barriers of different technologies. Although general policy has the advantage of stimulating cost-efficiency in the development of new technologies, it might resolve in too much focus on lower-hanging fruit, over-shadowing the development of other necessary technologies. To identify technology-specific problems, the Technological Innovation Systems framework is a useful tool.

Another important conclusion for addressing the financing problems is that a strictly economic or financial approach is not sufficient to resolve the financing problems. The entire socio-technical system has its influence on decisions of investment and entrepreneurial action. Next to knowledge development, mechanisms for resource mobilisation and market formation, the total socio-technical system should be taken into account in policy-making to stimulate technology development. The Technological Innovation Systems framework can be used for this, which means that policy should address all functions of the innovation system.

Policy recommendations

The outcomes and conclusions of the research lead to the following main policy recommendations.

Financing issues

- Install *Public Finance Mechanisms* for mobilisation of financial resources, and *market formation mechanisms* for the prospective of a future market. The *indirect effects* of these measures on financing costs should be taken into account, like the term of agreements, frequency of income and tax appetite of small companies;
- Stimulate *networks between investors and technology developers*;
- Provide *guarantees* for investors and install *export credit agencies*: the government shares the burden of negative outcomes of investments, but only spends the money if the project fails;
- *Financing of support schemes outside government budgets to minimize regulatory uncertainty.*

Stimulating entrepreneurship and experimentation

- Establish *incubators* to support start-up companies in entrepreneurial capabilities and networking;
- Develop *educational programs for entrepreneurial capabilities* at educational institutions;
- Make a *scan of the total process that entrepreneurs go through for different technologies*, identify the main barriers for each technology, take away these barriers and decrease the administrative burden through creating a *one-stop shop*.

Getting the innovation system right

- Make an *assessment of the “Technological Innovation System”* for the different technologies and a coherent policy to *align and stimulate all the functions* for each technology;
- *Understand and map the playing field of actors* for each technology. Bring all parties together in a *cooperative process*, with the goal of taking away problems of the technology, creating a pathway for the development of the technology including compensation of harmed parties if needed. *Incumbents and new entrants* should be equally involved in this process.
- Make a *thorough impact assessment* of the policy with scenarios for future development of technologies, including resource constraints and the total life cycle effects on the environment.

Table of contents

1.	Introduction	1
1.1	Financing problems of energy technologies in the demonstration phase.....	1
1.2	Research question.....	3
1.3	Outline.....	5
2.	Theoretical framework.....	6
2.1	Economic theory	6
2.2	Socio-technical systems	10
2.3	Background on micro-level issues and finance	14
2.4	Theoretical framework.....	21
3.	Research method	24
3.1	Research method	24
3.2	Case study approach	25
3.3	Case study protocol.....	26
4.	Demonstration phase technologies	31
4.1	The demonstration phase	31
4.2	Electricity production technologies currently in the demonstration phase	32
4.3	Case selection.....	33
4.4	Case demarcation.....	34
5.	The Technological Innovation System of offshore wind	36
5.1	Introduction	36
5.2	Structural components.....	37
5.3	Functional components.....	43
5.4	Functional pattern and functionality	50
5.5	The Valley of Death for offshore wind	53
6.	The Technological Innovation System of Solar Photovoltaics (PV)	55
6.1	Introduction	55
6.2	Structural components.....	57
6.3	Functional components.....	62
6.4	Functional pattern and functionality	70
6.5	The Valley of Death for solar PV	72

7.	General and specific issues for offshore wind and solar PV	73
7.1	Comparison TIS offshore wind and solar PV	73
7.2	Inducement and blocking mechanisms.....	75
7.3	Micro-level issues.....	77
8.	Discussion	79
8.1	Case study validity, comparability and generalisation.....	79
8.2	Reflection on theory use.....	81
9.	Conclusions and recommendations.....	85
9.1	Understanding the financing problems	85
9.2	Addressing the financing problems.....	88
9.3	Future research.....	91
	References	93

Appendixes

A.	Public Finance Mechanisms.....	101
B.	Summary Interviews.....	102
B.1	List of interviewed people.....	102
B.2	Summary interviews offshore wind	104
B.3	Summary interviews solar PV.....	107
B.4	Summary interviews validation.....	112
C.	Actor analysis offshore wind and solar PV	116
D.	Example of institutional complexity: comparison of the two Dutch offshore wind parks	120
E.	Functional pattern TIS offshore wind and solar PV	123
F.	Motors of sustainable innovation	125
G.	Scientific paper	127

1. Introduction

1.1 Financing problems of energy technologies in the demonstration phase

A broad portfolio of new energy supply and end use technologies is needed to cope with the challenges of climate change and sustainability while addressing the world's growing energy needs [Bazilian et al. 2008][IEA 2008][Sandén and Azar 2005]. All of the hundreds of stabilisation scenarios reported by the IPCC demand a range of new energy supply technologies to reach the stabilisation [IPCC 2007], including many technologies which still have to be commercialised. Therefore, the international community has placed technology high on the agenda for the UNFCCC negotiations at the 13th Conference Of the Parties in Bali. Technology is now one of the four building blocks of the negotiations (mitigation, adaptation, technology development and finance), laid down in the Bali Action Plan. The Conference Of the Parties wants agreement on:

“1.d. Enhanced action on technology development and transfer to support action on mitigation and adaptation (...)” [UNFCCC 2008a, 1.d]

However, change is difficult to accomplish in the energy sector for several reasons. Firstly, the energy sector is very large with long-term planning and therefore changes take a long time [Jacobsson and Bergek 2004][Grubb 2008]. A large part of the investments is made in physical assets, creating a fixed capital source without flexibility (sunk costs). Climate change and technology policies are usually designed to shift energy sector investments over the longer term and the immediate effects of most policies are limited. Secondly, markets are not easily formed for new energy technologies [Jacobsson and Bergek 2004]. New technologies face cost disadvantages when first deployed and the full public benefits of the technology cannot be captured by private sector investors in the market price for new technologies. Also, incumbent technology is sometimes subsidised and there are negative externalities that are not included in their price [Sandén and Azar 2005][FUNDETEC 2007]. The competition is only based on price and efficiency, which is a weaker innovation driver than product differentiation [Grubb 2008]. Finally, policy making for the energy sector is a highly political process in which incumbents often attempt to block the diffusion of new technologies by influencing the institutional framework [Jacobsson and Bergek 2004].

Development of new technologies from basic research through to a commercially mature technology is generally characterised by the technology development sequence, an example is shown in Figure 1-1. New energy technologies face different market failures and barriers when moving through this sequence, such as negative external effects of fossil fuel use that are not incorporated in the price, knowledge spill-overs to competitors, lock-in of existing technology and information asymmetries between different parties active in the market [Correljé and El-Ashry 2005][Haites et al. 2009][Martin and Scott 2000]. To stimulate the movement of technologies through the sequence a package of instruments is needed to address these market failures and barriers. Several studies argue that “technology-push” and “market-pull” mechanisms should be combined in such a package, because they address different parts of the problem: technology-push addresses the early stages of technology development, market-pull later stages [Grubb 2008][Bazilian et al. 2008][IEA 2008][Sandén and Azar 2005].

One of the most prominent barriers in the technology development sequence is a difficulty in financing projects [Haites et al. 2009][Bazilian et al. 2008]. Estimates of the investments needed throughout the different phases of the technology development sequence to meet particular mitigation targets range from 2 to 10-fold the current global investments in those technologies [Haites et al. 2009][Bazilian et al. 2008][IEA 2008]. At the same time, most countries have had a trend of reduction in spending on energy

R&D (mainly caused by dismantling of nuclear research, but also less coal and renewable research) and the energy sector has a relatively low R&D intensity [Sandén and Azar 2005]. However, this does not necessarily mean that there is no money, but that the money has to be guided into the right direction. For instance, a few years ago investors in the US were sitting on over \$70 billion of undisbursed cash, caused by inefficiencies in the markets for allocating risk capital to early stage technology projects [Branscomb and Auerswald 2002]. The total global investment in new physical energy assets is expected to triple between 2000 and 2030 [UNFCCC 2007]. Because of the long lifetime of these physical assets, the investment decisions that are taken today will affect the world's emission profile in the future. Therefore, a window of opportunity has appeared to direct the financial flows into more climate friendly new facilities. To address this issue, finance is another of the four building blocks of the Bali Action Plan, interwoven with technology development:

"1.e.Enhanced action on the provision of financial resources and investment to support action on mitigation and adaptation and technology cooperation (...)." [UNFCCC 2008a, 1.e]

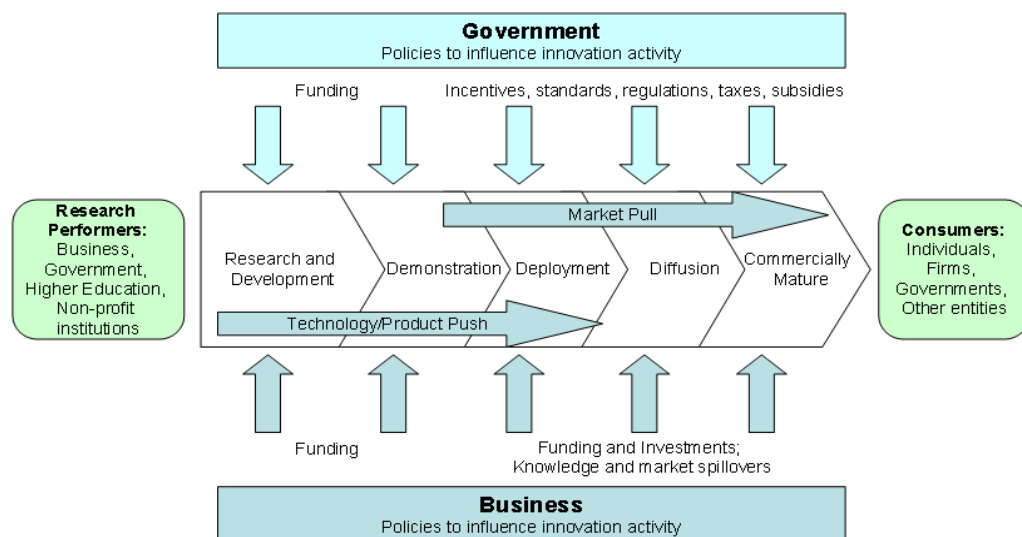


Figure 1-1. The technological development sequence [Grubb 2008]

Certain specific characteristics of new clean electricity production technologies affect their financing prospects. The relatively high up-front investment costs and often small project and industry size require more external financing which makes it more difficult to secure sufficient financing [Wiser and Pickle 1997][FUNDETEC 2007]. Furthermore, the timescales for return on investment that are commonly used by private investors are too short for environmental technologies [Wiser and Pickle 1997][FUNDETEC 2007]. Also, the electricity market is seen as a commodity market with a low rate of return and high volatility which makes it unattractive for investors, especially for new risky technologies [Sonntag-O'Brien and Usher 2004][Jacobsson and Bergek 2004].

These challenges are currently intensified by the financial crisis. Although its final effect on the development and financing of new energy technologies is not clear yet, it has become more difficult to acquire capital, resulting in delays, higher capital costs and termination of projects. Investments in sustainable energy in the first quarter of 2009 were 13,3 billion dollar which is 44% less than the last quarter of 2008 and even 53% less than the first quarter of 2008 [UNEP 2008a][New Energy Finance 2009a]. Although investments have gone up in the second quarter of 2009, a drop of between 26% and 39% is expected for 2009 compared to 2008 [New Energy Finance 2009a]. Despite the recession sustainable energy is also regarded as chance for the future and a way to enhance the economy

[PriceWaterhouse Coopers 2009][Platts 2009]. Therefore, country governments like the US and EU countries have included investments in sustainable energy in their economic recovery plans as a way to mitigate the economic malaise and quicken the economic recovery.

The financial gaps and barriers are specific for the different phases of the technology development sequence. It is well-recognized that, without government intervention, the private sector will tend to under-invest in research and development activities, resulting in a sub-optimal social welfare outcome [Ford et al. 2007][Griffith 2001][Alston et al. 1998]. The main reasons for this underinvestment were already recognised by Nobel Laureate economist Arrow in the 1960s: it is risky, the product can only be appropriated to a limited extent and there are increasing returns in use [Arrow 1962]. This has been a justification of government investment in R&D, especially in the early phases where the effect is strongest. More recently research has identified financial problems in the intermediate phases of technology development [Auerswald and Branscomb 2003][Murphy and Edwards 2003][FUNDETEC 2007]. Demonstration of the technology during this intermediate phase is an important moment in the development of a technology to prove both the technological and economic viability of the technology on a real-life scale. Also, it generates knowledge on user response and can serve as an advertisement for the technology, raising awareness levels of the technology among the public [Sandén and Azar 2005]

The financial gap causing problems for technologies in the demonstration phase is called the cash-flow “Valley of Death” [Bazilian et al 2008][Murphy and Edwards 2003][Auerswald and Branscomb 2003][Ford et al. 2007]. This Valley of Death is a combination of rising cash demands and a low ability to raise it. For a demonstration project on a real-life scale the cash demands are significantly higher than in the preceding R&D phase. The unit costs are still high but are expected to go down when the technology develops. Throughout the technology development sequence the funding generally shifts from mainly public finance to private finance. Since public finance is more focussed on early phase R&D there is often a declining availability of public finance in the demonstration phase. On the other hand, the uncertainties are usually still too large and the pay-back times too long for private investors, despite the elimination of part of the technical risks through testing small-scale prototypes or laboratory work. The negative influence of perceived uncertainty on entrepreneurial action is most severe in the take-off phase of technologies [Meijer 2008]. Another important problem is that there are differences in the values, requirements and goals of public and private investors. The economic crisis also has its effect here: a study of the expected influence of the economic crisis on the Valley of Death suggests that the Valley of Death is widening for low-carbon technologies [New Energy Finance 2009b]. This thesis research addresses this problematic phase in the technology development sequence.

1.2 Research question

The existing literature reveals several knowledge gaps concerning financing of new energy technologies in the demonstration phase. First of all, most of the Valley of Death literature origins from the United States and there is only one study that addresses the energy sector [Murphy and Edwards 2003]. Secondly, the studies that have examined the financing of technologies in early and intermediate phases all look at the problems from a different perspective. There is no clear picture yet of the total socio-technical system that influences the financing problems in the demonstration phase, including institutional, economic, technological and social factors. Thirdly, the suggested remedies and instruments are not specified for different technologies. Each technologies has specific characteristics that influence its financing situation, like the investment costs, the proportion of investment vs. operational costs, revenues, risk profiles,

learning rates, social acceptance and niche applications. These characteristics can result in technology-specific financing problems which ask for technology-specific instruments [Sandén and Azar 2005]. The aim of this thesis is to contribute to solving the financing problems of energy-sector demonstration technologies. The study should create more insight into these financing problems and provide policy advice on how to address them. The study provides information that could underpin pending changes in global policy with regard to technology cooperation and finance. The UNFCCC can be regarded one of the main “problem owners” of the financing problems for low-carbon technologies.

The following main research question is formulated:

.....

How can the financing problems in the demonstration phase of low-carbon electricity production technologies be understood and addressed?

.....

The research focuses on *low-carbon electricity production technologies*. The energy production sector is estimated as one of the sectors having the largest greenhouse gas reduction potential, next to buildings and forestry [UNFCCC 2008b]. At the moment, electricity production leads to 32% of global fossil fuel use and 41% of energy-related CO₂ emissions [IEA 2008]. Low-carbon electricity production technologies use no or only small amounts of fossil fuel to produce electricity and therefore involve low or zero CO₂ emissions (even renewable energy sources usually use fossil fuel for materials, fabrication, installation, etc.). In the *demonstration phase* the feasibility of a new technology concept has to be proven on a real-life scale in real-life conditions. What is exactly defined in this study as the demonstration phase and which *electricity production technologies are currently in the demonstration phase* is discussed in chapter 4. A precondition for this research is that there are *financing problems in the demonstration phase* for the technology, as described by the cash flow “Valley of Death” above. The electricity production sector mainly involves large-scale applications and clean energy sources often have relatively high investment costs and low operational costs. This results in high investment costs for a unit, which makes it plausible that the financing problems exists for these technologies. Section 2.3 will discuss these financing problems in more detail.

To answer the main research question, the following sub-questions are formulated:

-
1. *How can the financing problems in the demonstration phase of low-carbon electricity production technologies be understood?*
 2. *Which low-carbon technologies are currently in the demonstration phase?*
 3. *For specific technologies, what are the factors affecting the financing problems in the demonstration phase?*
 4. *How can the financing problems in the demonstration phase of low-carbon electricity production technologies be addressed?*
-

Climate change has made financing of low-carbon electricity production technologies a global problem. Furthermore, knowledge, networks, technologies and transactions in technology development cross geographical boundaries due to increasing globalisation. Technology developers tend to move to the areas with the most attractive conditions (e.g. subsidy and tax schemes). However, local circumstances are important: networks and relations with financiers are established more easily in close geographical vicinity and home markets play an important part in the early stage diffusion of a technology. Therefore, this

thesis has a global scope but it will discuss country- or region-specific issues if there are relevant differences for the financing problems.

1.3 Outline

Figure 1-2 presents an overview of the thesis research. A first rough image of the problem in combination with the existing knowledge base from reports on the problem has led to the research question. From the research questions, three routes can be identified: the theory, the research method and the relevant technologies, which recombine later in the research. Relevant theory from literature is discussed in Chapter 2. The problem poses certain criteria on the usefulness of the theories. Through assessing the theories for these criteria, the theoretical framework is constructed in section 2.4. The research questions lead to a research method, which is discussed in Chapter 3. Part of the research method is case study research. A case study protocol is presented in section 3.3, which is formed from the research method combined with the theoretical framework. The definition of the demonstration phase and which technologies are in the demonstration phase is discussed in Chapter 4. The choice which technologies to research as a case study is made in section 4.3 using theory on inductive learning and case study research. The selected technologies are researched through the case study protocol in Chapter 4 (offshore wind) and Chapter 5 (solar PV). In Chapter 6 the outcomes of the case studies are compared, leading to general and specific issues for the technologies. Chapter 7 discusses the validity of the results and the usefulness of the theories and methods used. With this discussion in mind, Chapter 1 describes the main conclusions of the research, including policy recommendations and recommendations for future research.

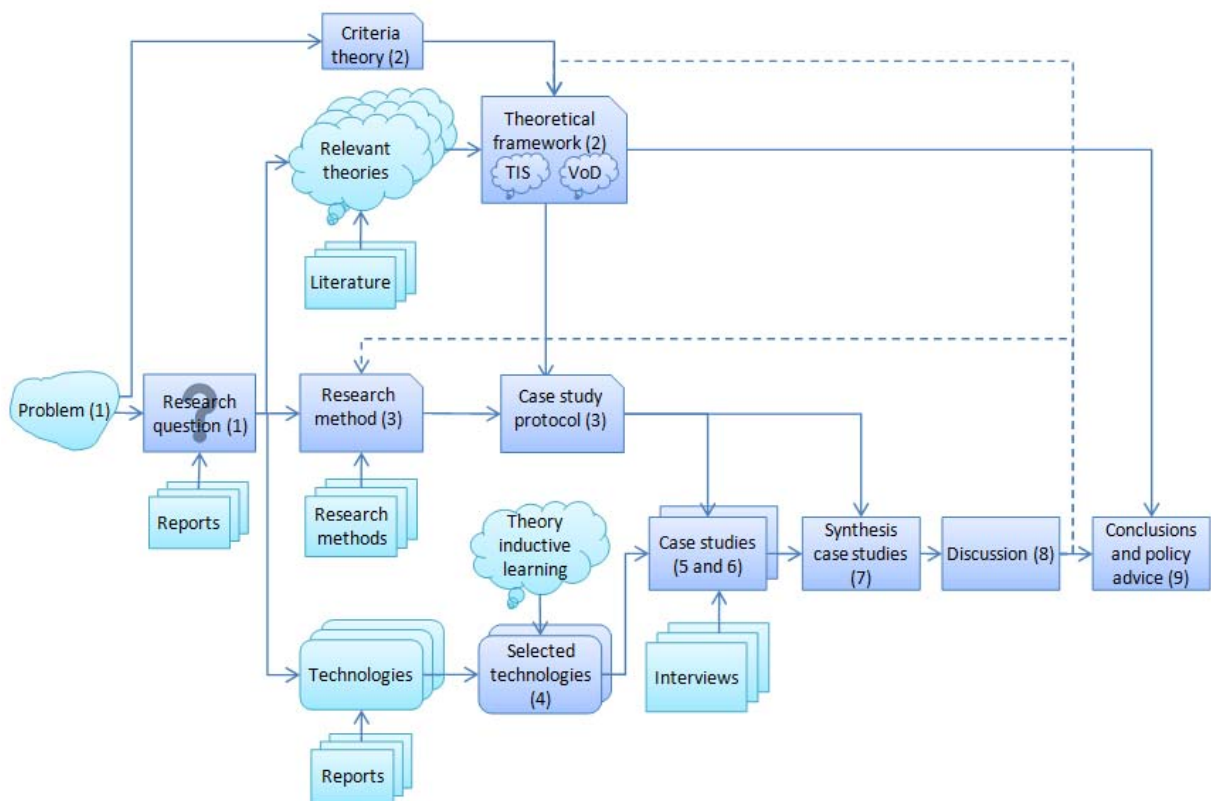


Figure 1-2. Overview thesis research.

The numbers between brackets are the chapter numbers where the subject is discussed

2. Theoretical framework

The goal of this chapter is to create a theoretical framework for the analysis from the important theories for understanding the financing problems. First, an overview of the relevant theories is given, including economic theory (2.1), socio-technical systems theory (2.2) and a background on finance (2.3). In section 2.4 the relevant theory for the theoretical framework is chosen based on criteria related to the nature of the problem and the suitability for practical use.

2.1 Economic theory

This section discusses two important economic approaches that are often used to understand processes of innovation and failures in bringing these innovations to the market: neo-classical economics (2.1.1) and institutional economics (2.1.2).

2.1.1 Neo-classical economics

Neoclassical economics (NCE) is concerned with the allocation of resources and goods in the economy through the operation of markets [Calhoun 2002]. The allocation of resources and goods takes place in a system of supply and demand which jointly determine price and quantity through reaching market equilibrium. If this system of supply and demand is perfectly competitive, the market equilibrium represents a social pareto optimum. Much of the NCE approach is focussed on predicting the outcomes of this equilibrium through formal models [Wilber and Harrison 1978]. The most important methodological assumptions of the theory are the autonomy of individual economic actors (individualism), utility-maximizing behaviour of individuals or firms (instrumentalism) and the conception of reaching market equilibrium (equilibration) [Calhoun 2002][Arnsperger and Varoufakis 2005]. However, these neoclassical market mechanisms only function optimally in perfectly competitive markets, which are in reality often not present. Imperfect markets lead to sub-optimal societal outcomes. To address this problem of the neoclassical model, the concept of market failures is used to understand markets that are not working perfectly. One of the first economists to discuss market failures in the market for new ideas and information was the Nobel Laureate Arrow [Arrow 1962]. A possible categorisation of market failures is: failure of competition (e.g. natural monopoly), public goods, externalities, incomplete markets, information failures (including information asymmetry) and macro-economic disturbances (like unemployment, inflation and disequilibrium) [Stiglitz 1988].

The market for risk capital investments in low-carbon electricity production technologies is an imperfect market, which hinders socially optimal outcomes [Branscomb and Auerswald 2002]. The electricity market in general contains several market failures, like natural monopolies, externalities, public good situations and information asymmetries. The focus here is on the market failures that have an influence on the chances for new, clean energy technologies. The market failures in the market for new ideas and technological information identified by Arrow are [Arrow 1962]:

- Natural monopoly: products are indivisible and have increasing returns;
- Public good characteristics: the public benefits of technology development are larger than can be captured by private parties investing in it. Therefore, economic actors are unable to appropriate full returns from their activities. One of the causes is knowledge spill-overs to other parties;
- Information failure: there is a lack of information on the outcomes of the development of the technology and there are information asymmetries between the investor and the technology developer, the latter having more knowledge on expected outcomes of the technology development.

A specific market failure for low-carbon energy sources is negative externalities of pollution and greenhouse gas emissions of conventional fossil fuel energy technologies which are not included in the price [Sandén and Azar 2005][FUNDETEC 2007]. It is doubtful whether existing policies of carbon and energy taxes and emission rights in some countries cover the full external costs. An important market failure that has developed recently is macro-economic disturbance of markets: the financial crisis and economic recession resulting from it.

These market failures do not explain all the problems for new energy technology development. Haites et al. [2009] identifies market failures as only one of the barriers for new energy technology development, next to barriers of scale, cost, economic, social and institutional nature. The shift to real-life scale is difficult to make, especially for small-scale technology developers and it is difficult to provide guarantees, collateral or other risk-sharing mechanisms because of the weak nature of their balance sheets [FUNDETEC 2007]. Environmental technologies often have relatively large up-front costs and transaction costs of new projects are relatively high, especially for smaller projects [FUNDETEC 2007][UNEP 2008b]. There are economic difficulties because markets for these new technologies are still immature and need to develop, there are no “whole product” solutions yet and multiple costly prototypes are often necessary [Murphy and Edwards 2003]. There is institutional and social lock-in of the incumbent technology concerning infrastructure, standards, user habits, a lack of knowledge and training for the new technology, etc. [Sandén and Azar 2005]. Another barrier can be constrained resources. For example, it is difficult to find longer-term financing which is needed for these technologies [FUNDETEC 2007]. Also, other resources than money might be limited, like time, information about technology and market prospects and people capable of validating the information [Branscomb and Auerswald 2002]. Lastly, another barrier is coordination and communication problems between the different actors involved, like ministries, agencies, technology developers, banks, and fund managers [FUNDETEC 2007]. One of the major barriers for sustainable development is uncertainties about the technology [Jacobsson and Bergek 2004][Meijer 2008]. The different uncertainties are presented in Table 2-1 below, together with an overview of the main market failures and barriers. The uncertainties are discussed more elaborately in section 2.3.2. The distinction between market failures and barriers can be subject of discussion, because market failures could be seen as a certain type of barrier, but barriers could also be seen as a certain type of market failure. Therefore, the boundaries suggested by Table 2-1 are not that strict and the market failures, barriers and uncertainties can be interrelated.

Table 2-1. Market failures, barriers, uncertainties for new low-carbon electricity production technologies. Although the table suggests strict boundaries between the three categories, the boundaries are not that strict in reality and there can be relations between market failures, barriers and uncertainties.

Market failures	Barriers	Uncertainties
-Failure of competition -Public good -Externalities -Information failure -Macro-economic disturbances	-Uncertainties -Scale -Costs -Economic -Social -Institutional -Constrained resources -Communication/coordination problems	-Market -Organisational -Resource -Technical -Force majeure -Financial -Regulatory

2.1.2 Institutional economics

The neoclassical economic approach of market failures combined with identified barriers from literature gives an indication of the causes of the financing problems of low-carbon electricity production technologies in the demonstration phase, but it is not adequate to provide a complete image of the complexity of the problem. Furthermore, institutions play an important role in the processes of technological change [Hofman 2005]. Therefore, the approach of institutional economics (IE) is discussed here. Institutional economists state that the neoclassical approach is incapable of explaining the real world [Wilber and Harrison 1978] and they criticise some of the main assumptions of NCE [Hodgson 1994a]. The concept of bounded rationality as often used in game theory claims that the rationality of individual agents is limited by the information that they have, the cognitive limitations of their minds and the limited amount of time to take decisions, which conflicts with the NCE assumption of perfect rationality. Also, variety in people's behaviour cannot be taken into account in the NCE. Furthermore, the concept of path dependency stresses the existence of dynamic evolutionary developments which cannot be incorporated in the static NCE model. Next to that, chaos theory has shown that outcomes of models can be very dependent on initial conditions and therefore it is difficult to make reliable predictions with the formal models often used by neoclassical economics [Hodgson 1994a].

Institutional economics (also called Old or Original Institutional Economics) is not aimed at prediction but at explanation and understanding:

"It aims first of all at understanding complex, evolving systems in which agents interact with the environment" [Groenewegen 2006, p.4].

Three general characteristics of institutional economics are that it is holistic, systemic and evolutionary [Wilber and Harrison 1978]. The concept of a "pattern model" is used which consists of (constantly changing) patterns of relations among parts and the whole. This concept is holistic because it focuses on the relations between the parts and the whole:

"the whole is not only greater than the sum of its parts, but the parts are so related that their functioning is conditioned by their interrelations (...)" [Wilber and Harrison 1978, p.73].

The belief that these parts make up a coherent whole and can be understood only in terms of the whole is a systemic notion. Also, it is evolutionary because the changes in these patterns are regarded as the essence of reality.

The main differences of institutional economics compared with classical economics are (compiled from [Hodgson 1994b][Groenewegen 2006] and [Wilber and Harrison 1978]):

- It rejects the NCE individualistic assumptions of exogenous preferences: preferences and characteristics of actors are not given, but endogenous;
- It rejects the emphasis on equilibrium in favour of an idea of cumulative causation. It is historical and multi-disciplinary and puts issues of evolution central;
- It focuses on institutions instead of individuals as main units of analysis;
- It pays attention to the role of power and conflict in economic processes and acknowledges the existence of non-rational behaviour.

The difficulty with the IE approach is that it is open-ended and never finished. It can only provide understanding and is therefore not as rigorous as many economists would prefer [Groenewegen 2006]. Institutional economics is a general name for many different schools of thought, some of which also touch on neo-classical economics. Two relevant schools of thought within institutional economics for studying innovation are discussed here.

New institutional economics

New Institutional Economics (NIE) is aimed at explaining institutions like firms and contracts, with a specific focus on vertical integration and the “make or buy” question [Groenewegen 2006]. An important NIE theory is Williamson’s transaction cost economics which aims to explain why certain transactions take place within and between organisations and why this asks for specific governance structures [Williamson 1998]. Williamson uses a four-layer model, showing all important institutions in different layers of society, see Figure 2-1. This model shows that the NCE’s focus at the lowest layer of actors and games is not sufficient to understand economic development: institutions at higher layers in society have an influence on the behaviour of actors. At higher levels institutions change on a slower pace, which is shown by the frequency in the figure, and are therefore more difficult to change.

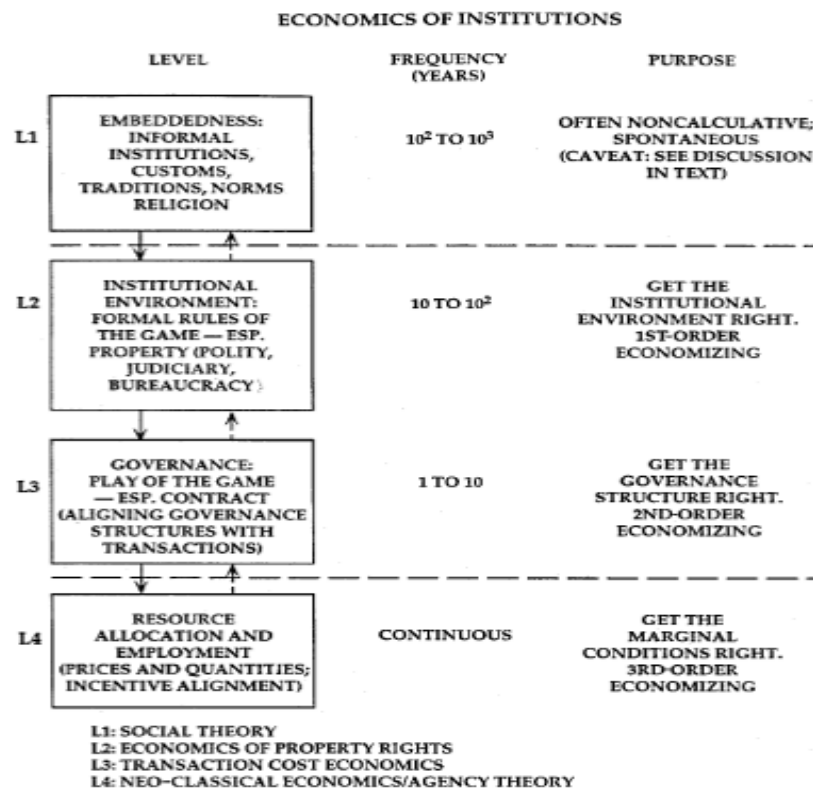


Figure 2-1. Four-layer model of Williamson [Williamson 1998].

Frequency means the frequency of changes taking place, and purpose shows the purpose of institutional changes at that level.

An important criticism of Williamson’s theory is that his institutions are the efficient outcome of rational individuals pursuing self-interest in reducing transaction costs, without taking into consideration how transactions take place in webs of social interactions [Granovetter 1985][Hofman 2005]. It is based on strategic behaviour and deceit by parties while the roles of trust and personal relationships are not taken into consideration. Also, Williamson’s model is still quite static, while reality is non-linear and dynamic. Some newer theories have picked up on this criticism and have developed more dynamic, historic theories [North 1990] and have taken innovation, learning and trust into account [Nooteboom 1999].

Evolutionary economics

Within institutional economics, evolutionary economics has paid particular attention to studying processes of innovation and technological advance. Evolutionary economics is based on evolutionary

theories in biology, and uses the concepts of variation, selection and evolution to explain economic development [Hofman 2005]. It is difficult to define evolutionary economics, because there is still no agreement on the characteristics of the label “evolutionary economics” [Witt 2008]. An important founder of evolutionary economics was Schumpeter, who thought that the most important firms in the economy are the innovating entrepreneurs who drive change in the system [Schumpeter and Backhaus 1934]. Firms innovate or imitate in a struggle for profits and the forces of growth of the economic system are innovation and selection in a dynamic environment.

The general characteristics of evolutionary economics are [Dosi and Nelson 1994]:

- Dynamics: it explains movement over time, or explains why something got where it is;
- Learning and discovery (generating variety) and a selection mechanism;
- It has an analogy with evolutionary biology including four elements:
 - A unit of selection;
 - Mechanisms and criteria of selection;
 - Adaptation;
 - Variation.

An important evolutionary theory developed by Nelson and Winter is based on routines with decision rules on how firms behave in specific situations [Nelson and Winter 1974]. There is a selection mechanism which leads to expansion of firms with profitable rules and contraction of those with unprofitable rules. There are several criticisms of the evolutionary theory, especially from sociologists [Hofman 2005]. From the theory of Nelson and Winter it is not clear what effect dominating paradigms can have on firms and innovations and how these paradigms evolve. Evolutionary economics does not discuss how routines are influenced by external developments. Another criticism is that the selection environment is regarded as a set of factors which are independent of the agents generating variation. In reality, there is constant interaction between the selection environment and the agents bringing about variation.

2.2 Socio-technical systems

Sociologists argue that systems of production and consumption are embedded in a wider societal context and emerge because of changes in human behaviour, interaction and practice [Hofman 2005]. Factors in this societal context are interrelated and only the total picture of interplay of factors can provide understanding of the success or failure of a certain technology. These systems around a certain technology are called “socio-technical systems”. A definition of a system is:

“a group of interacting, interrelated or independent elements forming a complex whole” [Carlsson 1997]

The concept of a system in social sciences is used as an analytical tool to better understand the dynamics of the system and its performance. It does not concern an existing system of coordinated and collective action, but partly unintentional and unplanned interactions of actors who do not have common objectives. In socio-technical systems theory there are two important models that try to capture the reality of technology development.

2.2.1 Technological transition model

Geels and Kemp [2000] have developed a socio-technical model showing a dynamic multi-level view on transition which is showed in Figure 2-2. The model shows three levels of importance for transitions to take place [Geels and Kemp 2000][Geels 2005]:

- **Micro-level - technological niches:** technologies are developing in technological or market niches where they are guarded from the larger market and can improve their inferior characteristics;
- **Meso-level - socio-technical regimes:** socio-technical regimes are a set of internally consistent (grown) rules and elements, carried by a network of social groups, which stabilises existing technology and makes it to some extent inert.
- **Macro-level - landscape developments:** developments external from the niches and regime which do have an influence, like material aspects (spatial planning, infrastructure) and softer elements (culture, lifestyle, common sense).

At the micro-level changes and learning take place at a much higher speed than at the meso-level and macro-level developments usually take place on a long timescale.

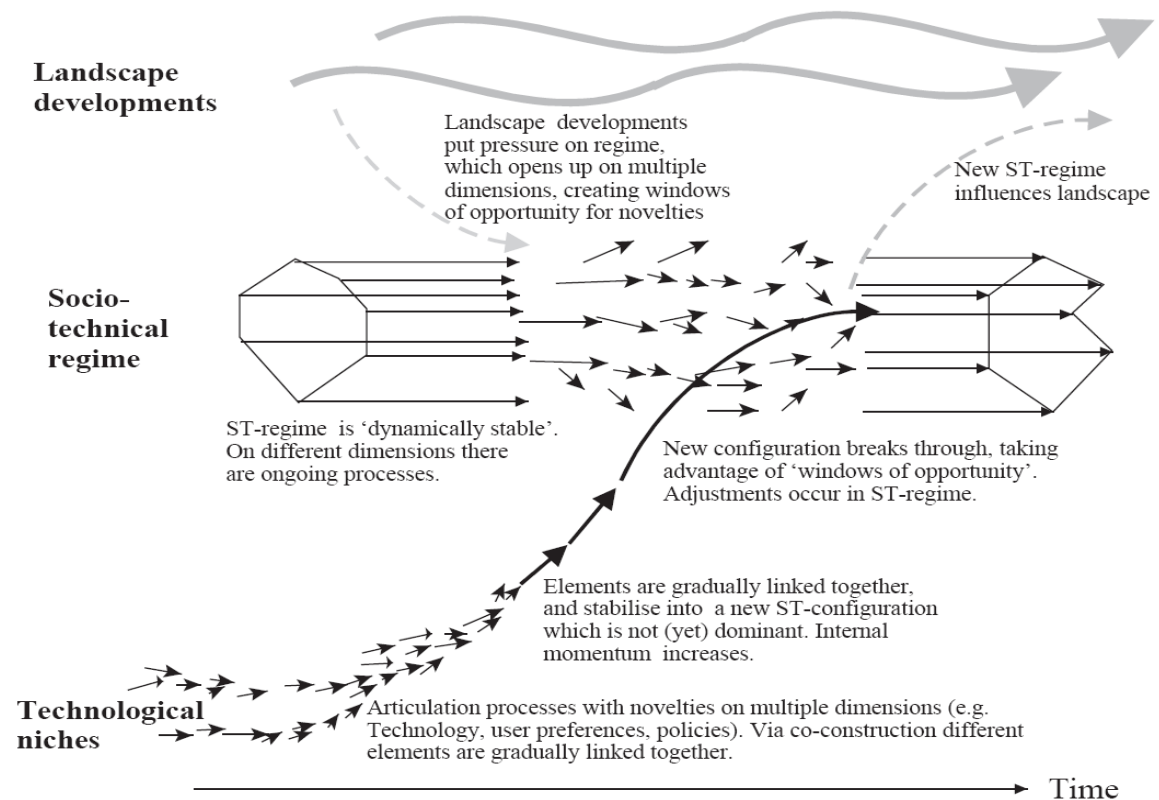


Figure 2-2. Socio-technical model showing a dynamic multi-level perspective on transitions [Geels 2005]

The model draws an interesting evolutionary image of technological transition, showing how a pattern of small developments at different levels (social, technical, economical, political) leads to an evolving socio-technical system. Demonstration phase technologies are in the niche level, struggling among other technologies to develop upwards to the meso-level. The three levels show that there are developments at higher levels that have an indirect influence on technology development. However, despite its usefulness as an image-drawing model, it is difficult to use this model as an analytical tool for policy analysis. Some critical questions remain: what are the circumstances for a niche to become so successful that it becomes part of the existing regime? How can these circumstances be created by public policy?

Literature on Strategic Niche Management (SNM) provides a useful addition to the transition model on the micro-level. It contains a conceptual model on how niches are developed and how they can be protected to develop in relative isolation from the regime [Suurs 2009]. Three dynamic processes shaping

the direction and outcome of niche development are learning, voicing expectations and niche formation [Raven 2006]. However, also it also does not show how niches transcend their niche status.

2.2.2 Innovation systems

The innovation systems approach focuses on the conditions that foster growth of an emerging technology so that it becomes large enough and diffuses in society to compete with or become the existing system. It stems from evolutionary economics and institutionalism [Nelson and Nelson 2002], but it also incorporates social and political aspects. Different definitions of an innovation system are used in literature. A very broad definition of innovation systems is:

“The determinants of innovation processes, which is all important economic, social, political, organisational, institutional and other factors that influence the development, diffusion and use of innovations” [Edquist 2005, p.182].

This definition is very useful to understand the comprehensiveness of processes of innovation, but it is less suitable for practical use. Another definition commonly used by scholars of innovation systems is:

“The components of an innovation system are the actors, networks and institutions contributing to the overall function of developing, diffusing and utilizing new products (goods and services) and processes” [Bergek et al. 2008]

Most innovation systems approaches study innovation within countries, sectors or industries, but a newer approach of “Technological Innovation Systems” focuses on specific technologies [Carlsson 1997][Bergek et al. 2008]. The innovation system contains actors, networks and institutions as structural components:

- Actors: people, firms or other organizations that influence the development, diffusion and utilisation of the innovations;
- Networks: transfer of knowledge (tacit and explicit) through market-related or non-market related networks (knowledge development, information sharing, influencing the institutions);
- Institutions: the norms and rules for interactions and the related value base, like culture, norms, rules, regulations and routines.

It is argued by Suurs [2009] that the three structural components should be actors, institutions and technology and the relations and networks between them. Technological components are artefacts and the technological infrastructures in which they are embedded. He argues that the importance of technological features has been neglected by the TIS approach in explaining the development of technology. Therefore it misses important feedback between technological change and institutional change, for example when malfunctions of the technology are taken away through subsidised R&D programs, which clears the road for more elaborate support schemes.

Later on, functional components were added to the framework to put more focus on activities, making the model more dynamic and more focussed on the role of entrepreneurs [Hekkert et al. 2007]. Different categorisations of the functions are used in literature (e.g. [Hekkert et al. 2007][Kamp et al. 2004][Jacobsson and Bergek 2004]). A recent study gathers all functions of innovation systems research and compiles it into a new classification, shown in Figure 2-3 (3a. Functions) [Bergek et al. 2008]. Through using the function approach, it is possible to systematically map the determinants of innovation, compare performance of systems and translate it to policy targets and instruments [Hekkert et al. 2007]. The scheme of analysis presented in Figure 2-3 can be used to go through the different steps of defining the innovation system, assessing its functionality and translating this into policy action.

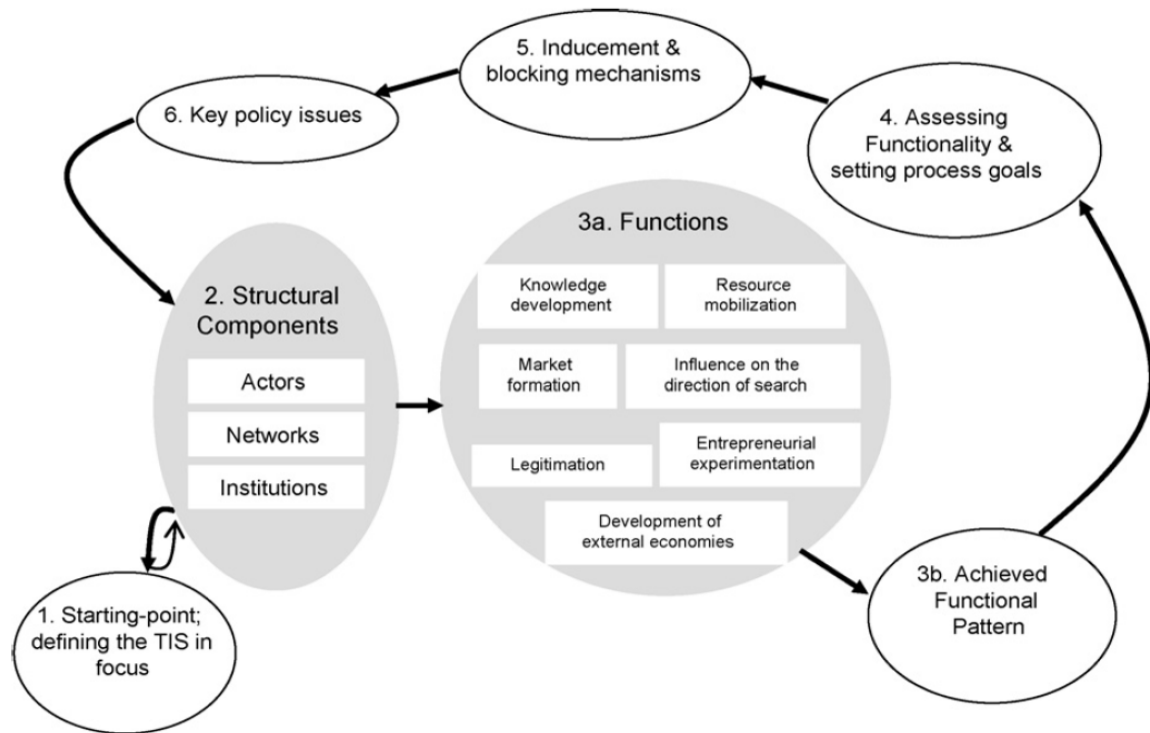


Figure 2-3. Scheme of analysis of the Technological Innovation Systems approach of Bergek et al. [2008]

The TIS approach pays attention to the dynamics of the system, by identifying the relations between the functions which can create positive or negative feedback loops (virtuous or vicious cycles). Suurs [2009] studied several sustainable energy technologies in the Netherlands, and identifies four specific feedback loops that are relevant for all the sustainable energy technologies, which he calls “motors of sustainable innovation”. The four motors are displayed in Figure 2-4 and explained in appendix 0.

The innovation systems approach has been accepted and adopted by academic researchers and policy makers at different levels (e.g. regional and national governments, European Commission, OECD) to understand technological change and innovations [Bergek et al. 2008][Hekkert et al. 2007]. Typical characteristics of the innovation systems approach are [Edquist 2005]:

- Holistic and interdisciplinary perspective;
- Historical and evolutionary perspective, innovation and learning at the centre of focus;
- Interdependence and non-linearity;
- Emphasis on the role of institutions.

However, the innovation systems approach also has some disadvantages. It does not make a difference between levels of influence (direct and indirect), like in Williamson’s four-layer model and the model of Geels and Kemp. Partly resulting from that, landscape aspects like cultural changes, spatial planning and infrastructure are difficult to place in the model. On the other hand, developments at the lowest, company-based level of business management and investment decisions can become under-exposed. Therefore, the next section will discuss some of these business management and financial issues.

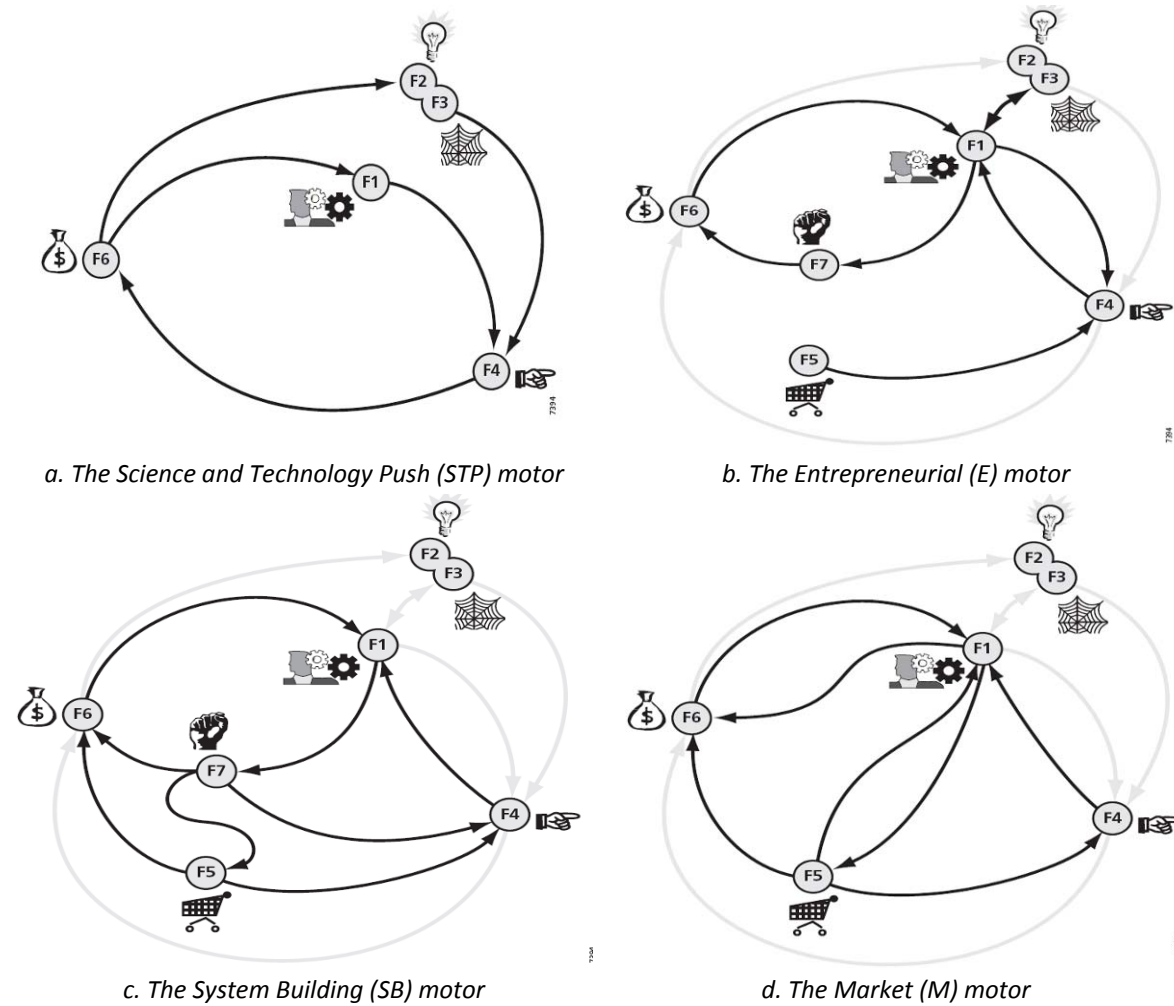


Figure 2-4. Four “Motors of sustainable innovation” [Suurs 2009]

F1= Entrepreneurial experimentation, F2= Knowledge development, F3= Knowledge diffusion, F4= Guidance of the search, F5= Market formation, F6= Resource mobilisation.

2.3 Background on micro-level issues and finance

Since the core of innovation is actually happening at the lowest (micro) level of the system, it is useful to zoom in on this level to understand the processes taking place there. This section discusses financing of innovation (2.3.1), uncertainties (2.3.2) and the concept of the Valley of Death (2.3.3).

2.3.1 Financing of innovation

Debt and equity

The two main forms of private capital are debt and equity. The difference between debt and equity is that the returns on debt are independent of the results of the investment while the returns on equity depend on the results of the investment [Dorsman 1993]. A holder of equity usually gets an ownership share in the company or project in which it invests. There are many mixed forms in between the two extremes, also called “mezzanine finance”. Important for capital providers is the order of priority in distribution of liquidation [Dorsman 1993]: creditors are paid first and shareholders get served last. There is a difference between senior debt and subordinated debt: senior debt gets served first before subordinated debt. After subordinated debt different kinds of mezzanine investors are served and lastly the shareholders. An

important parameter for a debt provider is the solvability of an undertaking (the ratio between debt and equity), which shows how much of the debt can be repaid with the assets (equity) of the company [Druten and Mossel 2009]. Important for the notion of solvability is the distinction between recourse and non-recourse financing. Recourse financing means that the loan is based on the assets of the borrower and the borrower is personally liable for the debt. Non-recourse finance usually involves collateral, but the borrower is not personally liable. The lender can seize the collateral in case of default, but bears the rest of the risk of the loan itself.

Project versus corporate finance

In the electricity sector, projects are financed either through project financing or corporate (balance) financing. With project financing, lenders look to the cash flow and assets of a specific project for repayment rather than to the assets or credit of the party developing the project [Wiser and Pickle 1997]. Corporate financing is an investment which is paid from the own balance of a company, which could come from debt or equity. Therefore, project financing usually involves non-recourse financing and corporate financing is usually recourse financing (on the firm, not necessarily on the shareholders of the firm). For project financing in the electricity industry long-term power purchase agreements or other contracts that provide a relatively secure revenue stream are usually necessary as a debt security, especially for renewable electricity technologies which have high up-front capital costs [Wiser and Pickle 1997]. Most financing in energy projects developed by non-utilities is project financing [Wiser and Pickle 1997].

Financial risk capital markets

Venture capital (VC) is often seen as a “free market” solution to financing problems of new innovative companies. Venture capitalists usually demand quite some control in the company, which is often contingent on performance: the innovator gets more control when the company is performing well, while the VC investors take control of the company when it’s performing badly [Hall 2005]. VC investors generally raise the value of the firm, especially if the abilities and experience of the capital providers are high [Hall 2005]. The described market failures of information asymmetries and public good characteristics lead to difficulties in acquiring capital for early-stage technology development and higher financing costs if capital providers are found, because the capital providers require higher risk premiums. Hall [2005] adds that the separated ownership and management of modern firms lead to principal-agent problems, where differences in goals between the two lead to investment strategies which are not optimal for the value of the firm. For example, managers tend to spend on activities that benefit them and risk-avoidant managers might not want to invest in R&D. Also, there is often a lack of collateral which reduces the possibilities for debt financing.

In venture economics different stages of financing are identified, as shown in Figure 2-5. The important venture financing stages for the Valley of Death are [Branscomb and Auerswald 2002]:

- Seed financing: a small amount of capital to prove a concept or to support product development, but rarely used for production or marketing.
- Start-up financing: funds for product development and initial marketing for companies that have only been in business for a short time and have not sold products yet. Often there already is key management, a business plan and market studies.
- First-stage financing: funds after initial capital for commercial manufacturing and sales.
- Second-stage financing: working capital for initial expansion. The company is showing progress and has started producing and shipping their product. So there are growing accounts, but the company might not make a profit yet so still needs capital for expansion of the business.

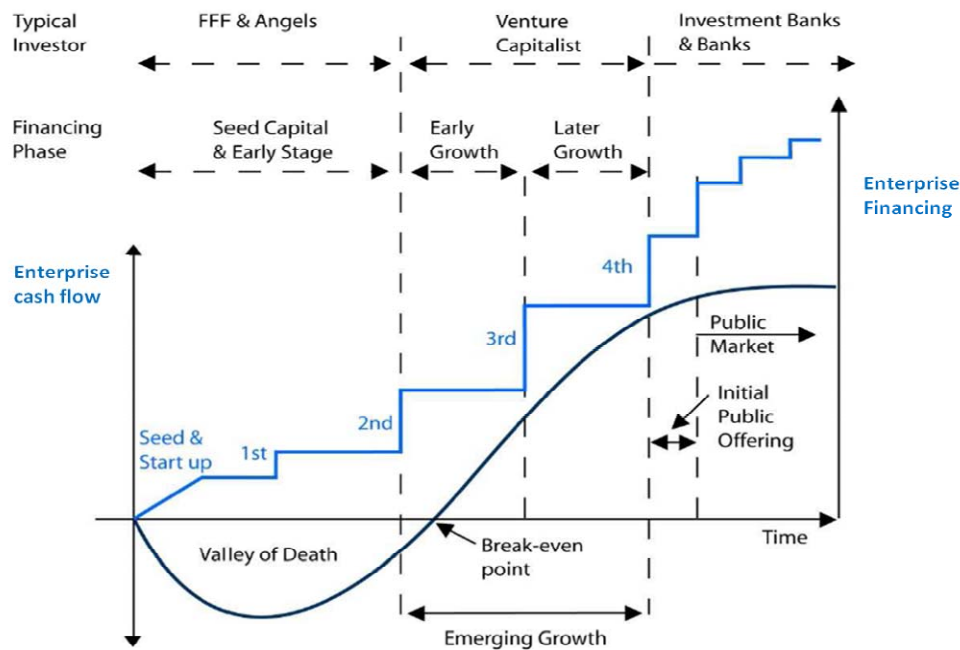


Figure 2-5. Financing life cycle [Mulder 2009]

A study of investments into early stage technology development (phase between R&D and product development) in the United States has shown that the main sources of funding for this stage are established firms (32-48%), angel investors (24-28%) and federal government funds (21-25%) [Auerswald and Branscomb 2003]. Angel investors are wealthy individuals or families that are often experienced in creating new companies or developing new products. Another term used for investors in these really risky ventures is “Friends, Fools and Family” (FFF). Established firms invest in start-ups or demonstration projects to keep on track with emerging technologies. Federal funds complement private funds but do not substitute them: the funding is designed to provide a part of the investments to stimulate private sector investment. Contrary to what is often thought, venture capital firms play a minor role in these early stages, which is confirmed by Figure 2-5, because they usually require a validated business case or proven prototype. Smaller sources of funding are universities and institutes and regional government funding.

Regional differences

Although the financial markets are international (especially the clean-tech market), regional aspects are important in early stage technology development investments [Auerswald and Branscomb 2003]. It is easier to acquire capital from sources close to home and especially investors who also want influence in the management of the company (angel and VC investments) tend to invest close to home. Furthermore, there are differences in the financial systems; the Anglo-Saxon countries are more financial-market based (equity) while the continental European economy is more bank-centered (debt) [Hall 2005]. The risk capital markets are more developed in North America than in Europe and European investors are more risk-averse, although most investors are more risk-averse since the financial crisis. Also, in Europe less of the venture capital goes to new firms (10%) than in the US (27%), the rest was used to finance all kinds of buy-outs [Hall 2005]. The VC industry in the US has quite specialised pools of funds with specialists in the industry in which they are investing [Hall 2005].

In developing countries, private financial markets usually hardly exist at all, although the number of VC and other funds for businesses in developing countries is rising, for an overview see [BiD 2009] and [KIT 2009]. An important part of energy technology investment in developing countries is foreign investment, direct or indirect through mechanisms like the Kyoto-based Clean Development Mechanism [UNFCCC 2007]. However, the demonstration phase is not covered at the moment by the financial mechanisms of the convention, which is an issue for a possible successor of the Kyoto protocol. Public finance from international organisations (e.g. Worldbank) and development assistance from developed countries remains important.

Public financing mechanisms

There are many different kinds of mechanisms which can be used by governments to mobilise private sector capital, like grants, guarantees, soft loans, innovation prizes and mezzanine finance. The different public finance mechanisms to stimulate technology development and leverage private sector investment are often placed at certain stages of the technology development sequence, as shown in Figure 2-6 below. The different public financing mechanisms and the terms used in the figure are explained in appendix A. An important indicator of the effectiveness of these measures is how much private finance can be leveraged with a certain amount of public resources.

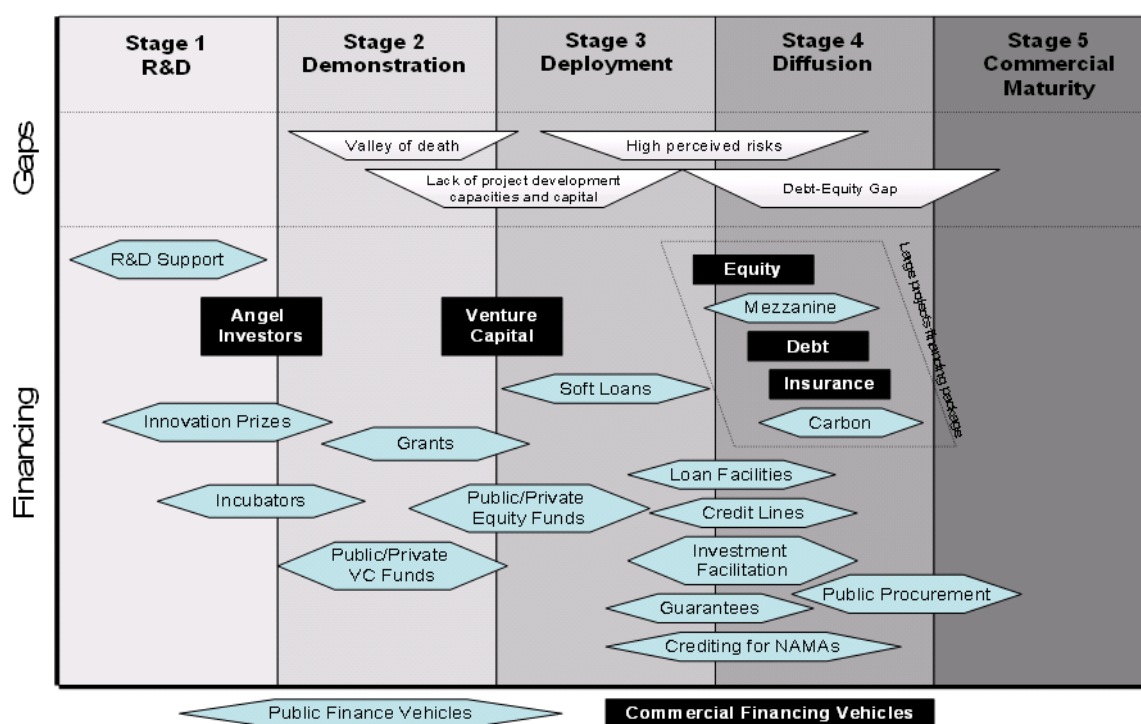


Figure 2-6. Public finance mechanisms in the technology development sequence [Haites et al.2009]

Next to mobilising private sector finance, governments can also take measures to decrease the financing costs of renewable energy projects, as studied by Jager and Rathmann [2008] and Wiser and Pickle [1997]. There are direct measures to reduce financing costs, including low-interest government-subsidized loans, project loan guarantees, and project aggregation [Jager and Rathmann 2008]. However, there are also indirect effects of policy measures on financing costs. The terms of contracts are important; long-term commitments are needed for support of low-carbon energy projects, because they have longer time

horizons than usual. Shortened contract periods and “out” clauses can result in difficulties in acquiring finance, like reduced debt maturity and risk premiums, and therefore higher financing costs. Furthermore, the effectiveness of policy measures like tax schemes can be decreased by a limited tax appetite of small companies [Wiser and Pickle 1997]. The income of small companies is not high enough for the tax credits and therefore not all projects and finance models can reap the full benefits of these schemes [Jager and Rathmann 2008]. Hence, direct measures like investments subsidies may be more effective, but these are more difficult to support from a public management point of view because money has to be allocated to the scheme from the government’s budget. Otherwise, small companies could get tax credits which they can sell to other companies or move backward or forward in their administration. Lastly, tax credits have the disadvantage of pushing the debt/equity mix to relatively more equity, which is more expensive financing [Wiser and Pickle 1997].

2.3.2 Uncertainties and risks

Innovation decisions are inherently surrounded by many uncertainties, especially for emerging technologies [Meijer 2008]. The terms “risks” and “uncertainties” are often used interchangeably for concepts that describe the uncertainty in outcomes of a certain investment. To understand the difference between the two it is important to explain the concepts.

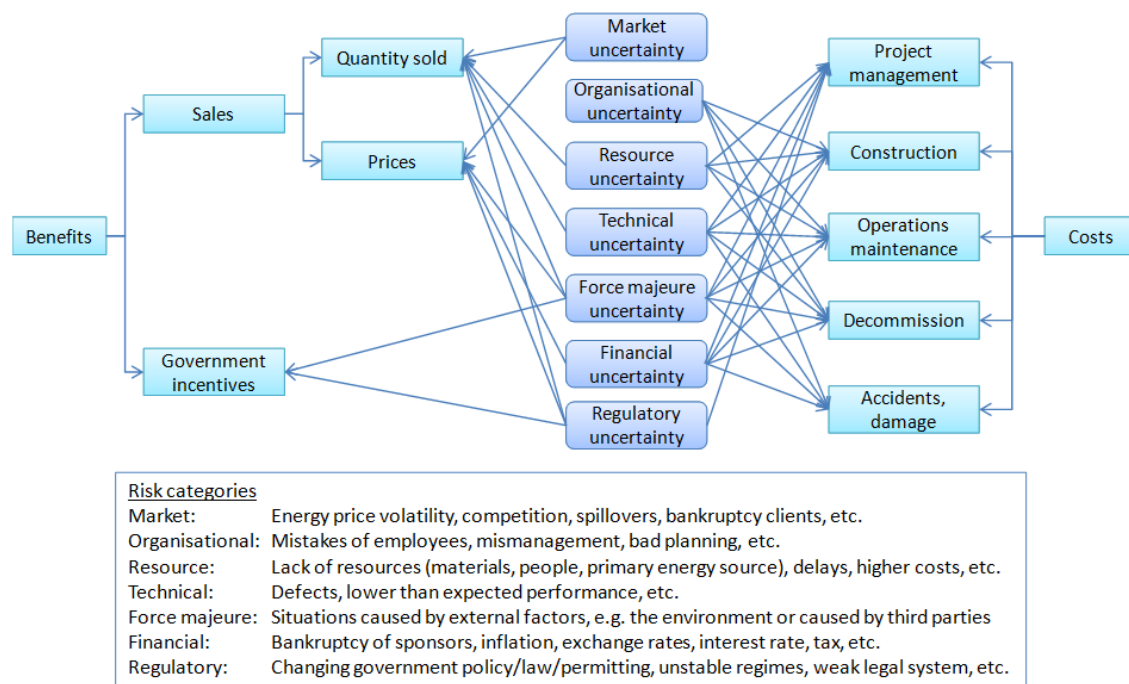


Figure 2-7. Uncertainty categories affecting cost and benefit parameters

Risk can be defined as:

“Randomness with knowable probabilities; i.e. situations in which probabilities that certain future states will occur are precisely known” [Meijer 2008, p.15]

Uncertainty can be defined as:

“Randomness with unknowable probabilities; i.e. situations in which probabilities are not precisely known” [Meijer 2008, p.15]

Both risks and uncertainties are important barriers for investments in new technology. Therefore, this study will use a broad definition of “uncertainties”, which means any deviation from a knowable future, including both risks and uncertainties. In literature on uncertainty, a difference is made between objective and perceived uncertainty. For this study, perceived uncertainties are important because investment decisions are influenced by uncertainties as perceived by the actors making decisions. In the terminology of risks and uncertainties, different linguistic bases are often mixed within categorisations. Some are named by their cause (e.g. technical, regulatory, resource risk), some by the phase or activity during which the uncertainty emerges (e.g. construction, operation, project management) and others by the affected parameter (e.g. revenue, environmental risk) (compiled from [Sonntag-O’Brien and Usher 2004][US DoT 2009][Joode and Boots 2005]). For this report, a categorization is made based on the cause of the uncertainty. Figure 2-7 shows how parameters (costs and benefits) are affected by the different uncertainties.

Decision-making under uncertainty

Figure 2-8 shows a conceptual model of decision-making for entrepreneurial action, which was tested through a series of case-studies on low-carbon energy technologies [Meijer 2008]. The model shows that entrepreneurial action is determined by a combination of the entrepreneur’s motivation to start with a certain project and the perceived uncertainties he or she has about the project. The motivation and perceived uncertainties are influenced by both internal and external factors of the project. Examples of internal factors are a partner leaving the project or a temporal license or subsidy for the project. Project-external factors are changes in the economic, technological or institutional environment. The entrepreneur can be a single person starting a company, but it also concerns entrepreneurial activities in new markets or technologies by large companies. For this study it is assumed that this model can also be used for the choice of an investor to invest in a certain company or project. Their motivation however may be more rational based on an extensive assessment of the risk/return profile of an investment [Sonntag-O’Brien and Usher 2004].

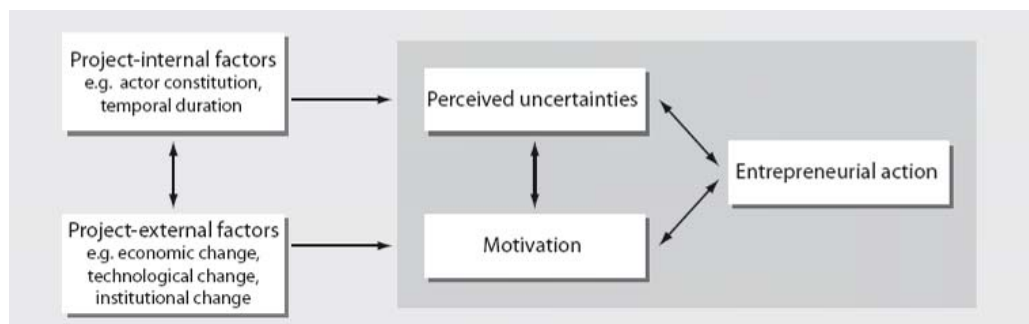


Figure 2-8. Conceptual model describing entrepreneurial action under perceived uncertainty [Meijer 2008]

A difficulty in risk assessment of new technologies is that there is a lack of (historical) data on the technology and financial institutions sometimes have a lack of experience with these new technologies and markets [FUNDETEC 2007][UNEP 2008b]. Therefore, there is high uncertainty for investors, which is why they are hesitant to invest in those projects and demand high returns in case they do invest. Limited data and a lack of technical expertise also makes it difficult to acquire insurance, because they cannot model and judge the technology projects. Although the insurance market for renewable energy projects is growing, there are still some important problems, especially with new/prototypical/scale-up technology [Marsh 2006]. Technical problems in handling, erecting, testing and commission are a major concern for

most renewable technologies, especially for technologies in harsh marine environments where installation, operation and maintenance carries large technical risks. Small scale problems bring along the difficulty of low insured values, which makes it difficult to make a profit on these projects.

2.3.3 The Valley of Death

The concept of a “Valley of Death” (VoD) has evolved from the specific financing problems of technologies in the demonstration phase. It relates to business management and is based on cash flow graphs of the development of technologies, showing a negative cash flow gap in earlier stages. Therefore it is also called the “cash-flow Valley of Death”. The concept draws an image with strong imaginative power referring to the US “Death Valley” as a harsh and barren terrain that a technology developer must cross before reaching friendlier environments.

Figure 2-9 is based on a model of the Valley of Death of the US National Renewable Energy Laboratory (NREL) [Murphy and Edwards 2003]. NREL has researched the causes and consequences of the Valley of Death for US energy innovations, focussing on the (dis)connection between the public and the private sector using three perspectives:

1. Cash flow problems;
2. Diverging values, requirements and goals between public and private sector;
3. Private sector perspectives on risks.

The remedies they suggest are to reduce information gaps and asymmetries between the public and private sector, to make the shift from a technology to a market focus sooner and faster and to look for novel co-investment partnerships with the private sector.

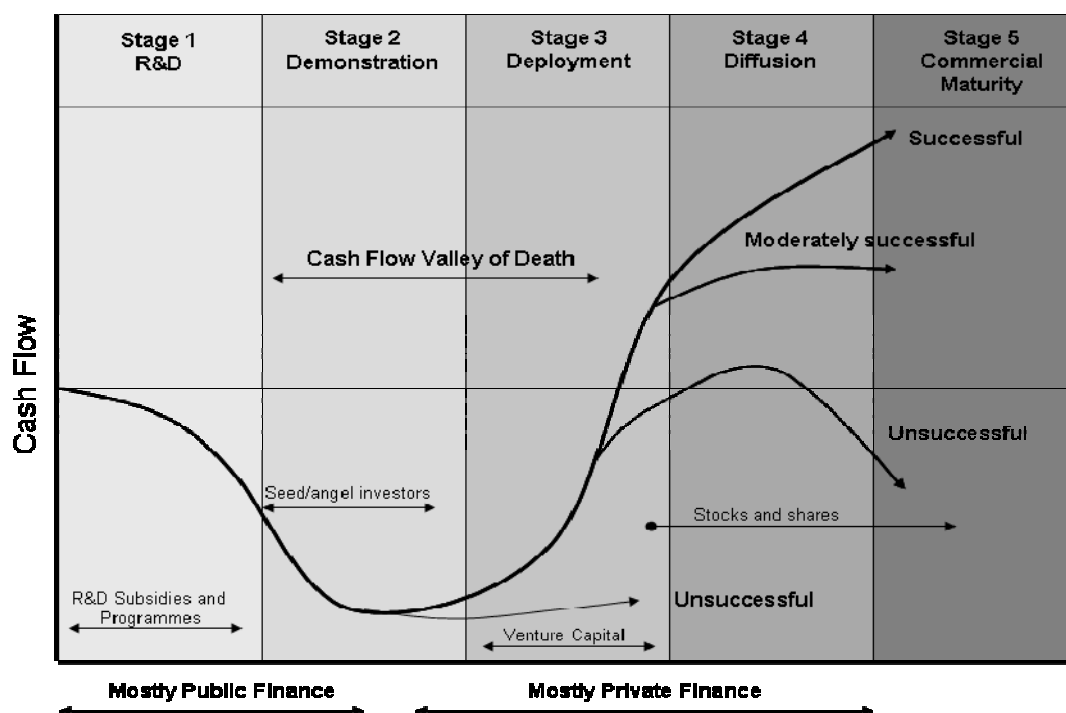


Figure 2-9. Cash flow Valley of Death in the demonstration phase [Haites et al 2009]
Includes different graphs for successful/unsuccessful projects and shows current primary investors in different phases

The Phoenix Public Policy research centre (US) takes a different perspective, claiming that part of the VoD is a natural consequence of government investment in early phase research [Ford et al 2007]. To prevent under-investment of the private sector (because the government has social welfare goals going beyond

private sector values) governments invest in early phases of the sequence without taking full account of the needed investments in later phases. Some suggestions are made in the study to improve the mix of government support along early and intermediate phases of technology research. Kline and Rosenberg [1986] argue that government funding should support research throughout the whole sequence. Several solutions to close part of the VoD by activities of universities are suggested: setting up spin-off companies based on universities' technology research, setting up joint research programs (successful in Germany), and licensing technologies [Williams 2004]. Another suggestion is that awards with prize money for innovations can help to close part of the gap [Wessner 2005].

The "Darwinian Sea" is another metaphor used to describe the transition from invention to innovation:

"the Valley of death describes a barren territory when, in reality, between the stable shores of the science and technology enterprise and the business and finance enterprise is a sea of life and death of business and technical ideas, of "big fish" and "little fish" contending, with survival going to the creative, the agile, the persistent" [Auerswald and Branscomb 2003, p.230].

They describe four challenges in this Darwinian sea:

- A lack of incentives or motivation for scientists for research aimed at commercialising technology;
- A disjuncture between technologist and business manager;
- Few sources of finance available between research funds supporting creation of ideas and the initial private investment if there is a validated business case;
- Enabling infrastructure: infrastructure needed to place products in the market and complementary or supporting assets (suppliers, training, auxiliary products and services).

The study concludes that maybe the chaotic character of the Darwinian Sea is necessary,

"to provide a wide range of alternative ways to address issues of technical risk, to identify markets that do not yet exist, to match up people and money from disparate sources" [Auerswald and Branscomb 2003, p.237].

Still, they think some of the Darwinian sea's difficulties can be resolved by a policy combination of supporting research to construct a solid business case and creating incentives for risk taking.

From the literature it can be concluded that a part of the Valley of Death exists because of the inherent characteristics of early stage technology development: the social benefits are larger than the private benefits, leading to underinvestment of private parties and/or overinvestment of the government. Maybe the chaotic character of this phase is even needed for a selection process of the best alternatives. The literature however agrees that it is possible to decrease the Valley of Death by providing government investment throughout the whole technology development sequence, providing incentives for private investments in intermediate phases and bringing the private and public sector together in earlier stages.

2.4 Theoretical framework

From these theories, a theoretical framework is constructed to address the research question. Two different aspects are important for choosing theory for this framework: the applicability of the theory to the nature of the problem and its practical use in answering the research question. Table 2-2 shows whether the different theories discussed in this chapter have characteristics that are important for this research. These characteristics are: holistic, dynamics, bounded rationality, multi-level, multi-disciplinary and a focus on innovation and the demonstration phase. The last criterion discusses the practical usability of the theory for the analysis and identifying policy issues. Using this table as a starting point, the chosen theoretical framework is explained here.

Table 2-2. Suitability criteria for the different theories

	Holistic, systemic	Dynamics, evolutionary, path dependency	Bounded rationality, trust, power,	Multi-level	Multi- disciplinary	Focus on innovation	Focus on demonstration phase	Useful as tool, identifying policy issues
Neo-Classical Economics [Arrow 1962][Stiglitz 1988]								
New Institutional Economics [Williamson 1998][North 1990] [Nooteboom 1999]		X (newer theories)	X (newer theories)	X				
Old Institutional Economics [Hodgson 1994b][Groenewegen 2006] [Wilber and Harrison 1978]	X	X	X	X	X			
Evolutionary Economics [Schumpeter and Backhaus 1934][Dosi and Nelson 1994] [Nelson and Winter 1974]	X	X	X			X		
Transition model [Geels and Kemp 2000][Geels 2005]	X	X	X	X	X	X		
Technological innovation systems [Bergek et al. 2008][Hekkert et al. 2007] [Suurs 2009]	X	X	X	X	X	X		X
Entrepreneurial action under uncertainty [Meijer 2008]		X	X			X		
Valley of Death [Murphy and Edwards 2003][Auerswald and Branscomb 2003][Ford et al. 2007]			X			X	X	X

Processes of innovation and technological advance shed a light on the failures of classical economics to explain the real world. Firstly, as argued in literature on innovation processes, innovation has a systemic nature [Edquist 2005][Hekkert et al. 2007]. It is both an individual act of organisations and institutions and a collective act of the system. Firms innovate in collaboration with other organisations and their behaviour is shaped by institutions providing incentives and obstacles. Therefore, technical change is regarded endogenous instead of exogenous to the economic system. Secondly, innovation is a dynamic and evolutionary process determined by events caused by interplay of different factors. A path-dependant history can lead to lock-in into a regime of existing technologies [Sandén and Azar 2005]. Also, the phenomena of innovation and imitation are not compatible with the neoclassical constant and given choice set [Nelson and Winter 1974]. Thirdly, individuals acting in the system do not make completely rational choices based on simple economics. For example, the consideration of an investor involves both conscious and unconscious thoughts and feelings about the investment, the technology and the entrepreneur [Murphy and Edwards 2003] [Interview Wiersma]. Therefore, bounded rationality and non-rational behaviour are more plausible to assume than rational behaviour with perfect information. Also, the role of power and conflict can be very important, for example the incumbents' political power to hinder new technologies [Jacobsson and Bergek 2004][Grubb 2008].

For these reasons, a systems or holistic approach to innovation is often seen as a more appropriate alternative [Bergek et al. 2008]. However, holistic economic approaches are also not sufficient to understand systems of production, consumption and innovation, especially for social utility functions like energy production. The success or failure of clean electricity production technologies is not only determined by technical and economic factors, but also by the social system in which it is embedded [Meijer 2008][Jacobsson and Bergek 2004]. Technological development happens through interplay of

factors at different levels, from fast developments in niches until long-term developments like the ecological, cultural and economic situation [Geels 2005][Geels and Kemp 2000]. It includes changes in social dimensions such as user practices, regulation and industrial networks [Hekkert et al. 2007]. Therefore, a multi-disciplinary approach is needed which is provided by socio-technical systems theory.

Both the transition model and the innovation systems theory are relevant for the nature of the problem. They have a focus on innovations but describe the socio-technical systems in a different way. The transition model has a very broad perspective, but it does not explain the underlying processes of innovation, which must be understood to explain such transitions [Suurs 2009]. These processes of innovation are the development of different low-carbon technologies, which are at the core of a transition to a sustainable energy supply. Also, issues of practical use remain with the transition model, because it does not describe the circumstances for a technology to become successful and how these circumstances can be created. The innovation systems framework can be used to sketch an image of the structural and functional components creating positive or negative circumstances for the development of demonstration phase technologies. Therefore, it is the best theory to understand the circumstances which explain the success or failure of a low-carbon electricity production technology to diffuse in the socio-technical system. The framework of Figure 2-3 can be used to translate this to policy goals and actions to address the financing problems. Therefore, the Technological Innovation Systems (TIS) approach is used to study the financing problems of low-carbon electricity production technologies.

The background on the Valley of Death and financing issues provides useful pragmatic information on the issue from a business management perspective. However, those approaches present a quite narrow view on the financing problems, while the amount of available finance, uncertainties and a disconnection between public and private sector are not the only cause of the financing problems. They do not give a total image of the direct and indirect factors which influence the circumstances for a technology, including social, economic, technical and political factors. The model of entrepreneurial action under perceived uncertainty of [Meijer 2008] links the business management perspective to these external factors (circumstances) which influence the entrepreneurial activities. However, it is a rather general model for entrepreneurial activities and it does not specify the external factors. Therefore, the TIS approach is more useful to study the differences between technologies, by describing the project-external factors for the different technologies.

3. Research method

The goal of this chapter is to define and motivate the research method of this study (3.1) and specify how the case studies are approached through use of the Technological Innovation Systems (TIS) framework (3.2) and how they are executed (3.3).

3.1 Research method

Interest in and use of qualitative research has been growing for the last decades [Flick 2006][Huberman and Miles 2002]. This is especially noticeable in social research because researched objects are becoming more differentiated and thus it is difficult to derive general theories and test them quantitatively [Flick 2006]. This thesis is based on **qualitative analysis** for two reasons. Firstly, it is assumed that technology-specific characteristics influence the financing problems in the demonstration phase, which indicates a variation in the researched objects (the technologies) of this thesis. Probably some aspects of the technologies can be compared and generalised, but others remain specific for each technology. Secondly, a large part of the researched system involves soft aspects like actors and their ideas, informal networks, exchange of (tacit) knowledge and conscious and unconscious considerations of investors, which are difficult to capture through quantitative research methods.

Stebbins [2001] argues that social research should always be exploratory, because its open and flexible character better represents social research than rule-bound and disciplined processes meant to confirm and settle theory. Exploratory research is meant to generate ideas to form theory, while the goal of confirmatory research is to test hypotheses. This research is of **exploratory** nature because the topic is researched for the first time from a multi-disciplinary viewpoint. Therefore, it is difficult to predefine a general theory or hypothesis that can be tested with empirical information. However, it will only concern the first stages of exploratory research because of its limited time. The end result will therefore not be a final perfect image, but a rough first sketch.

For this study two technologies are researched as **case-studies** to acquire understanding in the financing problems for different technologies in the demonstration phase. According to Yin [2003] case study research should be chosen when it is difficult to distinguish the studied phenomenon from its context, which is clearly the case with financing of the low-carbon technologies in the demonstration phase: the financing problems are related to a web of factors from the socio-technical system. The aim of case studies can be to provide description, to test theory or to provide theory [Eisenhardt 2002]. The case studies are used here to provide description of the financing problems of electricity production technologies in the demonstration phase. The protocol for the case studies is discussed in section 3.3.

Insight into the different technological systems is acquired through **interviewing** people working with or related to the technology. Many of the issues in the socio-technical system are not written down and cannot be derived from existing empirical data, like informal institutions, the ideas and perceptions of actors and their (informal) networks. Only through talking to the important actors in the network, (a part of) this tacit information can be gathered. According to Pole and Lampard [2002], the main types of interviews are structured (standardised) or unstructured (reflexive) interviews. The set-up of the case-study interviews is open and **unstructured** to acquire an image of the problem which is as open and objective as possible, asking for the respondent's reaction and opinion on the issue. The preparation of the interviews includes some general themes, which are adapted to the respondent's background. Next to the interviews, literature, news, reports and websites are consulted to enhance the image of the system. How this information is used and structured to give an image of the financing problems and the surrounding socio-technical system, is discussed more elaborately in the next sections.

3.2 Case study approach

This thesis makes use of two case studies to study the research question. Yin [2003] distinguishes between single- or multiple case study research, and exploratory, descriptive or explanatory case study research. To show the variety in technologies within the limited time of this study, two cases are chosen. Therefore, this is a multiple case study research in which the cases are not compared for every step of the analysis, but the general issues are compared at the end. The case studies are used in an exploratory way and will provide a first impression of the factors influencing on demonstration-phase financing. The information gathered by the exploratory case studies was used to decide on the theoretical framework as described in section 2.4. This theoretical framework is used to analyse and structure the case studies. This means the case studies are tuned to be used as descriptive case studies, describing the socio-technical system influencing the financing problems in the demonstration phase.

The framework of Bergek as displayed in Figure 2-3 is used to define the steps of the descriptive case study, which are discussed more elaborately in a case study protocol in the next section. The Technological Innovation System consists of the structural components, which develop slowly over time, and the functional components, which represent the activities taking place in the system. Because usually the eventual success or failure of the development of a technology can only be measured after decades, a way to assess the performance of the TIS during the process of technology development is to assess the functional components. The functions can be seen as intermediate performance criteria of the TIS, because it is expected that the chances of successful technology development will increase when actors, institutions and technologies are successfully arranged to contribute to positive development of the system functions [Suurs 2009]. There are certain mechanisms inducing or blocking the development of the different system functions and its positive dynamics, which can be traced to structural aspects of the TIS or endogenous factors. Policy should therefore be aimed at strengthening system functions and their dynamics through overcoming these structural drivers and barriers. Although the Bergek-TIS framework works well in general, for this analysis some changes are needed to make the TIS approach relevant and useable for the case studies.

Structural components

As described in section 1.2, it is expected that specific technological characteristics lead to differences in the financing problems of the technology and how to approach them. Therefore, it is crucial to consider these technological aspects in the TIS analysis. This argument is confirmed by Suurs [2009], who states that technology has been neglected by the TIS approach. The technological characteristics are structural components, because they are relatively static and do not concern activities. Furthermore, to acquire real understanding of the structural aspects of the TIS, it is important to realise that the structural components are interrelated. Technology and actors are limited and guided by institutions, while institutions are shaped by actors and are susceptible to alignment with technological change. Therefore, the structural components of Suurs [2009] are used: actors, institutions, technology and the networks and relations between them. The relations between the actors are discussed through a network analysis with the actor component. The relations between the different structural components are discussed separately.

Dynamics of the system: positive externalities, feedback loops and motors of sustainable innovation

Bergek et al. [2008] adds a new functional component to the TIS: “development of positive externalities”, which can be both pecuniary and non-pecuniary “free utilities”. This function is meant to incorporate external economies of diffusion of information and knowledge, but also to give a broader view on possibly existing external economies.

However, the function is not very clearly defined in the framework:

“This function is thus not independent but works through strengthening the other six functions. It may, therefore, be seen as an indicator of the overall dynamics of the system.(...) In sum, the analyst needs to capture the strength of these functional dynamics by searching for external economies in the form of resolution of uncertainties, political power, legitimacy, combinatorial opportunities, pooled labour markets, specialized intermediates, as well as information and knowledge flows.” [Bergek et al. 2008 p.418]

The specifically mentioned externalities in this definition (underlined) could also be attributed to other components: *resolution of uncertainties* and *information and knowledge flows* to the function “knowledge development and diffusion”, *political power* and *legitimacy* to the structural component “actors” and the function “legitimation”, *combinatorial opportunities* and *specialised intermediates* to the function “market formation” and *pooled labour markets* to the function “resource mobilisation”. Furthermore, in a later step of the Bergek’s framework (“3b. Achieved functional pattern”), feedback loops are identified which may actually relate to some of these positive externalities. For instance, if knowledge development and experiments lead to *resolution of uncertainties* through research outcomes, this leads to certain expectations of the technology which lead to a change in legitimacy and guidance of the search. Also, new entrepreneurs entering the system create advocacy coalitions with growing *political power*, which can lobby for more elaborate government programmes including market formation and resource mobilisation instruments. The externality therefore can be the trigger (catalyser) to set the cycle in motion or the fuel to keep the cycle going. This idea corresponds to the “motors of sustainable innovation” of Suurs [2009], which are displayed in Figure 2-4. These motors are partly related to the specific externalities mentioned by Bergek et al. [2008], where the externalities can be the fuel or the catalyser for the motor. The motors and how they are related to the positive externalities are explained in appendix 0.

All these concepts concerning the dynamics of the system present some overlap. Hence, for reasons of clarity, positive externalities are not discussed as a separate function, but the discussion of the functional pattern incorporates possible feedback loops creating virtuous or vicious circles, how they relate to the motors of sustainable innovation of Suurs [2009] and the positive externalities mentioned by Bergek et al. [2009] as triggers or fuels of these feedback loops.

3.3 Case study protocol

The case studies are described using a case study protocol. The case study protocol is schematically displayed in Figure 3-1. The different blocks represent the steps that are taken, starting with the demarcated case and the interviews as inputs and the TIS theory as a tool to analyse the cases. The numbers mentioned in the different activities represent the numbers from the activities in the framework of Bergek et al. [2008]. The cases are discussed separately until the “functional pattern and functionality”-step. After that, a reflection is made on the main differences in functionality between the cases. For the inducement and blocking mechanisms, the cases are discussed together, which means general and technology-specific mechanisms are identified. Before starting, the cases have to be demarcated and defined in focus, which is done in section 4.4. The different steps in the case study protocol are described below.

3.3.1 Interview analysis

The main goal of this step is to structure the information from the open interviews using the TIS framework. The issues mentioned by the respondents are arranged in a table with a row for each respondent and columns for the structural and functional components. This table gives an image of the problem from the eyes of experts of the technology.

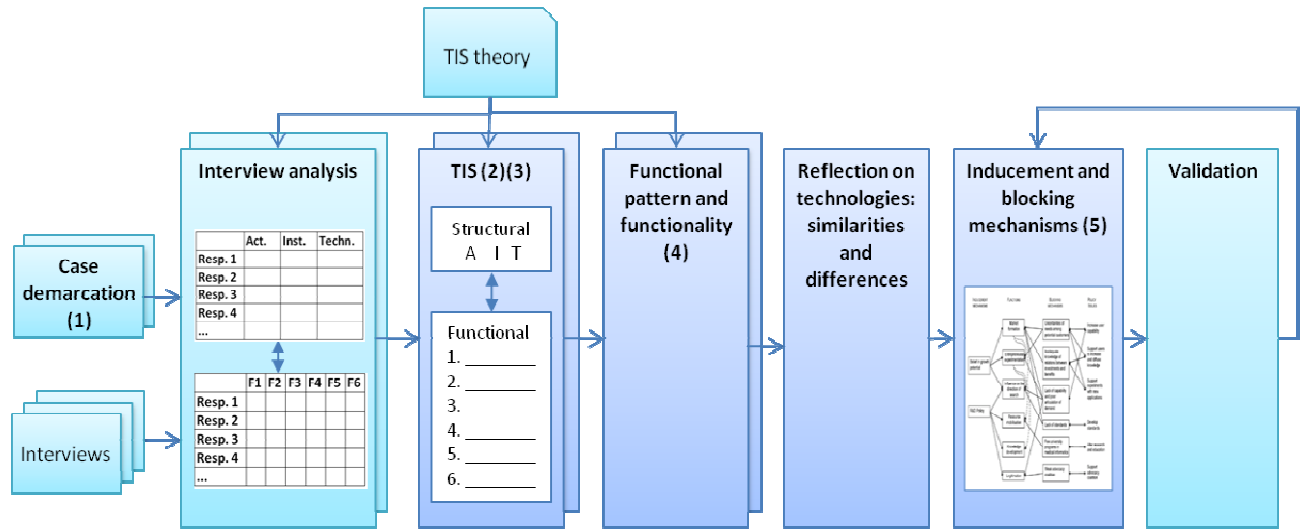


Figure 3-1. Case study protocol

TIS=Technological Innovation System, Act./A=Actors, Inst./I=Institutions, Techn./T=Technology, Resp.=Respondent. The numbers mentioned in the different activities represent the numbers from the activities in the framework of Bergek et al. [2008], displayed in Figure 2-3.

3.3.2 Technological Innovation System: Structural components

The main goal of this step is to identify the important structural components of the Technological Innovation system that influence the financing problems in the demonstration phase.

Actors

The interests, goals, visions and resources of the important actors are described, with specific attention to the perceived uncertainties of the different actors and the risks they have to take, which is important for the financing issues. The actors are divided on three different dimensions, derived from a method of Enserink et al. [2003]. Firstly, the *criticality* of each actor is assessed: an actor is critical when it has important resources to solve the problem that are not replaceable. The second dimension is whether the actor is *dedicated* to and therefore actively engaged in the problem or not. The last dimension is whether the actor's *perceptions, interests and goals are matching or contradicting* with the "problem owner", in this case the UNFCCC. The formal and informal relations between the actors are mapped in a network diagram, using a method connecting the actors in blocks through arrows representing different kinds of relationships, adapted from Enserink et al. [2003]. Three relationships that companies have in networks are supplier/buyer relationships, informal relationships and relationships through problem-solving networks [Carlsson 1997]. Because legislation and regulation of the public authorities have an important influence in the TIS a fourth relationship is added: a hierarchical relation of law-making.

Institutions

The definition of institutions used is:

"Regular, patterned behaviour of people in a society and the ideas and values associated with these regularities" [Neale 1994, p.402].

Williamson [1998] developed a model which shows all important institutions in different layers of society. Figure 3-2 shows an adapted version of the model which defines the institutions in the different layers more clearly, from the low-level interactions and games between actors (layer 1), to arrangements managing these interactions like contracts, join-ventures, mergers, norms and codes (layer 2), to the

formal rules, laws and regulation which set the boundaries for these arrangements (layer 3) and the institutional environment like norms, values and culture in which all these institutions are embedded (layer 4). The important institutions for the TIS can be mapped with this model, showing the important institutions and how they are interrelated and embedded in a total system of institutions. Institutions mentioned by the respondents are placed in the different layers of this model. Since stimulating technology through government policy usually involves an alteration of institutions, it is important to realise which other institutions (possibly at other layers) are influenced or might provide inertia to the desired changes. Furthermore, changes take place very fast at lower levels, while the higher the level, the longer it takes to change institutions.

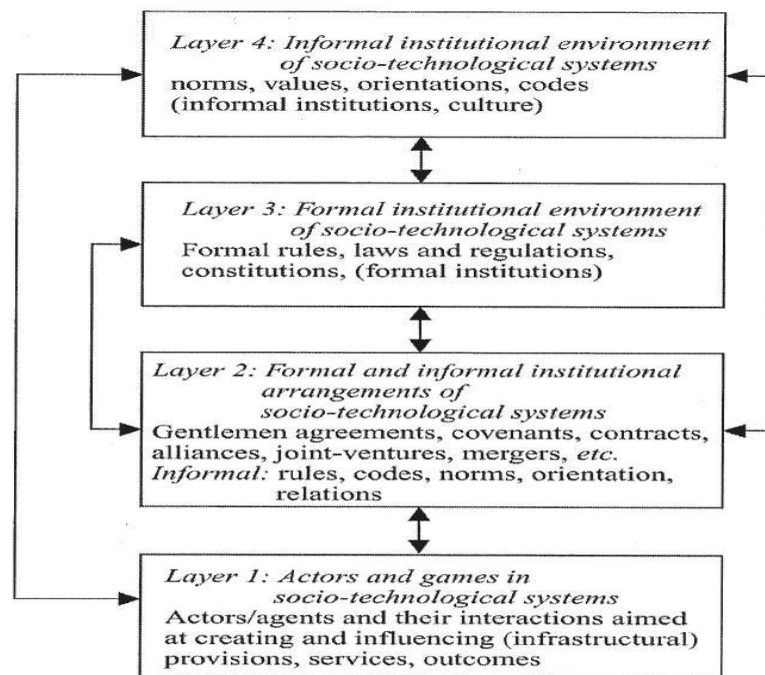


Figure 3-2. Four-layer model of Williamson, adapted by Koppenjan and Groenewegen [2005]

Technology

The technological aspects comprise artefacts and the technological infrastructures in which they are integrated [Suurs 2009]. This relates to the most basic aspects of the technology: what are the costs, reliability, effects of up-scaling, (theoretical) efficiency, emissions, impact on the environment, impact on the electricity network, kind of materials needed, etc. Next to that, it also relates to immaterial aspects of the technology, like the knowledge embodied in the technology and the characteristics of the value chain. Lastly, it also includes other components which are important for the technology development that can be regarded as tangible assets, like electricity infrastructure (lack or shortage of network, problems with feeding back into network), other infrastructure (ports, transportation infrastructure in developing countries) and complementary assets or resources.

Relations and networks

The relations between the structural components are an important part of the TIS [Suurs 2009]. The institutional framework is the “playing ground” for the actors and their games, interactions and arrangements. However, the actors can also change the institutions by influencing the political

environment. Actors can also change technological aspects by choosing a certain technology and improving the technology, but technology also changes the behaviour and routines of actors. Institutions can limit technology or stimulate technology and infrastructure is always embedded in an institutional framework of regulation. Technological change on the other hand also leads to alignment of institutions with the change in technology and infrastructure [Andersson and Jacobsson 2000].

3.3.3 Technological Innovation System: functional components and achieved functional pattern

The main goal of this step is to discuss activities and developments in the functional components of the TIS which are relevant for the financing problems in the demonstration phase.

Function 1. Knowledge development and diffusion

This function concerns the breadth and depth of the knowledge base and how well the TIS functions in the evolution of this knowledge base [Bergek et al. 2008]. It includes all issues that are mentioned by respondents concerning knowledge development, knowledge exchange, a lack of certain knowledge, specific knowledge issues that are relevant for that technology, etc.

Function 2. Influence on the direction of the search

This functions concerns forces which steer the actors in a certain direction, either towards the technology in general or pointing into a certain direction within the technology development, like competing technologies, applications, business models and markets [Bergek et al. 2008]. Factors related to this component are for example: regulation and policy, visions of important actors, economical developments, customer demands, bottlenecks in current technologies and expectations of growth potential.

Function 3. Entrepreneurial experimentation

Entrepreneurial experiments are important to take away a large part of the uncertainties that exist when developing a new technology. It fuels a process of learning through successes and failures. Entrepreneurial experimentation can be new entrants on the market, demonstration projects and development of new applications or technologies.

Function 4. Market formation

Markets for new technologies might not exist or the technology can have inferior characteristics to the current technology because it is not mature yet. Technological niche markets can emerge when the technology has a competitive advantage over other technologies in specific applications. Other niche markets have to be created, often through government incentives like feed-in tariffs or subsidies. The function includes both positive forces, like financial incentives and standards from the government, and negative forces, like slow entry procedures forming barriers for market formation.

Function 5. Legitimation

Legitimation is the process of social acceptance and compliance with relevant institutions of the new technology. It involves actions by different actors promoting the new technology or defending the old TIS. This function therefore includes all comments on reasons of different actors for developing or blocking development of the technology, changes in these reasons and actions of actors to increase legitimation, for example through lobbying or campaigning.

Function 6. Resource mobilization

The resources that are needed for technology development are financial resources, human capital and complementary assets. Complementary assets can include infrastructure, complementary products, services, etc. Extra focus is on the financial resource mobilisation because it is the topic of study.

3.3.4 Function pattern and functionality assessment

The main goal of this step is twofold: firstly to draw an image of the dynamics of the system through identifying a functional pattern of reinforcing relations between the functions and secondly to assess how good the TISs of the technologies are performing in terms of fulfilment of the functions and compare this for both technologies.

After the description of the functional components, the functional pattern is identified by checking for all possible influences of one function on another function if it exists in the TIS and whether examples can be found of the influence for the technology. A block diagram is made showing the influence of the different functions on each other, which reveals feedback loops (if there are any) that are reinforcing certain patterns, which can result in vicious or virtuous circles [Bergek 2002]. It is also discussed whether these cycles are related to any of the externalities mentioned by Bergek et al. [2008] or motors of sustainable energy of Suurs [2009].

When the total image is drawn of the structural and functional components and their interrelations, an assessment is made how well the different functions are developed (for specific geographical areas if there are significant differences), which can be seen as “intermittent performance criteria” of the success of the total TIS [Suurs 2009]. After this, a reflection is made on the differences and similarities of the functioning of the TISs of the two technologies. This will form the basis for identifying inducement and blocking mechanisms.

3.3.5 Inducement and blocking mechanisms and policy issues

The main goal of this step is to identify the general and specific inducement and blocking mechanisms for the technologies. The similarities between the two technologies present common problems and chances for the technologies. These common problems are caused by blocking mechanisms, while the positive developments are caused by inducement mechanisms. These blocking and inducement mechanisms are mapped in a block diagram showing on which functions they have an effect. Likewise, specific problems and chances appear for both technologies from the discussion of their differences, which can be translated to inducement and blocking mechanisms and two separate block diagrams for both technologies.

3.3.6 Validation and verification

To increase the validity and reliability of the research, the main outcomes of the case studies are discussed with the respondents and other experts. They are asked whether the identified inducement and blocking mechanisms and the related policy issues reflect their views

4. Demonstration phase technologies

The aim of this chapter is to identify which technologies are in the demonstration phase (4.2) through providing a more clear definition of the demonstration phase (4.1) and to choose which technologies to research as case studies (4.3) and clearly define these cases (4.4).

4.1 The demonstration phase

Technology development from basic research through to a commercially mature technology is generally characterised by the technology development sequence. Many different terminologies are used for this sequence, which all try to capture the essentials of a process which is in reality unpredictable and chaotic. The linear simplicity of these models is often criticised [Branscomb and Auerswald 2002][Kline and Rosenberg 1986]. One of the arguments is that innovations do not stem from basic research, but occur somewhere else in the process. For example, the bicycle was invented over a century ago while the theory behind it was not exactly understood [Kline and Rosenberg 1986]. In addition, innovation often includes iterative loops, multiple parallel streams and linkages to developments outside of a company.

However, a definition of the demonstration phase is needed for this study that best describes the financing gap in the demonstration phase. Therefore, a terminology of the technology development sequence is chosen which uses the concepts of “proof of principle”, “proof of feasibility” and “proof of manufacturing”. After it is proven in a lab or with a small prototype that the technology is working in *principle*, its *feasibility* on a real-life scale in real-life conditions is not proven yet. This has to be proven through (a) demonstration project(s). Proof of *manufacturing* means that a first real-life scale manufacturing line of the technology is working properly and that it is proven that the technology can be produced and sold on a large scale. This terminology is displayed in Figure 4-1 and is based on the terminology used in the Innovation Agenda for Energy in The Netherlands [Minez 2008].

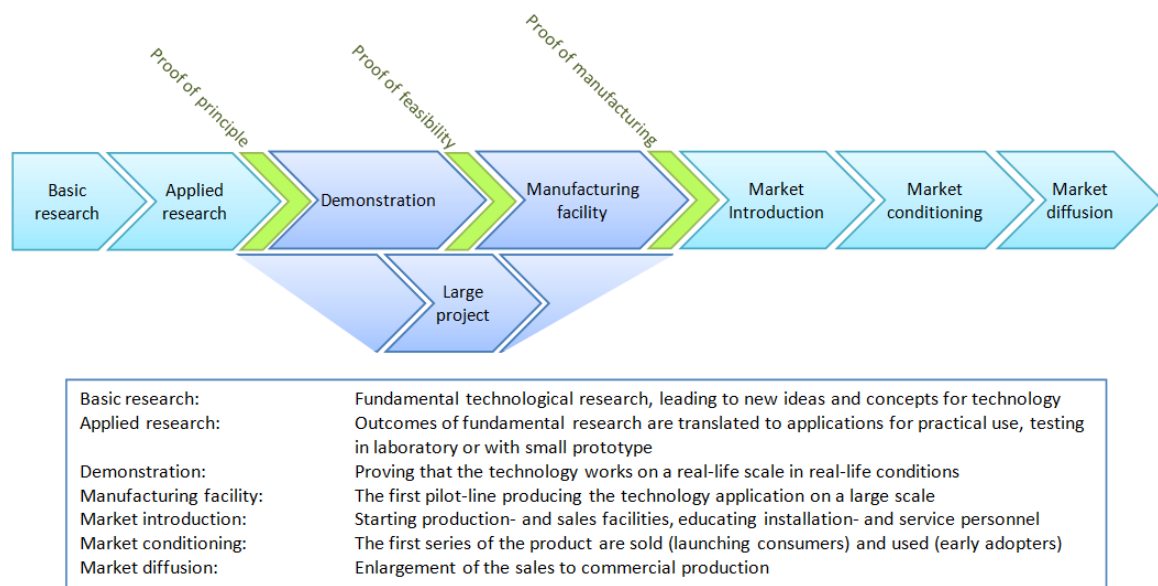


Figure 4-1. Technology development sequence, based on and adapted from Minez [2008]

New electricity production technologies often concern large-scale projects which combine several units and different technologies. After demonstration of one unit of the technology, the next step is demonstration of the technology on a large scale for electricity production, like multiple solar panels of

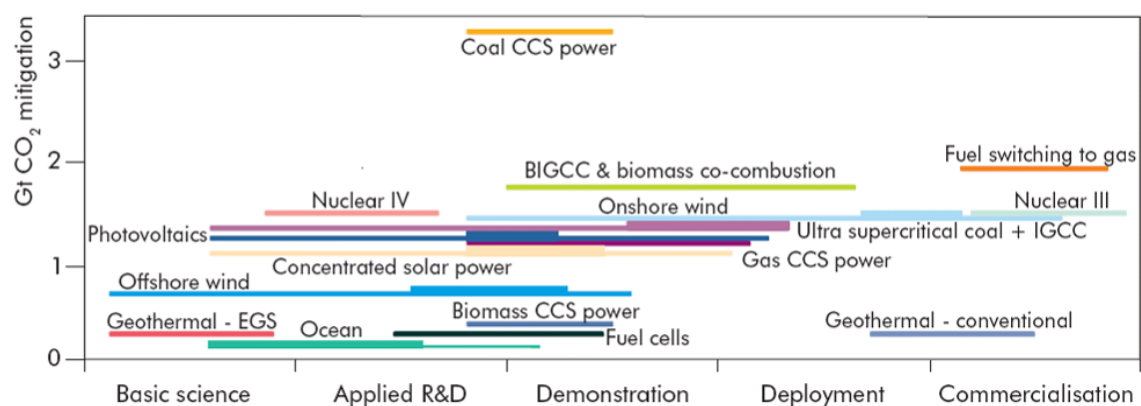
wind, wave or tidal turbines in a park or a complete concentrating solar power plant. This involves new aspects like system integration, logistics, system control and influences of the units on each other. Therefore, the definition of the demonstration phase used in this research includes the sequence from proof of principle until the proof of manufacturing, including the first large project(s).

So what exactly has to be proven for the “proof of feasibility” and “proof of manufacturing”? The main reason why market parties do not want to invest yet is because there are still too many technical and business uncertainties, which have to be taken away during the proof of feasibility and proof of manufacturing. Therefore, these early phases should lead to a working integrated system prototype and a viable business case [Auerswald and Branscomb 2003].

4.2 Electricity production technologies currently in the demonstration phase

Even with a definition of the demonstration phase it is difficult to determine which technologies are in the demonstration phase. Most technologies (e.g. solar photovoltaic) have sub-technologies or “generations” which in turn consist of different technologies for their materials, parts, system integration, etc. Also, the technology might work differently in various environments and there can be regional variations in the level of maturity of technologies [Haïtes et al. 2009]. All such cases can be regarded demonstration projects. The focus of this report is on the demonstration of new sub-technologies in new environments. Partial technology developments such as materials, parts, etc. are regarded as incremental innovations and not demonstrations.

Several studies try to classify technologies throughout the different phases of the technology development sequence [Haïtes et al. 2009][EPRI 2007][IEA 2008]. The International Energy Agency has estimated where the priorities are for R&D in different power generation technologies to reduce greenhouse gas emissions, as displayed in Figure 4-2. According to this, many technologies require attention in the demonstration phase: carbon capture and storage (CCS), onshore wind, photovoltaics, concentrated solar power, offshore wind, fuel cells and ocean power.



Notes: 1) See Annex C for detailed RD&D priorities for individual technologies. 2) Near-term indicates the next 10 to 15 years. 3) CO₂ emission mitigation in the BLUE Map scenario relative to the Baseline scenario.

Figure 4-2. Near-term technology development priorities and CO₂ mitigation for power generation technologies [IEA 2008].

However, this picture only shows very broad technology categories, which hide large differences between sub-technologies. EPRI [2007] places different renewable electricity production technologies on a curve of applied costs of full-scale application, which is usually increasing during R&D and demonstration and decreasing substantially through an increasing number of applied units after successful demonstration.

This graph, displayed in Figure 4-3 gives an idea of the differences between the technologies but uses a quite narrow and not well-founded definition of the demonstration phase.

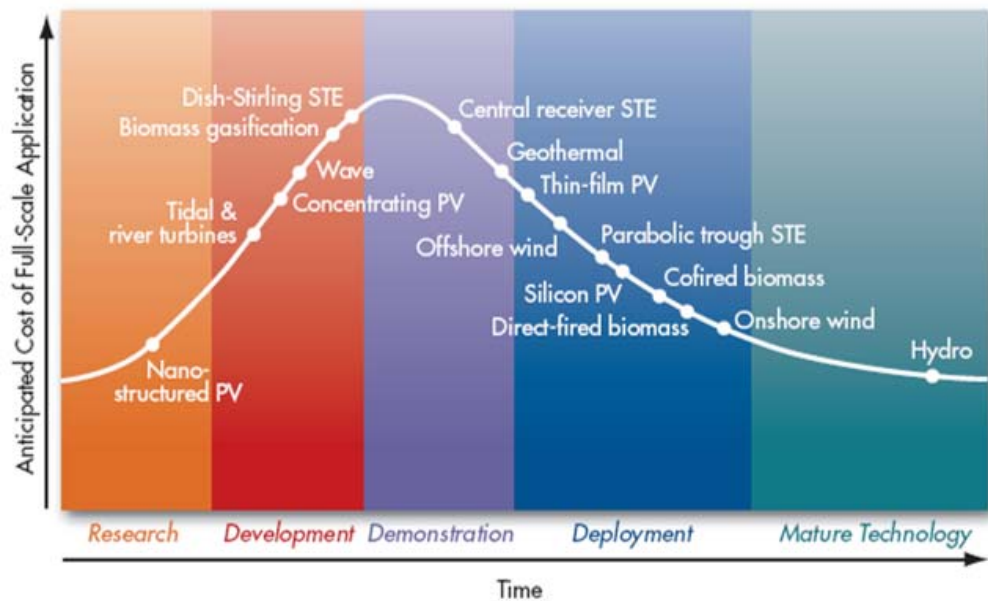


Figure 4-3. Electricity production technologies in different phases of the technology development sequence. PV = photovoltaic, STE = solar thermal energy (concentrating solar power) [EPRI 2007].

UNFCCC [2008b] has classified all climate change technologies in the categories “Research and Development”, “Demonstration”, “Deployment”, “Diffusion” and “Commercially mature”. The low-carbon electricity production technologies that are in the demonstration phase according to their study are:

- Offshore wind – floating;
- Geothermal (enhanced geothermal systems);
- Concentrated solar power/solar thermal (solar towers, Fresnel, dish-stirling, solar chimney);
- Ocean power (wave);
- Technologies related to electricity production: carbon capture and storage and hydrogen production, storage and distribution.

This study uses a clear definition of the different phases in the sequence. Also, it uses both literature and expert judgement to classify the technology, which seems to be the most elaborate and reliable classification. One difficulty with this study is that it only has a general category of solar photovoltaics, placed in the diffusion phase. Therefore, newer solar PV technologies like thin film and concentrating PV are added to this list of technologies in the demonstration phase.

4.3 Case selection

The technology cases have to be chosen on a theoretical basis of inductive learning. When selecting cases for qualitative research first the *population must be determined* and then *theoretical sampling* should be used for case selection (opposed to random sampling as used in quantitative research) [Eisenhardt 2002]. The chosen population is **low-carbon electricity production technologies in the demonstration phase**, which have been identified in the former section. For this research, technologies with a high ratio of capital costs vs. variable costs will be chosen for the case studies, so it is more likely that there are problems in acquiring finance for the high initial investment. Also, this prevents additional complexities of

high and uncertain variable costs for feedstock or fuel, which makes cases more difficult to compare. Carbon capture and storage is also excluded from the case study choice because it is not an electricity production technology, which makes the business case completely different (benefits are CO₂ emissions reductions and there are costs of electricity consumption).

According to Eisenhardt, theoretical reasons for sampling are:

“to replicate previous cases or extend emergent theory or to fill certain theoretical categories and provide examples of polar types” [Eisenhardt 2002, p.12].

For this research the last theoretical foundation is important; to search for polar types of technologies. Flick [2006] gives some other suggestions for sampling, like:

- Choose extreme or deviant cases;
- Choose cases that provide maximal variation and differentiation in the sample: a few cases are chosen that are as different as possible;
- Choose cases for convenience (e.g. available and accessible data and knowledge), especially with limited resources.

The two cases that are chosen to research are **offshore wind** and **solar photovoltaic** (PV). Both technologies have accessible knowledge and data in Europe and the Netherlands. The theoretical motivation of the choice is based on choosing polar types that provide more or less extreme cases and therefore represent maximal variation.

The aspects of difference are:

- Offshore wind and solar PV are reasonably polar examples for their scale, which relates to total investment needs and therefore the scale of the financing problem. Also, scale is related to (perceived) risk of investors, which is an important issue for financing.
- Expected issues of importance are different for the technologies, for example when considering the aspects of the socio-technical regime [Geels and Kemp 2000]:
 - Offshore wind: infrastructure, knowledge (combination of industries), the value chain (partly new value chain, no experience of the industry) and to a lesser extent the market potential (profitability);
 - Solar PV: functional domain (PV has different applications), market potential (profitability is a large problem), symbolic meaning (PV serves the direct consumer market, consumer opinion important) and the value chain.
- Stakeholders are a very important issue for the development of technology. The technologies have differences in crucial stakeholders:
 - Offshore wind: offshore industry, utilities, network companies, higher level governments (even international), nature- and wildlife groups, local interest groups (visual amenity) and port authorities/defence/fishery stakeholders;
 - Solar PV: consumers, building companies, housing corporations, low level governments.

4.4 Case demarcation

The approach of Bergek et al. [2008] states three choices that have to be made for the focus of the TIS:

1. The choice between knowledge field or product

The study is aimed at the *knowledge fields* of the electricity production technologies (offshore wind and solar PV).

2. The choice between breadth and depth (e.g. level of aggregation, range of applications)

The choice is for *breadth*, because the study is a first exploratory research of the financing problems of demonstration phase electricity production technologies and the case-studies are used to support this. It is not the main goal to acquire in-depth knowledge on solar PV and offshore wind.

3. The choice of spatial domain

The scope of the research is *global*, like discussed in the introduction.

The offshore wind case focuses on the demonstration of offshore wind in the North-West of Europe, which is the only place where offshore wind parks have been built until now. The time span researched is from the first offshore and near-shore wind parks in the 1990's until present. Although offshore wind is not completely in the demonstration phase anymore, this can be a useful source of information as a historical case. Some comments will also be made on floating offshore wind technology which is currently entering the demonstration phase.

The solar PV case focuses on newer generations of solar PV after crystalline silicon like certain thin film technologies and concentrating PV, which includes different sub-technologies concerning material use, configuration, etc. There are differences in the maturity of all these technologies, but for this case all solar PV technologies of which the application or production are currently (about to be) demonstrated at a real-life scale are included. The geographical scope of the case is worldwide, specific comments are made for developing countries.

5. The Technological Innovation System of offshore wind

In this chapter, the Technological Innovation System of offshore wind is analysed through studying the structural components (1.2), functional components (1.3) and the functional pattern and functionality of the system (1.4) after an introduction of the technology (1.1). Section 1.5 reflects on the financing problems of offshore wind and to what extent they can be regarded as a “Valley of Death”. The largest part of the information is based on the interviews with people from the offshore wind sector. A list of the respondents and summaries of the interviews are presented in appendix A.

5.1 Introduction

Onshore wind technology is quite far advanced in the diffusion phase, costs are approaching market commercialisation. The development of wind energy started mostly in the countries around the North Sea in Europe and the United States. This case focuses on offshore wind but onshore wind is discussed occasionally because it explains part of the development of offshore wind. Fixed-seabed offshore wind is growing rapidly and is projected to reach commercialisation between 2035 and 2040, when approximately 250 GW is installed [IEA 2008 p. 213]. Western Europe accounts for 99% of total installed capacity [IEA 2008 p. 213]. At the moment, there is over 1,47 GW installed power of offshore wind in Europe and according to the European Wind Energy Association another 37,4 GW is planned before 2015 (see Figure 5-1, Figure 5-2 and Figure 5-3) [EWEA 2009a][EWEA 2009b]. At the moment the United Kingdom and Denmark have the largest installed capacity, but Germany is planning a large capacity until 2015.

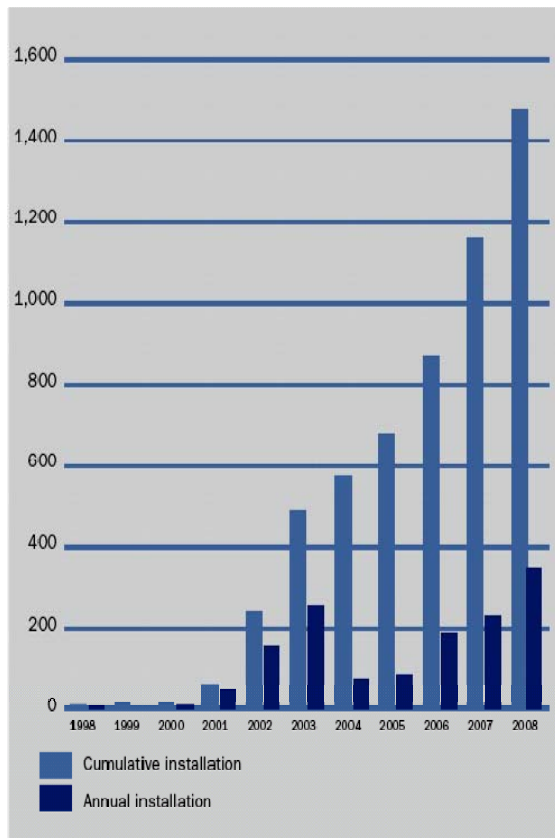


Figure 5-1. Development of offshore wind power in the EU 1998-2008 [EWEA 2009b]

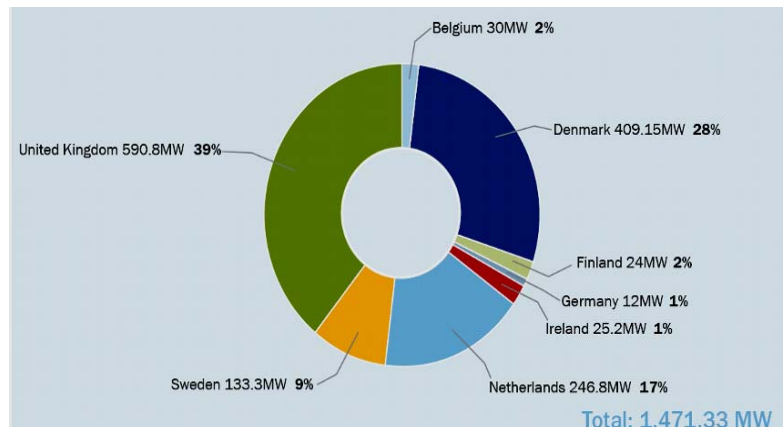


Figure 5-2. Operational offshore wind parks in Europe [EWEA 2009a]

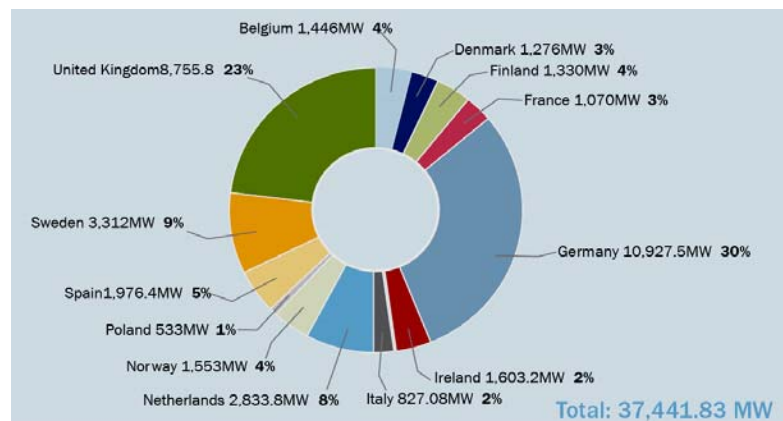


Figure 5-3. Offshore wind parks planned for 2015 [EWEA 2009a]

Offshore wind seems to be successfully crossing the Valley of Death at the moment. There still remains much to be improved on the technological side. Technology currently used for offshore wind parks is onshore technology placed offshore. Dedicated development of offshore technology which is taking place now, includes larger and more robust turbines and other new technologies, like “direct drive”, integration of the turbine and foundation, new ways of construction and other control and monitoring systems. A new technology entering the demonstration stage is offshore floating wind power. In deeper ocean areas, the current foundations of wind towers are not feasible or too expensive. Therefore, a whole range of different offshore floating wind power technologies are being developed for the floating part and the attachment to the sea-bed [Henderson et al. 2004]. The offshore wind turbine industry started from existing wind turbine companies, like Vestas (with the largest share of wind turbines installed offshore) and Siemens. However, Vestas had many technical problems with their turbines offshore, like at Horns Rev, and therefore temporarily withdrew from the offshore sector. Now a new generation of real offshore turbines is developed by companies like REpower, AREVA Multibrid, BARD and Darwind, some of which are new companies. There are large demonstration projects in project development or construction phase. Next to existing parks in Denmark, the UK and the Netherlands, Belgium is developing its first offshore wind parks (C-Power and Eldepasco) and Germany has started construction of the large demonstration project Alpha-Ventus, with two different turbine and foundation technologies. For exploiting wind energy in deeper ocean areas, Norway is investing in offshore floating technology, through two different projects: Hywind sponsored by StatoilHydro and SWAY sponsored by a range of investors including StatoilHydro, Lyse, Scatec and Rosenberg Verft [StatoilHydro 2009][SWAY 2009].

5.2 Structural components

5.2.1. Actors

Appendix A presents an extensive overview of the interests, goals, visions and resources of the actor groups that are important for the development of offshore wind. Table 5-1 provides an analysis of the actors according to whether they are dedicated or non-dedicated, critical or non-critical and have common or confronting perceptions, interests and goals to the policy maker, in this case the UNFCCC (see section 3.2.2 for explanation of these terms).

Table 5-1. Overview of the actors of the TIS of offshore wind

	Dedicated		Non-dedicated	
	Critical	Non-critical	Critical	Non-critical
Matching perceptions, interests and goals	-EU -Country governments -Project developers -Technology developers -Scarce suppliers	-Abundant suppliers		
Some things matching, some things not	-Local governments -Prominent knowledge institutes -Wildlife and nature groups	-Knowledge institutes -Electricity network system operators -Utilities	-Equity investors	-Utilities -Consumers -Debt providers
Contradicting perceptions, interests and goals	-Port authorities, defence and fishery -Local interest groups			

Table 5.1 results in two observations on financing of offshore wind demonstration. First, the financing problems depend on the party developing the technology or project. Large companies have better (financial) resources for project or technology development, while small companies or research institutes usually depend on external financing. However, many of the large companies (utilities, oil and gas companies) play an ambiguous role, because they direct some of their attention to new energy technologies, but they also have vested interests in the current fossil technology. Despite the fact that they are not critical when purely looking at their resources, they have political power which they can use to protect these interests, like lobbying for carbon capture and storage and biomass co-firing. Next to that, investors in small companies are not necessarily dedicated to offshore wind because there are many other businesses to invest in. Suppliers of scarce product and services (turbines, offshore installations) can also influence the TIS.

Second, broad societal consensus is needed for offshore wind parks. However, some societal groups objecting offshore wind (nature- and wildlife groups, local interest groups) have influenced the public opinion and hampered projects through objection procedures. Wildlife and nature groups were worried about the impact of offshore wind parks on sea animals and birds, but most of them have been convinced by now that offshore wind parks have a net benefit for the environment; studies have shown that the impact is minimal if the project is well designed and executed. Local interest groups prefer locations further offshore to prevent visual and noise amenity. In areas close to major ports the port authorities can place a constraint on the locations for offshore wind by protecting navigational routes.

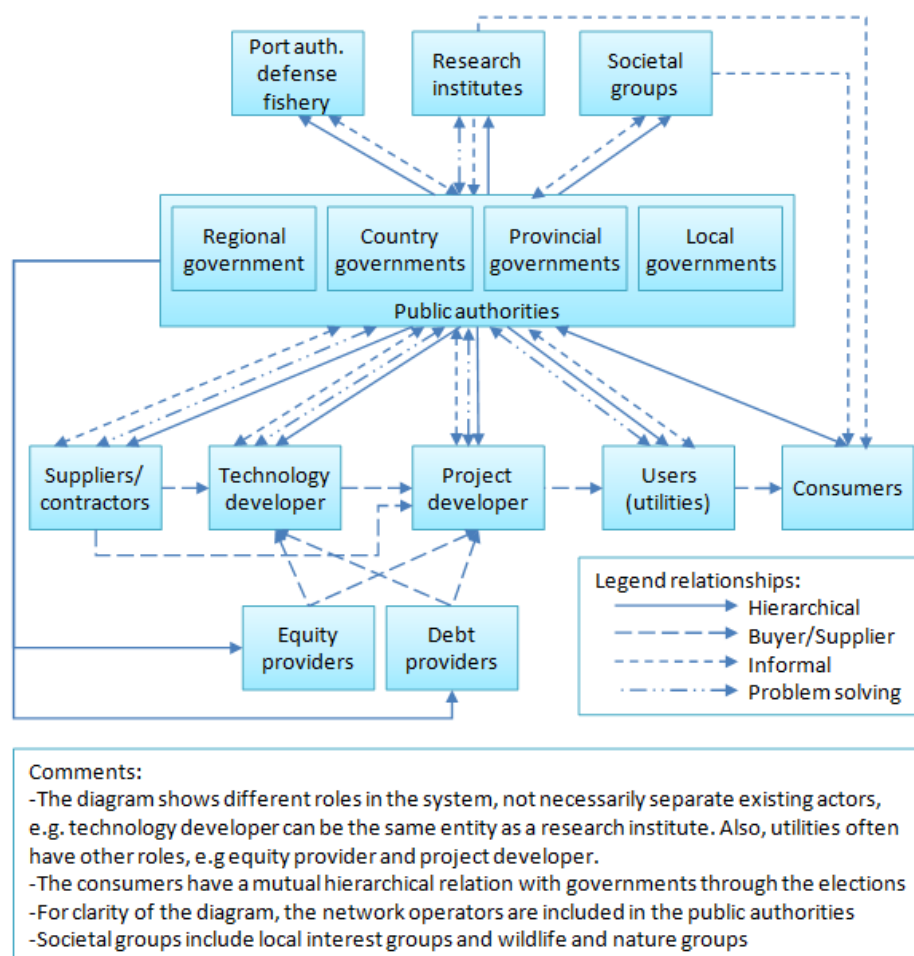


Figure 5-4. Network diagram of offshore wind

Figure 5-4 shows the relations between the actors. It shows the importance of governments through regulation. The problem-solving relationships, often originating from knowledge platforms installed by the government, provide additional benefits through establishing relations between potential partners for projects in the future, and creating positive expectations and advocacy coalitions. Relations between project developers, technology developers, users, contractors, suppliers and debt and equity providers are very important. Often several of these roles are incorporated in the same physical actors, e.g. a utility company can be project developer, supplier of part of the system, equity provider and user. A project usually concerns a web of different buyer-supplier relations and each relation presents a certain mutual dependency.

Several issues concerning this network were important in the development of offshore wind technology. Firstly, there were hardly any existing relations between the wind sector and the offshore sector in the beginning, so the part of the network concerning project developers, technology developers and their contractors and suppliers was underdeveloped. Secondly, the development of onshore wind in Denmark had a cooperative structure, which involved technology and project developers, local inhabitants (often farmers) and research institutes (Risø). Through these relations, the informal power of societal groups and inhabitants was used positively. Thirdly, the relationship between governments and the utilities is strong in many countries because of the former state monopoly status of those companies. For example, Denmark has a history of planned energy policy in cooperation with energy sector. In the Netherlands this strong relationship originates from the time when their joint company “Samenwerkende Electriciteits Productiebedrijven” (SEP) was closely related to the government.

5.2.2 Institutions

Table 5-2 shows the important institutions for offshore wind, ordered in the four-layer model presented in chapter 3. The formal institutional environment (layer 3), which is influenced by government legislation, determines arrangements and actions of actors in lower layers. Governments can create a conducive environment through easing the licensing process, creating incentives and grid connection regulation. The underlying values at layer 4 partly determine the formal environment at layer 3 and create institutional lock-in, like the EU’s paradigm of free competition which has changed the market through liberalisation and privatisation. Formation of networks is important for the interactions in the lower layers. The layer 2 arrangements between parties present different solutions for managing the risks of the mutual dependency relations in the web of supplier and buyers. Offshore wind parks have either Engineering, Procurement and Construction (EPC) contracts in which one party delivers a turn-key solution, but not many single entities have the capabilities to do this, or multiple contracting with guarantees for the product or service of the subcontractor, but this is an expensive solution. It is not possible to go into too much detail here, but transaction costs economics provides a theory on different governance structures to manage these relations (see section 2.1.2), based on asset specificity, uncertainty and frequency of transactions [Groenewegen 2006][Williamson 1998]. The box below presents an example of institutional complexity by comparing the two offshore wind parks in the Netherlands.

Table 5-2. Institutions of offshore wind in the four-layer model [Koppenjan and Groenewegen 2005]

Layer 1. Actors and games
<ul style="list-style-type: none"> ▪ <i>Large energy companies active in renewable energy technologies, but also protecting their current (fossil) business:</i> preparation for future changes and improving corporate image vs. lobbying for natural gas, co-firing of biomass, CO₂ capture and storage and biofuels ▪ <i>Smaller companies struggle to bring their technology to the market and develop projects.</i> ▪ <i>Some smaller companies develop the technology or project far enough to find interested private investors to take over the project, e.g. going through first stages of the project (location, design, permitting) before selling to a party with a stronger financial position.</i> ▪ <i>Lively economic activity in selling and buying projects</i> ▪ <i>Strategy of suppliers important, especially scarce providers, e.g. turbines</i> ▪ <i>Advocacy coalitions through growing industry</i> ▪ <i>Interest groups influence public opinion and the development of projects to protect their interests.</i>
Layer 2 : Formal and informal institutional arrangements
<ul style="list-style-type: none"> ▪ <i>Joint ventures between project developers or between contractors of projects</i> ▪ <i>Power Purchase Agreement (PPA) with an electricity supply company is usually a precondition for any external financing. If electricity supply companies engage in joint ventures, the mixed interests can lead to suboptimal project finance [Jansen 2007].</i> ▪ <i>Contracts with the builders and operators, determining who bears which risks.</i> <ul style="list-style-type: none"> - <i>Engineering, Procurement and Construction (EPC) contracts.</i> Not many “natural” parties have the capabilities to perform all the activities in the contracts [Jansen 2007]. Parties like Siemens Wind Power consider offering turn-key solutions. - <i>Multiple contracting</i> is quite usual in offshore wind projects, but is an expensive solution [Jansen 2007]. - <i>Guarantees for supplied products of (sub)contractors (e.g. the turbine)</i> ▪ <i>Financing agreements</i> <ul style="list-style-type: none"> - <i>Corporate financing: agreements fall under corporate management</i> - <i>Project financing: a range of other arrangements with external partners.</i> The first externally financed park Princess Amalia (NL) had various <i>smart arrangements</i> for insurance and financing, including cutting up the project in three for maximum use of tax benefits and put-options for investors like (see appendix D, comparison of the two Dutch offshore wind parks) ▪ <i>IP-rights can be important for value of developed technology</i> ▪ <i>Formal arrangements of research platforms</i> important to install networks between actors ▪ <i>Informal arrangements</i> through the creation of relations.
Layer 3 : Formal institutional environment
<ul style="list-style-type: none"> ▪ <i>Extensive licensing process</i> for the parks (building turbine, laying cables onshore and offshore, building transformation station). <ul style="list-style-type: none"> - <i>Environmental Impact Assessment</i>, time-consuming and costly - <i>Different zones have different procedures</i> (e.g. 12-mile zone and Exclusive Economic Zone in the Netherlands). - <i>Different approaches for location of the parks:</i> e.g. preference areas (NL) vs. whole sea open for application (DL) ▪ <i>Incentive policy of governments:</i> subsidies, feed-in tariff, renewables obligations or standards, public tenders and tax schemes. <ul style="list-style-type: none"> - <i>Tax benefits specifically for investment;</i> e.g. with Dutch EIA and VAMIL companies can administrate all the investments in the first year of the investment instead of writing them off during the project’s life and they can subtract over 100% (e.g. EIA 140%) of the investment value from their revenues. ▪ <i>Responsibility for the connection to the onshore grid:</i> responsibility in the beginning often unclear <i>Regulation on liberalisation and privatisation and unbundling of the network and production companies.</i>
Layer 4: Informal institutional environment
<ul style="list-style-type: none"> ▪ <i>General EU belief in market forces</i> for the energy sector, reflected in competitive market regulation (liberalisation, privatisation, unbundling and regulation for the natural monopolies of transmission and distribution) ▪ <i>Active or passive government role in stimulating technology</i> and whether the government should “pick winners and losers”, which differs between countries. <i>Industrial policy:</i> whether or not to support and protect its own local companies, <i>Common EU competition legislation</i> on this. ▪ <i>Who should pay for the stimulating measures:</i> the polluter/consumer (feed-in tariffs and taxation per unit of consumption) or the taxpayer (government subsidies)?

Example of institutional arrangements: the two offshore wind parks in the Netherlands

The OWEZ park (formerly Noordzeewind) was a joint venture of Shell and Nuon, financed 50/50 from their own balance. The project started through a tender from the government for the location and the subsidy. They founded two new companies, a B.V. and a C.V. The C.V. was used for tax benefits, because investments in a C.V. are subtractable from their income through the beneficial EIA and VAMIL tax regulation. They had an EPC contract with a joint venture between Ballast Nedam and Vestas, which shifted many risks away from Shell and Nuon.

The Princess Amalia park (formerly Q7) was an initiative of a small company (E-connection) who saw chances for an offshore wind park in the Exclusive Economic Zone, while there was not much regulation in this zone yet. Parts of the project have been bought and sold by different parties and it is now completely owned by Eneco, who took over the part of their former partner E-concern. It is the first offshore wind park with project financing, through a very complex construction with equity, subordinated debt and senior debt. They split up the project in three projects to have maximum benefit from the tax regulation, evading the investment ceiling (\pm €100 mln.) of EIA and VAMIL. Through a construction for the initial investments with put options, investors like IKEA stepped into the project. They have a warranty, operations and maintenance contract through a bonus malus system, which enables the project owners to repay the debt even in case of lower availability than expected.

More details can be found in appendix D.

5.2.3 Technology

Technology characteristics of offshore wind include low carbon emissions (some emissions from production and installation) and a high ratio of capital expenditures compared to operational expenditures. The intermittency of offshore wind makes it difficult to control and match to electricity demand and back-up from the grid or electricity storage is needed. The material demand is mainly steel which is becoming increasingly scarce and has seen a price peak in 2008.

Offshore wind involves interfaces between different parts of the construction (turbine, tower and foundation) and different parts of the park (effects of turbines on each other and on the electricity network). Therefore, there are many interrelated design choices which combine different disciplines (offshore engineering, aerodynamics, mechanical engineering, electrical engineering, etc.), leading to a complex design process for a total offshore wind park.

The conditions of the geographical location have posed difficulties for the equipment and lead to high costs of a park. Firstly, the conditions at sea are very harsh for the wind turbines: stronger wind forces, wave forces and salty water. The onshore technology used offshore was not optimal for these extreme conditions which caused technical problems, especially with the gearbox which converts the power of the slowly moving turbine axis to the fast moving generator axis. Dedicated offshore technology is now developed to cope with these conditions and to up-scale the turbines, which decreases the costs of foundation and installation per kW and increases electricity revenues (larger turbines have higher revenues at the high wind speeds at sea). Secondly, installation and maintenance is more difficult at sea and can only be done with good weather conditions leading to a more difficult and expensive design and project development process. Because of varying local conditions and the large variety of design variables, every project needs separate engineering. On the other hand, the conditions in the North Sea are relatively favourable for offshore wind with good wind resources and relatively shallow waters. There are differences between countries. For example, in the UK the parks can be built closer to shore and in shallower waters while in Norway the sea is too deep for bottom-founded constructions. Also, in Germany

they have to build far offshore because the protected Waddensee nature area stretches throughout the whole German shore.

Another issue is the electricity infrastructure. There is no existing electricity grid offshore and the capacity of the local electricity network where the park feeds in can be insufficient, which could lead to technical problems with the network. For example, a necessary upgrade of the local network for the Dutch park OWEZ cost extra time and money. The Danish network was more appropriate for decentralised production than the Dutch network making the implementation of wind energy easier. An issue of complementary infrastructure for offshore wind is port capacity: not many ports are large enough for offshore wind turbine turnover.

Construction and installation of offshore floating wind is different from offshore fixed wind turbines, dealing with even stronger forces of wind and water. Specific difficulties are the attachment of the construction to the seabed and the electricity cables that are swaying with the movements of the floating construction on the waves, causing durability issues.

5.2.4 Relations between the structural components

For offshore wind it is clear that actors try to influence the institutions: advocacy coalitions lobby for a more positive institutional framework, like the political power of new entrants in Germany and Denmark which helped to enable a more favourable policy framework [Bergek et al. 2008]. At the same time opponents and incumbents try to change institutions to their advantage, like Nuon and Essent who are lobbying for a SDE subsidy for co-firing of biomass in the Netherlands. On the other hand, institutions shape the behaviour of the actors. Subsidies stimulate actors to engage in offshore wind and difficult and changing licensing processes are a barrier for starting offshore parks. Privatisation and liberalisation in the European Union have had an impact on the structure, role and (financial) strength of the actors, separating the natural monopoly of transportation from the production of electricity. Actors have changed the technology in several ways. The opposition to onshore wind has guided a move to offshore technology, which was stimulated by the wind industry. The technology has been improved by several actors, although the lack of existing relations between the offshore and the wind sector was a barrier for the development of the technology. The technology has changed the behaviour of some actors; electricity network operators have to adapt to the implementation of large-scale intermittent power production on their network and the electricity market has changed because of more intermittent electricity production. The institutions limited a swift growth of offshore wind, because procedures were complex and uncertain and there was often no clarity about the responsibility for grid connection. On the other hand, there were also stimulating policy measures, like financial incentives and policy trajectories for offshore wind implementation. Technological change has also led to alignment of institutions with the technology [Andersson and Jacobsson 2000]. In the Netherlands, the SDE subsidy was extended to offshore wind with a separate, higher tariff. Also, the electricity laws of most countries regulating the installation and connection of electricity generators was not applicable outside the territorial waters [Mast et al. 2007]. Some countries extended the electricity law to these areas (e.g. Denmark, Germany) and in other countries the grid connection is the responsibility of the project developer (e.g. Netherlands).

5.3 Functional components

5.3.1 Knowledge development and diffusion

Extreme environment: from onshore to offshore

Several knowledge challenges resulting from the application of wind technology in a new environment were indicated by the interviewees. Firstly, the onshore technology used offshore faced technical problems because of the extreme environmental conditions. Through trial and error the industry learnt that specific offshore turbines should be developed, which could also be optimised economically through up-scaling. Developing this technology costs time; only now the first parks are built using specific offshore turbines (e.g. Alpha-Ventus). Secondly, the offshore sector and wind sector were not connected at first and the wind sector did not have any experience with projects at sea. Some respondents indicated that the offshore sector was keen on engaging in offshore wind because of decreasing income from oil and gas activities, but others disagreed that the offshore sector reacted quite slowly to the offshore wind developments, because the potential income from offshore wind was relatively small compared to other offshore activities. Thirdly, the combination of the sectors led to several problems. The complex interplay of wave and wind forces and the relations between the different parts of the park were (and still are) not completely understood. The varying local conditions in combination with the large number of interrelated design choices require a lot of “experience” knowledge to optimise the technology and bring down costs. This means that the demonstration phase is stretched, because a technology needs to be demonstrated in different environments and in different configurations to reduce technological uncertainties. There were practical problems because the calculation and design methods of the different sectors did not match. The parties do not want to give away their knowledge, so they end up in a complicated iterative design process: each party designs its part and they harmonise their designs in several iterative steps with the designs of the other parts. Lastly, the new technology required supporting technologies which did not exist yet, like specialised vessels and installation techniques. One interviewee indicated knowledge spill-overs from the offshore wind sector to the offshore sector: the offshore sector has learnt in using more ships instead of helicopters, using monopiles instead of platforms and less over-dimensioned design; the over-dimensioning for oil and gas platforms was too expensive for each wind turbine.

Swift market entrance vs. improving technology

Proven technology is important for bringing technology to the market but during the process of testing and adjusting the technology for the market a better technology can be invented. This leads to a dilemma between choosing for bringing an inferior technology to the market fast, or developing superior technology which will take longer to bring to the market. For example, Jansen [2007] argues that for easier financing of future projects, projects should be smaller and existing proven turbines should be used to decrease the risks. However, a possible superior technology needs opportunities for testing. For offshore wind this dilemma is emphasised because so much experience knowledge is needed to take away technical uncertainties.

R&D projects and learning

The interviews showed many examples of knowledge development and diffusion activities. Several countries have platforms for knowledge development, like We@sea in the Netherlands and the Stiftung Offshore Windenergie in Germany. Often there are R&D projects integrated in the offshore parks. The German project Alpha-Ventus uses different new technologies and integrates a large number of studies in the “RAVE”-project. Siemens Wind Power sometimes uses relations with regular clients to experiment with new equipment. In partnerships it is valuable to have a good knowledge combination, like the OWEZ

park in the Netherlands: Nuon's knowledge of the electricity market, electricity networks and licensing combined with Shell's knowledge of offshore construction, design and technology.

Offshore floating wind can benefit from some of the offshore wind knowledge, but a large part of the technology is completely different. The difficulty with offshore floating technology is that the effects of the combination of even stronger wind and wave forces on the installation are yet largely unknown. Also, a solution must be found for the durability of the swaying cables.

5.3.2 Influence on the direction of search

Geographical limits of onshore wind energy have directed the search to offshore wind energy, especially in small countries like Denmark and the Netherlands where "Not-In-My-Back-Yard" problems are largest. Limits on the technology are also directing the search, like suitability of different foundations for different water depths. However, governments can have an important influence in directing the search.

Government policy: external guidance of search

Governments played an important role in the early stages of the technology development to give direction to offshore wind. The Danish government was active from early on to stimulate wind technology development through an extensive package of measures and agreements with the utilities to build offshore wind parks. Their policy measures complemented each other well and stimulated technology development throughout the different phases [Buen 2006]. The Danish energy planning tradition through cooperation between the government and utilities helped the policy making process [Midttun and Koefoed 2003]. This led to the arrangement that each electricity company should have a certain percentage of offshore wind in their portfolio. However, these plans were dropped in 2004 after a political change which immediately halted the developments [Tempel 2008]. Germany had a strong science and technology policy which led to a powerful industry and large installed capacity of offshore wind [Bergek and Jacobsson 2003][JGCRI 2009]. In the Netherlands, the early stages of development for the onshore wind industry proceeded rapidly but problems with a procurement program from the government and a promised market expansion program which did not materialise led to the downfall of Dutch wind firms [Bergek and Jacobsson 2003]. The reactions of the respondents showed that the Dutch government has a reputation of changing policies, which has continued for offshore wind. The Dutch government had put out a tender for offshore wind parks, but changed its plans when there were too many offers on the tender. By then, the companies had already invested a lot of money and time in the tender process and therefore lost their trust in the government. The regulation and licensing also changed several times and the licensing trajectory is still not always clear (e.g. appointing areas for offshore wind parks). Hisschemöller [2008] argues that the current Dutch energy transition policy still lacks a clear and consistent framework and is aimed in the wrong direction of stimulating incumbent firms instead of small initiatives. In Sweden, the guidance from the government was bad from the beginning which led to a weak wind sector [Bergek and Jacobsson 2003]. The development of onshore wind in the UK started slow, but for offshore wind there is a conducive and stable policy framework with three rounds of growing installation targets [Tempel 2008].

High-tech optimisation vs. low-tech reliability: internal guidance of search

The countries have approached the development of wind technology differently, which is illustrated by a study of the difference between the Netherlands and Denmark [Kamp 2008][Kamp et al. 2004]. The Danish approach was pragmatic, based on learning-by-interacting and reliability, while the Dutch were focussed on high-tech research and learning-by-searching for the economically optimal technology. The

Danes had a strong cooperative structure between the knowledge institute Risø and local entrepreneurs, residents and wind turbine developers. The Dutch relied on the large utilities which were more focussed on natural gas and nuclear energy at that time. This resulted in a different design: the Dutch two-blade turbines were optimised for cost purposes (less material), but the Danish three-blade design turned out to be more robust and pleasant for the eye [Tempel 2007]. This difference in approach was one of the reasons why the Danish turbine industry was very successful and the Dutch industry faded. In Germany, like in Denmark, a number of different actors and designs were stimulated and there was learning from the diffusion of small-small application [Sandén and Azar 2005]. Germany also supports different actors and designs for offshore wind technology in the Alpha-Ventus demonstration project.

5.3.3 Entrepreneurial experimentation

Experimentation is especially important for offshore wind because experience knowledge is needed at different locations and with different configurations, but the large scale of the investment and uncertainties make experimentation difficult. Several small companies were front-runners in starting project development and sold the project later to larger parties. Specific difficulties for offshore wind were the complex and unpredictable licensing process and uncertainties about grid connection. Making a grid connection is a chicken/egg problem: without a park no connection, and without a connection no park. Another problem for offshore wind projects was the tight market for turbines and offshore installation and the fact that some specialised technologies were not available yet (e.g. vessels).

The interviews combined with news reveal a lot of information about experimental activity taking place in different European countries, sometimes supported by country governments to decrease the barriers and uncertainties for project developers. In Denmark the local cooperative structure led to early small-scale entrepreneurial experimentation. In Germany technical and market experiments are stimulated by government policy [Bergek and Jacobsson 2003], both for onshore wind and now in the Alpha-Ventus project (different foundations, turbines, location far from shore). They only have one operational offshore turbine now, because the parks have to be built far offshore and in deep waters outside the Waddensee. In the Netherlands, some first pilots were done and there is a test location of ECN, but the first large park took long. In Belgium, the design of the first park changed a few times (including a new Environmental Impact Assessment) and objection procedure caused large delays. The UK is the fastest developing market, turbines are placed in deep waters (45 m.) in Scotland [Tempel 2008] and a number of projects will try out very new technologies, including vertical wings, a new offshore-specific wind farm and a floating turbine [New Energy Finance 2009c]. The Norwegian public oil company StatOil Hydro is developing two types of floating wind turbines, of which the first is now tested at sea.

5.3.4 Market formation

For offshore wind, technical niche market formation is not possible because the only application is large-scale electricity production, competing with cheaper fossil fuel technologies. Therefore, a market has to be created which can be done through government incentives. There are differences between countries both in how the market was formed and how fast it was formed. Germany used feed-in legislation to create a market for wind energy and favouring local enterprises, which led to a swift market expansion [Bergek and Jacobsson 2003]. Denmark was also fast in developing a market through extensive policy schemes including feed-in tariffs and mandated agreements with electricity companies [Midttun and Koefoen 2003][Buen 2006]. As soon as both a national and an international market developed for the Danish wind technology producers, they had a buffer in case one of the markets was insecure [Midttun

and Koefoed 2003]. The Netherlands only had investment subsidies in the beginning, the market was formed a lot later which kept the technology stuck in the laboratory [Buen 2006]. In Sweden, the position of the industry was weak at the time of market formation because of the lack of experimentation in earlier stages [Bergek and Jacobsson 2003]. A very positive government framework is now booming installed offshore wind capacity in the UK.

The interviews showed that a variety of market formation mechanisms are used for offshore wind in Europe. The Danish government choose for a public tender, where the government did the licensing themselves and put out a tender. Another option is to have obligations or standards for electricity production companies to produce a certain amount of green electricity, like the UK's Renewable Obligations and the Dutch Green Certificates. Next to that, there are different kinds of subsidy schemes, each having advantages and disadvantages.

Technological niches

Among the respondents there was one example of chances of technological niches for offshore wind technology. The Ampelmann company developed a platform which provides safe and easy access to offshore constructions from ships which is usable for both offshore wind and oil and gas. Their project got government support because of its value for the offshore wind sector by lengthening the period that can be used for installation and maintenance, but most of the deployment up until now has been in the oil and gas industry.

Important issues are the size of the subsidies and whether the subsidy is open-ended or not; is there always a subsidy for the electricity producer or is there a maximum to the amount of projects or money? The subsidy can be paid by the government (like the SDE in the Netherlands) or by the electricity companies that have to buy the electricity (like the feed-in tariff in Germany). Most of the respondents were in favour of a feed-in tariff because it is more stable than subsidies paid out of government budgets which are renegotiated frequently. The feed-in tariff was an important reason for the market growth in Germany and now in the UK. An important issue is the responsibility for the grid connection, which is a substantial part of the costs. In Germany, the costs are for the Transmission System Operator (TSO) while the costs are for the project developer in the Netherlands and the UK.

5.3.5 Legitimation

The main reasons for wind energy are energy security (spurred by energy consumption growth, depleting fossil fuel sources and geopolitical tensions) combined with environmental concerns including climate change. The legitimation for offshore wind is a lack of space for large-scale diffusion of wind power on land and problems with local interest groups. It is expected that the European climate targets (20% renewable energy by 2020) cannot be attained without large-scale implementation of offshore wind energy [European Commission 2008]. However, there are differences between the European countries concerning the process of legitimation in society.

Engaging parties in the technology

Denmark had a strong legitimation process, determined by several factors (compiled from the interviews and [Buen 2006][Middtun and Koefoed 2003]). Denmark was highly dependent on oil imports, so the oil crisis of '73-'74 made them aware of the importance of diversification of energy sources. Also, there was a strong anti-nuclear sentiment and the Danes have had ambitious environmental policy goals from early on. The cooperative structure in Denmark helped the legitimation process for onshore wind through involving local inhabitants who participated and benefited in the projects. After a while, the growth of the wind industry led to large income and employment, leading to more legitimation of wind power. There was lobbying from the Danish environmental movement, local wind owners and industry associations. The central government and the power companies had a common interest in large-scale concentrated wind

power development: it would help the energy sector to meet their objectives and strengthen their position compared to new entrants on the market. Next to that, the Danish policy is characterised by long-term agreements between parties in the energy sector, which enabled cooperative agreement between the government and the power companies for the first parks. The German government also took care of an early legitimacy of wind power and the created wind turbine industry had a growing lobbying capability [Bergek and Jacobsson 2003]. For offshore wind, the “Stiftung Offshore Windenergy” works as a coalition to promote offshore wind energy. In the 70’s and 80’s the Netherlands had just discovered its natural gas sources which was regarded as the promise for future energy production together with nuclear energy. Many respondents have the opinion that the Dutch government’s focus has been too much on the large energy companies (companies like the utilities and Shell seem to have a large political power) and that their role has been more retarding while the small companies are actually the ones enabling change. The incumbent energy companies have an ambiguous role because they are shifting some of their attention to renewable energy, but are also protecting their vested interests in fossil-fuel based energy production. A study on wind energy development in Sweden argues that the lack of experiments in the 1980’s resulted from a poor legitimacy of wind turbines, mainly caused by the “nuclear power trauma”: everything in the energy sector was related to the debate whether or not to dismantle Swedish nuclear power plants [Bergek and Jacobsson 2003][Bergek 2002]. Renewable energy was only seen as a means to replace nuclear power so advocacy of wind energy was seen as anti-nuclear. In the UK, wind power started off late because they have a limited potential for onshore wind, but the legitimization for offshore wind is good because the potential is huge. Although the need for offshore wind is not very high in Norway because of its hydro capacity and oil and gas reserves, they are investing in offshore floating technology development. The reason for this could be future income when their fossil fuel reserves are drying up; they can export electricity to the rest of Europe through their strong interconnections [Tempel 2008]. Different reasons to engage in offshore wind came up from the interviews. In the Netherlands, early feasibility studies for the government showed that offshore wind projects could be economically viable with a certain subsidy level, which stimulated market interest. One of the electricity companies pointed out that due to privatisation production companies now have market interests which makes it more difficult to pursue societal goals like sustainability. However, there are hugely rising energy demands, the classical oil and gas fields are starting to become empty and there are climate problems, which are reasons for a company like Shell to be involved in wind power to know what’s going on. The role played by the offshore sector is not exactly clear. On one hand, the oil crisis resulted in less work in the oil and gas sector, making offshore wind more interesting: several companies did feasibility studies on offshore wind [Tempel 2008]. However, others think the offshore industry reacted slowly and stayed focused on oil and gas activities.

Resistance to the technology

An important legitimization issue for offshore wind is its impact on the environment, like the bird and animal life at sea. Many environmental groups objected (offshore) wind for that reason in the beginning, like “Vogelwacht Egmond” that delayed the Dutch park OWEZ through judicial procedures [Noordzeewind 2007]. Therefore a large research effort was needed on environmental impact and compensation measures. Usually an Environmental Impact Assessment is a precondition for a project. Research showed that there is no harm for birds, because they fly around or sit on the turbines if the design and the location of the park are right [RSPB 2009][Tempel 2008][BERR 2009]. Driving the monopiles into the seabed can be dangerous for the sea mammals because of the noise. Measures are taken for these animals, by gently scaring them away before the driving starts and starting the process carefully. After these studies and

compensation measures most of the environmental groups changed to a positive position because of environmental advantages of renewable energy. Societal groups objecting parks for the visual amenity also delayed the OWEZ park [Noordzeewind 2007] and different parties from the village Urk are now objecting a wind park in the Noordoostpolder in the Netherlands. To counter these societal groups, parks are now built more often outside the visibility range. The port authorities in the Netherlands, which are powerful actors because of the importance of the ports for the Dutch economy, put a constraint on the space for offshore parks sticking to a 2-mile zone between offshore parks and shipping routes. Combined with areas dedicated to the marine forces, locations left for offshore wind parks are further from shore. The government can play an active role to take away opposing forces, the Middelgrunden project just out of Copenhagen has shown that opposition can be decreased through active public involvement [Larsen et al. 2005]. However, liberalisation and unbundling of production and network companies has created a larger number of parties to deal with in creating legitimacy.

5.3.6 Resource mobilization

Financial resources

Figure 5-5 shows the investments and planned investments in offshore wind from 2001 until 2010. The reasons why investments were expected to go down after 2009 are delays in projects and increased costs of turbines and installation, from €1,75 million/MW in 2002 to €2,75 million/MW in 2007 [Westwood 2007]. Figure 5-6 shows a projection for the longer term with investments expected to go down a little after 2010. Due to the financial crisis, projections have changed considerably and it is unlikely that the expectations for 2009 and 2010 will be met. The financial crisis has made it difficult to acquire working capital for both project developers and investors and therefore the investments in offshore wind have gone down along with other renewable energy investments. The figures for 2008 and 2009 are not available yet, so the exact impact is not clear. However, the demand for wind turbines has almost evaporated due to a lack of capital and the lowest natural gas prices in six years and tax equity investors and turbine supply loans for developers are almost gone [New Energy Finance 2009d].

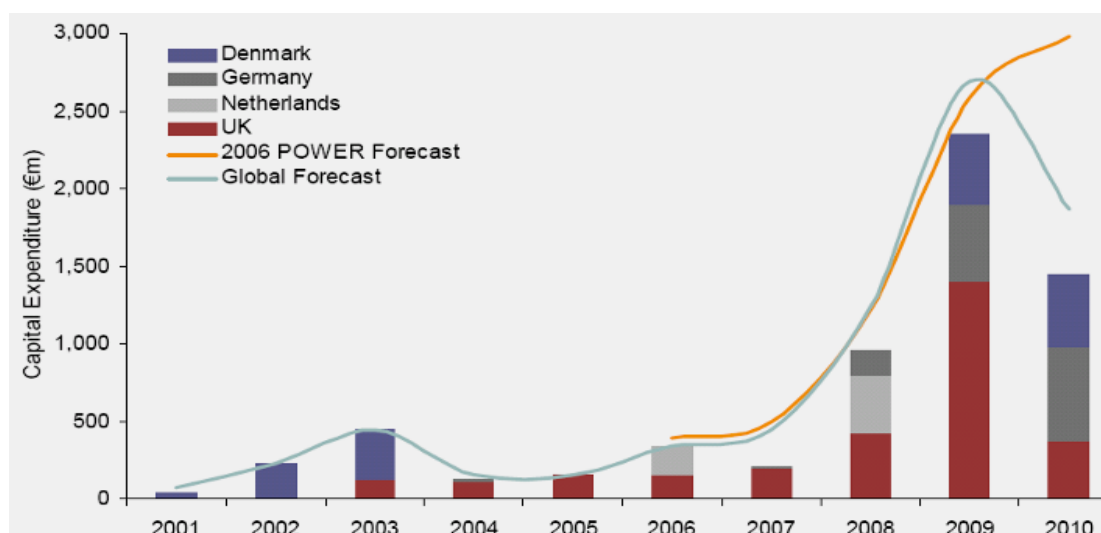


Figure 5-5. Offshore wind investments 2001-2010 [Westwood 2007]

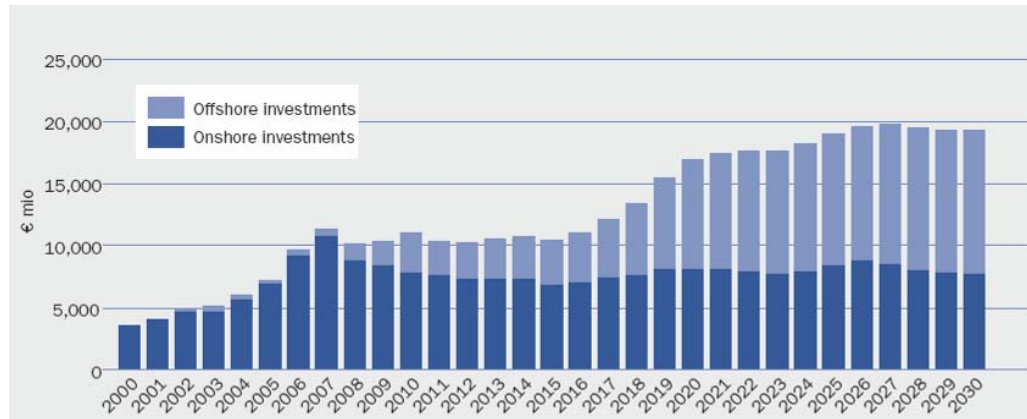


Figure 5-6. Wind energy investments 2000-2030 [EWEA 2009b]

Most of the financing in the offshore sector at the moment is still balance financing and financing as part of a portfolio of a company [Jansen 2007]. Although onshore projects are almost completely financed with debt, offshore projects at the moment usually have about 60-70% debt, which would ideally be more [Jansen 2007]. An important incentive for investments is a beneficial tax regime for new technologies.

Important obstacles for offshore wind financing are project economics, construction and operation risks and the permitting and pre-development process [Geest 2006]. Both cost and revenues of a park can be quite uncertain. Examples of the average investment cost per MW for the different parts of a project are given in Figure 5-7. At the cost side, all kinds of risks are important, of which construction and operation risks are most important. The construction phase risks include delays, budget overruns, interest, interfaces and contractors and the operation phase risks include wind availability, electricity price, costs of operation, technology and contracted parties [Jansen 2007]. The technical difficulties with the technology and the large amount of experience knowledge needed result in high uncertainties. At the benefit side, major uncertainties are electricity prices and revenues from government stimulation programs, which can fluctuate because of political changes. The permitting and pre-development process is a costly, lengthy and often unpredictable process which can also lead to cost overruns and delays. Consortia are often formed to share these risks. For the expectations of investors in the technology, the other functions are important, like legitimization (opposition and delays expected?) and influence on the direction of the search (can stable government policy be expected?).

	INVESTMENTS 1000 €/MW	SHARE %
Turbines ex works, including transport and erection	815	49
Transformer station and main cable to coast	270	15
Internal grid between turbines	85	5
Foundations	350	21
Design and project management	100	6
Environmental analysis	50	3
Miscellaneous	10	<1
TOTAL	1,680	~100

Figure 5-7. Average investment costs per MW of offshore wind farms Horns Rev and Nysted [EWEA 2009b]

Other resources

Scarcity of other resources than finance has caused delays and high costs. The normally expected price decreases through learning hampered because of a scarcity in production capacity and raw materials.

Until 2004, the cost of onshore wind turbines showed a learning rate of approximately 10% (each time capacity doubled, costs per MW installed went down by 10%) but in 2004-2006, the price of wind power increased by approximately 20-25% [EWEA 2009b]. Important issues concerning scarce resources are:

- Scarcity of turbine and turbine parts suppliers. Most companies also make onshore turbines, so offshore supply is coupled to the onshore market. Vestas stopped producing offshore turbines for a while because of technical problems, the onshore market provided a more stable income.
- Rising steel prices. Who bears the risks of price increases during the lead time of a few years?
- Installation and maintenance vessels. Vessels were already booked for years in advance. Construction of the Princess Amalia park was delayed for 3 months because of a broken crane. Specialised vessels for wind turbine installation were needed, but companies only develop them if they expect a certain critical mass of offshore parks for gaining return on their investment.
- Port capacity. Many ports are not large enough for offshore wind park turnover, e.g. the UK now uses the port of Vlissingen for an offshore park because their ports are not big enough.
- Scarcity of skilled (technical) workers.
- Electricity infrastructure could become a problem if the installed base would grow significantly in the future because the current net is not able to handle a large number of large-scale intermittent electricity production units. More capacity or more interconnection between European countries would be necessary, but these projects take about a decade to develop.

5.4 Functional pattern and functionality

5.4.1 Functional pattern

Figure 5-8 shows the functional pattern in a diagram of the 6 functions and their influence on each other. Explanation for each relation and examples for offshore wind can be found in appendix A. This diagram clearly shows that the system is dynamic because the functions are interrelated, which suggests that the policy framework should address all the functions. The function entrepreneurial experimentation is the most important function, which shows the importance of the topic of this research. The most important relations and feedback loops are discussed here.

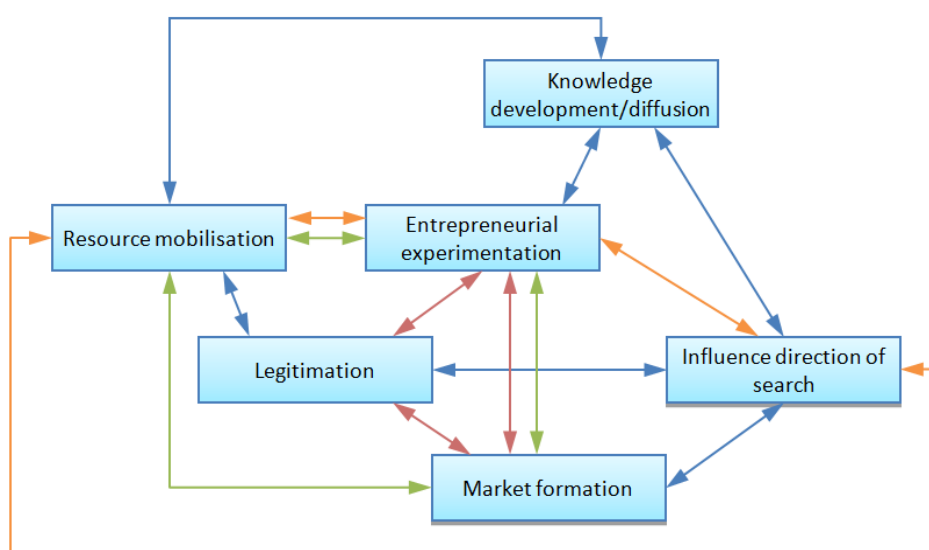


Figure 5-8. Functional pattern of the TIS of offshore wind

The colours represent the feedback loops including more than two functions, discussed below

There are several feedback loops which lead to virtuous or vicious cycles in the system:

- **Influence on the direction of the search ↔ Entrepreneurial experimentation**

Positive or negative expectations of the technology (IDS) lead to an increase or decrease in new entrants and activities (EE). Also, by giving direction to the search, it is easier to shape experiments. Experiments have certain outcomes, which feed in to the positive and negative expectations and the direction to which parts of the technology should be improved. This feedback loop is related to the externality of resolution of uncertainties and is a part of the entrepreneurial and market motors of Suurs [2009].

Example: Positive outcomes of feasibility studies in the Netherlands led to interested market parties for the first offshore wind park tenders. Technical problems during experimentation with onshore technology offshore guided the search towards specific offshore technology.

- **Resource mobilization ↔ Entrepreneurial experimentation**

If public or private resources are mobilised, there are more possibilities for entrepreneurial experimentation. Newly entered firms are making large investments, for example in infrastructure, and the experiments take away uncertainties for future investors. This feedback loop is related to the externality of resolution of uncertainties. The relation $RM \rightarrow EE$ is part of all motors, the total feedback loop is a part of the market motor of Suurs [2009].

Example: The demonstration project OWEZ (NL) was started because of a government tender including subsidy and because of success of offshore parks in Denmark and the Netherlands, the developers of the Princess Amalia park were able to acquire external investment from banks.

- **Market formation ↔ Entrepreneurial experimentation**

Market formation means that income of entrepreneurial projects is more secure, for example through government market formation mechanisms. Entrepreneurs try to create a market by actively promoting their technology, showing users that it is working and lobbying for market formation mechanisms with the government. This feedback loop is related to the externality of resolution of uncertainties and is a part of the market motor of Suurs [2009].

Example: Favourable feed-in tariffs in Denmark (and other countries) led to a swift expansion of new entrants. The Danish wind turbine industry and owners associations had an active informational role toward the public, stimulating demand for green electricity.

- **Market Formation ↔ Legitimation**

Market formation creates income and employment which legitimates the technology. Also, a growing industry will form advocacy coalitions to legitimate the technology. These advocacy coalitions lobby for better market formation mechanisms from the government. This feedback loop is related to externalities of legitimation and political power. Only the $L \rightarrow MF$ relation is part of the system building motor of Suurs [2009].

Example: New entrants in the German and Danish wind turbine system created jobs and income and increased the political power of the sector. Through this political power they enabled a more favourable policy market formation framework.

- **Market formation → Resource mobilization → Entrepreneurial experimentation → Market formation (Green)**

If a market is formed for a technology it is easier to mobilise resources for entrepreneurial activities, because the chances are higher that investments in the technology will be profitable. The entrepreneurs are actively engaged in increasing the market through marketing, awareness

and lobbying for market formation mechanisms from the government. This feedback loop is part of the market motor of Suurs [2009].

Example: A Power Purchase Agreement (contract with a buyer of the electricity) combined with a subsidy or feed-in tariff is a precondition for project financing. If project financing is possible, also smaller parties can start offshore wind projects, like the Princess Amalia wind park.

- **Entrepreneurial experimentation → Legitimation → Market formation → Entrepreneurial experimentation (Red)**

Ventures organise themselves in platforms lobbying for better policy frameworks, which can lead to better market formation mechanisms, which in turn leads to better possibilities for entrepreneurial activities. This feedback loop relates to the externality of legitimacy and is part of the entrepreneurial motor of Suurs [2009].

Example: The British Renewable Energy Association of renewable energy producers has lobbied with the UK government for implementation of feed-in tariffs.

- **Influence on the direction of the search → Resource mobilization → Entrepreneurial experimentation → Influence on the direction of the search (Orange)**

Positive expectations of the technology lead to government programs for stimulating the development of the technology and growing interest from private investors. The outcomes of entrepreneurial activities which can take place with these resources influence the expectations of the technology through its successes and failures of the technology.

Example: The offshore wind parks have been financed by government subsidies and parties who have high expectations of the technology. The success of most of the parks leads to further expansion and possibilities for external financing.

5.4.2 Functionality

A first conclusion is that all functions are important for a well-functioning TIS, which is emphasized by the dynamics of the system and the existence of feedback loops that enforce the functioning of the system. The influence of country government policy is evident and works through both the structural and the functional components. There are clear differences between the countries.

The Danish and German policies supported technologies throughout the whole technological development chain, stimulating all the different functions. Through providing a clear and stable policy from early on, they were able to *guide the search* and provide *legitimation* for onshore and offshore wind. They had incentives for *market formation*, *entrepreneurial experimentation* and *resource mobilisation*. The good start triggered a process of positive feedback loops of resolution of uncertainties and political power through a strong developing industry. Their successful policy continued for offshore wind, although their approach was different. Strong cooperative efforts (legitimation, direction of search) from the Danish governments with energy companies led to the realisation of the first offshore wind parks. The German offshore strategy is targeted at developing new specific offshore technology through experimentation with new technologies for the first large offshore park.

The Dutch policy lacked *direction of search*, *legitimation*, *market formation* and their approach of *knowledge development and diffusion* was too narrow, only focussed on learning by searching and early stage technology development. A clear and consistent policy was lacking: *market formation* was too late, there was not enough *direction of the search* towards wind energy and the *legitimation* process was not well managed. Focus was more on nuclear and natural gas, especially from the large energy companies

who had a strong political power. Implementation of offshore wind continued largely the same way and policy concerning subsidies, licensing and tendering was frequently changing which undermined investor's confidence and caused exits of local industry. An important issue remains the allocation of locations for future offshore wind projects, because this is limited by shipping, fishery and defence.

The UK was not really involved in onshore wind, which has a limited potential, but for offshore wind they started with a clear and stable policy involving several rounds aimed at the different stages of the development curve. They have not really developed their own industry; the UK is a large growth market for the existing German and Danish industry.

In Sweden and Belgium, a coherent policy was installed too late; therefore all functions were lagging behind on the other countries.

Norway does not really need offshore wind because of their hydro power and oil and gas reserves, but they see opportunities for the future in developing floating offshore wind. For Norway offshore wind with fixed structures is not relevant because the waters are too deep. Norway might be able to learn from the other countries in establishing policy to stimulate offshore floating wind.

In the late 90's and early 2000 the TIS for offshore wind in North-West Europe became more and more conducive, with climate change and energy security issues increasing *legitimation* for offshore wind. Europe is front-runner in setting climate targets and it is expected that their target of 20% renewable energy in 2020 cannot be achieved without a significant expansion of offshore wind capacity. Therefore, most countries have set clear offshore wind targets and established market formation instruments, although discussions on the best market formation mechanism remain. There are even talks of building an offshore grid in the North Sea area, which would clearly be a sign of commitment from governments to offshore wind. However, the function *resource mobilisation* was the major element slowing down development, because of the scarcity of several resources. The cost decreases expected through learning curves did not take place because of high steel prices and a scarcity of turbine producers and offshore installation capacity (including vessels for construction). Also, port capacity and skilled workers were scarce. At the moment the financial crisis seems to be hugely slowing down further development of offshore wind projects and industry. Governments try to keep *directing the search* to offshore wind and many of them are installing or promoting "green new deals" to keep on stimulating the low-carbon economy. If the installed base would grow again significantly after this slowdown, the electricity infrastructure could become a problematic resource, because the timescales for needed adaptations to handle a large number of large-scale intermittent electricity production units are long.

The functionality can be related to the "motors of sustainable innovation" of Suurs [2009]. The "Science and Technology Push" motor existed in most countries, but the "Entrepreneurial" motor and the "System Building" motor worked very well in Denmark and Germany but not in the Netherlands. Now that the offshore market is developing, the "Market" motor is starting to play its part in most of the countries.

5.5 The Valley of Death for offshore wind

This case study has showed that the demonstration of offshore wind encounters many difficulties. But to what extent are the difficulties related to the financing problems of the Valley of Death?

Not surprisingly, the problems are much larger for small companies than their large competitors, which is confirmed by theory, surveys and empirical information for small start-up firms in R&D and high-tech in general [Hall 2005]. For large energy companies the cash-flow problems are smaller because they can finance projects from their own balance or they can acquire external financing more easily because of

their strong financial position. The private sector perspective on risks was a problem for these companies: offshore wind projects involve much higher uncertainties than conventional projects, which makes it difficult to justify the project to the internal organisation. An offshore wind project usually involves many different subcontractors, which makes it difficult to allocate all risks: many risks would be in a gray area between different subcontractors. A lot of (offshore) wind technology was developed by large companies, like Siemens, Vestas, Areva and GE, and most offshore parks are developed by large energy companies. However, while large energy companies can more easily develop projects, many of them have vested interests in the current fossil technology and therefore only move slowly to low-carbon technologies or through strong incentives. Small companies are dependent on external investors which makes the typical Valley of Death problems very relevant for them. They have to convince external private investors of their plans despite the much higher uncertainties compared to other investments. Some new dedicated offshore wind technologies are developed by smaller companies, like Darwind and Bard. Subsidies from governments are often more focussed on the front-end of the development sequence through R&D subsidies and on the back-end through market formation mechanisms. Therefore, demonstration projects might fall in between and the existing funding budgets are too small, representing only a small part of the total investment. Diverging values, requirements and goals between the public and the private sector can make it more difficult to solve the situation.

6. The Technological Innovation System of Solar Photovoltaics (PV)

In this chapter, the Technological Innovation System of solar PV is analysed through studying the structural components (1.2), functional components (1.3) and the functional pattern and functionality of the system (1.4) after an introduction of the technology (1.1). Section 1.5 reflects on the financing problems of solar PV and to what extent they can be regarded as a “Valley of Death”. The largest part of the information is based on the interviews with people from the solar PV sector. A list of the respondents and summaries of the interviews are presented in appendix A.

6.1 Introduction

The two forms of electricity production from solar energy are solar thermal energy and solar photovoltaics (PV). This case study focuses on solar PV, which involves direct conversion of light into electricity based on the photovoltaic effect: generation of a voltage difference at the junction of two different materials caused by visible or other radiation. The case study has a global scope and focuses on new PV technologies of which the application or production still has to be demonstrated on a real-life scale, like many thin film technologies and concentrating PV (explained below).

The installed capacity and production of solar PV technology is growing rapidly, as shown by Figure 6-1 and Figure 6-2. Germany, Japan and the United States together took account for 70% of installed capacity and 63% of global solar PV production until 2008 [IEA 2008]. This changed in 2008 because the installed capacity in Spain boomed stimulated by a very favourable feed-in tariff [EPIA 2009a]. China, India, Spain, Australia and Korea are expected to become important players globally [IEA 2008 p. 369]. Expansion is taking place at about 30% per year in developing countries, mainly in rural areas where electricity from the grid is either not available or unreliable [Lako 2008]. The outlook for solar PV technology seems to be favourable, because there are incentive schemes in various countries, large (hundreds of MW) plants are announced to be built and investments in the supply have decreased the scarcity of silicon [IEA 2008][EPIA 2009a]. However, the financial crisis also has its impact on solar PV and investments are delayed or cancelled, which leads to high uncertainties about the numbers that will be reached in 2009 [EPIA 2009a].

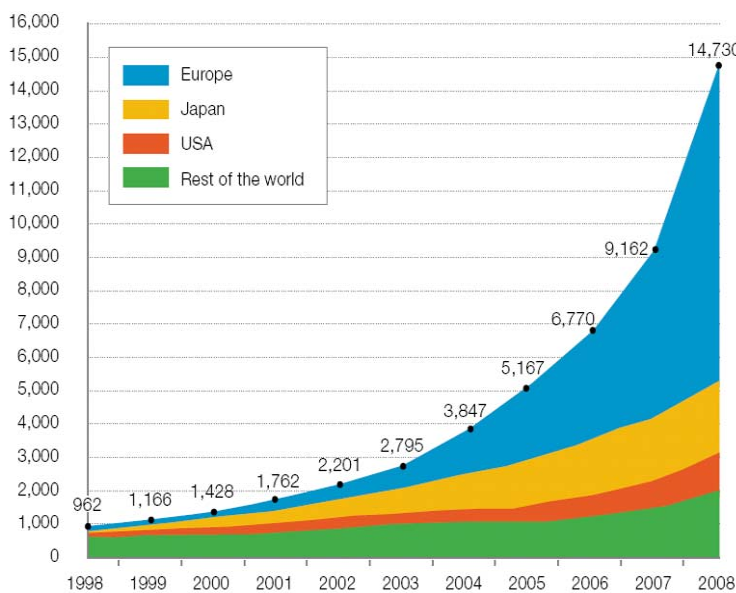


Figure 6-1. Historical development of global cumulative PV power installed per region [EPIA 2009a]

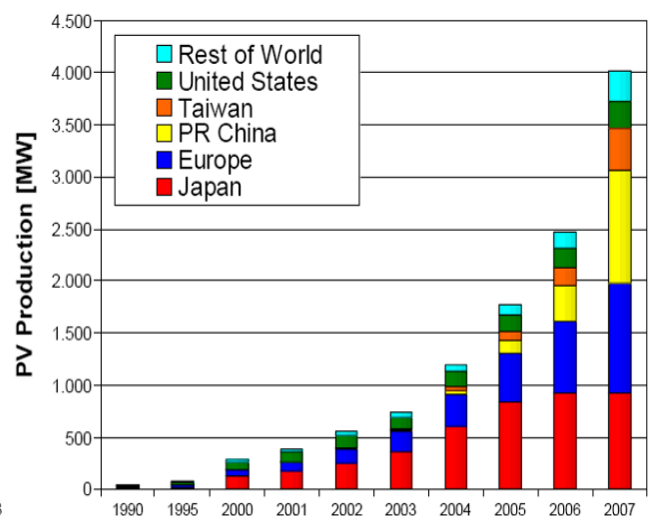


Figure 6-2. Global PV module/cell production [Jäger-Waldau 2008]

The solar PV market has been dominated by crystalline silicon cells (c-Si) with 90% of the current market share [IEA 2008]. The process to make silicon from sand is costly because it has to be processed at very high temperatures (high energy costs) with expensive clean rooms and a lot of the material is usually lost during sawing of the silicon to separate cells. Therefore, the costs of crystalline silicon cells are still too high to compete with retail electricity prices. The efficiency is about 15% which is expected to increase to 25-28% [IEA 2008]. However, c-Si seems to be reaching its optimum in efficiency and material use. Therefore, new generations of technologies are developed with interesting perspectives for cost reductions and niche applications. The main technology targets for solar PV in R&D and demonstration are [IEA 2008]:

- Increasing efficiency and decreasing material intensity and costs of crystalline silicon;
- Increasing efficiency and lifetime of thin film cells;
- Developing 3rd generation types: ultra-high efficiency, ultra-low cost, integration in buildings.

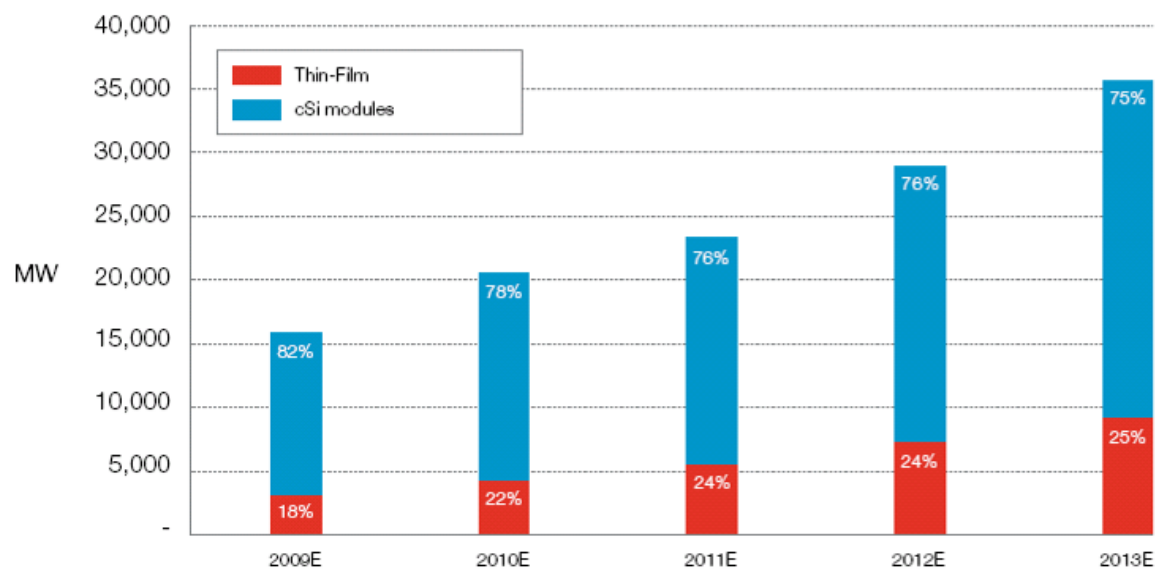


Figure 6-3. Production capacity outlook of crystalline technologies vs. thin film [EPIA 2009a]

Thin film technologies are called second generation technologies, which are promising for cost reductions and more flexible applications. Thin film technology now mainly uses amorphous silicon which means the ability of the silicon to transform light energy into electricity is enhanced by a process called “doping”. This results in solar cells with layers of silicon that are approximately thousand times thinner than crystalline silicon cells, leading to much lower material costs and lighter modules. Also, thin film cells are more flexible and therefore have more possible applications, for example in buildings. They can be produced more easily, for example in roll-to-roll processes, and have better appearance and reduced sensitivity to overheating [IEA 2008]. Thin film is currently growing faster than c-Si, see Figure 6-3 [EPIA 2009a], and is expected to obtain a market share of approximately 25-30% in 2010 [Jäger-Waldau 2008]. The main problems at the moment are lower efficiencies, (maximum about 11%), limited experience of lifetime performance and small production units [IEA 2008]. For thin film technology different materials are used: amorphous silicon (a-Si), cadmium telluride (CdTe) and combined materials based on the elements Copper, Indium, Gallium, Selenide or Sulphur (called CIGS) [Schermer 2009]. There are many different thin film technologies with different levels of maturity. Amorphous-silicon is the most mature thin film technology. Other technologies like CIGS and CdTe have better efficiencies, but require scarce elements: cadmium, tellurium, indium, gallium and selenium [Andersson and Jacobsson 2000].

Third generation technologies which might break through offering even thinner and more efficient cells are thin film organic and dye-sensitised (Grätzel) solar cells. Organic cells use cheap and easily produced organic materials (polymers), which can significantly decrease costs, and are more flexible than other thin film cells. The problem is that the efficiency is still low (4-6%) and that the material is unstable under sun and air influences, shortening the lifetime. Therefore, interviewed experts expect that a real breakthrough of organic solar cells will take decades. The problem with dye-sensitised cells is that they require the rare element ruthenium [Andersson and Jacobsson 2000]. Another promising technology is concentrating PV (CPV), in which the light of the sun is concentrated on a small area with a lens, prism or mirrors which makes the needed surface of the solar cell much smaller. Therefore it can become profitable to use expensive, very high efficiency cells, like III-V cells (made from materials in group III and group IV of the periodic table) which can be tuned to the light spectrum. However, direct sunlight is needed to concentrate which makes the technology only interesting in sun-rich areas, like Mediterranean countries and Africa. Many expect that nanotechnology, improving the structure of materials to increase their efficiency ("quantum dots"), will accomplish break-throughs in efficiency in the future for solar PV.

6.2 Structural components

6.2.1 Actors

Appendix A presents an extensive overview of the interests, goals, visions and resources of the actor groups that are important for the development of solar PV. Table 6-1 provides an analysis of the actors according to whether they are dedicated or non-dedicated, critical or non-critical and have common or confronting perceptions, interests and goals to the policy maker, in this case the UNFCCC (see section 3.2.2 for explanation of these terms).

Table 6-1. Overview of actors of the TIS of solar PV

	Dedicated		Non-dedicated	
	Critical	Non-critical	Critical	Non-critical
Matching perceptions, interests and goals	-EU -Some country governments* -Project developers -Technology developers -Intermediate consumers -Scarce suppliers	-Abundant suppliers		
Some things matching, some things not	-Local governments* -Prominent knowledge Institutes -Monopoly utilities*	-Knowledge institutes -Electricity network system operators -Utilities*	-Some country governments* -Local governments* -Consumers -Intermediate consumers -Debt providers (developing countries) -Equity investors	-Debt providers
Contradicting perceptions, interests and goals				

*The scope is worldwide so there can be significant differences between governments, utilities, etc.

The solar PV industry consists of small private corporations and wholly owned subsidiaries of large corporations. There are many small companies with limited financial strength who depend on external investors. Because of tight risk capital markets, these investors are not dedicated to solar PV, although since a few years there is a clear interest in solar PV investments. For solar PV there are no real opposing actors. However, the direct consumer market, which is an important market for the technology, can be difficult to reach because most of the consumers are not dedicated to the technology. The large electricity companies could be important users, but may change slowly and use their political power to protect their vested interests in fossil fuel based power generation. A specific actor group of solar PV is intermediate consumers which are mainly project developers in the building sector. These actors have the choice to integrate solar PV systems in their buildings, but they are not the end-users of the electricity. This presents a principal-agent problem as a result of which the intermediate consumer might not receive full benefits of the investment through the rental or sales price of the building [Jaffe et al. 2004].

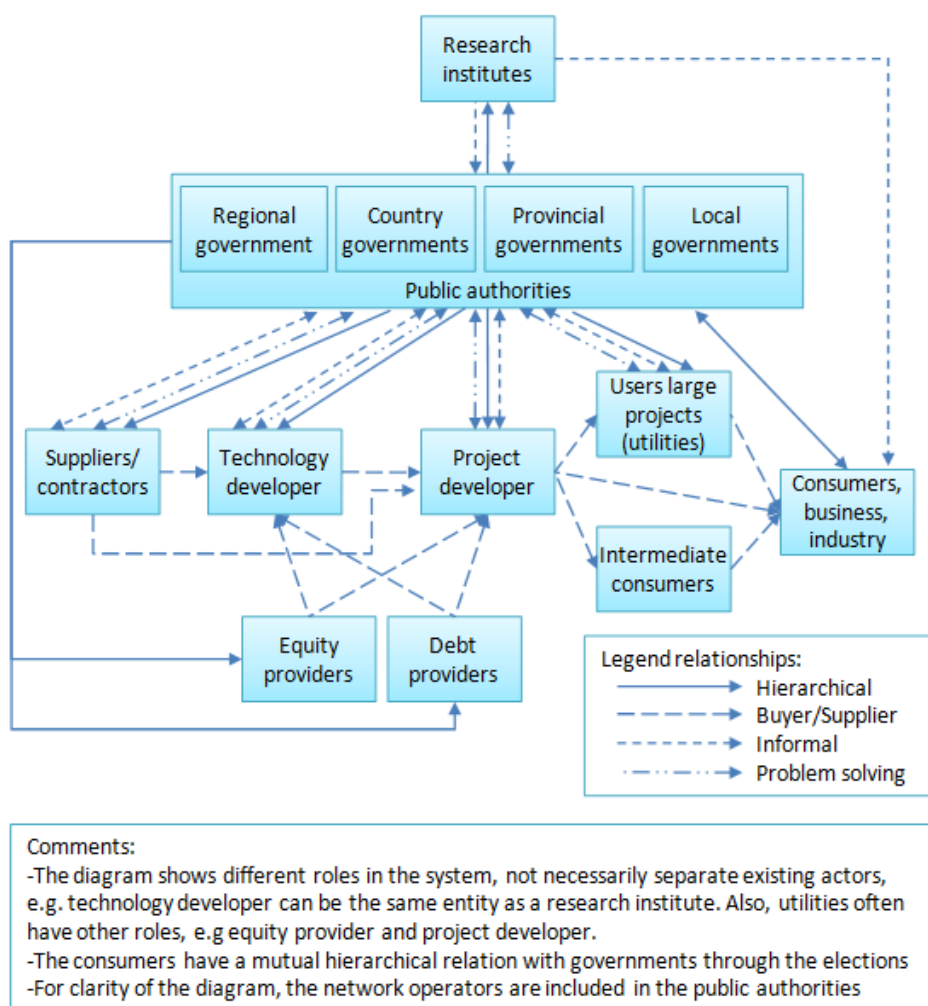


Figure 6-4. Network diagram solar PV

The global scope of the solar PV case leads to variation within the described actor groups, especially the governments and the utilities: some are positive and dedicated and some are not. Also, whereas Europe has a free electricity market, in other countries electricity production is often a monopoly function which makes the utilities a more powerful actor. There are important differences between developed and less developed countries. In less developed countries the government role is more determining for the success

of entrepreneurial activities in the country, because infrastructure is not well developed and social issues like corruption, crime, instability and a lack of judicial power lead to high uncertainties. A difficulty of the developing country market is that most of the consumers do not have capital to invest in (even small) solar PV systems nor the track record to easily obtain loans. Therefore special debt providers like micro-finance can facilitate implementation of the technology. For developing country markets there are several foundations active which can provide funds for starting projects that stimulate development, sustainability, (renewable) energy, etc.

Figure 6-4 shows the relations between the different actors in a network diagram. It shows the importance of governments through regulation. The problem-solving relationships, often originating from knowledge platforms installed by the government, provide additional benefits through establishing relations between potential partners for projects in the future, and creating positive expectations and advocacy coalitions. The connections between project developers, technology developers, users, contractors, suppliers and debt and equity providers are very important. Often several of these roles are incorporated in the same physical actors, e.g. a solar PV system company can be technology developer, project developer, supplier of part of the system and equity provider. A project usually concerns a web of different buyer-supplier relations and each relation presents a certain mutual dependency.

6.2.2 Institutions

Table 6-2 shows the important institutions for solar PV in the four-layer model presented in chapter 3.

Table 6-2. Institutions of solar PV in the four-layer model [Koppenjan and Groenewegen 2005].

Specific developing country institutions are put separately under the dotted line

Layer 1. Actors and games	
<ul style="list-style-type: none"> ▪ <i>Large energy companies active in renewable energy technologies, but also protecting their current (fossil) business: preparation for future changes, improving corporate image vs. lobbying for natural gas, co-firing of biomass, CO₂ capture and storage and biofuels</i> ▪ <i>Smaller companies struggle to bring their technology to the market and develop projects</i> ▪ <i>Some smaller companies develop the technology or project far enough to find interested private investors to take over the project, e.g. going through first stages of the project (location, design, permitting) before selling to a party with stronger financial position</i> ▪ <i>Strong international competition in solar PV market, driving innovation</i> ▪ <i>Joint research programs research institutes and industry, incubators</i> ▪ <i>Lively economic activity in selling and buying of companies and projects</i> ▪ <i>Decisions of top-management large companies developing technology, allocating money and keep believing even in bad times</i> ▪ <i>Advocacy coalitions through growing industry</i> 	
<ul style="list-style-type: none"> ▪ <i>People (and local entrepreneurs) prefer small size items (in large quantities) over large investments (and stocks), people are not used to guarantees</i> 	
Layer 2 : Formal and informal institutional arrangements	
<ul style="list-style-type: none"> ▪ <i>Financing agreements</i> <ul style="list-style-type: none"> - <i>Corporate financing: agreements fall under corporate management</i> - <i>Project financing: a range of other arrangements with external partners</i> ▪ <i>Venture and angel capital investments in solar PV and shareholder capital</i> <ul style="list-style-type: none"> - <i>Clean-tech markets quite global (maybe because technology originates from Europe but the big markets are the US and Asia?)</i> - <i>Differences risk capital markets US-Canada-Europe: European markets least developed and most-risk avoidant, US markets most developed and least risk-avoidant, Canada in between, more social than US (many small seed-capital funds)</i> - <i>If VC acquired, more easy to get debt from banks</i> ▪ <i>Arrangements between technology developers and private investors (exclusivity, licensing, starting a joint venture, etc.)</i> <ul style="list-style-type: none"> - <i>IP-rights and certification often important for value of developed technology for market parties</i> 	

- *Arrangements important to prevent spill-overs to competitors*, difficult if developer of a specific part (e.g. concentrator) has two different partnering companies for the other parts (cell producer). Being a pure-play foundry can be an advantage (like Cedova), because each design is specifically designed for each customer, which takes away spill-over risks.
 - *Vertical integration of companies in the value chain*, to prevent spill-overs and dependency on suppliers or buyers, and competition of other cheaper suppliers.
 - *Power Purchase Agreement (PPA)* with an electricity supply company is usually a precondition for any external financing.
 - *Contracts with the builders and operators*, determining who bears which risks.
 - *Engineering, Procurement and Construction (EPC)* contracts. The main contractors try to control the whole chain to have more certainty about the quality of their supplied system.
 - *Guarantees for supplied products of (sub)contractors*, determining how much power the system should generate with a certain amount of sun during the day, with fines for not reaching this.
-
- *Financing from development and sustainability foundations can be important*, e.g. NCDO, Worldbank, Energy4all, Picosol.
 - *Collateral or steady cash flow needed for loan, which people do not have*,
 - *Micro-finance possibility*
 - *Leasing constructions for entrepreneurs*
 - *Franchise constructions with local entrepreneurs*, because they know the market, the population, their culture (e.g. tribalism, family and friendship relations can be very important).

Layer 3 : Formal institutional environment

- *Licensing process* for projects, in some countries more difficult (Italy) than others, or more unpredictable (Southern Europe)
 - *Incentive policy of governments*: subsidies, feed-in tariff, renewables obligations or standards, public tenders and tax schemes.
 - *Government funding influences the level playing field for local companies*: strong international competition. Choice for a country or European energy strategy?
 - *Subsidy procedures for end-users often complicated*
 - *Government funding not always for pilot projects* (e.g. Netherlands no demonstration financing or only small sums, maybe in the future expansion of the current innovation subsidies. Germany up to €15 million projects)
 - *Electricity network management*
 - *New ways of managing needed for intermittent supply and demand and feeding back*
 - *Access to grid connection for solar PV owners*
 - *Regulation on liberalisation and privatisation, and unbundling of the network and production companies*.
 - *Utilities now have market interests*, more difficult to get them into sustainable energy;
 - *Certain equity/debt percentage demanded by central government for system operator companies*; can lead to less equity for production companies
 - *More parties with market interests to deal with after unbundling*
-
- *Instability countries, corruption, bad governance (leading to crime, safety problems, bad infrastructure) can be severe problems*. In more stable countries, there are also more NGO's, Worldbank, etc. active like in Mali.
 - *Development cooperation subsidies from developed countries important*;
 - *Developed country governments want PPP to stimulate foreign investment* (e.g. Nigeria)
 - *Duties on renewable energy products and its parts*

Layer 4: Informal institutional environment

- *General EU belief in market forces* for the energy sector, reflected in competitive market regulation (liberalisation, privatisation, unbundling and regulation for the natural monopolies of transmission and distribution)
 - *Active or passive government role in stimulating technology* and whether the government should "pick winners and losers", which differs between countries
 - *Industrial policy*: whether or not to support and protect its own local companies
 - *Common EU competition legislation* on this.
 - *Who should pay for the stimulating measures*: the polluter/consumer (feed-in tariffs and taxation per unit of consumption) or the taxpayer (government subsidies)?
-
- *Cultural norms and values, like tribalism, tolerance of corruption, etc.*
 - *Perception and reputation of (energy) technologies*, e.g. in Nigeria solar energy had a bad reputation because it was once implemented with unreliable technology and without sufficient education.

The formal institutional environment (layer 3), which is influenced by government legislation, determines arrangements and actions of actors in lower layers. A country's solar PV policy is important for the competitive advantage of its businesses because there is considerable international competition in solar PV. There are not many institutional barriers concerning regulation and permitting, although the possibility to feed electricity back to the grid is needed. The centralised electricity network management presents a barrier for solar PV, which needs a more decentralised system for large-scale deployment. Formation of networks is important for interactions at lower layers. The layer 2 arrangements between parties are important, presenting different solutions for managing the risks of the mutual dependency relations, uncertainties and competition and spill-over issues in a web of supplier and buyers. Vertical integration is quite common in the solar PV sector to control the supply chain. A possible theory to understand some of the reasons for different governance structures to manage these relations (including vertical integration) is presented by transaction cost economics (see section 2.1.2), based on asset specificity, uncertainty and frequency [Groenewegen 2006][Williamson 1998].

Institutions matter for bringing technology to developing countries. Formal institutions are important (corruption, duties and the government's efforts on infrastructure, sustainable development and safety) but informal institutions may be even more important in these countries, like trust, tribalism, reputation of the technology and the willingness to make investments for long-term revenues.

6.2.3 Technology

Advantageous characteristics of solar PV technology are its low emissions (only construction and installation), low maintenance (few moving parts) and modularity which makes up- and down-scaling for both small-scale and large-scale applications easy. Maintenance is a problem for the rotating concentrator system of CPV which is vulnerable to defects. The newer generation technologies use flexible materials which also makes it suitable for bended or bending surfaces. Also, some of these technologies are aesthetically more attractive and semi-transparent, which means they can replace window panes in some cases [Lako 2008]. These characteristics make the possible application area of solar PV technology very large; from small cells for consumer electronics or clothes to application in buildings and large-scale power plants. The main problems are that solar PV technology is an intermittent energy source, the costs exceed those of conventional energy sources with low efficiencies and the materials are often difficult to produce (c-Si) or to obtain (CdTe, CIGS, dye-sensitised). The electricity production of a PV unit is dependent on the solar spectrum and the number of sun hours on a certain geographical location, especially for concentrating PV which needs direct sunlight. Electricity infrastructure is important because intermittent power generation is more difficult to control and to match to electricity demand and therefore needs electricity storage or back-up from the grid to deal with over- or under capacity.

The used material is an important issue for solar PV. Material characteristics like its conductive properties and the number of excitons produced determine the efficiency of a solar cell. Also, some materials have a better stability than others, many materials degrade under sunlight. Unfortunately, there is a trade-off between efficiency and stability versus costs: cheaper materials are usually less efficient and stable. R&D and technology development activities are aimed at taking away this trade-off by developing more efficient and more stable, but cheaper solar cells. To do this, fundamental research is performed on the properties of materials and how they can be manipulated, for example by doping the material with other molecules and changing the material structure on a nano-scale. The problem is that a part of the fundamental knowledge on how the processes exactly work is still lacking. An extra difficulty for technology development is that the technology combines different highly specialised knowledge fields,

e.g. on developing and producing materials, integration of modules and systems, production methods, ancillary products, etc. This means that developing a new technology involves different parties and a complex buyer-supplier network. Some technologies benefited from knowledge spill-overs: crystalline silicon technology benefited from existing knowledge and machinery from micro-electronics and organic solar cells from production and development of LED and other organic materials. For other technologies, these machines did not exist yet.

For developing countries the technology should preferably be robust and not too complex. Infrastructure is important: usually electricity infrastructure in those countries is bad, especially in rural areas, which provides an opportunity for non grid-connected applications. However, batteries are needed if there is no back-up from the grid, which are expensive and have short lifetimes. Other infrastructure is also important, which is often bad in those countries, like roads, railways and ports.

6.2.4 Relations between structural components

Institutions determine the playground for the actors and their interactions and can shape the behaviour of actors, for instance, subsidies stimulate actors to install solar PV systems while the administrative burden is a barrier for consumers. However, the actors are also changing the institutions because the solar PV industry and environmental organisations have lobbied for a more positive framework for solar PV, like the industry associations Holland Solar and ODE in the Netherlands [Negro et al. 2009]. Opponents and incumbents try to change institutions to their advantage, for example the Dutch utilities that have coal-fired power plants who are lobbying for SDE subsidy for co-firing of biomass. Several actors are active in improving the technology and the technology is improved through learning-by-doing and customer responses. But with increasing diffusion of the technology the behaviour of actors could also change: consumers getting used to managing their own electricity supply and network operators adjusting their network management to decentralised electricity supply. With increasing diffusion of the technology alignment of the institutions with the technological change in the electricity supply system is needed [Andersson and Jacobsson 2000], because there are now many small electricity producers for which regulation is needed. However, institutions also determine the speed of technological change when there are barriers like lengthy procedures for subsidies, grid connection, feed-in tariff, etc.

6.3 Functional components

6.3.1 Knowledge development and diffusion

According to several of the respondents, there is strong international competition in the solar PV sector, between industry as well as research institutes, which is driving innovation. The solar PV sector has been a fast developing sector with relatively much money but a lack of knowledge. Therefore many companies developed their own R&D units. Economic fluctuations like the current crisis have an influence on knowledge development, because companies often cut R&D budgets in time of recession, which does not have severe effects for the companies on the short term, but can result in a set-back on the longer term. Some companies realise that even in crisis times you have to keep innovating, which can lead to a front-runner position as soon as the economy starts growing again.

Solar PV is a complex high-tech technology, for instance, a triple junction solar cell is a tunnel diode with approximately 20 layers. From the interviews with technology developers it was clear that each party only has knowledge of a specific aspect of a solar system and therefore it is necessary to work with different partners on a technology, often a combination between research institutes and industrial parties. A

different kind of knowledge is needed for producers of solar cells and producers of equipment to make solar cells. In the future nano-technology is expected to be important, which is even more high-tech and crosses the most disciplines involved in the solar cell. Changing the nano-morphology of the material can improve the characteristics of materials; the size of the so-called “quantum dots” determines the colour of light absorption by the material. This means very fundamental knowledge on the process from light to electricity is needed to come to real breakthroughs in efficiency. At the moment the development of solar cells is more incremental.

The need for cooperation has led to several knowledge networks stimulating knowledge development and diffusion, like the Joint Solar Program and FOM-research (Fundamental Research on Materials) in the Netherlands and the European Photovoltaic technology platform. Different kinds of partnerships are possible between private parties and the research institutes. The industrial company could get the Intellectual Property (IP) rights or an exclusive licence for the technology, they could start a company together or the research institute simply performs contract work. Patenting and certification of the technology is usually an important strategic issue to interest market parties in the technology. R&D subsidies are vital for all these knowledge and technology development programs. However, it is also important to secure seed financing for the first stages of bringing the technology to the market. According to some respondents, many promising projects never reach the market, especially in the Netherlands and maybe the EU in general.

Developing countries

Knowledge development and diffusion is very different in developing countries, it usually concerns technology from developed countries brought to developing countries. This technology is often too expensive for developing countries and it must be tuned to local conditions (e.g. more robust). Also, local users should be educated on how to use the system and local employees have to be trained in installation, maintenance and commercial and marketing capabilities if they are mobilised to approach the market. For example, a large solar PV project in Nigeria partly failed because of a lack of education and training. Also, Nice International had problems with their solar systems because of mistakes in the installation and the local employees were not trained well enough at that time. For entrepreneurs in developing countries it is therefore important to know whether there are local companies involved in solar energy and whether people and institutions have awareness of solar energy.

6.3.2 Influence on the direction of search

There have been positive expectations of solar cell technology for a long time. Studies in the 90's indicated that large-scale production could decrease the costs to 1 USD/W_{peak} for c-Si and 0,5 USD/W_{peak} for thin films [Andersson and Jacobsson 2000], which is now 6-7 USD/W_{peak} for c-Si [Lako 2008]. According to respondents the expectations at the moments are that grid parity (costs equal to retail prices) is reached soon, within 15-20 years depending on geographical location. The interviews revealed that the development of solar PV technology has been steered mostly by market demand. The strong international competition causes market-pull: companies have to innovate in reducing production costs and increasing revenues to survive. The high material use of expensive pure silicon is limiting further cost improvements for crystalline silicon, although some improvements are expected by new production methods which prevent sawing losses, like roll-to-roll production. The search has mainly moved to thin film PV technologies. However, different applications for solar cells pose different demands on the technology, which makes it plausible to believe that different solar PV technologies will serve different markets. Therefore, the internal direction of the search towards specific solar PV technologies has also

come out of the market. Many experts expect that nanotechnology will deliver break-throughs in solar PV technology. Although some people suggest that the dominance of crystalline silicon PV locks out superior thin-film designs [Menanteau 2000], amorphous silicon seems to have benefited from a period of scarcity of crystalline silicon wafers and is gaining market share. Calculations on the a-Si thin film technology of Nuon-Heliantos showed that grid parity could be reached if the technology is completely developed. In the future, the availability of scarce materials is expected to become a limiting factor for several technologies (CIGS, CdTe, dye-sensitised, certain doping materials) [Andersson and Jacobsson 2000].

According to an investor in solar PV technology, belief in the technology is very important: the overall leader(s) of a starting venture or project must really believe in the concept. Investors in early stages of technology development (sometimes called “fools”), must be convinced so they have the same belief in the technology. Technology development within a large company seems easier, but the top management of the company must also really believe in the goal of the project and sufficient money must be allocated to it. The same counts for governments: the German government has shown to believe in solar energy technology while they were not the most logical country to be solar PV front-runner because of their geographical location. Any stimulating government needs to provide stability for the longer term; an instable and changing policy can be destructive for the growth of the technology. For example, the Bush administration slowed down solar PV development in the US while they used to be front-runner in solar PV technology development together with Japan.

The Five D's

“Dromen-Denken-Durven-Doen-Doorgaan”

Dreaming-Thinking-Daring-Doing-Continuing are the “five D's” for successful entrepreneurship in Dutch proposed by an investor and technology developer in solar PV. It reflects the importance of continuing belief in the “dream”.

Developing countries

Solar PV is regarded by many as a major chance for developing countries, because electricity can be produced locally with small-scale units without installing extensive grids and many developing countries have a lot of sun hours and high solar intensity. Therefore, there are several foundations which have a vision of sustainable energy for developing countries, often combined with a vision of development through commercial activities, like the Free Energy Foundation, the Energy4all foundation, Pico Sol and the Good Energies foundation. These foundations support companies that start solar PV projects in developing countries, see [BiD 2009].

6.3.3 Entrepreneurial experimentation

Worldwide, there are many entrepreneurial activities taking place in new production technologies for silicon PV, thin film and Concentrating PV (CPV). There are many new entrants on the market, also from emerging economies, which is confirmed by the decreasing market share of the ten largest PV manufacturers together, from 80% in 2004 to 57% in 2007 [Jäger-Waldau 2008]. The interviews revealed quite some information on entrepreneurial activities in new technologies. There are several commercially available thin film amorphous silicon technologies, using different processes and materials. Organic solar cells are newer, but some entrepreneurial activity has started and a few companies have already acquired venture capital. Konarka Solar is a company making organic solar cells called power plastic. Also, there is experimentation with conducting plastics, e.g. in LED-applications (Philishave), which might benefit organic solar cell technology development because it is the reverse process of organic solar cells. The two pioneering companies in the CPV business are Amonix (US) and Solarsystems (Australia), the latter having two large-scale systems. Now more and more CPV producers are entering the market. In Cyprus there is a

large CPV park, co-financed by the German government. The company Concentrix, a spin-off from the Fraunhofer Institute in Germany, is developing demonstration projects in Spain. The existence of seed capital funds and incubators in a country stimulates entrepreneurial activities. In Canada, there are several of these incubators from research institutes, sometimes linked to seed-capital funds.

When the technology is ready for entrepreneurial experimentation partnerships with industrial partners become more important. It is advantageous for a technology developer to have in-house equipment for testing that is as flexible as possible. However, competition and knowledge spill-over issues between producers of different parts of a solar system (e.g. concentrator and solar cell producers) can be a barrier for new combinations between companies. A producer of a solar cell for a CPV system might spill-over knowledge on the existing concentrating PV system when entering a new partnership with a concentrator producer. Also, any newly developed concentrator system competes with its current system, which is a disincentive to engage in this new partnership. Vertically integrated companies (like Azur and S'energy) have the advantage that they can put new ideas in their own systems. Because of the

financial crisis many projects are delayed or cancelled at the moment. Some other factors influence delays, for example, merger processes can postpone decisions on entrepreneurial activities. Also, sometimes private parties demand for certified technology, which delays the entrepreneurial activities.

Entrepreneurial activities in the Netherlands

The solar PV industry in the Netherlands is small, but covers the whole value chain [Chalkias et al. 2009]. Here are some examples. The Ribbon-Growth-on-Substrate process from ECN is a new roll-to-roll production process for silicon PV, which is now a joint venture with private parties. Another ECN project is a pilot line with back-contacted solar cells, which was one of the last projects benefiting from the Dutch demonstration subsidy "EET". Nuon-Helianthos has a working pilot line of solar PV thin films and has plans to build a large production facility producing 50-70 times more. They use the produced films to test and show the technology. The TU Eindhoven and the HOS centre in Eindhoven are making organic solar cells. The Radboud University is starting a partnership with Suncycle, which is developing a concentrator, and Cedova, a producer of semi-conductor products which might take over the solar PV (III-V) technology from the university. Sunergy, with seed capital investment company S'energy is trying to develop business throughout the whole value chain of solar system production.

Developing countries

Entrepreneurs in developing countries

Among the respondents were entrepreneurs trying to set up a solar PV business in developing countries. *Ecoru* is selling solar systems for rural and urban use in Nigeria. *Kamworks* makes solar systems for NGO's and tries to target the consumer market with small PV products. It is coupled to a program to train local young people, sponsored by the foundation Pico Sol. *Nice International* has solar powered ICT-based service centres providing internet, education and cinema to the locals. They all use local people to do the sales and are considering a franchise formula for the future.

There is a lot of entrepreneurial experimentation in developing countries. These entrepreneurs indicate that they prefer proven technology, because there are already many other uncertainties concerned with setting up business in developing countries. Also, it is important that the technology is reliable to establish trust in the technology. Several companies want to use franchise constructions with local entrepreneurs who get technical, marketing and business training, because these local entrepreneurs are trusted more easily and they know the local culture and market. The difficulty with franchising is financing the projects, because the entrepreneurs neither have the capital nor the track record to get a conventional loan easily.

6.3.4 Market formation

Solar PV technology has mostly developed in certain niche markets, like space applications for expensive but high efficiency technologies like III-V cells. Japanese consumer electronics has been a nursing market for thin film PV [Andersson and Jacobsson 2000]. Now a number of commercial niche markets exist and larger niche markets are within sight. The modularity of the technology provides opportunities for both large-scale and small-scale applications. In the interviews several comments were made on the suitability of the different technologies for different markets. In developed countries there seems to be a move towards larger-scale applications and the built environment is the most important target market. Large-scale parks and small-scale systems for rooftops are expected to stay dominated by crystalline silicon in the near future. Thin film technologies are interesting for integration into buildings because of their flexibility, lighter weight and better appeal. However, amorphous silicon thin films cannot be rolled up and bended too much. More flexible technologies like organic PV can be interesting for small scale applications which do not need much electricity, e.g. integration in clothes, electronics, etc. The reversed organic technology is suitable for LED-applications. For CPV sun-rich areas like Africa and Mediterranean countries are target markets. The total configuration of the system is important for the niche market it can serve, e.g. Suncycle's concentrating technology can be suitable for roof-tops because it is relatively flat.

Despite the fact that the market has almost doubled each year the last decades, the technology still needs market formation support from governments. The interviews brought up the discussion on which incentive structure is best for market formation. Feed-in tariffs have boomed installed capacity in countries like Germany and Japan. In the Netherlands and Spain the subsidies are capped and instable over a longer period, which has led to bankruptcy of several companies and other companies fled to other markets. For accessing markets, certification is a pre because most market parties demand certified technology. There are some infrastructural barriers for large-scale diffusion of solar PV, because a large number of units feeding back electricity to the grid demands changes in the usually centrally-based networks.

Developing countries

The "Bottom of the Pyramid" market is a concept of growing interest in the private sector, which refers to major expected business prospects in selling large quantities of products with small margins to the huge market of 4 billion people who have less than \$2 per day [Prahalad 2006]. The idea is that through serving these markets, people get more choice and independency and therefore a better quality of life. Solar PV could address these markets, especially for small-scale applications in rural areas where there is no or unstable electricity supply. For example, a country like Nigeria has a large population but a very bad condition of the electricity supply (there is a net, but no supply). However, Nigeria is also an example of the higher risks in these countries, with safety issues, corruption, crime and instability. In contrast, Mali is much poorer but more stable and therefore there are more organisations active. They have a tender procedure for installation of solar PV in several areas in Mali including a subsidy of 80% of the investment costs.

"New products in new markets"

One developing country entrepreneur stated that one of the basic rules of entrepreneurship is that you should never start-up a company with a new product in a new market. Therefore the company Kamworks has the existing NGO market as a steady income stream while it is trying to launch its new small solar PV products at the direct consumer market.

The interviewed entrepreneurs indicated that production of electricity usually does not have sufficient value to constitute a valid business case, especially not if there already is (unstable) electricity supply. Another added value should be found. Combinations with local entrepreneurs which can enhance their

business with a solar PV system seem best, like mobile phone charging, a sewing machine for a tailor, light for a hairdresser, etc. Ecoru is working on a project for powering banks and ATM's through cooperation with another company. The added value of Nice International is the internet, cinema and education, while people hardly make use of the battery recharging service. Also, these companies often have a steady stream of income from orders for NGO's instead of the direct consumer market. A specific issue of the developing country market is that consumers do not want to pay high initial costs to obtain long-term revenues, like for rechargeable batteries.

6.3.5 Legitimation

The main reason for developing solar PV technology is the growing global energy demand combined with depleting classical oil and gas sources, geopolitical issues and environmental problems including climate change. Energy security was a major driver for Japan, who is heavily dependent on imported oil, gas and uranium: only 4% is produced domestically [ANRE 2006]. According to several interviewees it is expected that different solar PV technologies will become competitive with electricity retail prices (grid parity) in the next decades. There seem to be hardly any opponents of the development of solar PV technology, the problem is to activate consumers to switch to solar PV technology. Build-up of an industry leads to income and employment for a region, which can legitimate government stimulation. The interviews provide an ambiguous image of the role of incumbent firms. On one hand these large companies can be important investors and developers of new technologies. On the other hand, they usually have vested interests in fossil-fuel based electricity supply and many respondents have the opinion that incumbent firms have hampered change in the electricity supply system by using their political power to protect these interests. Legislation on liberalisation and unbundling of production and network activities has created a larger number of parties to deal with in creating legitimacy. Also, because of privatisation the production companies now have market interests which makes it more difficult for them to strive for societal goals like sustainability.

Developing countries

The legitimation for solar PV in developing countries is stronger because there are often large rural areas without electricity grid, which makes decentralised solutions like solar PV competitive sooner. Also, many of these countries have sunny climates and higher irradiation. However, the interviews indicated that people are often not familiar with the technology, which makes it difficult to address these consumers and establish trust of the technology and the company selling it. For example, an entrepreneur in Nigeria noticed a bad reputation of solar PV in Nigeria because it was once not very well implemented with quite unreliable technology and without good educational support. For the attractiveness of a country to start business there it is important whether the country's government facilitates the technology and is engaged in developing infrastructure.

6.3.6 Resource mobilization

Financial resources

Investments in solar power have grown most rapidly of all renewable and energy efficiency technologies (19% of new capital), reaching € 19.7 billion in 2007 with average annual growth rates of more than 250% since 2004, which is mainly driven by large project financings [Jäger-Waldau 2008].

Compiled from the interviews, important investors in solar electricity technology are:

- Large or medium companies developing new technology (Akzo, Shell, Nuon, Cedova);
- Angel, seed and venture capital. The real early-stage investments are often done by “friends, fools and family”. The growing venture capital market for solar PV used to be a driver, but this risk capital market is hit hard by the financial crisis;
- Own capital of entrepreneurs;
- Large investors like Good energies, Google, EDF;
- Some stock market companies.

The solar PV market is dominated by corporate finance. Several parties acknowledged that the problems described by the concept of the Valley of Death are indeed relevant for many solar PV technology developers. It is a young industry with many small companies which do not have large financial resources or possibilities acquire debt. The possibilities to acquire venture capital can differ per country and although these capital markets are international, it is more difficult to acquire capital abroad [Auerswald and Branscomb 2003]. For example, there is a lack of venture capital for small firms in the Netherlands while in Japan the PV companies are subsidiaries of financially strong large companies, which explains part of the success there [Negro et al. 2009]. There used to be a lot of risk capital available in the US, therefore venture capitalists were also investing in more risky ventures like solar PV technology. The US venture capital for solar PV increased from €0.97 billion in 2006 to €2.2 billion in 2007 [Jäger-Waldau 2008]. Research institutes developing technology also do not have the resources to do demonstration projects, although they might be able to do some small pilots in-house. If research institutes earn more money with their innovations, for example through licensing, they have more capital to re-invest.

The interviews also showed that government subsidies are sometimes not applicable to demonstration projects or it only constitutes a small share of the investments for large projects (maximum 20-25%); the rest must come from the collaborating parties themselves, which is often even a precondition for the subsidy. The Netherlands only has R&D investment subsidies and market formation subsidies, but no investment subsidies for demonstration. In Germany they do have financing for larger projects up to approximately € 15 million. Local governments can also allocate money to entrepreneurial activities in their province. Beneficial fiscal regulation is also very important for investments. Legislation on privatisation, liberalisation and unbundling has its influence on the financial strength of energy companies. The Dutch unbundling legislation demands for a high equity/debt rate for the network companies (to have strong network companies), which means there is less equity and therefore less financial strength for the production companies to invest in low-carbon sources.

At first, banks and other investors were afraid to invest in solar PV technology because they did not know the technology and had no knowledge to judge it. Now it is quite easy to obtain external finance for solar PV projects from debt providers [EPIA 2009b]. More and more investors have their own solar PV technology experts, like the Rabobank. The risks of solar PV projects are relatively low and predictable: energy production is predictable for 25 years so if the production incentive (like feed-in tariff) is stable over that period revenues can be predicted accurately. PV technology is proven with lifetimes of 25-40 years, although this would be more uncertain if newer technology is used. There are also investment companies and pension funds investing in solar PV projects, like Gilatz Investments, SOLON Solar Investments and Meinl International Power. There is an active market in buying and selling solar PV projects and companies.

The financial crisis is also a problem for solar PV. Companies are cutting their R&D expenses, which they can do without directly noticing the consequences. Fortunately, some companies realize that they have to keep innovating. The perceived risks of investments are higher now, so fewer banks are engaged and they prefer smaller projects (< €50 million) [EPIA 2009b]. High-quality projects meeting the legal requirements will get financing, but it takes longer to close the deal [EPIA 2009b].

Other resources

The main resources other than money that have been and can become a problem for solar PV are the materials. Solar PV did not follow the cost reductions as expected by its learning curve the last couple of years, which was caused by an under capacity of crystalline silicon production [EPIA 2009b]. There was also a shortage on the market for PV panels, but this has changed now: module prices have dropped 10% to 20% since the beginning of the year [EPIA 2009b]. Most promising thin-film designs could be constrained in the longer term due to their requirement of scarce materials [Andersson and Jacobsson 2000][Negro et al. 2009]. A problem for new technologies can be that suppliers of specific machines do not exist. Crystalline silicon could use micro-electronics machinery and organic cells can be made with standard equipment for mixing polymers. In some countries skilled people can also be scarce, like in the Netherlands [Negro et al. 2009].

Developing countries

Entrepreneurs in developing countries partly have other financing sources, including own capital, government development assistance funding and sponsoring from foundations. There are a lot of venture capital, private equity and other funds for projects in developing countries. For example, the book *“Venture Capital and Private Equity funds for development”* describes many of them [KIT 2009]. Also, there is an organisation “Business in Development” who matches investors to entrepreneurs in developing countries, which also supports the entrepreneurs with trainings [BiD 2009]. In the Netherlands there are high subsidies (PSOM, Daey Ouwens fund) from the Ministry of Foreign Affairs for partnering countries and least developed countries. Many of the entrepreneurs have NGO projects as their principal market and spend a part of their resources on the direct consumer market. Western technology is usually too expensive for developing countries, therefore these companies have to be very innovative in their cost policy and the products have small margins. For example, Ecoru partners with another company for procuring larger volumes together to get the systems as cheap as possible.

On a smaller scale financial resources are also a problem. High up-front investments of solar PV products are a problem for both consumers and local entrepreneurs, often a few dollars is already a large investment. Because local entrepreneurs and franchisers do not have enough financial strength, some companies are thinking about leasing constructions for the equipment of the franchisers. Nice International is also trying to get leasing contracts for themselves to solve the problem of high investment costs for the equipment. Pico Sol has specific goals of making local people owners of the systems: local people have to pay or find funding for a part of the project and the employees of Kamworks can become shareholder of the company. Another important problem in developing countries can be infrastructure like the electricity grid, ports, roads, etc.

6.4 Functional pattern and functionality

6.4.1 Functional pattern

The functional pattern of solar PV shown in Figure 6-5 is the same as offshore wind, therefore the relations and feedback loops will not be discussed here again. In appendix A, all the relations are explained including examples from the TIS of solar PV.

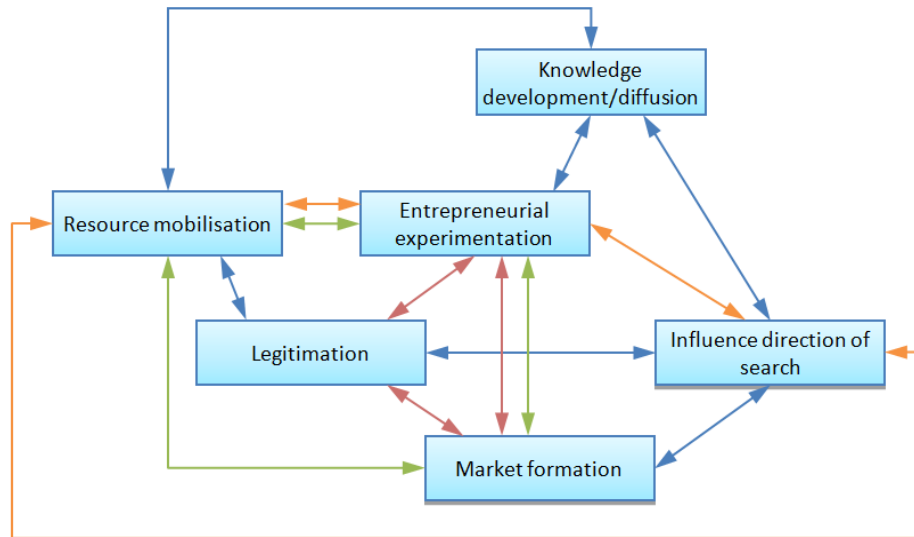


Figure 6-5. Functional pattern of solar PV

6.4.2 Functionality

In general, the functions *knowledge development and diffusion* and *entrepreneurial experimentation* have been good in several countries. Germany, Japan and the US have been front-runners in solar PV development, but countries like China, India, Spain, Australia and Korea are catching up. The development of the functions is dependent on government policy, like the slow-down of the US under the Bush administration has shown. Important issues for technology development are decreasing the costs of solar PV systems and increasing the efficiency and stability of the materials for newer technologies.

Stimulated by energy security issues, environmental concerns and high expectations of the technology, the *legitimation* of solar PV has been strong the last years, which has led to strong *influence on direction of the search* by governments towards solar PV technology. There are high expectations that solar PV technology will play an important role in future sustainable energy supply and grid parity is expected for several technologies in many countries in the coming 10-20 years. There is not much opposition against solar PV, because the technology does not really have negative external effects. The different applications of the modular technology lead to direction of the search in specific technological niches, stimulated by strong international competition.

Market formation seems to be the most difficult function for solar PV, because the technology is a lot more expensive than incumbent technologies and several other low-carbon technologies. However, technological niche markets offer opportunities for diffusion of solar PV technology, leading to cost reductions because of learning-by-doing and economies of scale in production. There is strong market-pull for innovations through international competition on the solar PV market. However, for large-scale diffusion of solar PV, the consumers must be activated, who are often still reluctant to invest in solar PV.

High costs, uncertainties and difficult administrative processes are barriers for consumers. Therefore, government support of market formation is needed, which is possible through identifying or creating market opportunities, for instance through market formation mechanisms like subsidies, feed-in tariffs, obligations, public procurement, etc.

Concerning *resource mobilisation* it seems that although demonstration technologies face Valley of Death problems, promising solar PV technologies should be able to acquire capital because there is a lot of interest in solar PV from investors. High-quality solar PV parks meeting legal requirements can find debt financing, even in more difficult economic times. However, the size of the company developing the technology and the capital markets in that country matter for the mobilisation of resources. Specialised machines have been a problem for some of the newer technologies and a lack of skilled workers can be a restriction in some countries. Solar PV materials can become scarce in the future, especially for several thin film technologies, and the recovery of these materials can have severe effects on the environment.

The “Science and Technology Push” motor and “Entrepreneurial” motor of [Suurs 2009] have been important in speeding up the solar PV developments. The “System Building”-motor has also played a role, but seems to be less important than for offshore wind. Because of the existing market niches, the “Market” motor was very important from an early stage on.

Developing countries

Most developing countries only have low-tech *knowledge development and diffusion* in their own countries. There is more and more *entrepreneurial experimentation* taking place, which leads to technology transfer but not necessarily to knowledge transfer. Often, the technology still comes from developed countries and local population is only trained for operation, maintenance, installation and sometimes construction. Entrepreneurial activities in developing countries are much more difficult, because there are usually high uncertainties (stability, market, crime, safety), corruption, a lack of sound infrastructure and low developed capacities of people and institutions.

The *legitimation* for the technology is even stronger in developing countries because they often have sunny climates, electricity can lead to economic development and the current electricity supply systems are usually weak. However, for these countries the technology is even more expensive. Also, there might be opposition to the technology if it is not trusted. For technology developers and entrepreneurs from developed or emerging countries the *direction of the search* is difficult: to understand what local people actually want and need and how the market works.

Market formation is a problem for solar PV in developing countries because the purchasing power of consumers is low. Electricity from solar PV as a product is usually too expensive for the mainstream market. Therefore, additional value must be found in complementary products or services, preferably for companies that can create higher revenues through the electricity supply. Related to this problem is *resource mobilisation*, because people in the local market do not have the financial strength to do large capital investments or get a loan. Also, people often do not want to make large up-front investments for long-term benefits. However, mobilisation of public funding is often easier, because there are high subsidies and several funds available for entrepreneurship in developing countries. On the other hand, uncertainties for private investors are much higher.

6.5 The Valley of Death for solar PV

This case study has showed problems for the demonstration phase of solar PV technology. But to what extent are the financing problems of the Valley of Death relevant?

Several parties acknowledged that the problems described by the Valley of Death are indeed relevant for many solar PV technology developers. The problems are much larger for small companies than their large competitors. Small solar companies are financially weak and it is often too early for private investors because of the high uncertainties. However, many of the large companies do not dare to take the risks, because of a risk-avoidant attitude and reserved shareholders. Eliminating part of the uncertainties before starting a project costs time and money. The government funding needed for demonstration projects is often not available, like in the Netherlands where there is no large-scale demonstration funding from the government.

However, the financing problems seem to be smaller in general than for offshore wind. One reason is probably the smaller scale and modularity of solar PV, which makes the size of the initial investment much smaller: even investments for large PV projects are usually less than €100 million. Also, angel and venture capital markets seem quite engaged in the solar PV market. The uncertainties of the technology are high but lower than for offshore wind, because of the smaller scale and lower technical uncertainties (no moving parts, friendlier environment). Much of the first solar PV technology development took place in large existing companies, like the Japanese Sharp, Mitsubishi, Sanyo and Hitachi, for whom the cash-flow problems are not very significant because they can finance projects from their own balance. However, there are also many small financially weak companies who depend on external investors, which they have to convince of their plans despite the much higher uncertainties than other investments. The influence of the incumbent energy firms is smaller for solar PV because the development of the technology can take place without them, selling solar PV applications directly to consumers. However, this direct consumer market is difficult to address.

7. General and specific issues for offshore wind and solar PV

The aim of this chapter is to identify similarities and differences in the cases of offshore wind and solar PV (1.1), in order to make the next step in Bergek's TIS to general and specific inducement and blocking mechanisms for the technology (1.2). Next to the TIS issues, a general observation from the interviews is that developments at the micro-level of the socio-technical system are important, which are discussed separately in section 1.3.

7.1 Comparison TIS offshore wind and solar PV

7.1.1 Similarities

There are **several external factors** that influence both technologies. The combination of a growing energy demand, depleting classical oil and gas fields, geopolitical issues of energy supply and worries about climate change has led to a high need for low-carbon electricity production technologies. Also, there are high expectations that both offshore wind and solar PV will play an important role in a sustainable future. However, a disadvantage of these renewable energy sources is that they have relatively high investment costs. Furthermore, they are at the moment both affected by the financial crisis.

There are also similarities between the technologies which are related to the TIS itself. Inherent to the demonstration phase is the fact that uncertainties (especially regulatory and technical uncertainties) play a critical role and the fact that government policy is crucial for both technologies, which has led to differences in technology development between countries. For both technologies there is a **difference in problems between large and small companies** as technology and project developers. For large companies it is much easier to develop technology because they have their own (financial) resources and their financial strength makes it more easy to acquire external capital than small companies. However, these large companies seem to change slower than small newcomers in the industry, which are generally more dynamic, innovative and willing to take risks. This relates to another similarity: the **large incumbent companies have an ambiguous role** which can be slowing down change in the energy supply system. Although these companies undertake action towards low-carbon electricity production sources, they also have vested interests in the current fossil-fuel based industry and might use their political power to influence the institutional framework to protect these interests. Especially since lifetimes of electricity generation units are very long (20-30 years) and their knowledge and management is based on conventional technologies, they have incentives to protect their technological basis. For new companies who do not have these vested interests it is easier to make a choice for change. Lastly, new companies starting entrepreneurial activities in low-carbon technologies create additional advantages: they form **advocacy coalitions** trying to create more positive circumstances for the technology and they **create income and employment** which is a legitimation for governments to stimulate the technology.

Figure 7-1 shows the general mechanisms that have been inducing or blocking both technologies. Most of these mechanisms relate to the similarities discussed above. Some of the inducement and blocking mechanisms are related to exogenous factors and are therefore (almost) impossible to change through policy measures. To understand the problem it is important to realise that these mechanisms exist, but they will cannot be changed through policy. The mechanisms that can be altered through government policy are displayed with a bold line around the box.

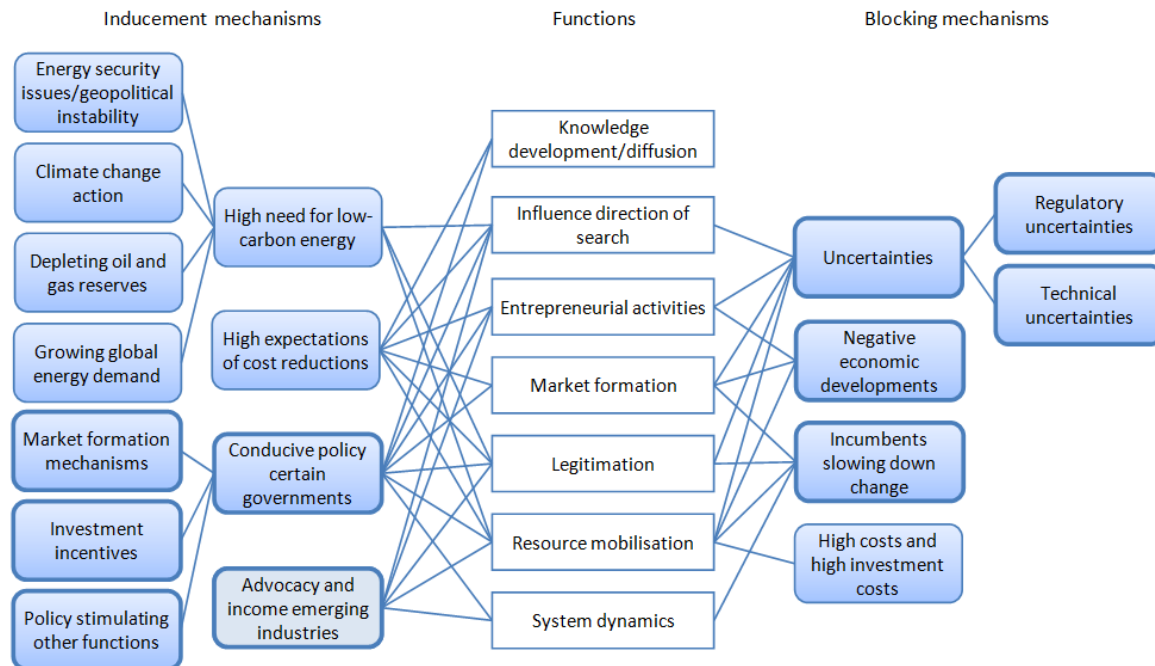


Figure 7-1. General inducement and blocking mechanisms for offshore wind and solar PV

The bold blocks are mechanisms that can be influenced by government policy

7.1.2 Differences

The first major difference is that the **financing problems** seem to be smaller for solar PV than for offshore wind. For example, sound large-scale solar PV projects can usually acquire external (debt) financing, while external project financing is still rare for offshore wind. A first reason for this is the scale difference between the technologies: solar PV projects are often under €50 million with large projects up to €100 million, while a reasonable offshore wind park easily exceeds €100-200 million. Because offshore wind parks are difficult to finance, investors can also be more hesitant to invest in offshore technology which is dependent on the development of these parks. Furthermore, **technical and regulatory uncertainties** are higher for offshore wind than for solar PV. The revenues of solar PV systems are quite predictable while the produced electricity for an offshore wind park is more difficult to predict. Also, solar PV technology is relatively maintenance-free while the technical uncertainties are high for wind turbines at sea: each location needs its own engineering and the harsh and unpredictable marine conditions increase chances of defects and make maintenance difficult. Therefore, more experience knowledge is needed to take away these technical uncertainties but this is more difficult to finance, creating a chicken-egg problem. Another aspect of these technical uncertainties was the impact of the technology on the environment (sea life, birds), which was impossible to determine without learning-by-doing risking animal life sacrifices.

The technologies cope with different **knowledge issues**. The lack of knowledge of offshore wind concerned the interfaces of the technology, the interactions with forces from the environment and the impact of the technology on the environment. This lack of knowledge was amplified by the fact that the connection between the two segments of the technology was missing: the wind sector and the offshore sector. The knowledge problems of solar PV are of a more fundamental nature: the process from light to electricity taking place at nano-scale is not completely understood. This means that offshore wind is further in the process of technology development, while for solar PV different technological directions still

seem possible. The risk of investing in a certain solar PV technology are therefore higher but there is also a higher chance of break-throughs in technology development.

Another important difference is related to **market formation**. Because of the characteristics of the technology (scale, modularity, flexible material), solar PV has more different applications and can serve different technological niche markets. This gives more opportunities for diffusion of the technology and has caused strong international competition which leads to cost reductions. Offshore wind only addresses the market of large-scale electricity generation. While the main customers for offshore wind are therefore the utilities, solar PV technology can also focus on the direct consumer market. This difference is also relevant for other technologies: for solar PV a number of commercial niche markets exist and larger niche markets are within sight, while the share of solar thermal power (with huge long-term potential but few niche markets) is decreasing.

Concerning **legitimation** there are also clear differences. For offshore wind there were several opposing powers because of its impact on the environment; affecting sea life, birds, neighbours and actors competing for space at sea. For solar PV there is no serious opposition. However, the crucial actors for large-scale diffusion of the technology (consumers) are often not actively supporting the technology. Therefore, the difficulty for offshore wind is in taking away opposing powers, while the difficulty for solar PV is to convince and activate non-dedicated actors.

The **role of the government** seems to be more important for offshore wind than for solar PV because more institutional alignment is needed. Offshore wind has more institutional barriers such as more complex permitting processes, determining locations, opposing powers and infrastructure (grid connection and local capacity). The main barrier for solar PV is its costs (and some administrative barriers) which only requires appropriate market formation and resource mobilisation mechanisms. Lastly, **scarcity of resources** along the supply chain has been a larger problem for offshore wind (turbines, offshore installation, port capacity) than for solar PV (silicon, solar panels). However, scarcity of materials and the impact of extraction of materials on the environment might be a problem for solar PV in the future.

7.2 Inducement and blocking mechanisms

Next to general inducement and blocking mechanisms for both technologies, there are also specific inducement and blocking mechanisms for offshore wind and solar PV, which are shown in Figure 7-2 (offshore wind) and Figure 7-3 (solar PV). Again, some of the inducement and blocking mechanisms for the technologies are related to exogenous factors and are therefore (almost) impossible to change through policy measures. It is important to know these mechanisms to understand the problems, but they cannot be changed through policy. The mechanisms that can be altered through government policy are displayed with a bold line around the box.

The diagram of offshore wind shows that there are mainly blocking mechanisms for offshore wind parks, which is a problem for entrepreneurial activities and for resource mobilisation, because the blocking mechanisms can lead to higher costs and delays. Many of the blocking mechanisms are related to government policy or can be taken away by it, which confirms the observation that the role of the government is more important for offshore wind. For solar PV, the functions that have the most blocking mechanisms are market formation and resource mobilisation, which corresponds with the fact that the technology is still very expensive and therefore needs financial support.

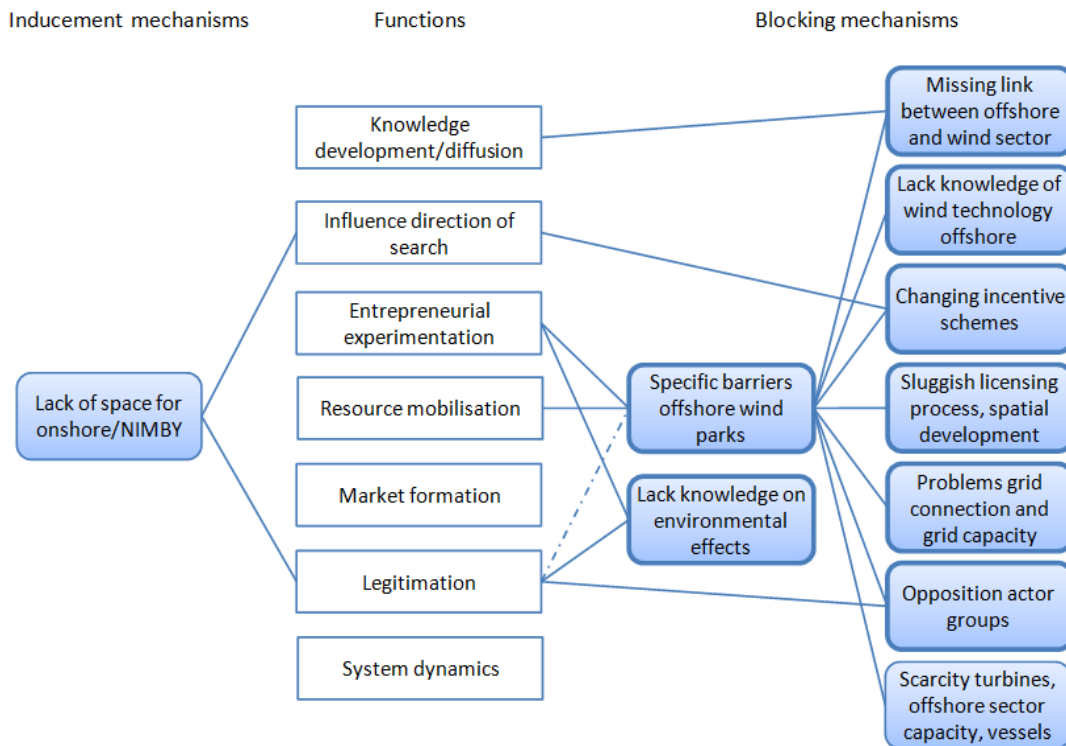


Figure 7-2. Inducement and blocking mechanisms for offshore wind

The bold blocks are mechanisms that can be influenced by government policy

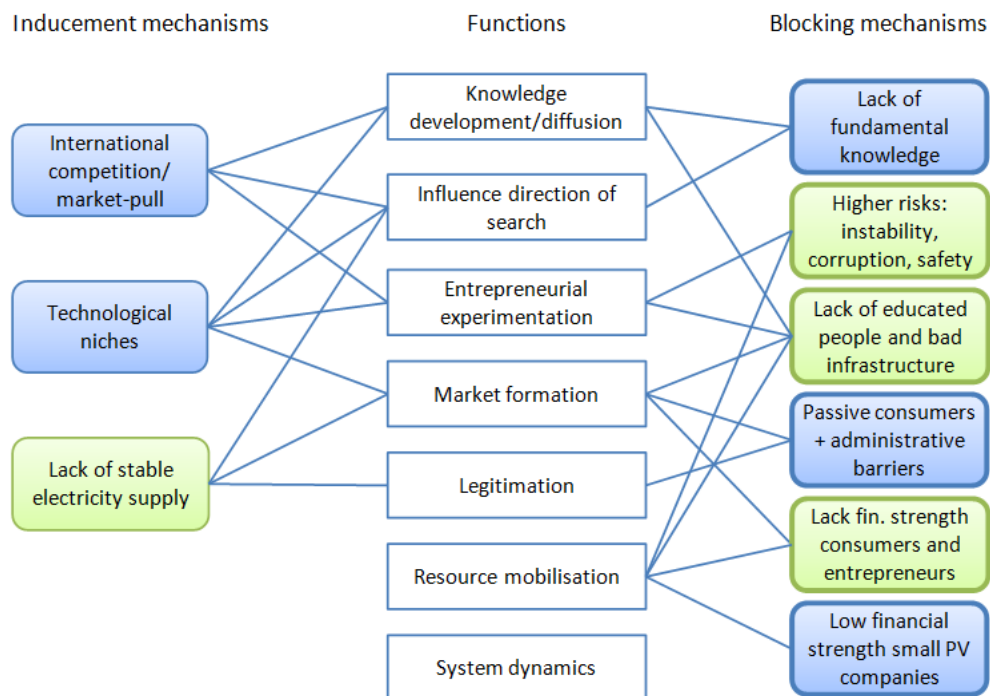


Figure 7-3. Inducement and blocking mechanisms for solar PV (turquoise=developing countries)

The bold blocks are mechanisms that can be influenced by government policy

7.3 Micro-level issues

“The history of every industry leads us back to men and to energetic will and activity. This is the strongest and most prominent reality of economic life. The economy does not grow into higher forms by itself.” [Schumpeter, 1934]

Another general observation from the interviews is that developments at the micro-level of the socio-technical system matter, like individual management, capabilities, personality and networking skills. This relates to the concept of “economic competence”, which states that developed knowledge must be exploited in the right way to lead to innovation [Suurs 2009]. This section highlights some important issues with examples from the interviews. In the beginning of the research some interviews have been done with entrepreneurs undertaking technology development in other technologies than solar PV and offshore wind. Examples from these interviews are also used here, the companies are explained in the boxes below.

Ampelmann

The Ampelmann company developed a platform which provides safe and easy access to offshore constructions from ships which is usable for offshore wind and oil and gas exploitation.

C-energy

Ecofys is developing a turbine for wave and tidal stream electricity generation. The turbine is tested in the province Zeeland (NL) at a marine terminal of an oil company.

Superwind

The Superwind project is based on a fuel cell, which converts natural gas or biogas into hydrogen, electricity and heat. It is flexible in operation between producing a lot of heat and electricity with almost no hydrogen or the other way around. Therefore, the fuel cell can complement fluctuating electricity production from intermittent sources, flexibly producing additional electricity. The produced hydrogen can be stored and distributed as a fuel at a multi-fuel distribution point of the company Delta-Oil.

Networking

Networking is important for new entrepreneurs to establish relations with all kinds of partners for the new business. As described by the Valley of Death literature, there is often a disconnection between the public and private sector [Murphy and Edwards 2003][Auerswald and Branscomb 2003]. Therefore, technology development should preferably take place in a network including parties from the technology and the market side. For example, the initiator of Ampelmann had good connections in both private and public sector through his work in the industry and at the university, which were beneficial for starting up his company. As he puts it himself, he is *“just really good at drinking coffee”*. Both the Superwind and the C-energy project were able to gather a diverse project team of interested parties around the project. These coalitions provide mobilisation of resources (pecuniary and non-pecuniary), political power and a supporting basis in both private and public sector. The partnership between the foundation Pico Sol and the Cambodian solar PV company is beneficial because Kamworks does the “hardware” work and Pico Sol provides part of the projects, access to more NGO’s and takes care of the training of local people.

The entrepreneur

In most of the new unconventional projects there is one front-runner pulling the project forward, who has a vision or dream of what should happen. The entrepreneurs from the interviews were all examples of a few or single people undertaking these projects out of a belief in the project and its sustainability. This

stresses the role of the entrepreneur as a leader of innovation as identified by Schumpeter [Schumpeter and Backhaus 1934]. Governments cannot stimulate every dreamer out there, but they can create an entrepreneurial environment in which people with good ideas are stimulated to take a chance, for example through educational programmes. The Superwind project is to some extent missing a suitable front-runner. Delft University seems to be pulling the project, but they are not the suitable party to develop the project in a commercial way. The small benefits of production of electricity, heat and hydrogen and supply of biogas and waste heat are spread among five different parties. There is no party (yet) representing the main benefit of the project: flexible electricity production complementary to intermittent electricity production from wind turbines or solar cells to enable a stable electricity supply.

Market diversification

Another important issue is what was called by one interviewee as “two legs to jump”: the fact that several companies have two (or more) markets or sources of income with different levels of uncertainty to provide them with stability. They either serve another market (e.g. the NGO market in developing countries) or perform other activities next to the exploitation of the technology, like consultancy work. This relates to the economic concept of portfolio management, in which companies and investors spread their risks through being active in different branches with different risk profiles. It is important to realise whether the market and the product are new or existing. It is difficult to start with a new product in a new market, so then at least a back-up market is needed for the company.

Management capabilities

The capabilities of the management of a company are crucial for the success of the undertaking. For example, technology developers who have better knowledge on the complexity of financial markets can develop better innovative financial models [FUNDETEC 2007]. Literature on the Valley of Death stresses the fact that technology developers often do not have a market focus and do not have the capabilities to bring the technology to the market [Murphy and Edwards 2003][Auerswald and Branscomb 2003]. An experienced developer of new companies claims that the stages after the proof of concept and business plan are the most difficult, because there is no management and no team. Creativity of the management is needed to find solutions to their problems, like financing, insurance, dealing with intellectual property rights, etc. Literature from the US shows that companies that are successful in early stage technology projects use different funding options to fund their project including contract work, income from licensing patents, the sale of spin-off firms, and cost-cutting [Auerswald and Branscomb 2003]. The interviews indicated that entrepreneurs, especially in developing countries, find the most creative ways to acquire financing for their companies. Ampelmann also used all kinds of creative contract constructions to get financial and in natura sponsoring (e.g. parts, device rental) from different parties for the development of the Ampelmann.

8. Discussion

8.1 Case study validity, comparability and generalisation

Validity case studies

The conclusions of the case studies have been sent for approval to all the interviewees to provide a check of the interpretation of the interviews. The conclusions of the research and the policy recommendations have been discussed with several investors and policymakers of the Ministry of Economic Affairs and their executive organ Senternovem. Furthermore, much of the information from the interviews was confirmed by a cross-check with literature, which also provided some additional information and data. However, there are some shortcomings of the case studies.

First of all, although the cases are defined internationally and the intention was to interview international parties, the largest part of the respondents are from the Netherlands and therefore the cases provide more information on the Netherlands. This is caused by the fact that it is much easier to access information and people in your home country through an existing network of relations: there was not much response from organisations who were contacted without an existing contact. Secondly, there were not many interviews with developers of large solar PV projects, because it is difficult to reach these companies. Since the Netherlands is not very active in large-scale solar PV, there were few existing contacts in large-scale solar PV and some companies were too busy at the moment. Thirdly, the case-studies are broadly defined, leading to a general image of the problems and general conclusions, but therefore in-depth details are limited, especially for solar PV. This means that the exact outcomes and problems differ per country and per project, statements about the technologies should not be regarded as law-like rules for all solar PV and offshore wind projects. Because of the open approach of the case-studies, they are not exhaustive: some information might be overlooked, especially for the broader solar PV case.

Furthermore, networks were not discussed in detail in the case-studies, which was based on theoretical considerations (see section 3.2) and the fact that there are too many networks to discuss with a wide geographical scope of the case. This has also been an issue for the actor analysis, only aggregated comments were made on actors groups, it was not possible to identify the exact role of certain entities. This means that the conclusions drawn on actors and their relations might be true in many cases, but are not defined “truths” for all instances in solar PV and offshore wind.

Finally, there is a risk that the outcome of the case studies is influenced by “group think”, because a large part of the empirical knowledge is from interviews with people within the same sector. People functioning in a same group often tend to reinforce certain general thoughts in the group. Therefore, the fact that certain information is confirmed by other interviewees could result from “group think” rather than the same idea originating from different people.

Comparability case studies

The offshore wind case is partly a historical case study while the solar PV case is mainly focussed on the present. It is easier to determine “what went wrong” than “what is going wrong”, so maybe some issues for solar PV have not emerged yet from this case study. Also, the solar PV case is very broad, which makes it less detailed than the offshore wind case, which had a clear geographical boundary. The offshore wind case was immediately drawn to financing problems for large projects, which relates to the fact that project development is the main stumbling block for offshore wind, while the solar PV interviews led to more information on corporate development. Therefore, less information was available on corporate development of offshore wind and on project development of offshore PV. These factors present

structural differences between the cases, which makes it more difficult to compare the cases. However, for these reasons the cases are not compared on each aspect but only general conclusions are drawn on similarities and differences of the technologies.

Generalisation

The general and specific technology issues cannot be generalised one-on-one to low-carbon electricity production technologies, two case studies are not sufficient to do so. However, the general drivers of a high need for low-carbon electricity production technologies, positive policy frameworks and advocacy coalitions and income from emerging industries are probably similar for other technologies. Also, uncertainties and negative economic effects like the financial crisis are blocking new electricity production technologies in general, although differences might exist between the technologies. Differences in uncertainties were perceived in the case studies, because the regulatory and technical uncertainties are higher for offshore wind than for solar PV. Also, for biomass-based technologies resource uncertainties become important because of the feedstock, which adds a new dimension to the problem.

The high cost and high investment costs depend on the technology; feedstock or fuel-based technologies like biomass have relatively lower investment costs and higher operating costs. Also, the role of the incumbent can be different, depending on the extent to which the technology is compatible with vested interests in the current business. For example, many utilities are lobbying for co-firing of biomass and carbon capture and storage, because this can be a solution for the future and social acceptance of fossil fuel-based power plants.

The offshore wind case is overlapping with onshore wind technology, because it is impossible to describe offshore wind developments without understanding of what happened beforehand. This means that the TIS studied does not concern a technology which started on a blank sheet of paper, just as the studied new solar PV technologies are related to the existing crystalline silicon technology. A completely new pioneering technology might have different barriers than these two cases.

Technology-specific issues

The technological issues which appeared from the cases give an impression of the kind of technology-specific issues that can be relevant, especially since the technologies were chosen for their representation of variation in technologies. A non-exhaustive list of technology-specific issues is presented here, combining the outcomes of this study with a study on sustainable energy criteria for venture capitalists [Mulder 2009]:

- Product and technology: scale, modularity, flexibility, (theoretical) efficiency, materials (characteristics, stability), technical challenges, complexity technology (fundamental knowledge, interfaces, different sectors/knowledge fields), maintenance needs, area requirement, sustainability issues (biomass).
- Environment: Availability of the energy source (storage or back-up from grid needed and available), impact on environment (animal casualties, electromagnetic interference, noise, scenic pollution), impact environment on technology (e.g. offshore conditions), dependency on permitting procedures and government incentives.
- Market: Standards, technological niches, complementary products, match with market demand, availability and price of resources, delivery time and costs of components and services (e.g. installation), lack of skilled workers, contracts (long or short term, peak or base load).
- Finance: Investment costs, ratio of Capex/Opex, uncertainties, costs, warranties and insurance, sensitivity to volatility of fossil fuel prices, price of feedstock (biomass).

8.2 Reflection on theory use

8.2.1 Technological Innovation Systems

The Technological Innovation Systems framework is chosen for this study because of its theoretical relevance to the problem and its practical use in identifying the factors creating positive or negative circumstances for the development of demonstration phase technologies. The theoretical relevance of the theory has been confirmed for several reasons. Firstly, it was possible to fit most of the information from the open interviews into the framework, drawing an image of the problem in the eyes of the respondents. All structural and functional components were covered by the information from the respondents. This seems to indicate that the framework covers the important issues for success or failure of new electricity production technologies fairly well. The only limitation was the focus of the TIS on the regime level of transitions, which makes it more difficult to place micro-level and landscape developments (see below). Furthermore, the TIS theory describes the dynamics of the system through the functional components, but also acknowledges effects of lock-in and path-dependency leading to rigidity of the system, represented by the structural components. The multi-disciplinary nature of the problem is reflected by the theory because the components address economic, social, cultural, political and technical issues. However, the technical issues are somewhat under exposed in the original theory, which is why “technology” was added as a structural component (see below). Because of its attention to actors as structural components and their activities shaping the functions, concepts of bounded rationality, imperfect information and strategic behaviour are taken into consideration. To emphasise these aspects, a method was used for the actor analysis which identifies the different interests, goals and perspectives of the actors. The TIS approach was instrumental in practical use through systematically describing the system of structural and dynamic components which shape the circumstances for a technology to successfully transcend the niche level to the regime level. It provides the opportunity to point out the main drivers and barriers government policy should address through analysing the system. However, some difficulties of the TIS theory were encountered for this study.

Structural component “technology”

The structural component “technology” was added in this study to address differences between the technologies. Therefore, an important question is whether the assumption is true that technology-specific aspects significantly affect the functioning of the system. The answer is yes, which can be clarified with some examples. The modularity and flexibility of solar PV lead to more easy market formation, while the high-tech character hampers fast developments in knowledge development and diffusion and hinders market formation in countries with less-educated populations. The infrastructure dependency and difficult location of offshore wind leads to barriers for entrepreneurial experimentation. Also, the environment determined by offshore wind technology led to difficulties for knowledge development, entrepreneurial experimentation and legitimation. More examples can be mentioned which clearly show the importance of technological aspects for the TIS and therefore for the chances of success for the technology. A recommendation is therefore to include technology as a structural component in the TIS framework.

Networks and relations between structural components

Networks are more dynamic than structural components and discussed partly in the functions knowledge development and diffusion, legitimation and entrepreneurial experimentation. Also, formation of networks could be regarded as a form of an externality. For these and more practical considerations (see previous section), networks were not included as a separate structural component in this study. The

relations between actors are described with the actor component and attention is paid to the relations between the structural components. It can be questioned to what extent networks are indeed structural or more dynamic components of the system. Therefore the analyst of a certain TIS should decide whether or not to take networks into consideration as a separate structural component. Nevertheless, it is important to pay attention to the connections between structural components. For example, infrastructure cannot just be technically changed to a more decentralised system; the institutions have to be aligned and the actors involved have to change their routines and behaviour (network operator, consumers, utilities). Also, the actions of actors are limited by institutions and institutions are limited by actors and technology. These relations can provide additional lock-in for the system, because more than one structural component has to be addressed to change the system.

Positive externalities

The functional component of positive externalities was not discussed as a separate component because of its vague definition and overlap with other dynamic aspects, like reinforcing relations between functions creating vicious or virtuous cycles and “motors of sustainable innovation”. Externalities can be a trigger or fuel for these cycles. To prevent obscurity in the analysis, a clear choice must be made on how and where to discuss externalities. It is best to discuss these dynamic aspects together: externalities, feedback loops creating vicious and virtuous cycles, “motors” of innovation, etc. Furthermore, the economic notion of externalities is sometimes mixed with “influences from the external environment”. It must be clearly defined that externalities are related to the economic concept of “free utilities”, which can also be internal of the economic system.

Connection between structural and functional components

The TIS theory does not provide clear guidance how to deal with the relation between the structural and functional components. In existing literature, the structural components are often not even analysed separately, which might be because functional components are more relevant for short-term policy issues; they can be changed on a shorter term through policy while structural components are more difficult to change. Nevertheless, it might be needed to change structural components because they determine the functional components; most of the inducement and blocking mechanisms are related to structural issues in the TIS. If they must be changed, the question is how this should be done; through rigorously changing the structural components or through gradually moving the functional components towards the change? Questions on how to deal with this connection might be food for thought for the future of the theory.

Actor and institutional analysis

The TIS theory also did not provide a clear approach for the analysis of the structural components. Therefore, methods of Enserink et al. [2003] were used in this study for the actor and institutional analysis. These analyses provided more insight into the Technological Innovation Systems: which actors are really important for the development of the technology, to what extent are they actively engaged and do they have the same point of view as the “problem owner”? What are the relations between the actors that should be considered? Which institutional levels are most important and how are they interrelated and influenced by other levels? These analyses showed some clear differences between offshore wind and solar PV. However, these methods also require a larger effort and can be too detailed for certain studies, so a briefer analysis might suffice depending on the detail of understanding needed for the analysis.

Landscape developments and events

It is not exactly clear in the TIS theory where the so-called “landscape” issues from the transitions theory should be placed. Landscape developments like the economic recession, climate change and geo-political developments have a large impact on the TIS. In this study the relevant landscape events are interwoven with the components of the system and taken into consideration in the inducement and blocking mechanisms, but not discussed with the policy issues because they generally cannot be changed through policy. These landscape events might deserve a separate place to discuss, for example in the introduction of the TIS.

Micro-level issues

The focus of the Technological Innovation Systems theory is mostly on the regime (meso-) level describing the circumstances for innovations to become part of the regime, although the functions connect to the micro-level by sketching an aggregated image of lower-level developments. However, the actual processes of innovation that are also crucial for technology development are taking place at the micro-level of the transitions model [Suurs 2009]; issues of business and strategic niche management are important for technology development. This could mean that in some cases a general discussion of the TIS does not provide a complete image of the issues for technology development, especially when discussing new (demonstration) technologies. A way to overcome this may be to pay more attention to certain functions when using the TIS theory to analyse technologies in specific phases of technology development, e.g. knowledge development and diffusion in early stages, entrepreneurial experimentation in the demonstration phase and legitimation and market formation in later stages. For this study more attention is paid to the function of entrepreneurial experimentation and resource mobilisation.

In any case, perceived uncertainties of actors are very important for the development of technologies because they influence their decisions. The way actors deal with uncertainties determines how the institutional system will look like, including the interactions and arrangements between actors. Therefore, Meijer [2008] argues that government policy should take account of these uncertainties next to stimulating the functions. It could be useful to find a way to combine or integrate uncertainties with the TIS approach. Perhaps “resolution of uncertainties” can be a separate function.

8.2.2 Valley of Death

An important question for this study concerns the urgency of the financing problems characterised by the “Valley of Death”: is it indeed so difficult to cross? There are several reasons to believe it is an urgent and valid problem, at least for the technologies researched. Most of the respondents acknowledged that it is a problem and many barriers and difficulties were mentioned, although the problems are smaller and different for technologies developed within large companies. Furthermore, there is no obvious financing source for this stage. Public financing usually only provides a small amount of the total costs. The uncertainties are very high which makes it difficult to find private financing. The relevant private sources are mainly angel and seed capital, which are not abundant. As mentioned by a respondent: *“you should find the “fool” who wants to invest”*.

However, three important factors determine how large the financing problems are: the size of the company, the size of the investment and the uncertainties. Large companies can often finance projects themselves and have more possibilities of acquiring external finance because of their financial strength. If the risk of not retrieving return on investment is high, an investor is more willing to make a smaller

investment than a large one. Lastly, if the technology or project does not involve that many uncertainties anymore (or predictable uncertainties: risks), it should be possible to acquire (external) finance.

On the other hand, it was also mentioned by several respondents that the phase after demonstration, when large amounts of working capital and sound management are needed to scale up the production of the technology (sometimes called the “Mountain of Death”), can be a larger problem. It is difficult to determine which phase is more problematic. Probably it differs per company, depending on the circumstances: is there a mother company or institute involved and how is the (financial) situation of this company? What is the amount of capital needed and how large are the scaling-up steps? Are the circumstances (e.g. the TIS) positive for the company? How is the situation of the risk capital market in the country and which public finance mechanisms are in place?

In any case, this thesis shows that financing problems are a part of the problems of new low-carbon electricity production technologies to reach the market and the technologies demand for specific (financial) guidance through the different phases of development to reach competitive grounds with conventional technologies.

9. Conclusions and recommendations

9.1 Understanding the financing problems

The first aim of this research is to find the best way to understand the financing problems in the demonstration phase of low-carbon electricity production technologies. Technology development from basic research through to a commercially mature technology is generally characterised by the technology development sequence. There are many different terminologies used for this sequence, which all try to capture the essentials of a process which is in reality non-linear, chaotic and unpredictable. The demonstration phase starts when the principle of the technology is proven in a laboratory or with a scale model and the technology has to be proven on a real-life scale in real-life conditions for the first time. The first pilot lines and first large-scale projects containing multiple units of the technology (e.g. an offshore wind park) can also be considered as demonstrations of the technology. The demonstration usually involves significant up-scaling of the technology and therefore also of the capital requirements, which often leads to financing problems for the technology developer.

To describe the financing problems in the demonstration phase of technology development, the concept of a cash-flow “Valley of Death” is often used, which is caused by a combination of rising cash demands (the units costs are high and only expected to go down as the technology develops) and a low ability to raise it: public funding is more focussed on early phase R&D and the uncertainties and pay-back times are still too large for private investors. The notion of a Valley of Death is relevant for low-carbon electricity production technologies, as this research has shown. There is a significant increase in scale of the capital demands when the technologies move from R&D to demonstration. Furthermore, there is no obvious financing source for this stage. Public financing usually only provides a small amount of the total costs while private financing is difficult to acquire because the uncertainties are very high. The most relevant private sources are mainly angel and seed capital, which are not abundant. The scale and uncertainties of the technology and the entity developing the project or technology influence the severity of the financing problems.

However, the available finance and uncertainties are not the only causes of the financing problems; there are other barriers and difficulties for the demonstration of the technology and the technology in general which affect investment decisions. Therefore, the concept of the Valley of Death is too limited to understand the financing problems of low-carbon electricity production technologies and the differences between the technologies. Processes of technological change are embedded in a wider societal context, which is why they cannot be described by technological advance and economics only. This is even more obvious for technology relating to societal functions or public goods, like utility or infrastructure technologies. There are many direct and indirect factors influencing the circumstances for a technology, including social, cultural, ecological, economic, technological and political factors, which influence the future expectations taken into consideration in investment decisions. For example, a lack of social acceptance of a technology and the existence of strong opposition groups in society can delay or block the future development of the demonstration technology. On the other hand, societal changes of environmental consciousness and ecological changes in climate have led to an increased demand for sustainable energy sources. Furthermore, the energy sector is a highly political business, where governments intervene in the market because of its natural monopoly and public good characteristics and markets are dominated by former or current state monopolies that have significant political power. These examples show processes at different levels of society which relate to different disciplines of science (economics, politics, sociology, technology, etc.). Therefore, a multi-disciplinary and multi-level approach

is needed, which socio-technical systems theory tries to provide. Two important models are the transition model [Geels and Kemp 2000][Geels 2005] and the Technological Innovation Systems framework, a.o. [Bergek et al. 2008][Hekkert et al. 2007][Suurs 2009]. The transition model does not explain the underlying processes of innovation and it does not describe the circumstances for a technology to become successful and how these circumstances can be created. The Technological Innovation Systems framework sketches an image of the structural and functional components of the system creating positive or negative circumstances for the development of demonstration phase technologies. Therefore, the Technological Innovation Systems theory is the most suitable for this research to analyse the financing problems and translate the analysis into policy recommendations.

To discuss financing problems of low-carbon technologies in the demonstration phase it is important to determine which low-carbon technologies are currently in the demonstration phase. Technology development is usually not a linear process. Also, most technologies have sub-technologies and “generations”, the technology might work differently in various environments and there can be regional variations in the level of maturity of technologies. This has led to different classifications of sustainable energy technologies throughout the phases of the technology development sequence [UNFCCC 2008b][EPRI 2007][IEA 2008]. A selection from these studies leads to the following list of low-carbon electricity production technologies in the demonstration phase:

- Offshore wind – floating;
- Geothermal (enhanced geothermal systems);
- Concentrated solar power/solar thermal (solar towers, Fresnel, dish-stirling, solar chimney);
- Ocean power (wave and tidal);
- Newer solar PV technologies (thin film, organic solar cells, concentrating PV); and
- Technologies related to electricity production: carbon capture and storage and hydrogen production, storage and distribution.

To analyse the variety of possible financing problems of these technologies, offshore wind and solar PV are chosen as case studies because they represent reasonably polar examples in scale and because they have a large variation in difficulties and stakeholders.

So what are the factors affecting the financing problems in the demonstration phase for low-carbon electricity production technologies in general and offshore wind and solar PV specifically? There are important differences in financing problems for the different low-carbon electricity production technologies. For a technology in general, the financing problems are directly influenced by the scale of the investment in projects and the uncertainties related to the project and the technology. The scale of solar PV is much smaller which makes experimentation easier to finance and the modularity of the technology offers flexibility in experimentation scales. Investments in a large solar PV park are usually below €50-100 million, while a reasonable offshore wind park easily exceeds €100-200 million. Also, the technical and regulatory uncertainties are larger for offshore wind than for solar PV. The harsh environmental conditions offshore (wind, waves and salty water) and the moving parts in the turbine lead to a higher chance of defects, while maintenance offshore is difficult. Regulatory uncertainties are larger because offshore regulation and spatial planning (including the electricity grid) are not as developed as onshore. For separate projects or technologies, the entity developing the technology or project is important. Large companies have more financial strength than small companies. Public technology developers may have more difficulties in understanding how the technology can be brought to the market

and how private investors should be approached. Lastly, while large incumbent firms have the financial strength to develop projects, they also have mixed interests in low-carbon technologies because of their vested interest in fossil fuels. New low-carbon energy companies might be more dynamic, but have less financial strength and established power in the energy system.

Next to the direct financing issues, there are also indirect issues affecting the financing problems, which vary among technologies. Each technology for instance has specific barriers, regulatory problems, knowledge gaps and a different configuration of the playing field of actors. An analysis of the direct and indirect factors affecting the financing problems of offshore wind and solar PV has resulted in “inducement and blocking mechanisms” which are stimulating or blocking development of the technologies in the demonstration phase. Both technologies have several positive factors in common resulting from high expectations of cost reductions of the technologies and environmental and energy security issues, which have led to a high need for low-carbon technologies, stimulating policy frameworks and advocacy and income from the emerging industries. On the other hand, they both have relatively high costs and high investment costs and many uncertainties. They face inertness through the role of incumbents, which are investing in new technologies but may react slowly because of their vested interests in fossil fuel based technologies. Negative economic developments like the current financial crisis increase the financing problems. The specific barriers and drivers of the two technologies are displayed in Table 9-1. This table shows that offshore wind has more barriers than solar PV, which is mainly related to the offshore location causing regulatory and technical uncertainties and barriers. Solar PV has more possible applications than offshore wind, which leads to technological niches and therefore more flexibility of the technology.

Table 9-1. Inducement and blocking mechanisms for offshore wind and solar PV

	Inducement mechanisms	Blocking mechanisms
Offshore wind	<ul style="list-style-type: none"> - Lack of space for wind turbines onshore 	<ul style="list-style-type: none"> - Lack of knowledge of wind technology offshore - Lack of knowledge of environmental effects of the technology - Missing connection between the offshore and wind sectors - Changing incentive schemes in some countries - Sluggish and changing licensing and spatial development processes - Problems of grid connection and capacity - Scarcity of turbines, offshore sector capacity and vessels - Opposition of actor groups (nature and horizon conservation)
Solar PV Developed countries	<ul style="list-style-type: none"> - International competition/market pull - Technological niches 	<ul style="list-style-type: none"> - Lack of fundamental knowledge of the technology - Passive consumers - Administrative barriers for consumers - Financial weakness of small PV companies
Solar PV Developing countries	<ul style="list-style-type: none"> - Lack of stable electricity supply 	<ul style="list-style-type: none"> - High risks (crime, corruption, political instability, etc.) - Lack of educated people - Bad infrastructure - Lack of financial strength of consumers and entrepreneurs

The direct and indirect factors influencing the financing problems of low-carbon electricity production technologies in the demonstration phase are to a large extent related to characteristics of the technology. Combining the experiences from this research with previous research on sustainable energy

characteristics for venture capitalists [Mulder 2009] leads to several categories of technology characteristics relevant for financing of new electricity production technologies:

- Product and technology, e.g. scale, modularity, flexibility, efficiency, materials, technical challenges, maintenance and area requirements;
- Environment, e.g. availability of the energy source, impact on environment, impact environment on technology, dependency on permitting procedures and government incentives;
- Market, e.g. standards, technological niches, complementary products, availability and price of resources, components and services;
- Finance, e.g. investment and operational costs, ratio of Capex/Opex, uncertainties, warranties and insurance.

9.2. Addressing the financing problems

Now that the financing problems in the demonstration phase of low-carbon electricity production technologies are better understood, the question that remains is: how can they be addressed? The fact that financing problems and their causes vary for different low-carbon electricity production technologies demands for a technology-specific analysis and technology-specific policy. For example, the varying playing fields of actors of the different technologies should be approached differently, bottlenecks or gaps in regulation that should be addressed are often specific for technologies and the knowledge gaps that should be filled are different for each technology. Meijer [2008] argues that governments should even provide specific support for a limited amount of pioneer projects. However, general technology policy can offer cost advantages through synergy and is usually designed to create an environment in which the most cost-efficient technologies “win” through selection by the market. Technology-specific policy can lead to “picking winners and losers” by governments which might result in suboptimal outcomes in terms of cost-efficiency of the technologies. On the other hand, through market-based policy schemes the lower hanging fruit (easier and cheaper technology development) is usually picked first by market parties, which puts off the development of promising but for the moment still more expensive solutions which are needed for the long-term future. Also, because the market failures in the demonstration phase (e.g. information asymmetries, public good characteristics and externalities) demand for interference by the government in the market, governments face a dilemma. A solution to this problem could be to leave the decision on which projects or technologies deserve support to an independent institute rating the projects [Meijer 2008]. Still, knowledge institutes also do not have the complete information to make a decision on these projects; there are always information asymmetries between project developers and the entity choosing the projects. Also, next to an “objective” choice of the best technology, there are strategic interests of countries in certain technologies, like potential income from new sectors, strategic resources (fossil fuel fields, wind and solar sources) or a strategic geographical position (locations to store CO₂, location at important interconnection of electricity or other infrastructure). To conclude this debate, the urgency of the need for these new technologies, the risk of attention being limited to lower hanging fruit, strategic interests of countries and the market failures and barriers which are specific for the technologies point to a need for a certain degree of technology-specific policy. The fact that governments are hesitant to mingle in commercial stages of technology development might even be one of the causes of the Valley of Death [Murphy and Edwards 2003]. The specific problems for different technologies should be analysed as has been done for offshore wind and solar PV in this study. While the general problems can be addressed through general government policy, the technology-specific problems and barriers have to be addressed separately to assure timely development of the needed technologies to address energy security and climate change problems.

Another important conclusion for addressing the financing problems is that a merely economic or financial approach is not sufficient to resolve the financing problems because the entire socio-technical system has its influence on decisions of investment and entrepreneurial action. The case studies demonstrated that all functional components are important for a well-functioning TIS, which is emphasized by the dynamics of the system and the existence of feedback loops that enforce the functioning of the system. For financing problems in the demonstration phase, most specific attention should go to mobilising financial resources, stimulating entrepreneurial experimentation and decreasing uncertainties. However, investment decisions are affected by the expectations of the future of the technology, which is influenced by the socio-technical system. Therefore, the socio-technical system should be taken into account in policy-making to stimulate technology development. The Technological Innovation Systems framework can be used for this, which means that policy should address all functions of the innovation system to enable the transition of low-carbon electricity production technologies from R&D to commercial application. The conclusions of the financing problems of electricity production technologies in the demonstration phase lead to policy recommendations based on financing issues, stimulating entrepreneurship and experimentation and getting the innovation right.

Financing issues

- Install both *public finance mechanisms*¹ to stimulate the mobilisation of financial resources through leveraging private sector investment and *market formation mechanisms* for a positive prospective of the future market for the demonstration technology. The *indirect effects of these mechanisms* on financing costs should be considered². To be able to acquire financing without very high risk premiums, agreements of mechanisms should correspond to the lifetimes of low-carbon energy projects, which are longer than usual, and provide a stable income with periodical payments to make the agreement useable as a debt security. For tax mechanisms the limited tax appetite of small companies should be taken into account. Solutions for this are using direct measures like investments subsidies or providing small companies with tax credits which they can sell or move backward/forward in their administration.
- Found *networks between investors and technology developers*, which improve the chances of success in finding finance for demonstration projects; examples are the ACE-net, PFAN and BiD³. In general, governments can be actively engaged in improving the connection between technology developers and the private sector to enhance trust, decrease information asymmetries and enable an earlier market focus of technology developers. Also, market perspectives could be included into the criteria for public financing, which demands an earlier market focus of technology developers.
- Provide *guarantees* for investors to address uncertainties, through which the government shares the burden of failed investments, and establish *export credit agencies* for entrepreneurship in developing

¹ More information on public finance mechanisms is provided in [UNEP 2008b].

² More information on uncertainties and the influence of policy measures on financing costs in [Jager and Rathmann 2008] and [Wiser and Pickle 1997].

³ The *ACE-network* is one of several angel capital networks in the US, which is a nationwide Internet network where small companies looking for investors can show their offerings as promising opportunities for investors [Acs and Tarpley 1998]. The *Private Financing Advisory Network (PFAN)* wants to bridge the gap between sources of financing and developers of climate friendly and technology transfer projects in emerging or developing countries through identifying projects that may be suitable for private sector finance and providing them with project financing coaching and consulting [CTI 2009]. *Business in Development (BiD)* is an online network where entrepreneurs who want to start a business in developing countries can present their business plan to investors who want to invest in developing countries. It also brings the entrepreneurs in contact with coaches and experts [BiD 2009].

countries⁴. The advantage is that governments only have to spend the money if the project fails and a low interest rate could be calculated to compensate for inflation. The market party should also take a certain risk, therefore the government guarantee should cover only a part of the investment, which relates to the risks that cannot be estimated by market parties, i.e. technical risks. In general, governments can make public financing contingent to the outcome of the financed activity: in case of success, it retrieves the investment; in case of failure the investment is not reclaimed. Other ways to share risks are to participate in projects and to invest in infrastructure (e.g. an offshore grid)².

➤ To minimize regulatory uncertainty², *support schemes should be financed outside government budgets* as much as possible, for example through levies on energy consumption or obligations/feed-in tariffs for energy companies. Government budgets are renegotiated frequently, which makes policies depending on these budgets more vulnerable to fluctuations. In general, policy should be aimed at providing as much long-term stability, reliability and predictability as possible.

Stimulating entrepreneurship and experimentation

➤ Establish *incubators*, especially linked to technological research institutes and universities, to support start-up companies in their entrepreneurial capabilities and networking. Start-ups can also benefit from the network and learning of other start-ups and experienced businesspeople linked to the incubator.

➤ Develop *educational programs* for entrepreneurial capabilities and promoting entrepreneurship at universities and other educational institutions.

➤ Make a *scan of the total regulatory process that entrepreneurs go through for different technologies*, which identifies the main barriers for each technology. Try to take away these barriers and decrease the administrative burden through creating a “one-stop shop” for permits, subsidies and other regulative matters, with transparency and good communication of the process.

Getting the innovation system right

➤ Make an *assessment of the “Technological Innovation System”* for the different technologies and derive a coherent policy which *addresses all the functions* for each technology. Design this policy for long-term use, including a planning with targets for the different technologies and spatial planning for the large-scale electricity production technologies.

➤ *Understand and map the playing field of actors* for each technology. Bring all parties (including opposition forces) together in a *cooperative process*⁵ with attention to criticism of the technology, which is aimed at taking away problems of the technology and creating a pathway for the development of the technology including compensation of harmed parties if needed. A strategy must be determined how to deal with the role and power of *incumbents vs. new entrants* in this process, both should get sufficient and equivalent attention in the process if they show sincere commitment and activity to the technology.

➤ Make a *thorough impact assessment* of the different technology policies, including scenarios for future development of the technologies. Resource and environmental constraints are important in assessing the impact of large-scale diffusion of the technology⁶.

⁴ The Danish Eksport Kredit Fonden (EKF), insuring Danish business and industry against commercial and political risks of financing export projects in uncertain markets, is an important stimulator for the Danish wind power industry.

⁵ Process management aims to offer a solution for managing decision making in networks through designing and managing an interactive process. More information in [Bruijn et al. 2002]

⁶ The study of Andersson and Jacobsson [2000] suggests a methodology to assess whether the present rate and direction of technological change is compatible with the development of a sustainable society, which includes long-term resource and environmental constraints to the diffusion of a new technology. They give an example of this methodology for different solar cell technologies.

9.3 Future research

Since this study has a very broad scope and an exploratory nature, there are many topics for further research to provide better understanding of the financing problems and how to address them.

Technological Innovation Systems theory

The Technological Innovation Systems framework has shown both its theoretical relevance and its practical usability to describe the financing problems in the demonstration phase. However, this study encountered some deficiencies of the framework. Firstly, the framework tends to neglect structural aspects of the technology, which are therefore added as a structural component. Secondly, the relations between the structural components should also be considered, because they can be important for the outcome of the innovation system: technology can often not be changed without changes in institutions and behaviour of actors, actions of actors are limited by institutions and technology and institutions are created around actors and technology. These relations can provide additional lock-in for the system, because more than one structural component has to be addressed to change the system. These deficiencies and some obscurities of the theory discussed in section 1.2.1 could be taken into consideration in future research using the Technological Innovation Systems theory.

Micro-level issues

Micro-level issues of business development and strategic niche management are only discussed briefly in this study and not much work has been done yet on the “Valley of Death” problems for new energy technologies. Some of these issues could be valuable to research more in-depth, e.g. how large is the financing gap for certain technologies in certain regions, how does the private sector perceive the uncertainties and to what extent are the values, goals and perceptions of the public and private parties different? Especially significant are uncertainties for parties and how they deal with them: the arrangements to manage these risks are important for high-uncertainty demonstration projects. A more detailed research on these arrangements and governance structures for the different (mutually dependent) relationships will provide more understanding of the sector, for instance using theories of transaction cost economics and risk management. Also, the role of strategic niche management in new energy production technologies could be studied more elaborately.

More empirical research

Technology-specific issues are important, but this study has only researched two technologies. Therefore, more research is needed to provide understanding of the financing problems of a broader portfolio of new technologies to address energy security and climate change issues. Also, this may lead to more clarification of technology specific characteristics and the general issues of importance for new electricity/energy technologies. It might also be needed to do some more specific work on sub-technologies, e.g. types of thin film PV and concentrating PV.

To be able to provide more specific policy advice, studies into more specific regions or countries are needed, especially when addressing problems of developing countries.

Policy research

For a more concise policy advice an important question is which public financing mechanisms and market formation mechanisms are most suitable for certain technologies or technology characteristics and for certain phases of the technology development sequence.

A short term issue is how the outcomes of this study should be seen in the context of the current negotiations on a successor of the Kyoto protocol and how certain elements of the policy recommendations could be translated to international policy measures.

An interesting issue is the role of the market in these problems: what is the power balance between incumbents and new entrants, how do liberalisation and privatisation influence innovation in the energy market and how can the market be steered to stimulate a change of the energy system? Especially in the light of current mergers in the energy sector and energy market policy discussions in Europe, the relation between innovation and the power balance and financial strength of companies is a very relevant issue.

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A. Public Finance Mechanisms

The different public finance mechanisms to stimulate technology development and leverage private sector investment in technology development are often placed at certain stages of the technology development sequence, as shown in Figure A-1 below. The different public financing mechanisms and the terms used in the figure are explained here.

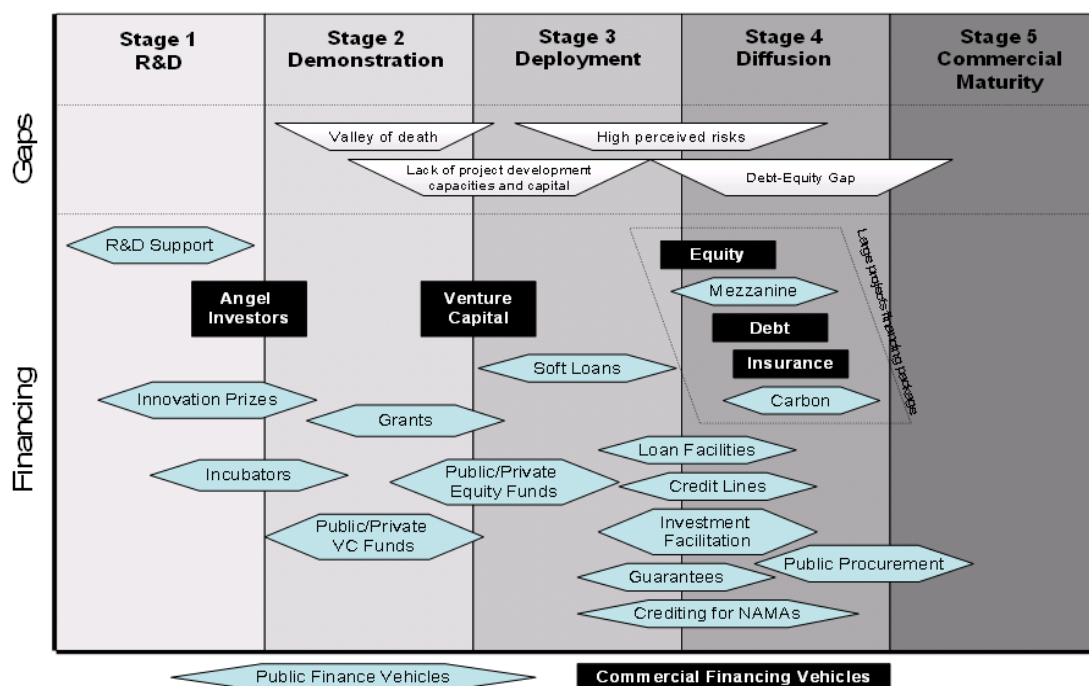


Figure A-1. Public finance mechanisms in the technology development sequence [Haïtes et al.2009]

Mechanisms where the funding from the government is not retrieved in cash:

- **R&D Support:** Support with public money for R&D projects and institutes
- **Innovation Prizes:** Prizes awarded to innovative concepts through contests
- **Incubators:** Organisations where young start-up firms are assisted in their growth process together with other start-ups, where they usually get management support, training and skills and can benefit of the network of other start-ups and the experienced managers of the incubator.
- **Grants:** A certain amount of money granted for a specific purpose or part of a project.

Mechanisms where the funding from the government is retrieved in cash in case of success:

- **Public/Private venture capital (VC) funds:** Equity investments in technology innovations/companies, for which they get a stake in the company or project in return.
- **Public/Private equity funds:** Equity investments in companies and project, for which they get a stake in the company or project in return.
- **Mezzanine finance:** All financing forms between pure equity and pure debt: in case of liquidation, mezzanine investors retrieve their money after the debt holders, but before the equity investors.
- **Loan facilities/soft loans:** Facilities to loan money to companies (provide debt). Soft loans have beneficial criteria for start-up firms, e.g. a longer debt repayment period or lower interest rates.
- **Credit lines:** Credit lines to commercial financial institutions for providing senior and mezzanine debt

Other mechanisms:

Guarantees: Sharing project risk with investors.

Public procurement: Specific policy for the procurement of products and services for its own use, or tendering

Carbon finance/crediting for NAMAs: Financial mechanism related to the trade of Carbon credits and sustainable development in developing countries regarding National Appropriate Mitigation Actions

Investment facilitation: (Advisory) networks and other programs to facilitate investment

B. Summary Interviews

B.1 List of interviewed people

Offshore wind		
Research institutes		
Eeke Mast	Delft University of Technology	PhD researcher at Faculty of Aerospace Engineering, scenarios for offshore wind in the Netherlands
Linda Kamp	Delft University of Technology	Assistant Professor at section of Technology Development and Dynamics, Faculty Technology, Policy and Management. Finished PhD research on the development of the innovation system of (onshore) wind in Denmark and the Netherlands.
Karina Veum	ECN Energy research Centre of the Netherlands	Senior Researcher at the Unit Policy Studies, renewable energy group; offshore wind expertise
Technology & business platforms		
Chris Westra	ECN Energy research Centre of the Netherlands, We@sea	Senior Consultant at ECN Unit Wind General manager knowledge platform We@sea
Andreas Wagner	Stiftung Offshore Windenergie	Managing Director Stiftung Offshore Windenergie, involved in large demonstration project Alpha-Ventus in Germany
Technology developers		
Jan van der Tempel	Delft University of Technology Ampelmann DOT	Associate Professor at section of offshore engineering, Faculty of Civil Engineering, specialised in offshore wind. Director of Ampelmann B.V.: a ship-based platform that provides safe and easy access to offshore structures decreasing the down-time of the turbines by increasing the time slot for maintenance. Started a new project, DOT; in which direct-drive wind turbines pump up water and using water height difference in a hydro plant. Direct drive to reduce copper use and decrease defects, because there is no generator and gearbox.
Eric de Beer	Siemens Wind Power	Technical Project Manager at Siemens Wind Power, developing floating offshore wind turbine
Project developers		
Huub van Rooijen	Noordzeewind Shell	Managing Director at NoordzeeWind (offshore wind park) Manager Wind Power Development at Shell Energy Europe
Johan Dekkers	Noordzeewind Nuon/Weom	Permit Manager at NoordzeeWind (offshore wind park) Head Asset Development offshore wind Nuon
Suppliers		
Ernst Soons	Siemens Wind Power	Technical Project Manager at Siemens Wind Power
René Hendriksen	Darwind	Chief Operating Officer at Darwind, developing new offshore wind turbine

Solar PV		
Research institutes		
Miro Zeman	Delft University of Technology	Professor at the section Electronic Components, Technology and Materials, Faculty of Electrical Engineering, Mathematics and Computer Science. Solar Cell Group, research on a.o. thin film and nano solar PV technology

Laurens Siebbeles	Delft University of Technology	Professor at DCT/Opto-electronic Materials, Faculty of Applied Science. Expert in organic, dye-sensitised and nano solar PV technology.
Wim Sinke	ECN Energy research Centre of the Netherlands	Senior Staff Member at ECN, Unit Solar Energy
John Schermer	Radboud University Nijmegen	Head of Institute for Molecules and Materials, leading the research on high-efficiency III-V solar cells
Technology developers		
Paul de Jong	ECN Energy research Centre of the Netherlands	Researcher at ECN Unit Solar Energy, working on a new module technology with back-contacted solar cells
John Reid	Cedova	CEO and Co-founder at Cedova, a pure play foundry for growth and processing of III-V compounds. Looking for business entrance in production of III-V Solar cells.
Zbigniew Barwicz	Sixtron	President & CEO Sixtron Advanced Materials, a developer of thin film coatings for solar cells
	Nuon-Helianthos	Business controller at Helianthos B.V., a NUON Company developing thin film solar PV cells.
Project developers		
Jan-Cees Jol	Econcern (Ecofys)	Senior Consultant at Ecofys, involved in consultancy for solar PV projects
Investors		
Benno Wiersma	Sunergy Investco	Director Sunergy, company investing in different parts of the solar PV value chain
Solar PV companies in developing countries		
Raouf Saidi	Ecoru Energy Research Centre of the Netherlands (ECN)	Co-owner of Ecoru Researcher at ECN, Unit Policy Studies
Henry de Gooijer	Pico Sol Kamworks	Consultant at Kisol Coach at Pico Sol Cambodia Program manager Cambodia at Pico Sol
Ties Kroezen	Nice International	Managing Director of Nice International

Validation		
Investors		
Hage de Vries	Dutch utility Equity investment fund	Currently senior sustainable business developer for a Dutch Utility, former Fund manager of an equity investment fund specialised in renewable energy project investments.
Eduard Brinkman	Rabobank International	Renewable Energy and Infrastructure Finance, Project Finance and Senior Associate at Rabobank International, specialised offshore wind
	Rabobank International	Manager Renewable Energy and Infrastructure Finance at Rabobank International, specialised solar PV
Policy makers		
Willem van der Heul	Ministry of Economic Affairs of the Netherlands	Policy advisor at the Direction of Energy and Sustainability, Ministry of Economic Affairs of the Netherlands
Ed Buddenbaum	Ministry of Economic Affairs of the Netherlands	Policy advisor at Ministry of Economic Affairs of the Netherlands, specialised in (offshore) wind.
Bert Janson	Senternovem	Senior consultant at Senternovem

B.2 Summary interviews offshore wind

	Actors	Institutions	Technology
Eeke Mast Delft University of Technology	<ul style="list-style-type: none"> -Country government -Wind energy sector: turbine manufacturers and project developers -Technology developers/knowledge institutes -Port authority (not positive in NL) -TSO (grid connection) -Local people -Suppliers -Utilities 	<ul style="list-style-type: none"> -Subsidies, obligations -Licensing procedures -Municipality, 12-mile and exclusive economic zone different. Electricity law only applicable on land → grid connection duty TSO. Preference areas vs. open sea. -EIA procedure, long and sometimes changing -Idea for a one-stop shop now -Rules grid connection 	<ul style="list-style-type: none"> -No grid offshore -Local network capacity often insufficient -Onshore turbines placed offshore -Gearbox weak element of wind turbine -Good wind resources and shallow waters in North Sea area -Extreme weather conditions
Linda Kamp Delft University of Technology	<ul style="list-style-type: none"> -Country government: -Wind energy sector: turbine manufacturers and project developers -Technology developers/knowledge institutes -Local governments (province and municipalities) -Local people -Utilities 	<ul style="list-style-type: none"> -Subsidies, obligations -Licensing procedures -Focus on high-tech vs. reliability 	<ul style="list-style-type: none"> -Danish network more appropriate for decentralised production than the Dutch network -Extreme weather conditions
Chris Westra ECN	<ul style="list-style-type: none"> -Country government -Government agency providing subsidies (NL Senternovem) -Large energy companies → project development -Small project developers -Turbine manufacturer -Insurers -Investment companies -Offshore vessel company (Gusto Msc) 	<ul style="list-style-type: none"> -Subsidies, obligations -Licensing procedures: Municipality, 12-mile and exclusive economic zone different. Preference areas vs. open sea. -EIA tax exemptions -Smart financing arrangements for Princess Amalia windpark 	<ul style="list-style-type: none"> -Different configurations two parks in the Netherlands, Princess Amalia more reliable turbines (smaller) - Forces on the wind turbines and the combined influences with the electricity network have been different than expected; higher. Still a lot of developments possible, maybe to gravity-based, assembly onshore, controlling a total park instead of separate turbines, etc. - Problem with floating is the cables that hang loose and sway; also the whole construction takes more space
Karina Veum ECN	<ul style="list-style-type: none"> -Country government -Large energy companies -EU 	<ul style="list-style-type: none"> -Subsidies, obligations -Permits/licenses needed, differs per country: building, EIA, environmental permits, operation, grid connection 	<ul style="list-style-type: none"> -Extreme weather conditions
Andreas Wagner Stiftung Offshore Windenergie	<ul style="list-style-type: none"> -Country government -Manufacturing companies (not the resources to develop projects) -Public parties -Neutral organizations (knowledge institutes) -Project development company (selling their licenses) -Transmission System Operator, laying cable 	<ul style="list-style-type: none"> -Licensing procedures -Government subsidies -Obligation TSO to make grid connection 	<ul style="list-style-type: none"> -Local conditions at sea: in UK, parks closer to shore and in shallower waters possible than in DL -Very long connection to the onshore grid, (~40 km to island, ~5 km through Waddenzee, ~10 km onshore, in total almost 65 km). 2 different types of turbines and to different types of foundation tested. These choices increase the learning, but also the financial risks
Johan Dekkers Nuon	<ul style="list-style-type: none"> -Dutch government/agency (Senternovem) -Energy company (utility + oil company) -Bank -Offshore company/construction company -Turbine manufacturer 	<ul style="list-style-type: none"> -Licensing procedures -Government subsidies -Obligation TSO to make grid connection 	<ul style="list-style-type: none"> -Extreme weather conditions (salt)
Huub den Rooijen Shell wind	<ul style="list-style-type: none"> -Country government -Energy company (utility + oil company) 	<ul style="list-style-type: none"> -Licensing procedures -Government subsidies -Obligation TSO to make grid connection -Tax exemptions like EIA/MEP/REB 	<ul style="list-style-type: none"> -Capacity local power grid (was problem for NL park OWEZ)
Ernst Soons Siemens Wind power (SWP)	<ul style="list-style-type: none"> -Country government -Turbine manufacturer -Foundation company -Certification company 	<ul style="list-style-type: none"> -Licensing procedures -Government subsidies -Obligation TSO to make grid connection 	<ul style="list-style-type: none"> -Extreme weather conditions -Every project needs separate engineering because of local conditions -Interfaces between different parts of construction (tower, turbine, foundation) important/difficult with different parties
René Hendriksen Darwind	<ul style="list-style-type: none"> -Country government -Sustainable energy company (Econcern) -High-power electrical conversion systems supplier (Convertteam) -Knowledge institute (ECN) -Financial companies -Energy companies (utilities) -Heavy Industry -Existing wind turbine companies 		<ul style="list-style-type: none"> -Extreme weather conditions -Darwind wants to address market niche of turbines for difficult environments. Unique Selling Point: Highest 'earning power' (NPV) for customer (by lowest installation and maintenance cost, highest power production)
Eric de Beer Siemens Wind Power (SWP) Hywind floating	<ul style="list-style-type: none"> -Energy company -Contractors 		<ul style="list-style-type: none"> -Location conditions: depth water, distance from shore. Good climate conditions
Jan van der tempel Delft University of Technology Ampelmann DOT	<ul style="list-style-type: none"> -Country government -Companies offshore sector (contractors) and subcontractors (Ampelmann = subcontractor) -Large energy companies -Companies wind sector -Research institutes (including incubator) -Banks 	<ul style="list-style-type: none"> -Government subsidies -Patenting technology -Licensing agreement with university + agreement to take over patent if technology successful -All kinds of smart agreements with investors, also in natura -Technosprint loans from banks 	<ul style="list-style-type: none"> -Extreme weather conditions: strong forces, only short time windows for installation and maintenance

Respondent	Knowledge development & diffusion	Influence on direction of search	Entrepreneurial activities	Market formation	Legitimation	Resource mobilisation
Eeke Mast Delft University of Technology	<ul style="list-style-type: none"> -Technology development vs. proven prototypes -Tuning wind tech for offshore conditions difficult (stronger wind, waves, salt). There was no offshore wind technology, just onshore turbines placed offshore -Focus on large projects and utilities (NL) vs. do-it yourself (DK) -Three blades vs. two blades -Lack of experience wind sector with offshore -Combination offshore and wind sectors → calculation and design methods did not match at first 	<ul style="list-style-type: none"> -Changing behaviour NL government in licensing -Allocate locations -Responsibility for grid connection not always clear, TSO not responsible at sea. Government decision needed. -Oil crisis + less work in oil and gas for offshore sector -Focus on large projects and utilities (NL) vs. do-it yourself (DK) → three blades vs. two blades -In Dk, obligation for utilities to build wind park 	<ul style="list-style-type: none"> -Licensing and procedures difficult and long -Grid connection expensive and difficult → chicken/egg problem -Cooperative structure in Denmark -Turbine producers busy enough with onshore market 	<ul style="list-style-type: none"> -Subsidies or obligations (Dk) -Grid connection expensive and difficult → chicken/egg problem 	<ul style="list-style-type: none"> -Proven prototypes needed for financing -Oil crisis + less work in oil and gas for offshore sector -Proven reliability Danish turbines stimulated growth 	<ul style="list-style-type: none"> -Costs location: close to shore but government policy -Vessels scarce, critical mass for specialized vessels -Turbine market tight, companies stopping production temporarily. Turbine costs high because of high steel prices -Steel prices for turbines high, who bears risk for rising prices? -Investment and R&D subsidies
Linda Kamp Delft University of Technology	<ul style="list-style-type: none"> -DK: learning by interacting, bottom-up, NL: learning by searching, top-down -Focus on high-tech optimisation or low tech/reliability → three blades vs. two blades -Lot of “experience” knowledge needed because of extreme conditions 	<ul style="list-style-type: none"> -DK: learning by interacting, bottom-up, NL: learning by searching, top-down -Focus on high-tech optimisation or low tech/reliability → three blades vs. two blades -NIMBY problem (in NL large → far from shore) -NL focus always mostly on research, not later stages 	<ul style="list-style-type: none"> -In NL, pilots were done, but first large park took long -Cooperative structure in Denmark → experimenting 	<ul style="list-style-type: none"> -Subsidies or obligations (Dk) -Market formation in NL 20 years later than Denmark → technology stuck in laboratory 	<ul style="list-style-type: none"> -Large energy companies not serious and not interested: NL had own gas, nuclear promise in 70's/80's -Energy companies large political power in NL, former SEP -NIMBY problem: people should participate in projects like in DK -NL local authorities not willing to cooperate in onshore (imposed by central government) -Cooperative structure in Denmark 	
Chris Westra ECN	<ul style="list-style-type: none"> -Offshore industry is learning from offshore wind industry (not the other way around). Offshore industry reacted slow, rich from oil and gas. -Combined forces on turbines and electricity network more complex than expected -Floating: swaying cables difficult problem 	<ul style="list-style-type: none"> -Find solution for driving the poles and the poles left in the seabed after decommissioning: gravity-based -Licensing trajectory still not clear (NL) → areas not assigned -BE: design changed a few times → new EIA, took long 	<ul style="list-style-type: none"> -Small companies developing the project and selling to large companies before construction starts -Not the large but the small private companies made the business large; -BE: design changed a few times → new EIA, took long -Turbine producers busy enough with onshore market 	<ul style="list-style-type: none"> -Tax exemption regulation (EIA, etc.) -Subsidies; feed-inn/SDE etc.. Open end or not. Problem NL: there were only investment subsidies, SDE too late -DK: government does licensing, after that a tender → all public money 	<ul style="list-style-type: none"> -Large energy companies negative role in sustainable energy in NL -NIMBY problem: people should participate in projects like in DK -Not the large but the small private companies made the business large -Offshore industry reacted slow, rich from oil and gas. 	<ul style="list-style-type: none"> -Tax exemption regulation (EIA, etc.) → way to acquire capital -Investment subsidies -Utilities pay for the feed-in tariff → stable money source -Port capacity scarce: many ports not suitable for offshore wind (size) -Vessels scarce, critical mass for specialized vessels -Turbine market tight, companies stopping production -Steel prices for turbines high -Lack of competent workers with technical skills
Karina Veum ECN	<ul style="list-style-type: none"> -Onshore technology placed offshore → difficult with weather conditions 	<ul style="list-style-type: none"> -Limits onshore wind (DK) -Large income and employment from wind sector (DK) -Strong industrial policy (DL) -Government stimulating testing different new technologies (DL) -Positive framework enabled by government (UK) -Bad industrial policy (NL) -BE: design changed a few times → new EIA, took long 	<ul style="list-style-type: none"> -Small companies developing the project and selling to large companies before construction starts -BE: design changed a few times → new EIA, took long -Cooperative structure in Denmark → experimenting -Government stimulating testing different new technologies -Turbine producers busy enough with onshore market 	<ul style="list-style-type: none"> -Positive framework enabled by government (UK) -Bad industrial policy (NL) 	<ul style="list-style-type: none"> -Cooperative structure in Denmark -Large income and employment from wind sector -UK: onshore wind, biomass and hydro potential limited, but very large offshore wind potential -Positive framework enabled by government (UK) 	<ul style="list-style-type: none"> -Investment subsidies -Positive framework enabled by government (UK) -Bad industrial policy (NL) -Turbine market tight, companies stopping production (technical problems)
Andreas Wagner Stiftung Offshore Windenergie	<ul style="list-style-type: none"> -Offshore Stiftung for knowledge exchange -20 R&D projects around the Alpha-Ventus, gathered in “RAVE” -Cooperation 3 companies for Alpha-Ventus → increased learning 	<ul style="list-style-type: none"> -Alpha-Ventus innovative project, at difficult location and with new technologies -Obligation TSO to make grid connection 	<ul style="list-style-type: none"> -Offshore Stiftung to build coalition for first projects -Alpha-Ventus innovative project, at difficult location and with new technologies 	<ul style="list-style-type: none"> -Obligation TSO to make grid connection -Feed-in tariff, first 9 ct/kWh, later 13 ct/kWh with an earlier starters bonus of 2 ct/kWh extra -UK higher feed-in tariff, but grid-connection paid by project developer 	<ul style="list-style-type: none"> -Offshore Stiftung as a coalition to promote offshore wind energy -Cooperation 3 companies for Alpha-Ventus 	<ul style="list-style-type: none"> -Offshore Stiftung to bring parties together for financing -Government financing for the projects of the Stiftung. Grant government for license Alpha-Ventus -Cooperation 3 companies for Alpha-Ventus to share risk
Johan Dekkers Nuon (before Weom)	<ul style="list-style-type: none"> -Feasibility studies for government. Many parties involved → later interested in building park -Good combination Nuon (buying electricity, licenses, electricity/ cables/grid, etc.) and Shell (offshore knowledge, construction, design, technology) -There was experience onshore, but offshore much different (salt, different installation, less possibilities for maintenance, etc.) 	<ul style="list-style-type: none"> -Feasibility studies for government. Study showed positive results. Many parties involved → later interested in building park (like Weom) -Government tender -Nuon needed Green Rights (government obligation) → wanted to buy the electricity 	<ul style="list-style-type: none"> -High risks → long time to cover and allocate, can be barrier for projects 	<ul style="list-style-type: none"> -Government tender -Nuon needed Green Rights (government obligation) → wanted to buy the electricity 	<ul style="list-style-type: none"> -Feasibility studies for government. Study showed positive results. Many parties involved → later interested in building park (like Weom) -Parties judicially objected to the park (Vogelwacht Egmond, Egmond Boulevard) -Nuon needed Green Rights → wanted to buy the electricity -Research showed no harm for birds: they fly around or sit on turbines -Measures to scare away animals before starting to drive the piles (which can be dangerous because of the noise) 	<ul style="list-style-type: none"> -Large companies → own balance finance -High risks → long time to cover and allocate, can be barrier for investment -Special vessels needed (carry more poles → less time for driving piles) but not available in the beginning. Vessels scarce -Turbine market tight -Steel prices for turbines high -Port capacity scarce; many ports not suitable for offshore wind (size)
Huib den Rooijen		-Changing regulation government. E.g. financing	-Licensing procedures take long and can be	-Grid connection	-Hugely rising energy demands, classical oil and	-Licensing procedures take long and can be

Shell wind		→ NL: REB/MEP and Green certificates.	unpredictable (objections) -Grid connection -High risks → can be barrier for projects - Barriers during development phase: •Technology: choice of turbine, installation technology •Permitting: objections of parties (the rest went quite smoothly) •Grid connection to land: capacity local power grid had to be expanded; this was done by the local system operator at their request. •Financing: changing regulation of the government (in the beginning REB, later MEP)	- The economical story behind the park was simple: •They wanted to build a park •It should be economically viable.	gas fields starting to become empty, climate problems -Shell wanted to be involved into the offshore wind sector to know what’s going on -Studies showed that it could be economically viable	unpredictable (objections). Concessions oil and gas very well-known -Changing regulation government (financing → NL: REB/MEP) -High risks → can be barrier for investment - Most important risks: •Market risk: electricity price •Technology: defects •Changing regulation: e.g. “groencertificaten”
Ernst Soons Siemens Wind Power (SWP)	-Every project needs separate engineering because of local conditions -Interfaces between different parts of construction (tower, turbine, foundation) important/difficult with different parties -What is optimal scope for SWP in delivering turn-key solutions? Positive for clients + technical integration possible -Not possible to overdimension poles like in oil&gas single constructions→too expensive for large number of turbine poles -Sometimes R&D projects integrated in project, experimenting new equipment etc.	-Government policy. UK government long-term planning with rounds.NL government changed plans after there were too many offers on the tender→ companies had invested money and lost trust.	-Grid connection -Demonstration projects more difficult; things unknown. Therefore different contracts. -Sometimes R&D projects integrated in project, experimenting new equipment etc	-Grid connection	-NL: changing policy led to companies lost of trust in government -Companies tend to choose same contractors and certification companies → known quality -Experimenting with new equipment only done with regular clients usually	-Different certifications needed; triangle between certification company and foundation- and turbine producers. Lot of information flows -Siemens has its own bank, used for own projects, but sometimes also for clients
René Hendriksen Darwind	-Testing two prototypes at test location ECN -New industry → special vessels and special installation techniques needed	-Government not clear yet about their plans. Two important things: 1) clarity about plans, timelines, tenders, permitting, locations, etc. 2) financial incentives (grid connection, subsidies, guarantees)	-Testing two prototypes at test location ECN - Convincing early adopters / launching customers of their interest in investing in not-yet-proven technology -Question is whether the product will fulfil the expectations and specifications	-Darwind wants to address market niche of turbines for difficult environments -Subsidies government -Offshore wind far more expensive than onshore -Important risk whether market will be found -Market is developing in North-Sea, e.g., UK, Denmark, Netherlands. ROW minor at present	-Darwind wants to address market niche of turbines for difficult environments -Econcern as mother company, Converteam also shareholder -Question is whether the product will fulfil the expectations and specifications and will find a market	-Econcern as mother company → need additional finance -Testing two prototypes at test location ECN -Large amount of working capital needed after demonstration (no revenues yet) might be more difficult than the VoD -Financial crisis makes it difficult to acquire working capital -Special vessels and special installation techniques needed, but scarce (new industry) -Financial incentives government (grid connection, subsidies, guarantees)
Eric de Beer Siemens Wind Power (SWP) Hywind floating turbine	-Uncertainty on economic feasibility -Offshore floating more comparable to onshore. The design of foundations is very different, needs large input from offshore sector knowledge. Operations and maintenance more laborious, but turbine design not much different -Other turbine dynamics, larger distances to shore, and even smaller window of weather conditions for accessibility (O&M).	-Looking for oil and gas alternatives, but in Norway no shallow waters	-Hywind project of StatOil Hydro -Uncertainty whether project is feasible is a barrier	-Uncertainty whether project is feasible is a barrier	-Technological feasibility of the design, installation and operations, incl. maintenance are a driver -Limited area of shallow waters in the world, none in Norway, many deep waters. -Good climate conditions -No visual amenity and impact on environment -Limited oil and gas reserves -Incentives for parties: more technological knowledge, feasibility studies, expanding portfolio.	-Corporate financing by StatOil Hydro
Jan van der tempel Delft University of Technology Ampelmann DOT	-Idea originated from PhD research -New project DOT more difficult because it combines more disciplines -DOT uses less copper and direct drive is less vulnerable -Scale of DOT is much larger		-Started as spin-off from university	-Market niche was both offshore wind and offshore oil and gas	-Benefit for offshore wind sector in increasing time window for installation and maintenance at sea. -Legitimation for DOT; using less copper and direct drive is less vulnerable	-Use of resources university; cheaper services, students to work on design, doing contracting work, etc. -Subsidy from country government -Financing (partly in natura) from different parties; special deals in return -Large amount of working capital needed after demonstration (no revenues yet) might be more difficult than the VoD

Comments:
-Abbreviations of the countries are used. NL = Netherlands, DK= Denmark, DL = Germany, BE= Belgium
TSO=Transmission system operator
NIMBY=Not In My Back Yard
O&M=Operation and Maintenance
VoD=Valley of Death

B.3 Summary interviews solar PV

	Actors	Institutions	Technology
Miro Zeman Delft University of Technology	<ul style="list-style-type: none"> -Large industrial company (Akzo) developing technology -Research institutes (partner in development) -Country government (Ministry of Economic Affairs, Senternovem), providing subsidies -Electricity supply company (Nuon), bought technology developer -Consumer/user 	<ul style="list-style-type: none"> -Research subsidies from Ministry of EA + EOS lange termijn -Akzo's unit bought by Nuon -Clear government policy needed -Consumer subsidy needed -Government policy determines success: differences US, Japan, China 	<ul style="list-style-type: none"> -Partners research group all had own knowledge and infrastructure for that -No existing machines to supply parts (for crystalline silicon, micro-electronics machines could be used) -Feeding back into grid important
Laurens Siebbeles Delft University of Technology	<ul style="list-style-type: none"> -Research institutes -Energy companies (Shell, Nuon), reasons to invest: get IP-right, have feeling of what's happening, contact with graduate students, use of technologies themselves -Large companies (e.g. Philips) -Suppliers (e.g. materials) -Country government (Senternovem) 	<ul style="list-style-type: none"> -Shell/Nuon financing research programs → IP-rights -Research subsidies 	<ul style="list-style-type: none"> -Environment: light degrades many materials
Wim Sinke ECN	<ul style="list-style-type: none"> -Fundamental research institutes: should partly stay independent from private sector. Pressure on them from governments to acquire money from private sector -Private sector: producer cells and producers facilities and machines to produce cells. Solar companies not very large, so difficult position to take large (financial) risks. Strategy depends on many things, their ownership (shareholders), financing, stability, etc. -Institute ECN, bridge between fundamental and private. Steps out of companies if successful. -Country government (Senternovem) -Regional government (EU) -Investment companies (stock market, own capital, venture, large investors) 	<ul style="list-style-type: none"> -IP-rights/patenting. Who gets IP rights in partnerships? -Government policy on financing institutes: money from private sector important for research institutes -Joint research programs/contract work institutes & start-ups -Government funding for large pilot projects; in NL ceilings are low, now trying FES-funding (NL), but never structural. -Private sector sometimes does not want public participation, because they have to give up some rights -International level playing field: also important for government funding. Strong international competition 	
Paul de Jong ECN Developing back-contact solar cells	<ul style="list-style-type: none"> -Research institutes -Country government (Senternovem) -Private parties/solar PV industry -Regional government (EU) -Network system operators -Electricity producers (utilities) and energy companies 	<ul style="list-style-type: none"> -Demonstration subsidies: missing in NL (used to be EET, now EOS, but ceiling too low). Always max. 25-35% subsidy. Maybe change of EOS/FES in future? Germany does have financing for these larger amounts, € 1-10/15 mln. -Certification important for market parties -Dutch or European energy policy/strategy? -Agreements between institutes and market parties in joint projects, like licensing and exclusivity. . -Other way of managing electricity nets needed for intermittent sources and demand. More parties and with different (market) interests to deal with after unbundling. -Feed-in tariff vs. capped subsidy -Privatisation etc. → utilities now market interests 	<ul style="list-style-type: none"> -Meters needed that can actively intervene (smart meters now only observe) -Geographical location impacts technology choices: CPV and CSP only work with direct sunlight, so only applicable to Southern-Europe. Flat-panel PV is the primary technology choice for NI and mid Europe
John Schermer Radboud University Nijmegen	<ul style="list-style-type: none"> -Technology developers (also complementary technologies): companies and institutes -Suppliers parts -Country government (subsidies) 	<ul style="list-style-type: none"> -Relation concentrator and cell producer important--> knowledge spill over and competition problems if one of them partners up with a new party -Vertical integration between cell and concentrator producers -Feed-in tariff or something comparable needed -Agreements for cooperation with private parties, e.g. licensing, starting company together, etc. Not standard 	<ul style="list-style-type: none"> -Principle CPV: large areas of expensive solar cell materials (high purity semiconductors) are replaced with relatively cheap optical components (industrial metals and plastics) -Geographical location: only direct sunlight possible for CPV and CSP
John Reid Cedova	<ul style="list-style-type: none"> -Producers of semi-conductors, concentrators and system integration -Research institutes -Country government (Senternovem) 	<ul style="list-style-type: none"> -Deals with technology developers and other companies supplying part of technology -Cedova is a pure-play "foundry"; designs specifically made for client → no spill-overs -Vertical integration (e.g. Azur) -Subsidy for research and process knowledge. Subsidies often have as a precondition that the companies put in their own capital -Venture capitalists investing in solar PV. If VC, it is easier to get loans from the bank 	
Nuon-Helianthos	<ul style="list-style-type: none"> -Producers thin film and complementary products -Technology developer: large company -Energy companies -Country government (Senternovem) -Regional government (EU) 	<ul style="list-style-type: none"> -Subsidy from government and EU for different programmes -Certification of product important for market -Law on separation networks and production → financial issues, certain debt/equity % demanded for network companies 	
Zbigniew Barwicz Sixtron	<ul style="list-style-type: none"> -Seed-capital investors (small amounts ~ few 100.000 CND) and VC investors (larger amounts). Expected ROI most important, but criteria Europe (focus on technology) different than US (focus on management, market, etc.) -Technology developer -Research institutes + incubators -Country government 	<ul style="list-style-type: none"> -Seed-capital investors -Incubators from research institutes -Current investors shareholders -Canadian Scientific Research and Experimental Development program tax benefit: companies can get certain % back from man-hours on technology research and early-stage development (optimisation and production not included) -Other governmental support for clean-tech market introduction, optimization and/or consumer awareness/activation. Important: new jobs and high value-added jobs? -Canadian VC market like US, but less developed and more socialistic: many small seed funds. Government used to have VC; not anymore -Clean-tech capital markets quite global, maybe because originates from EU but market in US or Asia. 	

Benno Wiersma S'energy Sunergy	-Technology developer/research institute -Investment partner -Utility, not very innovative, reserved (former state monopoly, shareholders local governments) -Large technology company -Angel investors/friends, fools and family	-Decisions top-management company, must allocate money and have belief, continue through bad times -Trying to integrate complete value chain in Sunergy -IP-rights or licence sometimes precondition for investment -For everything that is arranged beforehand, a risk premium is paid -Fiscal arrangements positive (US 100% subtractable)	
Jan-Cees Jol Econcern (Ecofys)	-System supplier (main contractor) and many sub-contractors (often local parties) -Advisor -Project developer -Institutes certifying, testing -Investors (pension funds, investment companies, utilities). In developing countries maybe NGO's -Country governments -Local governments -Debt providers	-Permitting and reports needed for projects -Financial close on a project important; but delays in this close are costly -Good subsidy schemes in several countries (DL, SP), with long-term certainty -Arrangements for allocation of risks → guarantee arrangements with suppliers, certification, testing, etc. -System suppliers try to control whole supply chain to decrease risks -Different regulation in different regions (e.g. in Italy) -Political situation developing/North-African countries can be a problem.	-Offshore wind more technical risks, because of harsh marine environment, difficult accessibility of the turbines and mechanical parts that more easily defect -Infrastructure could become a problem for some countries. Also, more difficult control is needed of the network. Not a problem yet on the short term, e.g. for Germany maybe a problem in the medium term
Raouf Saidi Ecoru	-Company; project developer -Country government of company (NL) -Country government of market (Nigeria) -Suppliers parts -Local entrepreneurs; prefer large quantity of small products instead of large capital-intensive and do not like stocks (also for spare parts) -NGO's, Worldbank, etc. -Banks	-Subsidies from NL difficult: Nigeria no partner country -Free energy foundation -Franchise system; trust and tribal issues very important, so better to have local people -Local entrepreneurs not used to guarantees but they insisted -Instability country and corruption problematic -Nigeria wants PPP, but companies have many risks: safety (kidnapping), destruction pipelines, criminality, etc. -Project in Mali with kind of tender to exploit a specific area, with 80% subsidy -Duties: e.g. in Nigeria not on renewables but on batteries	-Infrastructure in country important: nets, roads, ports, etc. -No grid → batteries needed, which is a barrier (expensive and short lifetime) -Local conditions: urbanisation, demographics (many children)
Henry de Gooijer Kamworks	-Technology company in Cambodia -Foundation for solar energy in developing countries -Funds for subsidies -Consumers; local people -Consumers; local NGO (projects) -Private sponsors, companies and people	-Funds for entrepreneurship in developing countries (e.g. Daey Ouwers fund, Worldbank subsidy, GTZ) -Making people partly owner of the assets of the project -Employees shareholder of the company -Franchise construction for local entrepreneurs -Micro-finance is more targeted at entrepreneurs -VC and PE funds for entrepreneurship in developing countries, network organisation BiD	-Not too difficult technology for developing countries
Ties Kroezen Nice International	-Foundation for sustainable energy in developing countries -Investor (middle-large company) -Consumers -Sustainable energy entrepreneur -Local franchisers -Country government (Ministry of Foreign Affairs, subsidy) -Suppliers of solar systems -Local and international banks	-Subsidy from Ministry of Foreign Affairs -Franchise concept, including leasing -Collateral or steady cash flow needed for loan	-Electricity supply unstable. But there is electricity supply, so difficult to compete with only that -Internet connection unstable

Respondent	Knowledge development & diffusion	Influence on direction of search	Entrepreneurial activities	Market formation	Legitimation	Resource mobilization
Miro Zeman Delft University of Technology	-Research group with combined knowledge -Specialised knowledge on different aspects of system - Nanotechnology crosses all disciplines → cooperation with other groups -Parallel to pilot line, new line of research on 2 nd generation of the technology (adding layer/packing cells, different materials, optimizing total cell) -Machines supply side had to be developed -Contact with industrial partners to bring technology to market sooner -Learning effects through growing network	-Calculations showed costs competing with retail electricity if completely developed - Akzo planned steps: 1) small scale, 2) up-scaling to pilot-line, 3) production. -Efficiency too low → 2 nd generation needed -Building industry as a target market -Stimulating government can help → clear policy. Providing certainty for long term. US used to be same as Japan, because of Bush US slowed down. -Industrial partners to understand the demands of the market -Nanotechnology important in search for the future, basic knowledge on materials	-Pilot line at Akzo (paid by Akzo): rolls made to test and show (not sell) -Search for 2 nd generation technology -Partnerships with industry -Akzo's unit bought by Nuon	-Calculations showed costs competing with retail electricity if completely developed -Subsidies consumers -Niche market = building industry, also international (not direct consumer market)	-Akzo pushing development of their roll-to-roll process -Calculations showed costs competing with retail electricity if completely developed -Rolls pilot line used to show -Building industry as a target market -Pressure from management on group Akzo sometimes -Stimulating government helps (US/Japan) -Modular, up-scaling is easy -People can earn money with it by feeding back into the grid	-Pilot line paid by Akzo + terrain Akzo -Different institutes had resources for part of the technology development -Research subsidies government, EOS-LT -Suppliers machines did not exist (for c-Si, they could use micro-electronics machines) -Financial crisis might be problem for building factory now
Laurens Siebbeles Delft University of Technology	-Research on <u>quantum dots</u> , organic cells, gratzel cells. Nanotechnology can improve characteristics of all materials (light absorption, free excitons, etc.). Trick is controlling nano-morphology, size dots determines colour of light absorption. Fundamental research, product = publications -FOM-research and Joint Solar Program, partly paid by Shell. Sponsoring company could have IP-rights. -Important to get more fundamental knowledge on process of light to electricity for breakthroughs in efficiency. Now development of (organic) solar cells slow; incremental improvements	-Fundamental knowledge needed on how the process of light to electricity works -Controlling nano-morphology, modifying characteristics materials -Search for improving efficiency and stability of materials (before the search was for cheaper materials)	-Konarka Solar, company making organic solar cells (power plastic) -Experimentation with conducting plastics, e.g. in LED-applications (Philishave) -Institutes making organic solar cells: TU Eindhoven, HOS centre in Eindhoven	-Niche-applications: small scale electronics, which do not need much electricity. Also LED-applications (other way around). -Costs c-Si too high, driver for newer generations	+Organic, very flexible like plastic bag. Thin film not that flexible, not rolling up/bending often, etc. +Cheaper (than other solar PV) +Production easy (like plastics) -Efficiency low (problem for needed area, for large scale efficiency must be at least 10%). -Stability materials in sun and air, shorter lifetime (degrading). -C-Si: very pure, expensive production	-Research subsidies government -Large companies investors (Shell, Nuon) -Lack of fundamental knowledge

	-Real breakthrough of organic will take decades, niche markets, now too expensive.					
Wim Sinke ECN	<ul style="list-style-type: none"> -Difference in knowledge between (1) producers of solar cells and (2) producers of equipment to make solar cells -ECN often implements new technology at (1) together with (2), because ECN has knowledge of processes of (1) -Knowledge development in different ways, partnerships with industry important: ECN developing technology and finding private party or joint research program or contract work -Patenting very important for strategic issues companies and institutes -International competition, also for institutes -Testing facilities at ECN or companies, as flexible as possible -Efficiency and stability problem for new generation cells -Crisis: companies cutting on R&D -International competition drives innovation, market-pull, technology push for newer technology -Companies did not used to have on R&D units, now they sometimes do. 	<ul style="list-style-type: none"> -Costs material problem for c-Si -Efficiency and stability problem for new generation cells -International competition strong market-pull; companies have to innovate in reducing production costs and increasing revenues to survive -ECN must use “antenna’s” to understand client’s demands for the longer term 	<ul style="list-style-type: none"> -Testing facilities at ECN or companies, as flexible as possible -A few companies active in organic etc., already acquired venture capital -Ribbon-Growth-on-Substrate (now company); project with private parties. -Crisis: delaying/cancelling projects -ECN often implements new production method/equipment with group (2) at group (1) producers (e.g. if developed together) -VoD indeed difficult to cross for technology developers; often too early for private parties (risks), solar market small parties with low financial strength. Dependent on funding governments (but no large-scale demonstration funding in NL) -International competition strong market-pull to keep on innovating. 	<ul style="list-style-type: none"> -International competition: market-pull -Thin film growing faster than C-Si, will probably obtain market share ~15-30% -Financial crisis affects sector: delay/cancellation of projects, some companies realize that they have to keep innovating. 	<ul style="list-style-type: none"> -Efficiency and stability problem for new generation cells -International competition: market-pull -Utilities now market parties → market interests, not necessarily sustainability 	<ul style="list-style-type: none"> -ECN has good means to test in-house, also to produce at real-life scale in reasonable amounts. Equipment as flexible as possible. -Sometimes testing at partners -Important investors in solar tech: stock market companies, VC, large investors (Good energies, Google, EDF). -If technology not developed far enough, private parties do not want to take the risk -Demonstration phase dependent on government funding, in NL not available for large projects (→ request for FES subsidy) -There used to be a lot of available capital in the US, so venture capitalists were also investing in more risky ventures -Financial crisis effect: companies are cutting their expenses (R&D without directly noticing consequences), planned investments in expansion of production are sometimes cancelled or delayed. For ECN possible new projects sometimes delayed or cancelled. Some companies realize they have to keep innovating. -VC market in US more developed, in EU more risk-avoidant
Paul de Jong ECN Developing back-contact solar cells	<ul style="list-style-type: none"> -Proof of concept + certification is needed to involve market parties -Solar PV companies now have own R&D departments, more difficult for ECN to excel, stay important -Solar was fast developing sector thanks to enormous capital injection but lack of know-how -Many R&D projects never reach market implementation, problem of NL and maybe EU-wide. Developing technology less sexy than research . Development costs are very high in comparison with research. No governmental incentive to support development. -Finding private partners important, agreements needed (e.g. exclusivity) 	<ul style="list-style-type: none"> -Government policy instable because of political changes -Dutch or European energy policy? 	<ul style="list-style-type: none"> -Pilot line back-contacted cells, one of the last benefiting from EET + ECN paid -Certification important for market parties 	<ul style="list-style-type: none"> -Certification important for market parties -Main application solar PV = large scale (power plants, buildings). ECN no focus on small-scale, electronics etc. -CSP and CPV direct sunlight needed → Africa, Mediterranean, etc. -Solar PV intermittency and feeding back problem → changes network needed -Capped subsidy (like NL and SP) problem (caused bankruptcy companies), feed-in tariff more constant, should be decreasing with learning curve. 	<ul style="list-style-type: none"> -Government policy instable because of political changes -Solar PV intermittency and feeding back problem → changes network needed, but coordination problem with many parties -Large energy companies large political power, e.g. in NL they have an influence until the highest levels of the political system 	<ul style="list-style-type: none"> -No government subsidy for intermediate phases (EOS/FES). Always max. 25-25%, rest from collaborating parties. Germany does have a funding structure up to € 1-15 mln. -Industry not able to provide large sums; young market, small parties, high-risk profile and what potential? -Institutes like ECN also do not have the resources themselves -Parties have plans on hold because of crisis -Licensing creates money for new investments
John Schermer Radboud University Nijmegen	<ul style="list-style-type: none"> - III-V solar cells complementary to concentrators, because of high efficiency. Combination of optical and solar cell knowledge (different parties) -III-V cells can be tuned to spectrum, expensive cells but through concentrating you need less material -Concentrators can be based on prisms, mirrors or Fresnel lenses -Rotating system of concentrator is difficult to get maintenance-free 	<ul style="list-style-type: none"> -c-Si materials expensive, concentrating light is a way to largely decrease the use of this expensive material -Search for highest concentration factor possible to optimally use the principle of CPV 	<ul style="list-style-type: none"> -CPV used to be only 2 companies (Concentrix and Solarsystems), now more, financed by angel/venture capital? -Concentrix (spin-off Fraunhofer institute) is doing demonstration project(s) in Spain with subsidies -Solarsystems is active in Australia, also with 2 large-scale systems. -Cyprus has a CPV field co-financed by the German government. -Competition/spill-over issues between concentrator/cell producers makes new combinations difficult -Developing pilot plant different than other plant → parts produced by others -Specific for research group John Schermer: possibly partnership with Cedova, transfer of technology developing III-V cells 	<ul style="list-style-type: none"> -III-V cells until now for space application -Subsidies from governments, also abroad (Germany in Cyprus) -CPV will need feed-in or similar, needs niche market to develop: countries with a lot of direct sunlight, around the equator. -Specific for Suncycle: technology relatively flat, suitable for application on roofs -Market formation thin film: few years ago c-Si scarce → thin film jumped in 	<ul style="list-style-type: none"> -Legitimation CPV: solar cell materials expensive → replace large part of surface of solar cells with cheaper materials through optical concentration of the light -Concentrating PV is expected to be the first system to reach grid parity somewhere in the world 	<ul style="list-style-type: none"> -CPV companies financed by VC/business angels(?) -Availability of needed metals and plastics is important
John Reid Cedova	<ul style="list-style-type: none"> -Experience in semi-conductor products -Making triple junction solar cell is very complicated, tunnel diode with ~20 layers. They need knowledge from e.g. Radboud University to make good solar cells. -Cedova producing solar cells, others concentrator and system integration 		<ul style="list-style-type: none"> -Plans to develop very efficient III-V triple junction solar cells for in concentrator (with Suncycle or other company) -No spill-over or competition issues because Cedova is a pure-play “foundry” -Azur vertically integrated → can put ideas in own systems 			<ul style="list-style-type: none"> -Cedova has most of the machinery themselves to grow the cells -Subsidy is needed for research, the first systems and obtaining process knowledge -Money is mainly spent on man-hours, some on materials and equipment -Own capital is a precondition for subsidy. They are not looking for external finance now.

						-VC's are investing in solar PV. -But: business plan must be sound and good
Nuon-Helianthos (N-H)	-N-H new technology, other TF producers use other processes and materials -Partial product (foil) which can be integrated in building, clothes, etc. -Also developing newer generation TF technology at R&D unit N-H -Continues technology development -Looking for partners to develop product -Utilities not used to these innovations; core business was cables and coal and gas plants (and now wind)		-Other TF producers active, but they use other processes and materials -Nuon wants to build a large production facility (producing 50-70 times more), but the merger process is delaying the decision	-If technology is certified it is easier to sell to the market -Application/niche market is buildings -N-H technology is more risky than more mature technology: more difficult to produce (no existing turn-key production lines) and more risks. N-H has to prove it works and there is a market for it (which costs money and time) -Solar PV market has proven itself, almost doubling each year (although it is a difficult market now with the crisis) -Solar PV expected to compete with retail prices in 2015-2020 (depending on area)	-€7 mln promised subsidy of province Gelderland if factory in their province → economic development & work for province -Unbundling demands of the government lead to less possibilities and willingness to invest in renewables by utilities. -Merger process delaying decision -Solar PV market has proven itself, almost doubling each year (although it is a difficult market now with the crisis) -Oil is running out -Learning curves project the technology to be competing with retail prices on a certain term (although somewhat delayed)	-Subsidies provided reasonable amount of financing. Rest of the money from balance financing. -€7 mln promised subsidy of province Gelderland if factory in their province -Economic crisis also negative for solar PV -Dutch unbundling law: the demands for % equity/debt for the network companies were recently raised by the Minister → less equity for production companies to invest in renewables -Mature technologies have turn-key solutions for production

Respondent	Knowledge development & diffusion	Guidance direction of search	Entrepreneurial activities	Market formation	Legitimation	Resource mobilisation
Zbigniew Barwicz Sixtron	-Government tax benefit on man-hours spent on Scientific Research and Experimental Development -Later phases after seed-funding more difficult	-Government support for clean-tech market introduction, optimization and/or consumer awareness/activation -For government support important that the innovation creates new jobs and high value-added jobs -Government used to own VC funds, not anymore but maybe now (crisis) again?	-Seed-capital easy to find in Canada -Incubators from research institutes, sometimes linked to seed-capital funds -Government support for clean-tech market introduction, optimization and/or consumer awareness/activation -Phase after seed-funding more difficult; no management, no team, no customer feed-back. 5-7 out of 10 die after that	-Government support for clean-tech market introduction, optimization and/or consumer awareness/activation		-Seed-capital, easy in Canada. Also, VC-market more developed than Europe (less than US, more small seed funds) -Other government support (specific) -Canadian SR&ED tax benefit -Important issues for financing (but different focus EU/US): *timing: now bad because of crisis *business plan, with right business model *management; track record *concept proof; must-have or nice-to-have -Clean-tech global capital market, relatively capital-intensive but trendy at the moment for getting government money. -Large amount of working capital needed after demonstration (no revenues yet) might be more difficult than the VoD
Benno Wiersma Sunergy Investco	-Research institutes needed to develop new technology	-Overall leader must really believe in concept -Project- and top management of company must believe in the goal and sufficient money must be allocated -Investment in early stages often by “fools” -Germany believes in solar energy technology	-Dreaming – Thinking – Daring – Doing- Continuing (5 D's in Dutch) -Companies do not dare to take risks (utilities, other large companies). Shareholders reserved -Eliminating uncertainties costs time and money	-New kind of technology → additional risks solar PV: price energy, no commercial market subsidy yet, companies are small so budgets and possibilities to lend money also -Controlling complete value chain to prevent being played away by cheap Chinese manufacturers etc. -Innovation is crucial in this market, to compete with cheaper markets -Do not arrange everything beforehand (long-term contracts), because you pay a risk premium on the price		-These investments: high risk profile, real amount of money needed is at least 2x the estimated amount -Investment in early stages often by “fools” (& friends and family) -“Two legs” of financial basis: building projects and solar energy -Fiscal regulation more positive in US: 100% subtractable from income
Jan-Cees Jol Ecofys	-Ecofys involved in projects because of their knowledge on the permitting and reports needed for such projects -Certainty on technology needed: certain amount of electricity production guaranteed with a certain amount of solar radiation? Panels must be exactly the power (MW) as promised by the supplier. → Sometimes certification or a test institute taking samples needed	- There were good expectations of cost reductions, and now even more. Grid parity expected within 5-10 years in most parts of Europe.	- Many different parties stepped into projects, like utilities, pension funds and investment companies -Most of large projects used crystalline silicon, now also thin film projects. The company First Solar has built large plants of CdTe panels. - In some regions difficult to get through the administrative stuff; procedures are complex. E.g. in Italy regulation is different in each region. Political uncertainties are larger in Southern European countries -It took time to establish guarantee arrangements -There will probably soon be projects in developing countries and countries in North-Africa, several parties are exploring possibilities. Political situation in these countries is often a problem	-Large-scale PV projects developed were very profitable because of good subsidies with 15-20 years certainty (e.g. in Spain and Germany) -Market for solar modules and cells changing very much, prices and lead times used to be very high, but now down again. -System suppliers try to control the whole chain from cells to modules to systems, because then they have more certainty. -If grid parity reached, first the consumer market will move (pay most for their electricity), then the large parties (industry).	-Most important driver for solar PV is classical example of German feed-in tariffs, which stimulated application of solar PV. There were good expectations of cost reductions, and now even more. Grid parity is expected within 5-10 years in most parts of Europe.	-The problem for Econcern was that a large part of the investments for their projects had to be made beforehand. It can take quite long to get “financial close” on a project. Equity/debt rate often 20%/80%, large part of this 20% invested before financial close is certain. Delays in this stage (e.g. because of political problems or permits) can become problematic for the company - Investments into solar PV projects were quite secure: benefits and costs clear, good IRR/NPV possible (e.g. 8%) -First, banks and other parties were afraid to invest in the technology; they did not know the technology and had no knowledge to judge it -Now, investments in PV projects mainly debt. Technology has proven itself and the technical risks can be estimated quite well. Investors willing to use their rules less strictly. -Because of crisis back to old very strict rules, e.g. amount of equity demanded and certainty of the

						subsidy -Infrastructure could become a problem for some countries; changes to the net needed. Not really a problem for NL. Move towards decentralized generation, with two-way traffic. Much more system control needed for this. Installed base much larger in DL, but different opinions if and when this will become a problem. -For developing countries there might be possibilities through financing from NGO's, although there should still be private parties involved
Raouf Saidi Ecoru	-C-Si used because for Thin Film a larger surface is needed -They have different complete systems for rural and urban usage -Capacity building (people and institutions), local technical knowledge (maintenance)	-Business idea based on idea of Free Energy Foundation	-Proof business case with own capital to have good position for acquiring external financing -Franchise system: franchisers get training (also marketing/promoting the systems) -Franchisers want large quantities of small products; not capital-intensive and no stocks. Not used to guarantees -Many risks for companies -Project for powering banks and ATM's through other company -Combinations with business best: <u>mobile phone charging</u> , hairdresser, etc.	-Nigeria niche: large population, very bad condition electricity supply (there is a net, but no supply) -Problem: people not the capacity to pay, and/or variable income and therefore uncertainty → need microfinance -Risks: safety, corruption, crime, instability -Mali poorer, but more stable. Project Mali with tender with 80% subsidy -Import duties on batteries (not on renewables) -Developing countries niche small-scale, developed countries large-scale -Combinations with business best: <u>mobile phone charging</u> , hairdresser, etc.	-Trust and differences between tribes very important → local franchisers -Bad reputation solar because bad previous implementation; unreliable and bad education -Many risks for companies -Is the government engaged in developing infrastructure etc? This means knowledge and positive attitude government. Nigeria wants PPP, but conditions for companies bad (risks, infra). -Mali poorer, but more stability → more solar projects, more NGO's, Worldbank, etc.	-Own capital 5 founders. Most income from projects for NGO's, directly reinvested. Small margins. -Subsidies from NL difficult, Nigeria no partner -Partner with Girasolar to get total system as cheap as possible, larger volumes -Infrastructure problem (connection to grid, ports, roads) -There is a large project for the government; government must take risks of transport and grid connection
Henry de Gooijer Kamworks (Picosol)	-Preferably not to difficult technology -Technical and commercial training of local young people and entrepreneurs	-Idea of development through commercial activities -From commercial viewpoint, companies will have to look at what the people really want -In developing countries, development issues are mainly important (environmental targets are nice-to-haves)	-Local franchise entrepreneurs, different steps towards independence. Shops and carrier cycles -New product in new market difficult -Training of entrepreneurs by foundation Pico Sol -Business in Development network, matching investors and entrepreneurs	-Revenues mainly from NGO projects, only just profitable -Now targeting direct consumer market with small PV products. -New product in new market difficult. Therefore other market needed as support -After sales service needed → therefore local organization -Local people partly owner of project -Competing with other (Asian) products -Local population not much money	-In developing countries, development issues mainly important (environmental is nice-to-have)	-For funding in developing countries, development issues are mainly important (environmental is nice-to-have) -Funding from Worldbank competition, GTZ -Own funding + now employees can become shareholders -Do not want to loan money yet, because the country is still quite unknown, first more experience and capable employees -Local people partly owner of project -Picosol gathers money from donors for projects in Cambodia (built by Kamworks) -Now subsidy from Dutch fund for sustainable energy in developing countries -Capital for shops must come from subsidy; Kamworks financially not very strong yet -VC and PE funds for development (BiD) -Entrepreneurs in developing countries come up with creative ways to get financing
Ties Kroezen Nice International	-Some knowledge solar energy in Gambia (existing company) -Technical problems with systems, caused by bad installation and ignorance of employees -Training of local entrepreneurs (by Dutch technical manager) -Western technology too expensive for developing countries	-Idea/vision from Energy4all foundation	-2 pilots in Gambia. New idea of multi-utility shop with internet, cinema and education -PSOM subsidy specifically for entrepreneurship in developing countries	-Just making energy not a profitable business case → additional application needed to add extra value. Revenues now mainly internet, cinema and education (some recharging mobile phones) -Idea to use a franchise concept, but franchise has to be proven first -Existing electricity supply unstable → competitive advantage Nice -Business case with rechargeable batteries not feasible → Gambians do not want to pay high initial costs for long-term revenues	-Existing electricity supply unstable	-First investment completely Econcern -Second stage also subsidy (60%) from PSOM program -Local franchisers no capital and no possibility to get a loan (no collateral and no steady cash flow)→ leasing from Nice -Also Nice not that much capital → lease construction with supplier -Western technology too expensive for developing countries -High up-front investments problem for people in developing countries

Comments:
-Abbreviations of the countries are used. NL = Netherlands, DK= Denmark, DL = Germany, BE= Belgium SP=Spain
TSO=Transmission system operator
C-Si = crystalline silicon, a-Si = amorphous silicon, TF = thin film
IP-rights = intellectual property rights

B.4 Summary interviews validation

Investor: Transcript Interview Hage de Vries, 20 July 2009

Currently senior sustainable business developer for a Dutch Utility, former Fund manager of an equity investment fund specialised in renewable energy project investments.

What can policymakers do to address the financing problems of technologies in the demonstration phase?

There are demonstration subsidies, but they are often for projects that are scaled back from the final real-life case, for example 1 turbine onshore instead of a whole park offshore. It would be interesting if governments would invest in cases which really reflect the future reality.

However, the main issue with financing demonstration projects is “picking the winner”: the technology with the highest (social, economical, technical) benefits. For private investors, it is about picking the technologies which deliver the highest future benefits in money. Even venture capitalists look for certainties and they have to look for the future value of the technology. This is not a task for the government. Governments can create the right circumstances for investments in new energy technologies by creating a stable (predictable) policy environment.

Guarantees

An interesting option might be for the government to give guarantees for demonstration projects (passive financing), e.g. a guarantee that the investor will get €200.000 of an investment of €1.000.000 back from the government if the project fails. This way the downside risks for investors are decreased. Compared to investment subsidies for demonstration projects, the advantage for the government is that they can keep the cash in their pocket, they only have to spend the money if the project fails. Governments could even ask for a price/interest on the guarantee, e.g. of 2-3% for inflation correction. A disadvantage could be that the guarantee is not hard cash for the project developers, but that is not what it should be used for: it should be used to attract private investors.

Stable home market

Next to giving guarantees, they also have to develop a reliable and stable policy for the future. Important in this respect is to create a stable home market for technology developers. For example, the Dutch wind turbine industry has disappeared as a result of the lack of a stable home market.

Feed-in tariffs/Demonstration vs. exploitation phase

Feed-in tariffs are not leading for demonstration projects, because demonstration projects are often not intended to have many benefits from generating electricity. The value of a demonstration project is in proving the proof of concept for the technology. The technology becomes more valuable when the technology is developed further and the uncertainties are decreased. Therefore it is better to stimulate through the capital expenditures of demonstration projects, market formation is for the later production phase. A stable market formation is important for the expectations of the future of the demonstrated technology. For this market formation it is indeed preferable to have a stable, predictable policy environment. It could help if the mechanism is not financed through the government budget, but for instance through a mechanism like in Germany.

Similarities and differences solar PV and offshore wind

For solar PV, the amount of capital needed for demonstration projects is probably less than for offshore wind which means that there is probably a better access to capital. An investor normally prefers several small investments over one large investment, because then the risk is spread.

However, many of the risk parameters for normal projects are not leading for demonstration projects. For example, a demonstration offshore wind project needs wind to show that it is working, but it is not necessary to place the demonstration project on the very best wind spot, as the project is not intended to produce and sell as much electricity as possible, but to prove the concept of the technology

The investment decision

The investor tries to estimate (simplified):

- The future market of the technology: how many of the products can they sell? This is done with different future scenarios.
- What has to be done (technically) to reach this and how much money will this cost?

Then they have to make the decision whether the future cash flow or the future value of the company that they expect is worth the investment in the demonstration now.

Most investors have the intention to sell the technology in later phases to other parties. The reason to sell the technology is firstly because risk capital investors can use the money from selling a technology or company to finance new projects with potential high benefits. The first party has the greatest risks, but also the greatest potential benefits (Return on Investment), but both risks and

benefits decrease when the technology is developed and sold to other parties. Secondly, exploiting a technology (building factories, realising projects) demands different competences than nurturing a young technology and decreasing its uncertainties.

Expectations of the future of the technology are important for the investors. On one hand, in estimating the future market of the technology, factors involved in legitimization, actors etc. are definitely important, although some blank spots will remain. In estimating the costs, factors like bottlenecks in resources and licensing trajectories are important. However, it is difficult for governments to prepare for possible future projects, because they do not know the future demands for projects. They can make sure that procedures are as transparent as possible.

Investor: Transcript Interview Eduard Brinkman, 27 July 2009

Renewable Energy and Infrastructure Finance (wind), Project Finance and Senior Associate at Rabobank International

Reaction on the conclusions of the research

I follow the main conclusions of the research. My experience is that issues like technical challenges, personnel, availability of materials and costs can often be solved by entrepreneurs. The most important precondition for entrepreneurs to start such a challenging trajectory is a stable investment climate. This is exactly what we have missed in the Netherlands until now. The general comment of entrepreneurs in the wind sector is that there is one certainty in the wind sector: the government evaluates and changes her policy every three years. Since wind projects have an economic period of 10-15 years and need to be structured on expected cash flows, it is impossible to take up the earlier mentioned challenges if the expected cash flows change every three years. Furthermore, there is a licensing trajectory of 3 to 12 years before everything is finished, which demands even more for long term commitments from the government. Even a licensing trajectory as long as in the Netherlands (it would be good if this would be better organised) is workable if the policy does not change; because then a long term planning is possible to make. If you add the above periods you want a horizon of 20-25 years of certainty of government policy for entrepreneurs. In that case an entrepreneur is willing to take up all the other (many) challenges.

Government policy

My vision for a simple but effective policy is to use an unfunded/assessment scheme, which has the advantage of being independent of political colour. In general, governments can change every 4 years which leads to changes of policy depending on a left- or right winged government. Available government funding is allocated to those items that are chosen by the current government, which endangers long term policies.

Through an unfunded scheme this risk can be mitigated because there is no money used from the government budget, the money is cashed through the end users. The proposition could be that each inhabitant has to pay an amount or percentage X extra on the energy bill, as a green or sustainable energy premium. This amount or percentage is set each year according to the costs made for the scheme in the year before and the expectations for the coming year. An authority collects and pays out this money in proportion among the following sectors:

- New technology development and research
- Solar/wind/geothermal/wave/tidal/(4th generation nuclear?)/biomass/bio fuels.

Based on a budget, the amount necessary to reach the 20/20/20 goals of the Dutch/EU government can be determined. I would add another "20" to these goals: such schemes should be maintained for at least 20 years, which makes the scheme politically stable and a long time horizon guaranteed.

The height of the budget can be determined through consultation rounds with the sector, but it is important that the government gradually retreats from the sector as the sector is becoming more mature. Also, the scheme should correspond to the Dutch wind speeds and the height of other schemes in Europe.

A possibility is a government guaranteed floor price. The price is set by the market, but if it drops under a certain level, the government pays the difference from a budget funded by the unfunded/assessment scheme. This way there is normal functioning of the market with flexible market prices, but there is the certainty for investors of a fair minimum price. This is a relatively cheap way to subsidise without really influencing the functioning of the market. The minimum price should be sufficient to finance projects.

Investor: Transcript financing specialist from the Rabobank, 13 August 2009

Manager Renewable Energy and Infrastructure Finance at Rabobank International

Conclusions

The conclusions are a good indication of the problems of financing of new energy technologies. Financing of new technologies is difficult because you want a certain degree of certainty as an investor. A large existing company with a good financial position can do some R&D and development themselves for their own risk. For offshore wind project finance is becoming more common, for which

you need more certainty about the project, also on a longer time horizon of 15-20 years. However, the current offshore wind projects have not even been operating for that long. Especially with new technologies and new small companies developing the technology, the financing is more difficult, because they cannot give guarantees easily. E.g. a large company like Siemens can develop new floating offshore wind turbines, but technology from a small company like Bard is more difficult to finance.

Other aspects and barriers are indeed important: some technologies fall just outside of subsidy categories (e.g. tidal, some forms of bio energy), licensing and grid connection procedures and capacity of the network, objection procedures of foundations of interest groups (which get subsidy from the government in the Netherlands), etc. There are differences between countries, licensing procedures are difficult in the Netherlands and Italy but more easy in Belgium and Spain. Subsidies in the Netherlands are behind of other countries and the solar budget is too small for large-scale projects.

The uncertainties for solar PV are indeed smaller than for offshore wind. A solar panel is quite straightforward and there is usually only one party developing the project under one contract. For offshore wind the risks are larger: there are limited time slots for building because of the weather, you never know the hardness of the sea bottom, the turbines are damaged by salty air and water, etc. Also, there are several building contracts with different subcontractors, which makes it difficult to determine who is responsible for defects: there is always a gray area between the different guarantees. Also, the availability of vessels for construction is a risk if a vessel drops out (e.g. broken crane for the Q7 park).

Rabobank

Lizette's unit is focussed on financing of renewable energy, and their opinion is that for this sector you have to take the risk of new technologies, their strategy is focussed on innovative technologies. They have a large knowledge centre with specialists for different technologies (solar, wind, bio) and technology advisors. They sometimes even provide mezzanine capital with more risk, because they have specialists that can judge the technology.

Policy

It would be very useful if the government could give a kind of guarantee for projects with new risky technologies. However, it is difficult how to distinguish the good projects from the "golddiggers". Maybe a team of engineers/technology advisors could decide whether a technology should be able to get the guarantee. A guarantee is needed for technical issues, like lifetime and output of the technology. Price risk is something that investors can handle themselves.

Policy maker: Transcript Interview Willem van der Heul, 20 July 2009

Policy advisor at the Direction Energy and Sustainability at the Ministry of Economic Affairs of the Netherlands.

The Ministry's policy

Companies can request subsidies at the Ministry's executive body Senternovem, for innovative projects mainly the EOS program, but this is mainly for technology production and not for technology application projects. It is partly true that the current subsidies are not very applicable for demonstration projects, especially for thin film technologies. But newer solar PV technologies like thin film seem to be not advanced far enough for these projects: the technology developers are still busy with the production process, improving the process, the stability of the materials, etc. There is a new program to be installed under the "Innovation Agenda" of the government, worth 9 million euros of subsidies. One of the goals is to help technologies to get out of the "Valley of Death" and the program will also address large projects.

Non-conventional applications of solar PV technology

Thin film technologies are at the moment mostly used in conventional applications in the Netherlands, not in more flexible applications (exception is Weka). There is also much to do in non-conventional application of conventional technologies. More difficult projects than simple installation of a few panels on a roof face the problem that the capabilities of Dutch contractors (design, installation, architects) are often insufficient. There is not enough knowledge, capabilities and knowledge exchange. The Dutch sector is not as advanced as the German sector for example. So actually most of the problems sketched in the research are also partly relevant for conventional technologies.

Policymaking

Just having a market formation mechanism like the SDE in the Netherlands is not sufficient (also, SDE is only into place for the second year and its size for solar PV is small, only 25 MW). Mr. van der Heul is familiar with the Innovation Systems theory, but policymaking itself is usually more ad hoc and not so much theoretically underpinned. Senternovem does some more work on the theoretical foundation of policymaking. He recognises most of the issues mentioned by the 6 functions, but many of these issues are already addressed through policymaking based on experience. From his experience, he acknowledges that these different aspects have to be addressed. The EOS program sometimes has too much of a technological/engineering approach, while it is difficult to really diffuse

the technology into the minds of the people deploying the technology. Solar PV is a more difficult technology than solar thermal, because more things can go wrong with the technology.

The conclusion that technology-specific policy is needed is also true. Until 2000-2001 there were specific programs for technologies, including R&D, feasibility, demonstration, courses, folders, etc., with large budgets and separate groups of people working at the different programs at Senternovem. After this a rationalisation took place, in which it was also concluded that the technology programs led to too much fragmentation. The new program was “Duurzame Energie Nederland” (DEN) and later EOS, which are application-specific, e.g. sustainable energy in the built environment. This has led to attenuation and fragmentation of the technology knowledge; there are hardly any specialised solar PV employees. The Ministry used to be involved in a broad solar PV technology program of the IEA (PVPS), but now they are only involved in a few of the topics of this program (motivated by reasons of focussing and prioritising), which has led to a loss of knowledge for the Netherlands in some areas. The new innovation program can be seen as a sort of revival of the technology-specific policy, there will also be programs for wind and other technologies.

Policy executor: Transcript Senternovem, 31 juli 2009

The main conclusions of the report are clear and understandable. Many of the aspects mentioned in the policy advice and the theoretical background of technological innovations are recognizable from practice. However, in practice it is sometimes difficult to follow this kind of policy recommendations strictly because there is a lack of time to implement them and political issues play a role (e.g. the SDE scheme in the Netherlands is surrounded by political discussions). It is true that other aspects than purely financial issues are important: the actors should be mapped and a balanced strategy is needed to approach these actors.

Senternovem has just sent a proposal for the new innovation program for solar energy to the Ministry of Economic Affairs, which contains several important goals:

- Involving market actors who are not much involved now, like banks, private investors and insurers.
- Taking away technological bottlenecks, especially in the built environment, which is an important market because of the soon expected grid parity (households pay higher tariffs than industries). There are many activities taking place in the Netherlands (e.g. with the SDE scheme), but uncoordinated without standards. They want to standardise and certify installation of solar PV systems, with a special focus on integration in the building structure and cooperation between the different parties involved in the system. They prefer initiative from the installation companies themselves for this (through the sector association UNETO-VNI), the government can facilitate it.
- Stimulating demonstration projects, especially with building corporations, through an investment subsidy. The existing built environment is a far greater market than the newly built environment (which is only 45.000 houses a year). SDE subsidy is not very suitable for demonstration projects; payback times are long and uncertain. Included in the budgets for the investment subsidy are not only the panels, but also costs of the project management with the different parties, e.g. architect, installer, etc.
- Stimulating the combination of technologies, e.g. through smart grids, which is more aimed at the future.
- It involves all kind of activities like workshops with different actors, focused on technical aspects but also other aspects, like juridical aspects: are there regulatory bottlenecks or gaps?

The innovation program actually presents a more technology-specific approach (solar, wind, biomass, etc.). The disadvantage of generic policies, especially for solar PV, is that it tends to aim at the more cost-efficient technologies on a short term (e.g. wind and biomass).

C. Actor analysis offshore wind and solar PV

This actor analysis describes the visions, goals and resources of the different actors involved in the TIS of offshore wind and solar PV. Often these actors are the same for both technologies, but there are some specific actors for each technology and differences within actors, which is discussed with the specific actors. Sometimes one physical actor can incorporate several of the actor groups described here.

Public authorities

International authorities (UNFCCC)

Resources: capital and legislation of its different member countries

The UNFCCC strives for “*enhanced action on the provision of financial resources and investment to support action on mitigation and adaptation and technology cooperation*” [UNFCCC 2008a 1e]. Therefore, the UNFCCC is dedicated on financing of technology development and it is the “problem owner”.

>Critical (*important and irreplaceable resources*) and dedicated

Regional government (EU)

Resources: capital, legislation, knowledge of low-carbon energy technologies.

The goal of the EU is “*peace, prosperity and safety for its 498 million citizens- in a fairer, safer world*” [EU 2009a]. Concerning energy, it strives for a secure and sustainable energy supply and has the aim to obtain more than 50% of the energy for power generation, industry, transport and the home from carbon-free sources [EU 2009b]. In Europe, the EU capital constitutes an increasing part of the public finance of technology development and a large part of country legislation originates from the EU. The EU is the front-runner in climate change policy and has large resources in terms of capital and knowledge on low-carbon energy technologies (of its member countries).

>Critical (*important and irreplaceable resources*) and dedicated

Country governments

Resources: capital, legislation, permitting, infrastructure, impact on social issues and influence on public opinion.

Offshore wind: The country governments in Europe have ambitious targets for reaching a more sustainable energy supply. They also strive for economic development of their country and therefore want knowledge and business development in their own country. The countries have different policies and targets for solar PV and offshore wind, depending on the political environment, the (geographical) potential in the country for the two sources and the potential of a growing industry providing income and employment. The country government is also very important for the complementary infrastructure, like roads, ports, communication infrastructure, etc.

>Critical (*important and irreplaceable resources*) and dedicated

Solar PV: Since the scope of solar PV is global, the differences between country governments are larger. Their goals are the same, but there are large differences in political targets, capacity of governments and situation in the country. Infrastructure (electricity and complementary) can be a huge problem in less developed countries for entrepreneurs and the government’s willingness and capacity to improve it are important. The same counts for all kinds of social issues, like stability, safety, crime, corruption, capacity of companies and institutions, etc.

>Critical (*important and irreplaceable resources*), some dedicated, some not

Local governments (provinces, municipalities)

Resources: capital, permitting, local infrastructure and influence on local social issues and public opinion.

The local governments want economic development of their region or municipality and they also have certain sustainability goals. Knowledge development and business activities are ways to stimulate economic development, but they also want to prevent damage to the local environment. These resources are important: the amount of suitable locations is limited (especially for offshore wind in the smaller countries), so local permits and cooperation is needed. Some local governments are more dedicated to stimulating low-carbon technologies than others, again depending on politics and local potential for electricity generation and business development. However, if their region is targeted as a potential location for large projects, they become dedicated.

>Critical (*suitable locations limited*), some dedicated, some not (*dedicated at least in case of large project*).

Project developers

Examples: Wind: utilities (Nuon, Vattenfall, Dong, EWE, E.On, Eneco), other large companies (Shell), small project developers (E-connection, E-concern, Weom). Solar: vertically integrated firms and system suppliers (Phoenix solar, First Solar, OptiSolar, Arco energy), utilities with obligations (e.g. California)

Resources: capital (large companies), knowledge on different aspects of project development, employees having knowledge and skills to develop projects, network of relations with other companies,

Project developers want to develop profitable offshore wind or solar PV parks to stimulate their growth and profit. Therefore they lobby for a clear and stable government policy with financial stimuli and a more easy permitting process. The developer of a project can be different kinds of entities (including a consortium). There is an important difference between large and financially strong companies (utilities, oil and gas companies, large project developers) that can use their corporate finance and smaller companies that have to rely on project and non-recourse financing. For the large companies it is a combined question of whether the project will be profitable (including subsidies, benefits of knowledge development, etc.) and the risks are not too high and whether it fits to the company's strategy. For small companies, the financing problem is larger, because they rely on external investors which they have to convince of the profitability of the project and controllability of the risks.

>Critical (important, only replaceable if many project developers), dedicated.

Research network

Technology developers

Examples: Turbine manufacturers (Vestas, Siemens Wind Power, REpower, AREVA Multibrid, Darwind), solar systems (or parts) developers (Solland solar, Scheuten solar, Suncycle, Sixtron, Nuon-Helianthos etc.)

Resources: capital (large companies), knowledge (explicit and tacit), patents, (dedicated) machinery.

Technology developers are looking for ways to develop new technology or improve existing technology and bring this to the market. They need possibilities for experimenting and a growth of the installed base for cost reductions of the technology. The development of new technology usually starts in either a research institute or a large company. In the former case, the aim of the technology development is more a general advancement of society, while large companies are mainly focussed at earning money with the technology and creating competitive advantages. Large companies participate in research projects to get IP-rights, have feeling of what's happening, get in contact with graduate students or prospects of using the technologies themselves. The technology developed by research institutes usually transfers to either existing (large) companies or newly created spin-off companies. Financing can be a problem and therefore they demand for (more) public financial support, but the financing problem is larger if the technology starts at a research institute. This is where the Valley of Death problem is largest; the institute does not have the money for a demonstration project and needs to look for private parties that want to invest in the technology.

>Critical (important and irreplaceable resources) and dedicated.

Research institutes

Examples: Universities, ECN, Risø, IEA, Fraunhofer Institute.

Resources: knowledge, influence on public opinion.

The interests of knowledge institutes are firstly knowledge development and dissemination, and secondly their own continued existence and growth. Their vision on the situation is mixed, depending on the outcomes of their research on the advantages and disadvantages of the technology. The role of knowledge institutes can be different; some are more aimed at fundamental research, others on applied research. Research institutes can be driven away from fundamental research if the pressure to earn their own money through work with the industry becomes too high.

>Not critical (many institutes, only prominent institutes and technology developers critical), dedicated

Contractors, sub-contractors and suppliers

Examples: main and sub-contractors (OW: foundation, tower, turbine, cabling, transformation station, SPV: total system, cabling), suppliers (OW: turbines, towers, cables, foundation, transformation station, etc. SPV: materials, cells, balance of system parts, etc.)

Resources: knowledge, materials, equipment

The main contractors, sub-contractors and suppliers want growth and profit through selling their product or service. They want to do so with the least risk possible so they are cautious in giving guarantees. They can experience problems of scarcity of finance and they also need growth of their market for cost reductions. Contractors and suppliers that have new technology also need possibilities for experimenting with their (complementary) technologies.

> Only scarce suppliers (offshore vessels, turbines, silicon) critical, all dedicated (expansion of their market)

Electricity network system operators

Examples: Transmission network operators (Tennet), local system operators (Alliander, Enexis)

Resources: network, capital, knowledge on network construction, operation and maintenance

The task of the electricity network operators is to have reliable transportation networks with sufficient capacity. The network companies are important to provide the infrastructure with sufficient capacity and grid-connection. Feeding electricity back into the

grid is a difficulty for them to control their infrastructure, especially with small-scale intermittent sources, which is why they are engaged in the developments around renewable energy sources. In Europe, the network operators are government-owned companies separated from the production and supply companies. In other countries the production, transmission and supply are still integrated in (government-owned) monopolies. Therefore, governments in most countries control the network companies.

>Not critical (important resources, but controlled by government), dedicated

Users/consumers

Users large projects: utilities

Examples: Nuon, E.ON, Vattenfall, Eneco, EWE, Dong

Resource: existing base of consumers, electricity transport contracts

The utilities want growth and profit through supplying their customers with cheap and reliable electricity. Their vision on offshore wind and solar PV is mixed and differs among the companies. On one hand they might need them to meet renewable energy targets from the government and for their corporate image. Offshore wind is cheaper than most other renewable energy sources and can be important for them as an energy source for the future. However, especially in countries with a lot of sun solar PV can also become an interesting energy source. On the other hand, utilities have vested interests in the existing fossil energy supply which is cheaper and the intermittency of wind and solar energy makes it more difficult to ensure a stable electricity supply. A Power Purchase Agreement (PPA) with an entity buying the electricity (normally a utility) is usually a precondition for project financing. However, the large energy companies usually have strong political power which originates from their former state monopoly function, like the Dutch utilities which used to be gathered in the “Samenwerkende Electriciteits Productiebedrijven”, closely related to the government

> Not critical if free market (numerous utilities), critical if monopoly. Some dedicated, some not.

Consumers (residential, industrial, business)

Resources: choice for electricity supplier (and therefore influence on this supplier), vote in elections.

The end consumers of electricity want a cheap and reliable electricity supply and some want a sustainable electricity supply. Their vision is mixed; some of the people are advocating offshore wind and solar PV, others are objecting it. Therefore, it is important to take care that the general opinion on offshore wind and solar PV is positive. For offshore wind the end consumer is not very important (sales through utilities), but for solar PV small-scale systems for end consumers are an important part of the market. For these end consumers, pay-back periods and subsidies are important. For solar PV industrial and business consumers are also important, who can use solar PV for their own electricity supply. The difference with residential consumers is that they might have additional benefits from the solar electricity supply in the form of corporate image, but their choice might be based even more on economic than idealistic considerations. In developing countries the pure consumer market is difficult to reach, it is better to find small businesses that have high added value from the solar energy.

> Critical (solar PV), not critical (offshore wind), not dedicated (in general, small part of their life/business)

Intermediate consumers (solar PV)

Examples: Building corporations, building project developers.

Resource: choice for a solar PV system or not.

Another important consumer group to consider for solar PV is intermediate consumers that do not consume the electricity themselves but do have the choice for a solar system: companies developing buildings and renting them to consumers. The difficulty with these consumers is that the investor in a system is not getting the revenues of low energy costs, the renters or buyers are. However, part of the investment will be earned back by them through a high price of the buildings. More and more of these parties are starting to invest in solar PV, for these benefits and their corporate image.

>Critical (huge PV potential in built environment, large volumes of buildings), some dedicated, some not.

Financial partners

Debt providers

Examples: banks like Dexia, Rabobank, BNP Paribas, KBC, Société Générale, Triodos bank, Worldbank

Resource: capital

Debt providers want growth and profit from providing loans with as low risk/uncertainty as possible. New technologies are usually too uncertain for them; they want at least a proven prototype and business plan. For solar PV in developing countries debt providers can be very important to provide consumers with the capital to buy a solar system (e.g. micro-finance). There are debt providers specifically for entrepreneurship in developing countries

> Not critical (numerous debt providers, other financing sources in early stages), critical for solar PV systems in developing countries, not dedicated.

Equity providers: angel and venture capital and other investors

Examples: angel/venture capital (Econcern in Darwind, Prokon Nord in Multibrid), large companies developing technology (Siemens, Vestas, REpower), other investors (IKEA), funds and foundations for developing countries (NCDO, CleanTech fund, Worldbank, Picosol)

Resource: capital

Angel and venture capital providers also strive for growth and profit through return on their investments. They also want to minimize risks and uncertainties, but take larger risks than debt providers. Angel investors take the largest risks, but they often invest in businesses which have their personal interest, like sustainable development. The attitude of investors differs per region; in the US and Canada they are less risk-avoidant than in Europe. Also, European investors seem to be more focussed on the technology, while in North America they focus more on the management, timing, etc. Other investors can also be important, like with wind and offshore wind: investors are interested in the tax benefits of sustainable investments. In the Netherlands, companies like IKEA invested in (offshore) wind projects and they could subtract these investments from their taxable income with very beneficial provisions like the EIA and VAMIL tax regulation. However, they are usually only willing to do low-risk investments, e.g. the Princess Amalia wind park in the Netherlands had a construction in which they stepped out of the project before the risky period of construction started. For (offshore) wind technology development, the critical investors were mainly (large) companies developing the technology themselves. Solar PV relied far more on external financing, because many technology developers started as small companies. For financing of projects, the large companies (mainly utilities) have been most important, although lower risk projects are also financed by banks and other investors. There are special venture capital and private equity funds for entrepreneurship in developing countries. In developing countries projects can often also get subsidies or gifts from all kinds of foundations.

> *Critical (risk capital market is scarce), not dedicated (OW and SPV not their only business)*

Societal groups

Wildlife and nature groups (offshore wind)

Examples: Greenpeace, WWF, Milieudefensie, Royal Society for the Protection of Birds

Resources: influence public opinion, appeal procedures of permitting process

The wildlife and nature groups want protection of the nature and wildlife and therefore also development of sustainable energy. However, sustainable electricity production units should not harm the environment. This is mainly a problem for (offshore) wind: turbines hitting birds and sea-life affected by installation. For these groups an Environmental Impact Assessment (EIA) and (compensating) measures are important and through a good design and location birds are protected.

> *Critical (large influence on public opinion, delay or block projects), dedicated*

Local interest groups (offshore wind)

Examples: Egmond Boulevard, Lilbourne action group against the wind farm, Windstop.

Resources: influence public opinion, appeal procedures of permitting process

Local interest groups are protecting their surroundings from all kind of things that can negatively influence these surroundings (sometimes also called "Not-In-My-Back-Yard"), like pollution and other inconvenience including visual amenities. Many of these groups object to the construction of (onshore) wind turbines, which was a reason for offshore wind. However, they also object to parks within visibility range of the shore.

> *Critical (large influence on public opinion, delay or block projects), dedicated*

Port authorities, defence and fishery (offshore wind)

Resources: lobby power, appeal procedures of permitting process, influence public opinion

Port authorities want economic growth of their port and therefore want to protect the sea around the port as dedicated area for shipping. In the Netherlands, the port authority is putting a severe constraint on the locations for offshore wind parks by demanding a wide range between navigational routes and offshore wind parks. Their lobby is very strong because the growth of ports is important for economic growth. The same counts for the defence which need areas for their trainings and the fishery sector which needs areas to fish.

> *Critical (strong lobby power), dedicated*

D. Example of institutional complexity: comparison of the two Dutch offshore wind parks

To show the complexity of the development of offshore wind parks and the variety of different arrangements that are possible, it is interesting to compare the two offshore wind parks in the Netherlands: OWEZ (formerly Noordzeewind) and Q7 (Princess Amalia). They are in many ways different, including technology, regulation, arrangements and financing. Table D-1 summarizes the main characteristics of the two parks.

Table D-1. Main characteristics of OWEZ and Princess Amalia offshore wind park in the Netherlands
[Shell Nederland 2005][Phijffer 2007]

	OWEZ	Princess Amalia
Installed power	108 MW	120 MW
Turbines	36 x Vestas 3MW V90 _ 108MW	60 x Vestas 2 MW V80 _ 120 MW
Distance from coast	10 – 18 km (mainly within 12-mile zone)	23 km
Water depth	18 m	19 - 24 m
Electrical network	3 cables from park to onshore transformation station	Offshore transformation station connecting turbines; 1 cable to shore
Main subcontractors	Bouwcombinatie Egmond (Vestas en Ballast Nedam 50/50)	Turbines: Vestas Foundation: Van Oord
Financing	Balance	Project
Total investment costs	Appr. €260 million	€383 million
Financing	Shell 50%, equity Nuon 50%, equity	Equity and subordinated debt of sponsors (Q7 Holding and Eneco) Senior debt €189 million (9,5 year) €30 million contingent debt
Government support	- EIA and VAMIL, net benefit 14 million - CO ₂ capital grant €27,2 million for construction costs from government - MEP €0,097/kWh	-MEP subsidy per kWh -EIA and VAMIL

OWEZ (formerly Noordzeewind)

Sources: interviews, [Noordzeewind 2008][Runge 2009]

OWEZ is a joint venture of the energy companies Shell and Nuon initiated by the small wind energy company Weom (which is now part of Nuon). The joint venture won a competitive tender from the government for the location and subsidy. The project was financed fifty-fifty from the balance of the two companies. They founded two new companies, Noordzeewind B.V. and Noordzeewind C.V. The B.V. company is for running the project and the C.V. is there for tax benefits like EIA and VAMIL: the companies were not allowed to subtract investments into the B.V. from their revenues, but they are for investments in a C.V. company, because it is “judicially transparent”. Therefore, all the payments and contracts were administrated through the C.V. company.

The project includes a Monitoring and Evaluation Program (MEP) to generate knowledge for the development of offshore wind in the Netherlands. An Engineering, Procurement and Construction (EPC) contract is in place between NoordzeeWind and Bouw Combinatie Egmond (BCE), which is a project joint venture of Ballast Nedam and Vestas. The EPC contract is a turnkey contract, in which BCE is responsible for the whole design and construction of the park, except for the onshore grid extension and the data assessment for the MEP. The turnkey includes guarantees with fines in case of unexpected defects. All other parties involved have been sub-contracted (SC) by BCE. There is a Power Purchase Agreement with Nuon. Figure D-1 shows all the relevant parties in the project.

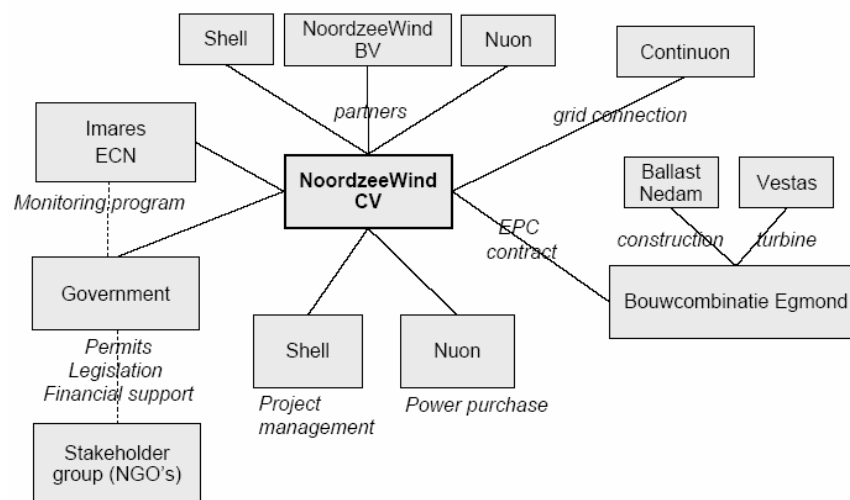


Figure D-1. Parties involved in Noordzeewind [Noordzeewind 2008]

Princess Amalia (formerly Q7)

Sources: [Phijffer 2007][Runge 2009]

The Princess Amalia park is in many ways different from the OWEZ park. The project was not started by the government, but a private party: E-Connection. Also, it is outside the 12-mile zone, which means other regulations of the Exclusive Economic Zone are applicable. E-connection thought it was a chance to get permits while there was not yet much regulation for this zone. E-connection sold the project to Evelop (Econcern) before realisation. It was owned and developed by Econcern N.V. and Energy Investment Holdings N.V. (EIH) (which is now part of Econcern), through the joint venture Q7 Holding B.V. and Eneco Holding B.V. Eneco has taken over Econcern's part of the project after the bankruptcy of Econcern. Vestas has a warranty, operations and maintenance contract through a bonus malus system, which enables the project owners to repay the debt even in case of lower availability than expected. The electricity is sold to Eneco, through a power purchase agreement (including subsidy per kWh).

There is a very difficult construction behind the financing of the project. It is the first offshore wind project in Europe that is financed through project financing, with a combination of equity, subordinated debt and senior debt. A special construction of structured financing is used for the equity and subordinated debt part of the project. This was a tax-driven structure in which investors were invited to do initial investments in the project with the possibility to exit through a put-option before any commercial risks were relevant in the project. Through this construction investors (e.g. IKEA) could generate tax savings because they could subtract these investments from their corporate income through the VAMIL and EIA regulations.

The project was split into three Project Partnerships (see Figure D-2) to maximize the tax benefit because the EIA and VAMIL had ceilings of about 100 million Euros of investments. All the limited partners were first owned by Triodos and Fortis. In 2004 and 2005 the limited partners of Telltale and Etesian were bought by the two different investors who reacted to the offer. Through a put option with a pre-agreed price that they had with the Q7 Holding, they sold the limited partners again to Q7 Holding in May 2006. Eneco stepped in to the project with an investment in the limited partners of Kaver in July 2006, also generating substantial tax benefits from this. For the senior debt it was the first offshore wind park with non-recourse financing. The main partners were BNP Paribas, Rabobank, Dexia Cr dit Local and Eksport Kredit Fonden (EKF). Next to the senior debt there was a contingent debt of  30 million from the senior lenders and  30 million contingent equity from Eneco to cover cost overruns or delays.

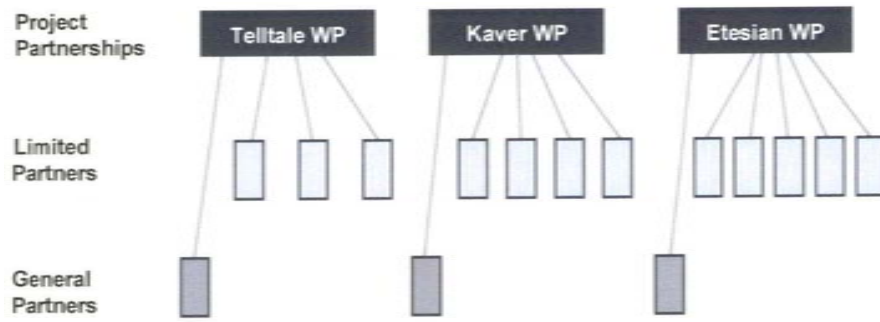


Figure D-2 Construction of partners in the Princess Amalia wind park [Phijffer 2007]

E. Functional pattern TIS offshore wind and solar PV

Table E-2. Explanation of relations in the functional pattern of offshore wind and solar PV

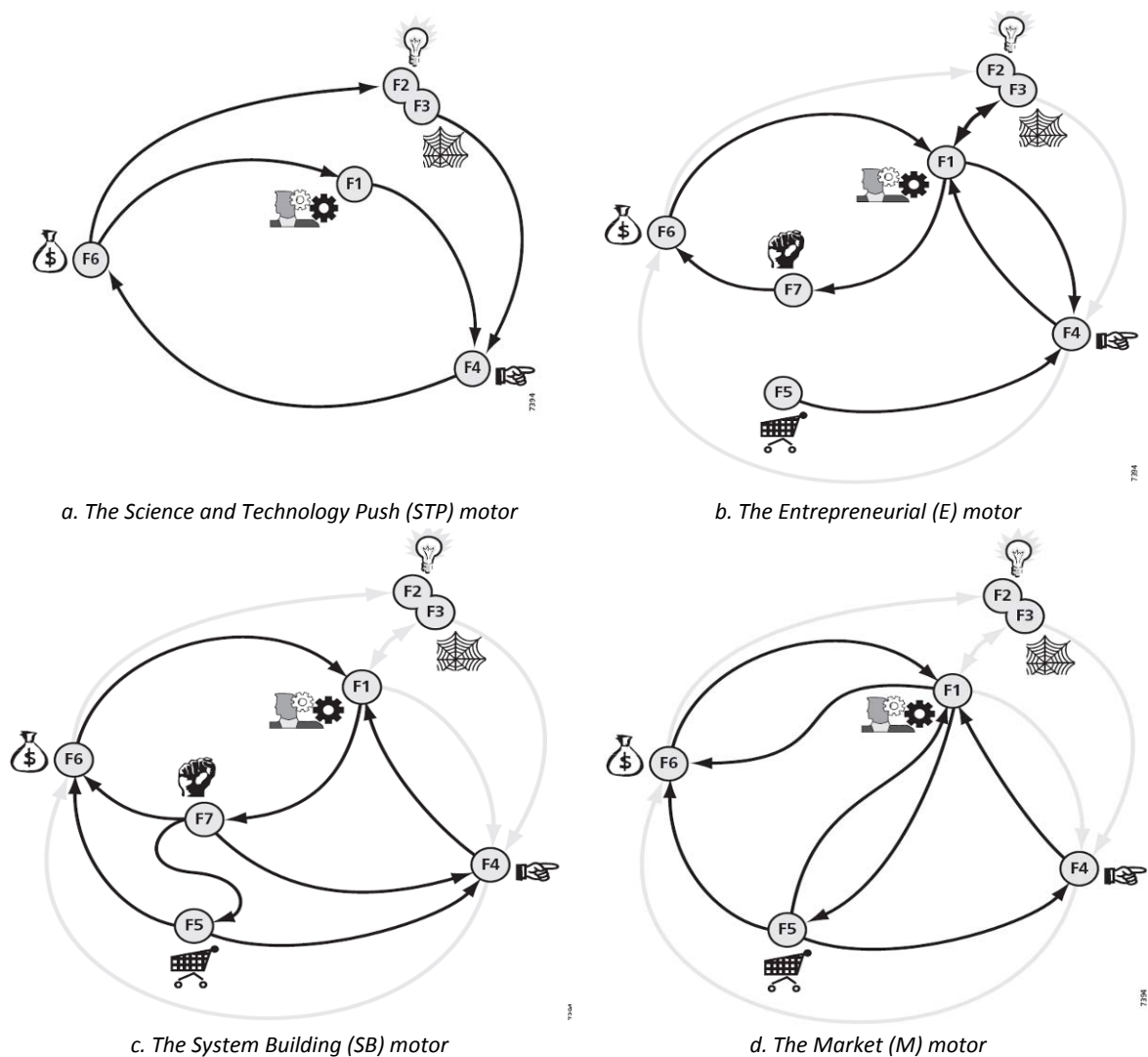
Abbreviations: KDD=Knowledge development and diffusion, IDS=Influence on the direction of the search, EE=Entrepreneurial experimentation, MF=Market formation, L=Legitimation, RM=Resource mobilisation. Motors: STP=Science and technology push motor, E=Entrepreneurial motor, SB=System building motor, M=Market motor

Relation	Explanation	Example offshore wind	Example solar PV	Motors
KDD→IDS	- Positive expectations and/or research outcomes leading to the set up of government-supported R&D programmes	-Offshore early stage Denmark + NI (solution for limited potential/NIMBY)	-Studies on learning curves showing expected grid parity → positive expectations	STP, E, SB, M
KDD→EE	-Feasibility studies and trials are complemented by learning-by-doing in commercially oriented projects	-Technology development leads to testing of the technology	-Technology development leads to testing of the technology	SB, M
EE→KDD	-Feasibility studies and trials are complemented by the learning-by-doing from the entrepreneurial projects -New ventures organise themselves in platforms with the aim of sharing knowledge	-Demonstration project including knowledge development and sharing: Alpha-Ventus and OWEZ.	-N-H project has a R&D project on 2 nd generation of the technology, which can benefit from experience knowledge of the pilot line -Holland solar branch organisation also for knowledge exchange	SB, M
EE→IDS	- The outcome provides incentives for other actors to initiate projects (or not). Also, experiments show which parts of the technology are working and which are not, giving direction to the search for improving the technology. -New ventures organise themselves in platforms, also to communicate and co-ordinate further technological development	-Errors in demonstrations with onshore technology placed offshore now leads to guidance to search for specific offshore technology	-Successful companies in solar PV show have led to positive expectations for the technology.	STP, E, M
IDS →EE	-Positive expectations and lead to new entries and activities	-Positive outcome feasibility studies NL, many of the parties engaged in those studies entered the first tender procedure	-Positive expectations about learning curve, grid parity, lead to projects → Akzo investing in Nuon-Helianthos	E, SB, M
EE→RM	-The experience from experiments takes away uncertainties on the technology for parties that want to invest in the technology. -The newly entered firms are likely to make large investments, for example in infrastructure	-Experiments provide a track record for the technology, which provides information to investors to judge investments, while they were first afraid to invest (take away uncertainties)	Experiments provide a track record for the technology, which provides information to investors to judge investments, while they were first afraid to invest (take away uncertainties)	M
RM→EE	-If more resources are mobilised there are more possibilities for entrepreneurial experimentation.	-E.g. projects started because of subsidies, FES/FP7, etc. -If project financing is possible, also smaller parties can start offshore wind projects, like the Princess Amalia wind park.	-Projects started because of subsidies (and other finance), e.g. the pilot-line of the back-contacted solar cells at ECN	STP, E, SB, M
EE→MF	-Entrepreneurs are active to create markets, through lobbying for market formation mechanisms with the government, demonstrating the technology to consumers and marketing	-The Danish wind turbine industry and owners associations had an active informational role toward the public, stimulating demand for green electricity.	-Branch association Holland Solar organising the Holland Solar days, meant to make consumers aware of solar energy	M
MF→EE	-Through formation of markets, money is available for more experimentation. Also, market formation can also come from subsidies and other incentives, which enhance the possibilities for experimentation.	-Renewables obligations and other incentives lead to more parties starting projects (SDE/feed-in etc. prerequisite for offshore wind project)	-Renewables obligations and other incentives lead to more parties starting projects (SDE/feed-in etc. prerequisite for offshore wind project)	M

EE→L	-Ventures organise themselves in platforms lobbying with governments for better policy frameworks -Experimental activities that show that the technology works increase legitimization	-POWER network. Lobby networks of German and Danish industry	-Solar industry organised in associations Holland Solar and ODE, tries to influence legislation for solar PV [Negro et al. 2009]	E, SB
RM→KDD	-Resources are needed for knowledge development programmes	Subsidies for research projects	Subsidies for research projects	STP, E, SB, M
L→MF	-Advocacy coalitions try to create a mass market for the emerging technology, through influencing consumer perception and lobbying for market creation mechanisms with the government	-Advocacy coalitions lobbying for good market formation mechanisms (e.g. vain attempts to get feed-in tariff in NL) -Consumer demand for sustainable energy	-Branch association Holland Solar tries to influence legislation for solar PV [Negro et al. 2009]	SB
MF→L	-Market formation creates income and employment which legitimates the technology and a more powerful industry is created forming advocacy coalitions	-Danish and German industries earning money → legitimization -New entrants in the German and Danish wind turbine system increased the political power of the sector helping to enable a more favourable policy framework [Bergek et al. 2008].	- German solar industry earning money → legitimization	
MF→RM	-If a market is formed it leads to investors being interested in the technology	-A Power Purchase Agreement (demand from a market party) including a subsidy or feed-in tariff is a precondition for project financing.	-Investment company Good Energies expects solar PV to provide 64% of global energy demand by 2100, which is a reason to invest in solar PV [Good Energies 2009].	SB, M
IDS→RM	-Positive expectations about the technology lead to investors being interested and governments installing subsidy programmes	Government expectations of offshore wind led to programs, including subsidies etc.	Positive expectations of solar PV, cost reductions, led to programs, including subsidies etc.	STP, E, SB, M
L→RM	-Advocacy coalitions lobby the government for policies aimed at creating resources for the technology	-Advocacy coalitions lobbying for (investment) subsidies -If good reason for the technology (legitimated), then money allocated by government (or tax benefits)	-Advocacy coalitions lobbying for (investment) subsidies -If good reason for the technology (legitimated), then money allocated by government (or tax benefits)	E, SB
MF→IDS	-Niche markets present business opportunities creating positive expectations, just as government incentives for the technology	-Financial incentives led to higher expectations entrants. Steadier financial incentives in Germany and Denmark led to better expectations in those countries than in NL.	-Financial incentives led to higher expectations entrants. Steadier financial incentives in Germany and Denmark led to better expectations in those countries than in NL.	E (niches), SB, M

F. Motors of sustainable innovation

Figure E-1 shows the four “motors of sustainable innovation” as identified in the dissertation of Suurs [2009]. The working of the motors is explained here.



F1= Entrepreneurial experimentation, F2= Knowledge development, F3= Knowledge diffusion, F4= Guidance of the search, F5= Market formation, F6= Resource mobilisation, F7=legitimation.

Figure F-9-1. Four “Motors of sustainable innovation” [Suurs 2009]

The Science and Technology Push (STP) motor

In the STP motor positive expectations and/or research outcomes [F4] lead to government- supported R&D programmes which are set-up and for which financial resources are allocated [F6]. These programs supported by the government lead to more scientific activities [F2], like feasibility studies and knowledge network activities like conferences and workshops [F3]. At the same time or as a next step, firms and research institutes are stimulated to participate in pilots and demonstration projects [F1], either initiated by the government or not. This leads to more outcomes on the feasibility of the technology [F4] and depending on the outcomes firms might decide to mobilise more resources [F6] for entrepreneurial activities [F1].

The Entrepreneurial (E) motor

This motor starts because firms, utilities and/or local governments see opportunities for commercial or societal gain in the future [F4] and therefore they enter the TIS by initiating experimental projects [F1], e.g. demonstration or pilots. Because the technology is not commercial yet, they lobby with governments [F7] for financial compensation for the project to cover part of the costs and compensate the risks [F6]. If they get the funding, the projects are started [F1] and the outcome of the project feeds back into the motor through influencing the expectations of the technology [F4].

The System Building (SB) motor

The system building motor is related to the entrepreneurial motor, but mainly concerns the formations of networks and platforms which actively stimulate the technology. New entrants undertake entrepreneurial activities [F1] hopefully leading to successful outcomes [F4]. These entrants start organising themselves in platforms with the aim of sharing knowledge [F3], but also to communicate and co-ordinate further technological development [F2, F4] and to lobby for resources, not for project-specific support, but for policies aimed to mobilise resources [F6] and form markets [F5] and to develop powerful platforms that support the TIS as a whole [F7]. Through these platforms, they also pull in more involved entrepreneurs [F1] and other organisations [F3] including local governments, intermediaries and interest groups. The most important goal of these platforms is usually to form a market for the technology [F5] and if it works this leads to more expectations [F4] and resource mobilisation [F6], leading again to more entrepreneurial activities [F1].

The Market (M) motor

In the market motor, all system functions are strongly fulfilled except for the support from advocacy coalitions [F7], because this is not as important anymore: market formation [F5] is no longer an issue of politics, but of regular business activities, i.e., marketing and promotion strategies linked to entrepreneurial activities [F1]. Because of the institutions which set up a demand for the technology [F5], there are high expectations of the technology [F4] and an increasing availability of resources [F6], which leads to more possibilities for new entrants [F1]. While the competition between the increasing number of new entrants is growing, it is likely that more investments are made [F6] and that marketing strategies are developed which increase the demand for the technology further [F5].

These motors partly relate to the specific externalities which are mentioned by Bergek et al. [2008], where the externalities can be the fuel or the catalyser for the motor. The relations are:

- Science and Technology Push motor: resolution of uncertainties, legitimisation, information and knowledge flows;
- Entrepreneurial motor: resolution of uncertainties, legitimacy and political power;
- System-Building motor: legitimacy, political power;
- Market-motor: resolution of uncertainties, legitimacy.

The Energy Valley of Death:

A closer look at financing problems of demonstration phase energy technologies

Silvia de Vaan

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Abstract

Low-carbon electricity production technologies face financing problems when leaving the R&D phase to be demonstrated at real-life scale in real-life conditions, which is often characterised by the concept of a cash-flow “Valley of Death”. This paper discusses whether the idea of a cash-flow Valley of Death is relevant and sufficient to understand the financing problems of new electricity production technologies in the demonstration phase. It shows that the Valley of Death has a too narrow view on these financing problems and might obscure other important issues. To really understand the financing problems, the whole socio-technical system of direct and indirect factors affecting the technology should be taken into account including economical, technological, social, cultural, ecological and political issues. Case studies of offshore wind and solar photovoltaics show that the financing problems depend on the scale of the investment, uncertainties of the technology, the entity developing the project and indirect factors from the socio-technical system.

Keywords: energy technology development, demonstration phase, energy finance, innovation.

1. Introduction

A broad portfolio of new energy supply and end use technologies is needed to cope with the challenges of climate change and sustainability while addressing the world's growing energy needs (Bazilian et al., 2008; IEA, 2008; Sandén and Azar, 2005). All of the hundreds of stabilisation scenarios reported by the IPCC demand a range of new energy supply technologies (IPCC 2007), many of which still have to be commercialised.

The development of these new low-carbon energy technologies encounters serious problems. One of the most prominent problems is a lack of sufficient finance for projects (Haite et al., 2009; Bazilian et al., 2008). Estimates of the finance needed throughout the different phases of the technology development sequence to meet particular mitigation targets range from 2 to 10-fold the current global investments in the technologies (Haite et al., 2009; Bazilian et al., 2008; IEA, 2008). The nature of the financial gaps and barriers seem to be specific for the different phases of the technology development sequence, however. It is well-recognized that without

government intervention the private sector will tend to under-invest in research and development activities, resulting in a sub-optimal social welfare outcome¹ (Arrow, 1962; Ford et al., 2007; Griffith, 2001; Alston et al., 1998). This has been a justification of government investment in R&D, especially in the early phases where the effect is strongest.

More recently, research has identified financial problems in the intermediate phases of technology development, especially in the demonstration phase (Auerswald and Branscomb, 2003; Murphy and Edwards, 2003; FUNDETEC, 2007). To describe the financing problems in the demonstration phase the concept of a cash-flow “Valley of Death” is often used (Bazilian et al., 2008; Murphy and Edwards, 2003; Auerswald and Branscomb, 2003; Ford et al., 2007).

¹ The main reasons for this underinvestment were already recognised by Nobel Laureate economist Arrow in the 1960s: there are high risks, the product can only be appropriated to a limited extent and there are increasing returns in use (Arrow, 1962).

This Valley of Death, shown in *Fig 9-2*, is a combination of rising cash demands and a low ability to raise cash, at that stage. For a demonstration project on a real-life scale, the cash demands are significantly higher than in the preceding R&D phase. The unit costs are high and only expected to go down through development of the technology and economies of scale. Throughout the technology development sequence the funding generally shifts from mainly public finance to private finance. Since public finance is more focussed on early phase R&D there is often a declining availability of public finance in the demonstration phase. On the other hand, the uncertainties are usually still too large and the pay-back times too long for private investors.

This Valley of Death concept is still relatively new and its body of literature is limited. Only one study discusses the Valley of Death for the energy sector (Murphy and Edwards, 2003). The relevance and usability of the theory for understanding the financing problems of technologies in the demonstration phase of technology development have not been extensively proven. This article discusses the financing problems for low-carbon electricity production technologies in the demonstration phase. It tests the hypothesis that the concept of a Valley of Death is not sufficient to understand the financing problems of electricity production technologies in the demonstration phase, because non-economic issues from the socio-technical system also influence the financing problems.

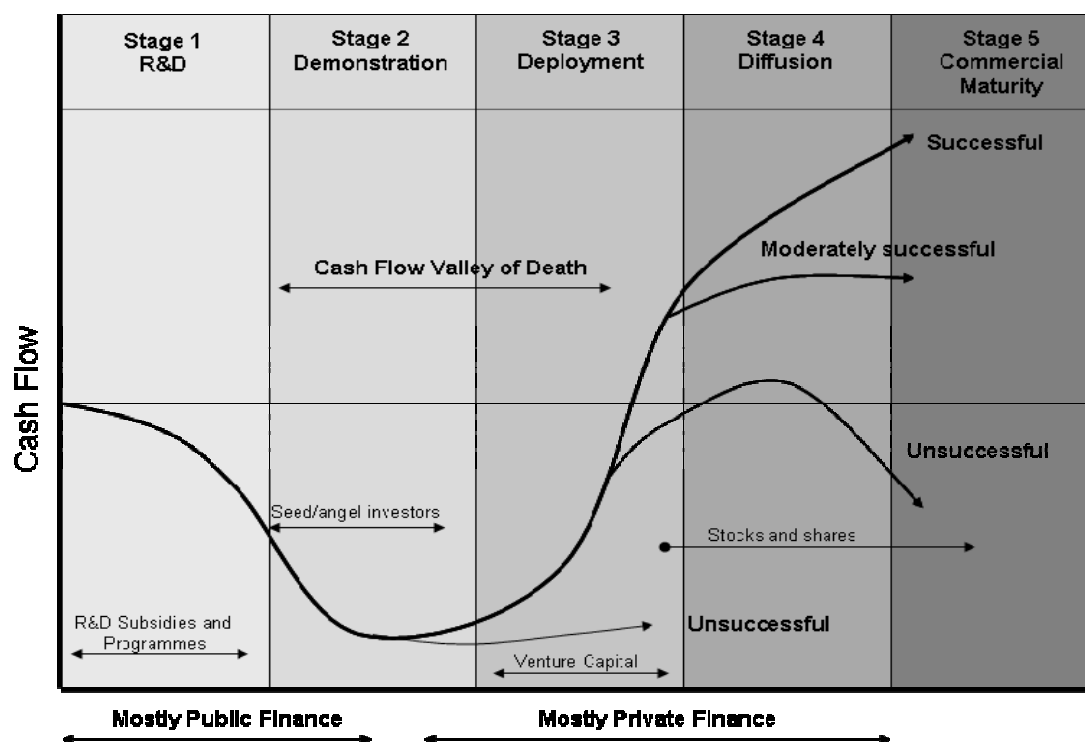


Fig 9-2. Cash flow Valley of Death in the demonstration phase, including different graphs for successful/unsuccessful projects and current primary investors in different phases (Haites et al 2009).

2. Theoretical background

The Valley of Death literature has a financial perspective on the technology development sequence from basic research through to a commercially mature technology. However, social scientists argue that a financial or economic approach alone is not sufficient to understand systems of production, consumption and innovation, especially for social utility functions like

energy production. The success or failure of clean energy technologies is not only determined by technical and economic factors, but also by the social system in which it is embedded (Meijer, 2008; Jacobsson and Bergek, 2004; Hofman 2005). Technological development happens through interplay of factors at different levels of the socio-technical system around the technology, from fast developments in niches until long-term developments like the ecological and cultural

situation (Geels, 2005; Geels and Kemp, 2000). It includes changes in social dimensions such as user practices, regulation and industrial networks (Hekkert et al., 2007).

Therefore, investment decisions are affected by a variety of direct and indirect factors which influence the current and future benefits and costs of a technology, including economic, technical, cultural, social, political and ecological issues. To give some examples: a lack of social acceptance of a technology and the existence of strong opposition groups in society can delay or block the future development of the demonstration technology. On the other hand, societal changes of increasing environmental consciousness and ecological changes in climate have led to an increased demand for sustainable energy sources. Also, the energy sector is a highly political business, where governments intervene in the market because of its natural monopoly and public good characteristics. Energy markets are still dominated by former (or current) state monopolies that have significant political power.

For these reasons, a multi-disciplinary and multi-level approach is needed to analyse the financing problems of new energy technologies in the demonstration phase. There are two relevant frameworks which try to understand the socio-technical system which surrounds the emergence of new technologies: the transition model (Geels, 2005; Geels and Kemp, 2000) and the Technological Innovation Systems framework originating from innovation systems theory (e.g. Bergek et al., 2008; Hekkert et al., 2007; Suurs, 2009). The transition model has a very broad perspective, but it does not explain the underlying processes of innovation, the circumstances for a technology to become successful and how these circumstances can be created (Suurs, 2009). The framework of Technological Innovation Systems (TIS) can be used to sketch an image of the structural and functional components creating positive or negative circumstances for the development of demonstration phase technologies, which can be translated into policy recommendations. Therefore, Technological Innovation Systems theory seems to be the best framework to understand the financing problems of crossing the demonstration phase for new energy technologies.

3. Methodology

The TIS framework has been used to study the financing problems of low-carbon electricity production technologies in the demonstration phase. The structural components of the TIS framework are the actors,

institutions and technology and the relations and networks between them (Suurs, 2009). The activities and interactions of the structural components lead to dynamics in the system. Within these dynamics, certain “key activities” should take place for the technology to develop, which are also called functional components (Bergek et al., 2008):

1. Knowledge development and diffusion;
2. Influence on the direction of the search;
3. Entrepreneurial experimentation;
4. Market formation;
5. Legitimation;
6. Mobilisation of resources.

There can be certain mechanisms in the innovation system that are either inducing or blocking these functions and therefore the development of the technology. These inducement and blocking mechanisms lead to important policy issues: how can the inducement mechanisms be stimulated and the blocking mechanisms decreased?

Offshore wind and solar photovoltaics (PV) were chosen as case studies because they represent reasonably polar examples in scale and because they have a large variation in difficulties and important stakeholders. The offshore wind case is a historical case focusing on the first demonstrations of offshore wind parks in the different North-Western European countries. The solar PV case focuses on new solar PV technologies of which the application or production are currently (about to be) demonstrated at a real-life scale, like many thin film PV and concentrating PV technologies.

The case studies are based on interviews with more than 30 actors from the offshore wind and solar PV sector, including researchers, technology developers (private and public), debt and equity providers, suppliers, contractors, policy makers and policy executors. The set-up of the interviews was open and unstructured to acquire an image of the problem which is as open and objective as possible, asking for the respondent's reaction and opinion on the financing problems of the technologies in the demonstration phase. The information from the interviews was cross-checked and supplemented with existing research on both technologies.

The analysis of the structural and functional components of the Technological Innovation System of both technologies is based on the interviews and literature. Through an assessment of the functioning of the Technological Innovation System several inducement and blocking mechanisms were identified.

These inducement and blocking mechanisms can be used to see whether the Valley of Death concept is sufficient to understand the financing problems: are the mechanisms only directly related to the economics of the project (and therefore to the Valley of Death concept) or are there also other important mechanisms which affect the financing problems indirectly? If there are many important indirect and non-economic issues from the innovation system, the Valley of Death concept is apparently not sufficient to understand the financing problems.

4. Case studies

The case studies show a variety of economic and non-economic issues affecting the financing problems. Several general issues are important for both technologies, which will be described here first. Additional specific issues for the technologies are discussed afterwards.

4.1. General issues for offshore wind and solar PV

From both case studies it appeared clearly that the financing problems are much larger for small companies than their large competitors. This is not very surprising and has been confirmed by theory, surveys and empirical information for small start-up firms in R&D and high-tech (Hall, 2005). Large companies can finance projects from their own balance or they are financially strong enough to acquire external finance relatively easily. Small companies have to rely on external finance, which means convincing investors of the project without large collateral to offer for the investment.

Furthermore, offshore wind and solar PV have certain inducement and blocking mechanisms in common, presented in *Tab. 1*. Positive factors are high expectations of cost reductions and an increasing need for low-carbon technologies (because of energy security, sustainability and growing energy consumption issues), which have led to stimulating policy frameworks and advocacy and income from emerging low-carbon industries. On the other hand, they both have relatively high costs and high investment costs and many uncertainties. They face inertness through the role of incumbents which are investing in

new technologies but change slowly because of their vested interests in the current technologies. Negative economic developments like the current financial crisis reinforce the financing problems.

Tab. 1 shows that in addition to the direct economic and financial issues, there are indirect non-economic issues that are important determinants for the development of low-carbon electricity production technologies and therefore for investment decisions in the technologies.

4.2 Offshore wind

Parallel to the general mechanisms mentioned above, specific inducement and blocking mechanisms for offshore wind resulted from the case study, which are presented in *Tab. 3*. Many of these mechanisms relate to the feasibility of large offshore wind parks, which is crucial for investments in the technology. A driver for offshore wind is a lack of space for onshore wind and resistance to onshore wind from local interest groups (noise, visual amenity), mainly in smaller countries like Denmark and the Netherlands.

Most barriers are related to the offshore location. For instance, it led to technical uncertainties about the functioning of the technology in the offshore conditions (harder wind, waves, salt) and to regulatory uncertainties because regulation for offshore application of wind energy was relatively new or did not exist (Mast et al., 2007). Furthermore, there was no existing connection between the offshore sector and the wind sector which made cooperation and technical integration difficult. Also, the effect of the offshore wind parks on the environment (e.g. bird life, sea mammals, visual amenity) was unclear, which initially led to opposition from nature- and wildlife groups and local interest groups. This opposition has caused large delays and cost overruns, for instance for the OWEZ park in the Netherlands (Noordzeewind, 2007) and Middelgrunden in Denmark (Larsen et al., 2005). The new location offshore also led to infrastructural problems: there was no grid offshore and regulation on the responsibility for offshore grid connection was usually lacking (Mast et al., 2007). In some cases the capacity of the local network where the offshore park would be connected was not sufficient, a problem that the OWEZ park in the Netherlands also encountered.

Tab. 8. Stimulating and blocking mechanisms for both offshore wind and solar PV

	Inducement mechanisms	Blocking mechanisms
Issues directly affecting current or future economics of the technology	<ul style="list-style-type: none"> - High expectations of cost reductions - Beneficial incentives of certain governments - Growing energy demand and depleting fossil fuel reserves 	<ul style="list-style-type: none"> - High costs and high investment costs - Reserved attitude investors caused by financial crisis - Uncertainties (mainly technical and regulatory)
Issues from the socio-technical system indirectly affecting economics of the technology	<ul style="list-style-type: none"> - Climate change, geopolitical energy security issues - Advocacy and income of emerging industries - Other policy measures of certain governments, e.g. bringing parties together, stimulating learning-by-doing, creating legitimacy, giving direction to technology development. 	<ul style="list-style-type: none"> - Incumbents slowing down change

Tab. 3. Specific stimulating and blocking mechanisms for offshore wind

	Inducement mechanisms	Blocking mechanisms
Issues directly affecting current or future economics of the technology		<ul style="list-style-type: none"> - Changing incentive schemes - High prices and long lead times of scarce turbines, offshore sector capacity and vessels - Lack of knowledge of wind technology offshore, leading to technical uncertainties - Sluggish and changing licensing and spatial development processes
Issues from the socio-technical system, indirectly affecting economics of the technology	<ul style="list-style-type: none"> - Lack of space for wind turbines onshore 	<ul style="list-style-type: none"> - Lack of knowledge of environmental effects of the technology - Missing connection between the offshore and wind sectors - Problems of grid connection and capacity - Opposition of actor groups (environmental, horizon concerns)

The issues for offshore wind presented in *Tab. 2* clearly show that important non-economic issues have indirectly influenced the financing problems. The importance of these non-economic issues from the socio-technical system for the financing indicates that policy should also address these non-economic issues. Two important differences in onshore and offshore wind policies between the North-Western European countries have shown that this is indeed important.

First of all, the Netherlands and Denmark have approached the development of wind technology differently: the Danish approach was pragmatic, based on learning-by-interacting and reliability, while the Dutch were focussed on high-tech research and learning-by-searching for the economically optimal technology (Kamp 2008; Kamp et al. 2004). The Danes had a strong cooperative structure between the knowledge institute Risø and local entrepreneurs, residents and wind turbine developers. The Dutch relied on the large utilities which were more focussed on natural gas and nuclear energy at that time. This resulted in a different design: the Dutch two-blade

turbines were optimised for cost purposes (less material), but the Danish three-blade design turned out to be more robust, more pleasant for the eye and in the end more successful (Tempel 2007). In Germany, like in Denmark, a number of different actors and designs were stimulated and there was learning from the diffusion of small-scale application (Sandén and Azar 2005). For offshore wind technology different actors and designs are supported by the German government in the Alpha-Ventus demonstration project. In Sweden, guidance from the government was missing from the beginning and there was a lack of experimentation which led to a weak wind sector (Bergek and Jacobsson 2003).

There are also important policy differences in the process of legitimation and cooperation between stakeholders. Denmark had a really strong legitimation process, determined by several factors (compiled from interviews and Buen 2006; Middtun and Koefoed 2003). Denmark was very much aware of the importance of diversification of energy sources since the oil crisis of '73-'74 because of their dependency on

oil imports. There was a strong anti-nuclear sentiment and the Danes have had ambitious environmental policy goals from early on. The Danish energy planning tradition with cooperation and long-term agreements between the government and utilities enabled swift cooperative action in both onshore and offshore wind development. The cooperative structure in Denmark which included local inhabitants participating in the projects helped the legitimization process for onshore wind. The growth of the emerging wind industry led to income and employment, leading to more legitimization of wind power. For offshore wind, the central government and the power companies had a common interest in large-scale concentrated wind power development: it would help the energy sector to meet their objectives and strengthen their position compared to new entrants on the liberalised market. The German government had a strong industrial policy and they took care of an early legitimacy of wind power, the created wind turbine industry had a growing lobbying capability (Bergek and Jacobsson 2003). The “Stiftung Offshore Windenergie” initiated by the government worked as a coalition to promote offshore wind energy. In the 60’s the Netherlands had just discovered its natural gas sources which was regarded as the promise for future energy supply together with nuclear energy. Since then the availability of gas has dominated the Dutch energy discussion. The incumbent energy firms had (and partly still have) a large political power. Furthermore, local governments were not willing to cooperate with the central government’s onshore wind plans, because the onshore wind policy was imposed on them without consultation. In Sweden, the lack of experiments in the 1980’s resulted from a poor legitimacy of wind turbines, mainly caused by a “nuclear power trauma”: everything in the energy sector

was related to the debate whether or not to dismantle Swedish nuclear power plants (Bergek and Jacobsson 2003; Bergek 2002). Renewable energy was only seen as a means to replace nuclear power so advocacy of wind energy was seen as anti-nuclear.

4.3 Solar PV

Tab. 3 shows the specific inducement and blocking mechanisms for solar PV. In general, the financing problems seem to be smaller for solar PV than for offshore wind, although there are more small companies involved. Angel and venture capital markets seem quite interested in the solar PV market. Part of the reason for this is directly related to the scale and the uncertainties of the technology. The size of the initial investment is much smaller and the modularity of the technology makes flexibility and up-scaling in application possible. Furthermore, solar PV does not have the barriers and technical and regulatory uncertainties of application offshore. The electricity revenues are quite predictable, the technology is relatively maintenance-free, chances of defects are lower (no moving parts, friendlier environment) and licensing and grid connection processes onshore are easier and better predictable.

Furthermore, the market for solar PV is more flexible: the modularity of solar PV and the flexibility of thin film technologies makes it suitable for different applications and therefore there are several niche markets for the technology. Also, the utilities do not need to be involved for the application of the technology. Therefore, solar PV technology seems to be more like a “normal” consumer good. However, the direct consumer market is rather difficult to address and there are administrative barriers to require subsidies and grid connection for a solar PV system.

Tab. 10. Specific stimulating and blocking mechanisms for solar PV

	Inducement mechanisms	Blocking mechanisms
Issues directly affecting current or future economics of the technology	<ul style="list-style-type: none"> - International competition / market pull - Technological niches - Developing countries: lack of stable electricity supply 	<ul style="list-style-type: none"> - Passive consumers - Financial weakness of small PV companies - Developing countries: high risks (crime, corruption, political instability), lack of financial strength of consumers and entrepreneurs
Issues from the socio-technical system, indirectly affecting economics of the technology		<ul style="list-style-type: none"> - Complexity of the technology/lack of fundamental knowledge - Administrative barriers - Developing countries: lack of educated people, bad infrastructure

Indirect effects of the socio-technical system are also important. An important aspect for solar PV is that there are not many forces opposing the application of solar PV technology because of the low impact of the technology on its environment. The technology is high-tech and complex and the process from light to electricity is still not completely understood. This means that development and improvement of the technology requires extensive R&D and demonstration efforts including various parties with different specialisations. The developing country market, which is regarded as an important market for solar PV, has additional barriers. Next to high risks related to the political and regulatory instability of many of these countries, there are numerous other barriers for entrepreneurs and investors in developing countries, like a lack of local knowledge and bad infrastructure.

Although most issues of the solar PV case are directly related to the economics of the technology, there are still some important indirect issues from the socio-technical system. Especially the developing country market clearly shows the presence of problems not directly related to the economics of a technology.

5. Conclusions

The financing problems of low-carbon electricity production technologies in the demonstration phase are different for each technology and project. These differences are mainly determined by characteristics of the technologies, for example the scale, flexibility, location, impact on the environment, complexity of the technology, etc. The financing problems are partly caused by factors directly relating to the economics of investing in the technology, like the scale of the investment, the uncertainties and the financial strength of the entity developing the project. However, there are also indirect factors from the socio-technical system that influence the expectations of the future of the technology and therefore affect investment decisions, like social acceptance, government policy and political changes, the playing field and political power of stakeholders, access to consumers and ecological developments like climate change. The case studies of offshore wind and solar PV show that these indirect factors can be just as important as financial and economic factors to understand the financing problems of these technologies in the demonstration phase.

The Valley of Death is a concept with a strong imaginative power of the financing problems in the demonstration phase, which gives a first indication of the problem. However, this image is too narrow to

fully understand the financing problems of low-carbon electricity production technologies. Addressing only economic and financial aspects might obscure other relevant issues blocking the development of these technologies. The total socio-technical system should be taken into account to understand the financing problems. The Technological Innovation Systems framework can be used to discover a wide range of issues from the socio-technical system that influence the development of a technology in the demonstration phase.

An important consequence for policy-makers is that policy aimed at merely providing financial incentives might fail because of other non-economic barriers blocking investments in a certain technology. These socio-technical factors can be just as important as the economics of the project, especially for technologies that fulfil a societal or public good function, like energy supply. Furthermore, since technology characteristics lead to differences in the financing problems of the technologies, policy makers should identify the technology-specific barriers and see how they can be overcome through technology-specific policy measures.

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