CONTENT:

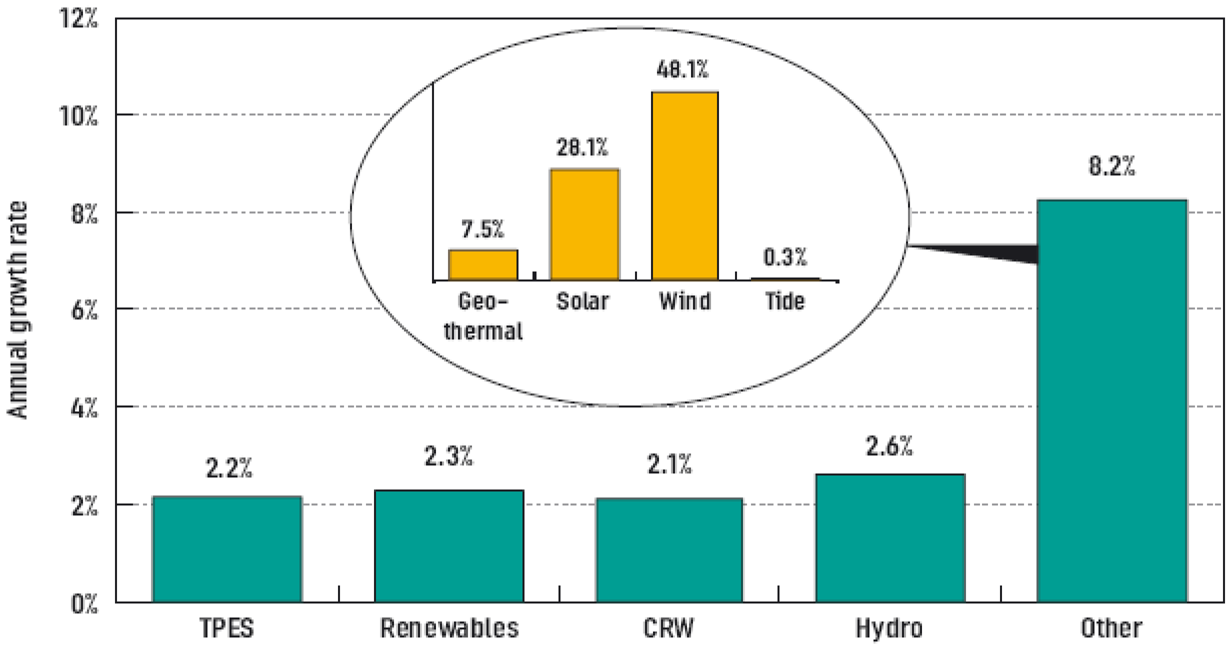
1 Introduction

Today, in many places around the world issues on global warming effects are debated. Scientists and researchers in energy, environment, economics and other areas try to discover facts and answer some of the questions everyone keeps asking; among that which possible solutions do we have to such a complicated and global problem as the greenhouse effect that is caused by CO2 and other anthropogenic greenhouse gasses. The greenhouse effect has been known for several decades but in this millennium the issue has been renamed global warming.

Faced with global warming we have seen more natural disasters and extinct animal species as the result of the climate changes. Some of these things were documented and made popular and widely known to the public by Al Gore in his award winning documentary film *"An Inconvenient Truth"* from 2006, which caused a lot of debate and increased the political focus on the issue in many countries. Furthermore, the *Stern Review* on the economics of climate change, also from 2006, documented in very far reaching conclusions that the global warming effects are real and in both medium and long term scenarios will have severe consequences for the world economy. Overall energy usage account for 65 % of total green house gas emissions and the power supply alone account for 24 % (Stern et al., 2006). The Stern Review consequently states that strong early action on climate change, e.g. RD&D investments in development of energy technologies and strict environmental regulations and CO2 quotas strongly outweighs the costs of climate changes in the laissez faire scenario. Therefore both the bio-ecological and economical evidence should motivate the political engagement to pursue the resolving of the issues by mitigation through technologies with lesser or no bio-ecological effects, compared to the high impact that present fossil energy technologies have.

During the last century, the world's energy consumption has increased very considerably. This has mainly been due to waves of industrialization in Japan, Europe and North America, and the fact that fossil fuels have been relatively cheap and appeared in more or less plentiful amounts. However growth patterns in recent time within the different energy technologies make some of the new technologies stand out as possible inheritors to "the fossil reign" within energy. The figure below displays the average annual growth of the energy supply sources.

Figure 1: Annual growth of energy supply sources from 1971 to 2004



Source: Ahm (2007) p. 390

The period from 1971 to 2004 has displayed an average annual increase of 2.2% in total primary energy supply (TPES), 2.1% for combustible renewables and waste (CRW), and hydro accounting for 2.6%. Total renewables supplies accounted for an annual growth rate of 2.3%, while the “other” category in the figure, (defined as “new” renewables and including geothermal, solar, wind, etc.), experienced a much higher annual growth of 8.2%. Due to a very low base in 1971 and to a fast-growing development, wind energy experienced the highest increase of 48% followed by solar energy with 28%.

However, what we will see in the next decade will be a somewhat more complex picture, due to for example rapid economic growth in China and India, depletion of oil resources, and global climate change propensity. Economic growth factors suggest that primary energy demand will double by 2037 and triple by 2057 (IEA, 2004; IEA, 2005).

Linked with the depletion of oil is the scientific concept of peak oil[1], which was investigated for the US government in the *Hirsch report* (Hirsch et al., 2005). The report concluded that time of peak oil can not be known for certain – nevertheless most key actors predict this to occur within the next 20 years. The implications will be rather drastic for the transportation sector and will require many innovations. Also it will imply dramatically price increases in general and could have particularly severe consequences for some developing countries. The main message from the report was that mitigation of peak oil effects must be initiated by governments rather sooner than later both on the demand side, i.e. higher energy efficiency, and supply side, i.e. transition to other energy forms. The figure below reveals different suggestions for the time of peak oil.

Table 1: Predictions of World Oil Production Peaking

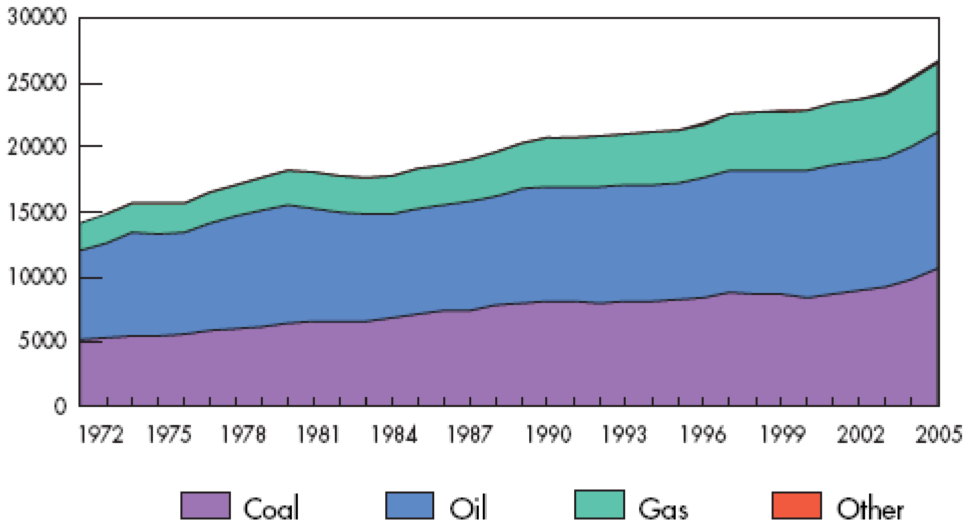
Projected Date	Source of Projection
2006-2007	Bakhitari
2007-2009	Simmons
After 2007	Skrebowski
Before 2009	Deffeyes
Before 2010	Goodstein
Around 2010	Campbell
After 2010	World Energy Council
2010-2020	Laherrere
2016	EIA (Nominal)
After 2020	CERA
2025 or later	Shell
No visible Peak	Lynch

Source: Hirsch report (2005), p. 19

The growth of energy consumption is also associated with environmental problems. Therefore for instance the *Climate Change Convention* and the *Kyoto Protocol's* efforts are focusing on the mitigation of greenhouse gases that are causing climatic changes, and on developing adaptive strategies to assist species, ecosystems, humans, regions, and nations in adjusting to the effects of global warming. The figure below, displaying the evolution in the global CO2 emissions, suggests that the concern is far from exaggerated:

[1] The point in time where oil production reach its maximum

Figure 2: Evolution in World CO2 Emissions by Fuel (Megatons of CO2)



Source: IEA (2007) p. 44

Thus, fuel related emissions of CO2 have increased considerably from nearly 15,000 megatons to well over 25.000 megatons since 1972, suggesting a doubling in the foreseeable future, which is furthermore aggravated by rapid economic growth in for example China[2] and India and substantial worldwide population growth.

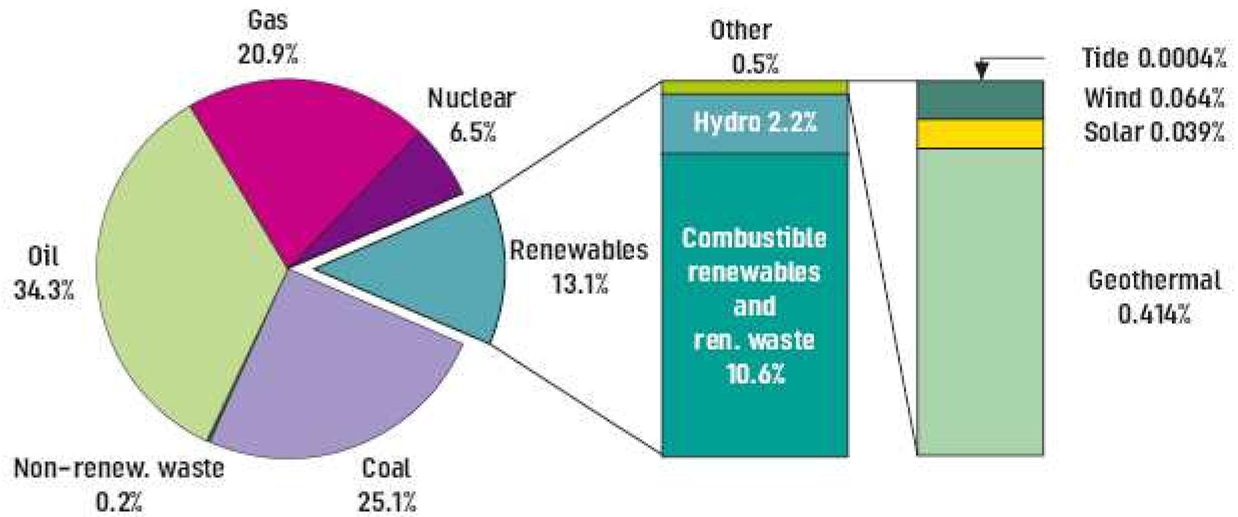
One of the main solutions to global warming and other environmental problems is to make use of cleaner and more energy-efficient technology. This means that in order to confine the future problems of global warming we need to reduce or limit our energy consumption significantly and promote the use of cleaner sources of energy. For this reason and the decreasing and limited amounts of fossil energy sources it is vital to realise the obvious possibilities there are for society in general in going through a transition to renewable energy sources as a means of keeping our standard of living. Although the new renewables still make up a minor part of the world's electricity production the sustained growth seems very interesting in this context. Many questions in the transition to other energy sources still remain to be answered; for example, which technologies will be able to satisfy our need for energy in the future?; how should the technologies and energy sources be mixed to the optimum societal benefit?; and how will we be able to make the energy infrastructure work regarding for instance fuels for transportation or transmission of power? Still we do not have the answers but we know that the energy innovations depend highly on government policies, public support,

[2] China accounts for no less than 40% of the recent increase in CO2 emissions according to Ingeniøren (2006).

rules and regulations, and strategies and programs (e.g. Jacobsson & Bergek, 2004; Foxon et al., 2005; Jacobsson & Johnson, 2000; Lipp, 2007). It is clear that substituting fossil fuels with RE comprises an important part in the strategies aiming at reducing CO2 emissions into the atmosphere and thereby mitigating global climate change effects.

However, it is still coal (25.1%) and oil (34.3%) that represents the largest parts of the global source of energy, while all RE sources account for 13.1%. Despite of the fact that they still make up a relatively minor part of the world's electricity production (0.064% and 0.039% respectively), RE technologies such as wind power and solar energy have improved vastly during the last three decades (cf. the figure below) while still improving in cost efficiency. At such, these RE sources are considered to have the abilities to replace a much greater part of fossil fuels as they become even more cost competitive in the near future.

Figure 3: 2004 Fuel Shares of World Total Primary Energy Supply



Source: Ahm (2007) p. 390

From an investors point of view many of these matters are interesting in judging the future potential for the different new energy technologies. The investments in renewables are increasing worldwide (World Watch Institute) and were especially located in the US and Germany in 2005. While Denmark has a significant established position within wind power with a high global market share (Vækstfonden, 2006), the picture looks very different when turning to solar power. As the table below displays, the OECD growth in solar photovoltaics (PV) has averaged more than 30% from 2000-2003, with Germany representing the highest growth of more than 51%. According to other sources like the Danish Energy Agency (Energistyrelsen, 2005) and World Watch Institute the average annual growth for the sector is 30 % or more.

Table 2: Growth in Photovoltaics demand (2000–2003)

Region	Percent Increase 2000–2003 (%)
OECD	32
OECD (Europe)	41.1
Germany	51.1

Source: Kreith (2007) p. 12

According to Danish experts, Denmark is lagging behind this considerable growth. Thus, according to the renewable energy expert and managing director of the Nordic Folkecenter of Renewable Energy, Preben Maegaard:

> *"Denmark is about to miss an obvious opportunity. On the market for solar cells, where the prospects were promising in the end of the 80s, Denmark's dream about an international position is destroyed – even though there definitely are niches where we are able to assert ourselves as sub suppliers and on counselling."* (Ugebrevet Mandag Morgen, 2008)

In this context, it would be very interesting to investigate if this is truly the case and why it seems to be so, as well as what the next step could be for Denmark in order to make prosperous conditions for innovation in and increasing diffusion of solar cells.

Therefore the aim of this study is to examine the driving forces, barriers and system relations that the Danish PV sector have as basis for innovations and what changes could be recommended for the future in order to optimize the framework conditions for innovation. This leads to the following problem formulation:

1.1.1 Problem Formulation

What are the Danish solar photovoltaic sector characteristics and dynamics seen in an Innovation System Perspective?

The above is our main problem formulation, which is linked with the following research questions.

- *What synergies and dys-functionalities for innovation are present in the form of drivers, barriers and system failures?*
- *What are the market potentials, possibilities and future perspectives for the photovoltaic sector in Denmark?*
- *And what policy implications can be stated following the analysis?*

In order to investigate these issues, the thesis is divided into the following chapters: *Cpt. 2* presents our methodological considerations that will elaborate how we have performed the study and collected the data and information, *cpt. 3* examines theoretical aspects concerning the innovation system theory and ends up presenting a framework for the analysis, while *cpt. 4* presents the photovoltaic technology with its characteristics, present status and the main production processes in the making of PV power equipment. *Cpt. 5* makes up the innovation system analysis, where the analytical framework is applied to the data and information, and expectations from key actors are found, which we can utilise to assess the potentials and possibilities for the sector. Last but not least, since the PV sector is a subdivision of the energy sector, which is governmentally regulated, we are inclined and encouraged further to examine policy and offer recommendations in *cpt. 6*, which could optimise the systemic interplay of innovation.. Finally, the conclusion about our findings ends the project in *cpt. 7*.

1.1.2 Boundaries of the system

As we investigate the Danish nation, the geographic boundaries are self-evident and for elaboration we refer to the section concerning the national innovation system, where a short introduction to the Danish innovation system is presented. The photovoltaic sector includes all the actors that provide products, services, knowledge or in other ways are related to development, application, and usage of the photovoltaic technology. The photovoltaic sector within the energy area is a subsector to the power utility sector and has niche applications with links to other sectors. Consequently, PV developments must be influenced a great deal by the electricity market and developments in other power and energy technologies. Nevertheless we see the PV sector as a system with its own institutions and organisation. As we will illustrate in *cpt. 4*, the basic PV technology is relatively easy to define. However digging in the surface shows several existing technologies and many more R&D projects that attempt to find new and efficient sub-technologies of producing power directly from the sun's irradiation.

2 Methodology

In this chapter we explain our data collection and some methodological considerations in relation to the field. We have set us out to perform an analysis of the systemic relations and synergies of the PV sector with relation to innovation in Denmark. This we will do through the use of the innovation system framework, which is an acknowledged theoretical framework within the literature. We refer to the chapter about innovation systems for further descriptions on the theoretical and analytical framework.

Firstly we address general methodological considerations including aspects about systems, which is followed by descriptions of how we have organised our study and then the section finish off with information about the process of data collection.

2.1 The Methodological Approach and Operative Paradigm

The methodological approach is a systemic way of viewing reality, collecting and handling data, and reaching conclusions about reality that is scientifically trustworthy. There are different methodological approaches that have different scopes. This could for example be to find causal connections between some factors that can be used to predict a part of reality under a premise of *"Ceteris Paribus"* (all other things remaining equal); so that the effect of a single independent variable on the dependent variable can be isolated. This approach, which is commonly used in economics and other logic-oriented sciences, is sometimes referred to as "the analytical approach". Another scope of an approach could be to find concepts, meanings, and intentionality in a specific part of social reality around actors in order to find underlying motives, typify some social phenomena of reality, and find constitutional ideals. This approach is commonly used in research areas where understanding is of the essence and is also known as "the actors approach" (Arbnor & Bjerke, 1997). However these examples are not the approaches we have used. We will apply a system approach.

2.1.1 A System Approach

We consider that a system as a whole in an important way determines how the components behave. Ancient Greek Aristotle recapitulated the general principle of holism in *Metaphysics* as "*the whole is more than the sum of its parts*", which is an expression often heard in systems theory. The above lying paradigm to this study is the view of reality as mutually dependent fields of information. This makes the relations between entities very important, because the relations determine which information is passed on and who gets the information. Another crucial aspect for us is what the information is used for, in other words, what is the purpose of the existence and exchange of information, i.e. the objectives and the aspect of finality of the relations. In order to research reality in a scientific method we need to view reality as a set of components with inter-related connections between them that as a whole forms a system (Arbnor & Bjerke, 1997). Sometimes it can be an advantage to study parts of reality in the whole of the inter-related context of which it appears, and not leave it out in a search for cause and effect connections.

So in our analytical framework we draw upon *systems theory* and the systems approach. Basically a system consists of components with relations among them. The components and relations are part of a coherent whole that has a function, i.e. is performing or achieving something (Edquist, 2005). In order to use systems theory in any way, the boundaries of the system must be identified and defined, in our particular thesis these are the elements that affect the innovation performance of the Danish photovoltaic sector. Systems can be distinguished as either closed or open. In order to explain or understand a system it is sometimes necessary to place it in its own context environment, and when doing this the system is considered open, e.g. there could be strong relations from PV to other technologies and sectors such as solar thermal energy or the building sector. When reflecting on the system model and whether or not it should be open or closed, the question is whether or not it is a necessity (Arbnor & Bjerke, 1997). Is it reasonable that we confine our system to a setting with closed borders and not take into account the relations the system has to the surroundings? If there are any important relations from the system of subject to the outside context the answer to this question has to be *no*. As we are investigating the PV sector in Denmark and the potentials for innovation, we have to use an *open systems model* since we cannot meaningfully disregard all relations to the international arena, other sectors and other technologies.

The innovation system approach views systems as open, learning, and structurally changing (e.g. Lundvall 2002; Edquist, 2005) – it is a self-organising systems model. This means that the systems in question are considered to be dynamic and constantly evolving. Systems theory is a source of ideas about how certain characteristics and behaviours of real systems can be focused. The focus of a system in economical and business theory is to make an input into an output that is of higher value than the input. And in the specific case of innovation systems the focuses is to create a policy framework that let innovation thrive unhindered by growing positive synergies and develop and evolve industrial maturity, social capital, and strong organisations within the system that can form a basis for new prosperous possibilities and potentials. Such a focus is determined by the relations between actors – the finality relations of a system. The components of the chosen innovation system of our research, the Danish PV sector, have to be approached and contacted in order to in fact state these concrete finality relations.

The Danish PV innovation system is a manifestation of objective reality and we seek to reproduce this reality in a systems model. In other words one could say that this is a study of a real individual system case and we intend to find possible relations in the system and form a simplified and clear model of reality itself. This is why we have conducted interviews with some central actors in the relatively small sector. Another characteristic about this study is that it contains aspects of induction from these interviews.

Our thesis is not only based on systems theory but also slightly on part of the *analytical approach* models – meaning the theories and models that can be used as a basis for forecasting. These theories and models focus on the usage of quantifiable measures such as statistics, for example the predictions about prices of electricity have proven to play an important role in the system. When we use these cause-effect models it is because they sometimes are important parts of the system. The analytical framework is found in section 3.7.

2.2 Methodical Procedures

As we fit our methodological approach to the study of the Danish PV sector, we need to make use of certain techniques for selecting units of study and collecting data in order to reproduce a picture of reality that can be considered valid. The results and integrity of our research depend on the techniques we have used and how well we have used them. These techniques include a review of the existing literature and data material, as well as personal interviews, which we will describe in the following.

2.2.1 Validity of the Study

Validity is an essential aspect of a research study because it influences the relation between theory and data. To any researcher it is quite important that the results of the study can be considered true and trusted by others, given any reservations of the study. All research results can to some degree be criticised but if certain methodological provisions are taken, the validity and following value of the results is improved and brought to a higher level.

To ensure our validity it is important that definitions and key concepts are perceived important and relevant to us as researchers and especially the persons involved in the Danish PV innovation system, which we have interviewed. These people have an interest in and an opportunity to decide whether an observation is correctly made and whether our results are reasonable and correct. In the process of ensuring validity we have tried to reflect the real system from as many views as possible, by approaching several actors and study all the secondary material (statistics, articles etc.) that time allowed. We have synthesised existing evidence with the expert knowledge collected in interviews.
It is also an advantage that definitions correspond to theory and are operational, which we have done our best to ensure in the analytical framework.

2.2.2 Qualitative and Quantitative Methods

The systems approach that we use is a mix of qualitative and quantitative methods. We certainly find statistics and causal connections interesting but we do not feel that we get the full picture of reality in our specific research subject, when we are only using these methods. As such, we ascribe more weight in our conclusions about the Danish PV innovation system to our primary data, the interviews. Other reasons that back up our methodology are that it has not been possible to find weighty data material and also our specific area of study is quite small in size. The interviews, which we will go through a methodical description of, can be characterised as qualitative research.

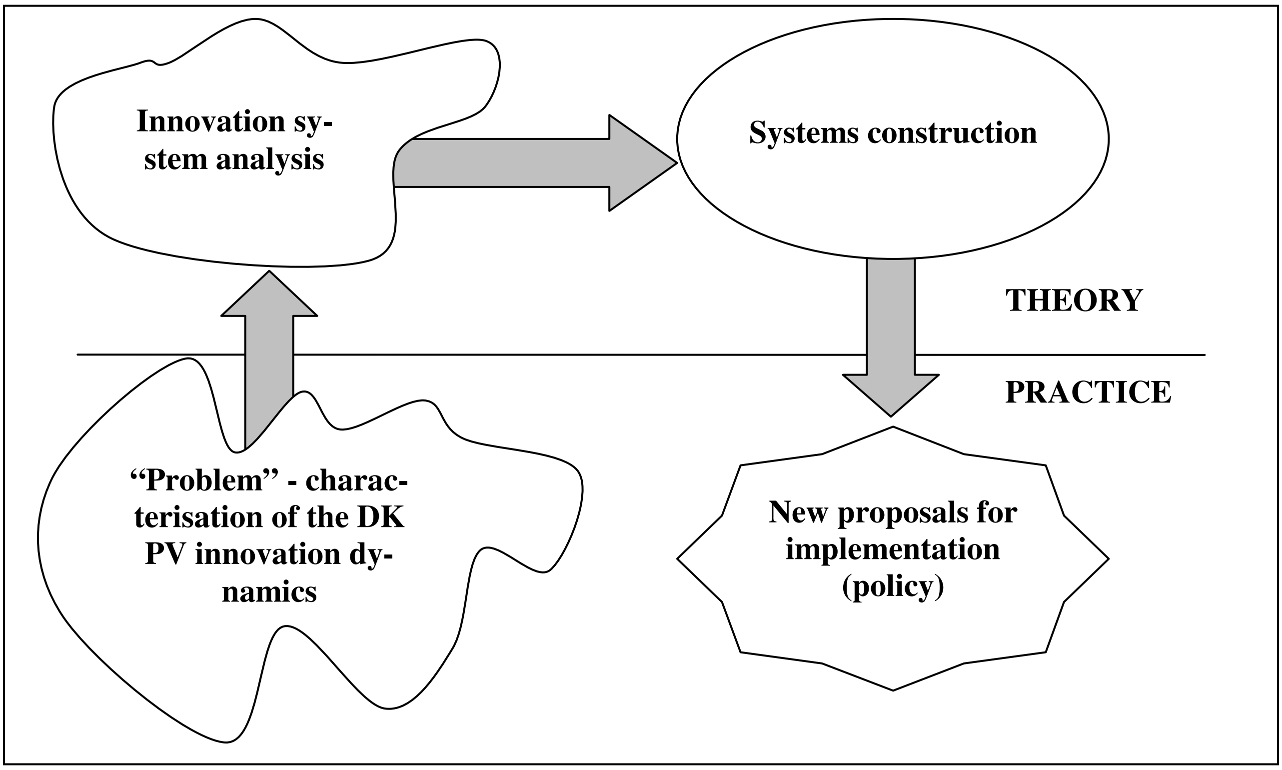
2.2.3 Qualitative Research

Qualitative research is all about exploring issues and understanding and finding the meaning in phenomena. It examines generally the 'why', not the 'how', of its topic through the analysis of relatively unstructured and specifically selected information and does not just rely on statistics or quantifiable measures, which are the domain of quantitative researchers. Qualitative research is used to gain insight into people's attitudes, behaviours, value systems, concerns, motivations, aspirations, culture and lifestyles. It is used to inform business decisions, policy formation, communication and research. Focus groups, in-depth interviews, content analysis and semiotics are among the many formal approaches that are used, but qualitative research also involves the analysis of any unstructured material, including customer feedback forms, reports or media clips (Rubin & Rubin, 2005). In-depth interviews, content analysis, reports and other media are the main qualitative sources of our investigation.

2.2.4 Project Design

In our study we have basically followed a goal-means model for system analysis, meaning that we have studied the PV sector to find out what means are necessary in order to reach an improved innovation performance of the overall system, which are linked with certain public energy related environmental goals. Our main purpose is to assess and guide the innovation performance of the system; however as the energy sector is governmentally regulated the PV subsector's innovation performance depends strongly upon environmental goals of the government, EU and the policy instruments related to the reaching of the goals.

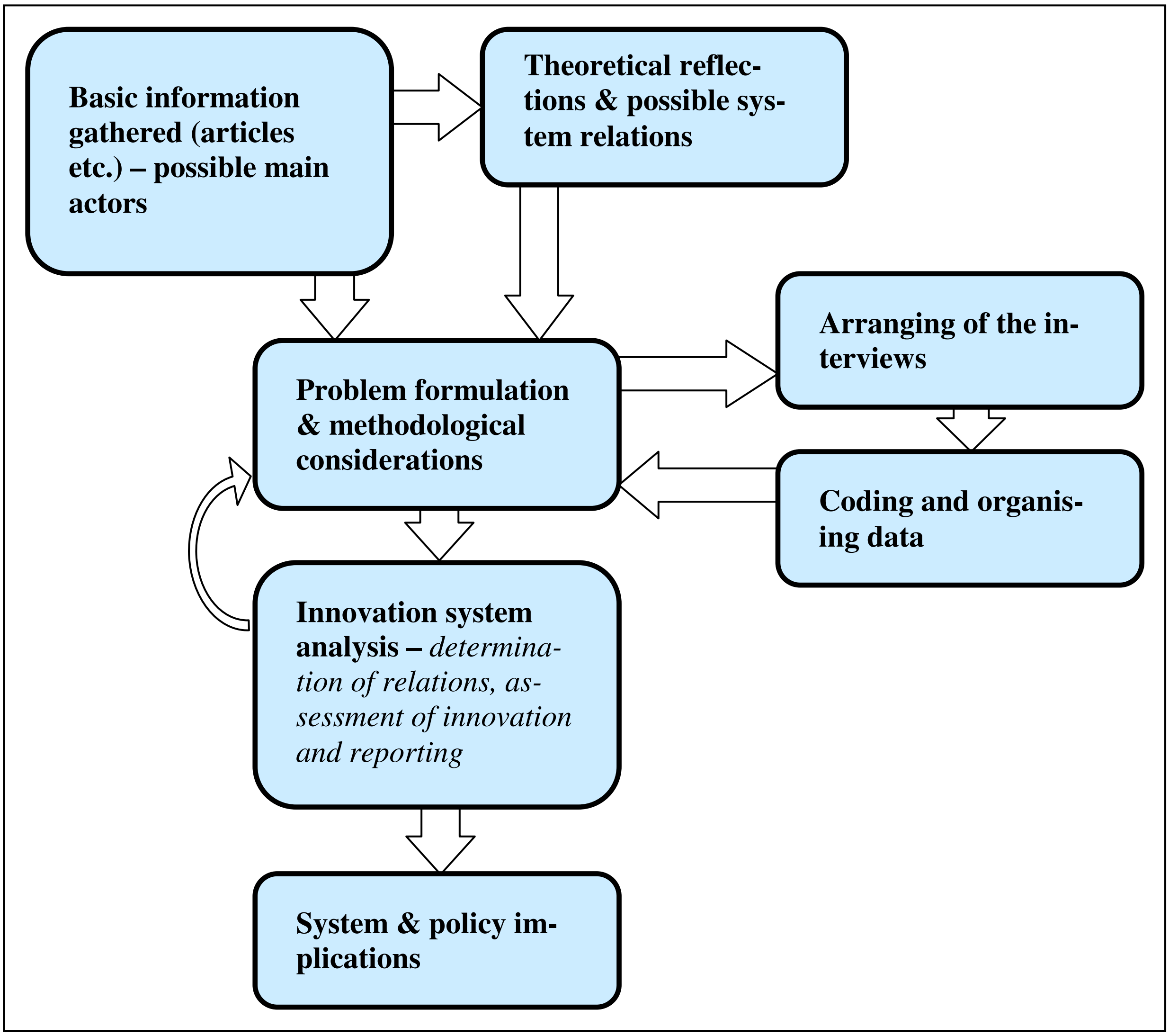
Figure 4: Model for goal-means system analysis



Source: inspiration from Arbnor & Bjerke, 1997

Following the model above we have gathered data from reality about the PV sector practice, which we can use to characterise the dynamics of innovation by means of the IS framework. Through the IS theoretical framework a depiction of a system emerges, which we draw on as the starting point for improvement proposals for the system. Beneath our project design is presented, which is how we practically have performed our study.

Figure 5: Project design for the characterisation of Danish PV sector innovation dynamics and following implications



The methodological considerations have been a central part of the project because it has been important for us to build a consistent analytical framework. We hope that our work on analysing the sector could be used as inspiration for further studies in PV and renewable energy technologies, and maybe even affect policy decision makers.

2.2.5 The Interview Study

The main purpose with the interviews is to observe and interact with the key actors and creators of knowledge within the Danish PV sector to find out what the essential drivers, barriers and system failures of innovation in the sector are.

A complicated and time-consuming process was to arrange the interviews but not the least to select the interviewees, in a way that we could get a broad insight into the sector. Firstly we needed an overview of the companies, authorities, and knowledge institutions. We did this by searching the internet, reading as many subject-related articles and news as we could get a hold of, and asking around (both by phone, mail, and in person)[3] and eventually we had formed a small database of interesting organisations and key actors. In the same process as we suggested an industry depiction of the actors, we also collected information about who was working with what and to a certain degree got an impression of which of the actors could be considered experts or innovators in their field, as these persons would be of high importance to our study.

Our interviewees are listed and characterised in the following table:

[3] Also in order to promote a snow-ball effect.

Table 3: Characterisation of interviewees

Date	Interviewee	Function as	Organisation	Competences within	Characterisation
06.05.2008	Kjeld Kærgaard Jensen	Business consultant	Aalborg Municipality	Regional business development	Authority rep
26.05.2008	Preben Maegaard	Managing Director & Writer	Nordic Folkecenter for Renewable Energy	RE, RD&D, International relations	Expert
26.05.2008	Jane Kruse *	Head of Information	Nordic Folkecenter for Renewable Energy	RE communication	Raconteur
05.06.2008	Remus Teodorescu	Professor	Aalborg University - Inst. of Energy Tech.	Sun & Wind Power Electronic Systems	Expert (Innovator)
10.06.2008	Yakov Safir **	Managing Director	Racell Solar A/S	Solar cells, BIPV	Entrepreneur
11.06.2008	Kenn Frederiksen	Energy Consultant & Project Manager	EnergiMidt A/S	BIPV & demonstration, Electricity supply	Intrapreneur
12.06.2008	Karsten Ries	Division Manager of Electronics	Mekoprint A/S	Power Electronics Business	Innovator
25.06.2008	Eik Bezzel	Managing Director	Photosolar Aps	BIPV & PV R&D	Entrepreneur (Expert)
25.06.2008	Dennis Aarø	Managing Director	Gaia Solar A/S	BIPV modules & installation	Innovator
26.06.2008	Leif Jensen	Senior Silicon Scientist	Topsil A/S	Silicon crystalline	Innovator (Expert)
26.06.2008	Ivan Katic	Managing advisor & researcher	SolEnergiCentret (Technological Institute)	SE development & demonstration, Business guidance	Expert (Innovator)

* Guided tour notes
** Phone conversation notes

We performed the interviews in the chronological order shown in the table. We had a low degree of standardisation with many open-ended questions in the interviews to keep a good flow in the interaction with the interviewees. However we used an interview guide with the key concepts to keep the important things covered. This interview guide can be seen in the appendix. For further explanation of the key concepts we use to uncover the synergy effects of the real system relations and their connection with the theoretical framework, we refer to the section about our analytical framework. In the following section we outline the technique we have used for extracting meaningful information and knowledge from the interview data.

2.2.6 Coding (stages)

Transforming qualitative information into knowledge can be done by thematic analysis, which is a process for encoding qualitative research. A theme describes and organises an observation, and can also be used for interpreting aspects of the phenomenon. Not all themes can be directly observed in the information but can in some ways be implied or tacitly underlying the phenomenon (Boyatzis, 1998).

In the coding-process we go through stages of perception and insight. Firstly the challenge is to develop themes and codes, which already began in the layout of the interview guide. The themes have been inductively created from the raw material (e.g. websites, articles, or the interviews) and deductively from IS theory or prior research. The essence is to find meanings of key concepts and map the beliefs, expectations and knowledge that the interviewees possess. The transformation of interview data and information into knowledge forms a basis for assessing and drawing conclusions about the finality relations and performance of the Danish PV innovation system.

3 The Innovation System Approach

This chapter will present the theoretical basis for identifying the innovation system of the Danish PV sector. It is based on some of the central academic literature on innovation systems and ends up in a framework with the purpose of understanding and mapping the systemic relations within the Danish PV sector. In this respect, we will fit together and apply the conceptual frameworks of national-, sectoral-, and technological innovation systems[4]. The reason for selecting these among others in the IS family should be found in the overall approach of this thesis. Turning to the problem formulation it is *"… the Danish solar photovoltaic sector…"* that forms the basis of the analysis. Therefore it seems apparent to make use of those branches in the innovation systems literature that are specifically related to the focus of this thesis.

That is, as we are dealing with a *nation*, (in this case Denmark), it is obvious to apply the *national* innovation system approach, whose importance and significance is additionally emphasized by its extensive use in several other studies on innovation, in academic circles as well as in policy contexts (Edquist, 2005). We argue that the same prove for the *sectoral* innovation system, because this thesis exactly examines the photovoltaic *sector*, which includes all firms dealing with products or services that contain or associate to the photovoltaic technology. Regarding the *technological* issue, we will in the coming introductory section to photovoltaics illustrate that PV is considered to be a technological domain and therefore the technological innovation system approach is applicable and the PV technology can be used for applying boundaries of the system in question. Even though there are similarities between these approaches, they emphasize different aspects and dimensions of innovation systems, mostly due to underlying differences in the fields of research, which has to be kept in mind when applying them in the analysis. This important issue will be further discussed in the part about our analytical approach.

3.1 Innovation

In this section the purpose is to arrange an overview of the main theoretical aspects of innovation and describe the concept of innovation.

A general consensus exists among policy makers and researchers that innovation is essential to economic growth and development (Lundvall, 1992). The concept of innovation is in some contexts

[4] Originally introduced as "technological systems" by Carlsson and Stankiewicz (1991). Initially it did not employ the language associated with the SI approach (Edquist, 2004 p. 200), even so this thesis will not distinguish between the two concepts, since they can justifiably be equated with one another (Jacobsson & Bergek, 2004; Bergek et al., 2007). Therefore, it will be termed as "technological innovation systems" only.

used on a daily basis and could have different conceptual meanings to separate individuals but it and different scholars have accordingly defined it differently.

Joseph E. Schumpeter was one of the first economists to analyse the idea of innovation and its influence on the economy. He regarded innovations as the dynamic element in the economy, and innovations as “new combinations” of existing resources. In his “Schumpeter Mark I”, characterized by “creative destruction” and technological ease of entry, he emphasized the significance of entrepreneurs and new firms and their importance to innovation, while the later “Schumpeter Mark II” focused on the impact of innovation in large, established companies with barriers for new entry and “creative accumulation” (Fagerberg, 2005; Malerba, 2005). In Schumpeter’s terms, innovation is new products, new production techniques, exploitation of new markets, new sources of supply, and new ways by which business is organized. In economics, most focus has been on the two first examples where the introduction of a new good is regarded as product innovation, while the introduction of a new method of production is comprehended as process innovation (Fagerberg, 2005).

Inventions are often placed in close connection with innovation. An invention could be a prototype or the idea for a new product, and in this respect, inventions can form the foundation for improved products or production processes, while *innovations* refer to the process of commercialisation by implementation of an idea in practice. The distinction between the two terms is not always obvious but normally there is a time lag between an inventive discovery and the time it takes be implemented in practice. This relates to the fact that it might require some other knowledge, specific skills or resources in the development before an invention can be utilised in an innovation on the market. The *inventor* is the first to discover the idea. However he cannot be sure to be the first to gain the benefits if he does not see the potential or if specific knowledge, skill or resource is missing. The *innovator* is able to combine the factors that make the idea useful in practice, thereby utilizing possible benefits (Fagerberg, 2005).

Innovations are differentiated in accordance with contemporary technological changes. There are two categories of innovation in this differentiation approach, namely incremental (or marginal) and radical innovation (or technological revolutions). The first is characterised by small improvements that continuously make things better. The second, radical innovations are fundamentally new types of improvements such as new products with features that have never been seen before. Radical innovations normally entail a technological revolution; denoting series of innovations which may have a significant impact. The latter type of innovation was, according to Schumpeter, the most important. However, it is a widely held view that incremental innovations is at least of same importance. In relation to the categorization of innovation it is argued that the incremental and marginal innovations promote the impact of radical innovation and technological revolution (Fagerberg, 2005).

The specific context must also be taken into account when one actor innovates, and another imitates this innovation. Imitating can also be mentioned as innovating in the regard that one who imitates an innovation puts this innovation into a different context than the original innovator did not think of or intend. Thereby this could lead to adjustments and incremental improvements of the original innovation. This fits well with Schumpeter's definition of an innovation of "new combinations" of existing resources as stated above (Fagerberg, 2005).

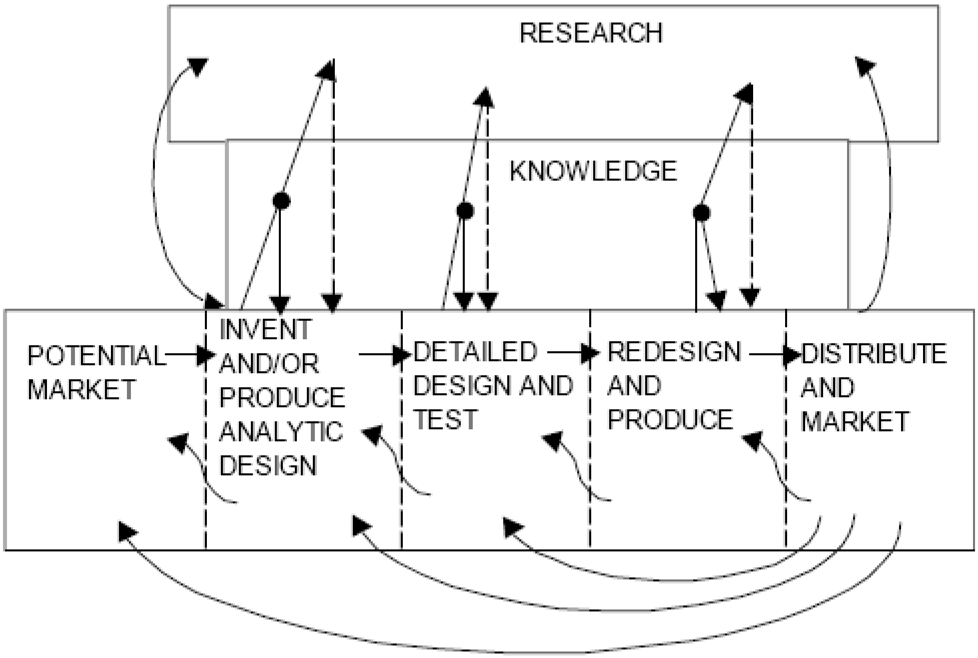
Schumpeter also argued that if imitators were to be successful, their chances will be improved if they increase the level of imitation and then become innovators themselves. This was done in an extension of an earlier way of thinking by Karl Marx. The original Marxian argument is: if a firm introduces a successful innovation it will gain a higher profit. Imitators will realise this signal and enter the industry, if entry barriers allow it, and get a share of the profits. This might undermine the original innovators' first mover advantage, but the entry of imitators implies that the growth of the industry will be higher than it would have been otherwise. The fact that the imitators would become innovators themselves, Schumpeter argued, is a natural step as an innovation tends to induce other innovations in the same field. Thus, diffusion of innovation becomes a creative process (Fagerberg, 2005).

The Marx-Schumpeter model of technological competition implies that innovation will concentrate, or cluster, in certain sectors and areas. Schumpeter's intention with the Marx-Schumpeter model was to explain long-run economic change. The main arguments for this is the fact that technological competition is the dominating form of competition and that "new combinations" of existing resources opens up new business opportunities and future innovation. These two arguments compose the basis for continues change (Fagerberg, 2005 p. 18).

3.2 The Concept of Innovation Systems

An innovation system (IS) is here defined as *"the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge''* (Lundvall, 1992). Inspiration for innovation stems from various sources and different stages of research, development, marketing and diffusion. Therefore, firms do not innovate in isolation but in cooperation with other organisations. This is the main idea behind this systemic approach, which underline innovation as being the result of a complex interaction between different actors - firms as well as institutions. Thus, technical change is not determined by perfectly linear sequences, but by means of feedback loops within the particular system (Freeman & Soete, 1997). This is shown in the figure below; the feedback loops is the interaction between research, the existing body of scientific and technological knowledge, the potential market, invention, and different steps in the production process:

Figure 6: The chain-link model



Source: Kline & Rosenberg (1986)

In this way, the lower part of the model shows those processes that take place within a specific firm (or a network of firms), while the upper part displays the firm's relationships within a broader context of the science and technology system that it acts in. Thus the entire innovation system benefit from knowledge flows that go back and forth between the agents.

The system surrounds firms and their ways of organizing their production and innovation as well as the channels by which they access knowledge from external sources such as other firms, research institutes and universities. In this way innovative firms are operating within a complex network of other firms, (both collaborating and competing), institutions, and suppliers and costumers (Fagerberg, 2005). The normal emphasized role of demand in economic analysis has a different emphasis when it comes to an IS analysis, where demand is not seen as an aggregate set of similarly characterized buyers but rather as heterogeneous agents who form relations with producers (Malerba, 2005).

More specifically, the IS consist of components and relations among them, where the main components are organizations and institutions[5]. Here, *organizations* have intentionally created formal systemic structures with an explicit purpose, being the players or actors of the IS, which may be firms (e.g. costumers, suppliers, and competitors), or non-firm organizations like universities and government agencies. *Institutions* are "the rules of the game", that is, sets of common habits, norms, routines, established practices, rules and laws regulating relations and interaction between individuals, groups, and organizations. The constituents together with knowledge and technology comprise the main dimensions of the IS, as the determinants of innovation processes, which consists of all central economic, social, political, organizational, institutional, and other factors influencing the development, diffusion, and use of innovations. In other words, an innovation system is functioning by performing and achieving development, diffusion and usage of innovations carried out through a network of various actors and supported by an institutional framework (Edquist, 2005). Hence, learning is the heart of the IS approach: as Lundvall has stated "*the most fundamental resource in the modern economy is knowledge and, accordingly, the most important process is learning*". (Lundvall, 1992 p. 1). Innovation systems have been categorized into among others[6] national innovation systems (Lundvall, 1992; Nelson, 1993), sectoral innovation systems (Malerba, 2002) and technological innovation systems (Jacobsson & Bergek 2004; Carlsson & Stankiewicz 1991). These approaches coexist and complement each other, dependent on the context.

In relation to our problem formulation we are interested in establishing the interdependent technological innovation systems in the sectoral system of solar PV within the geographic boundaries of Denmark. In the following we present the perspectives of these IS concepts, which takes its departure in national innovation system (NIS) and subsequently follows sectoral innovation systems (SIS) and technological innovation systems (TIS).

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[5] The SI approach is still associated with a certain degree of diffuseness, for example regarding the interpretation of the term institutions. For some authors, it is used for organisational actors, while others regard it as institutional rules. This thesis adopts the latter.

[6] Regional innovation systems, (RIS), (Cooke, 2001), is another approach of innovation systems studies. It is based on the idea that technology is connected to the concept of sticky knowledge and localized learning in regions, which can override national boundaries and are able to become more innovative and competitive by promoting stronger relations among companies and the infrastructure of the region. This thesis will not make use of the theories about RIS, as the Danish PV sector still only comprise a very small part of Danish business and therefore cannot be specified to a particular region.

3.3 National Innovation Systems

The concept of national innovation systems (NIS) is a component of the IS approach and was initially developed by scholars from SPRU[7] at University of Sussex and the IKE research group at Aalborg University with the main contributors Christopher Freeman (1987) and Bengt-Åke Lundvall (1988). It is based on the argument that understanding the linkages among the actors[8] involved in innovation is fundamental to improvement of technological performance and furthermore highlights the importance of interactive learning and nationwide institutions in explaining different innovation performances across nations. Here innovation and technological development is the outcome of complex interactions between actors that produce, distribute and apply different kinds of knowledge. As such, the way that these actors relate is vital to the innovative performance of a country, while being elements of a collective system in which creation and use of knowledge takes place, as well as the applied technology. The actors in the NIS are primarily private enterprises, universities and public research institutes, connected by linkages that take the form of, for instance, joint research, personnel exchanges, cross patenting and purchase of equipment. Institutions and societal incentive structures play a vital role for the stimulation and diffusion of knowledge and innovation (Lundvall, 1992).

The approach of NIS reflects the increasing importance of knowledge to economic performance, where knowledge flows are mapped complementary with measurements of knowledge investments. These knowledge flows become easier to detect mainly because of the rise of information technology. The idea is to compare and evaluate national channels of knowledge flows, identify possible bottle necks as well as market failures, and suggest policies aiming at improving their fluidity; that is localizing the links and relationships within industries, government and academia when developing science and technology. Such analysis may provide actors with the capability to evaluate the power of knowledge diffusion within the NIS, which is considered a vital determinant of economic growth and competitiveness (Edquist, 2004).

Although there is still no single common adopted definition, different authors have employed various approaches to the study of NIS. For instance, Nelson (1993) favours empirical cases over theoretical developments and emphasizes organizations that promote the creation and diffusion of knowledge as the main drivers of innovation. He also discovered that differences in innovation systems across countries are due to differences in their institutional setup. However, Lundvall (1992) argues for the importance of interactive learning, user-producer interaction and innovation in a

[7] Science and Technology Policy Reseach Unit
[8] Actors (or agents) can be individuals, organisations, authorities etc.

broader and more theoretical basis, and considers an innovation system as being jointly defined by *"the institutional setup"* and *"the structure of production"*. Furthermore, he recognizes the relatively narrow defined institutions to be embedded much more widely in a socio-economic system in which the scale, direction and outcome of innovation are determined by political and cultural implications as well as economic policies. Thus, both approaches highlights the importance of factors influencing innovation processes, but by different means as they each points out their very own determinants of innovation, reflecting the lack of a generally adopted interpretation of NIS. However, Charles Edquist has suggested a relatively more general definition of NIS, which includes *"all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion and use of innovations"*. Nevertheless, this definition should be considered very general, as *"we do not know the determinants of innovation systematically and in detail"* (Edquist, 2005 p.183). With these implications in mind, the next section provides a summarizing of the Danish NIS.

3.3.1 An Outline of the Danish National Innovation System

The Danish system is characterized by small-scale production and a significant public sector. There is a high degree of social equality in the society and a high level of income per capita. Also minimum wages are high, which makes it a relatively unattractive place for labour intensive industries. The production and exports are strongly specialised in low technology products and innovation is mainly incremental. In the public sector the main actors are the government, various ministries, most significant Ministry of Science, Technology and Innovation *(Ministeriet for Videnskab, Teknologi og Udvikling)*, and Research Councils who work out policies and are in charge of its implementation, while research and innovation activities are realized by universities, sectoral research institutes, other research institutes, science parks, and innovative incubators. The role of Research Councils *(Forskningsråd)* is very significant as they define new research trends and offer research counselling, and, very importantly, they manage the distribution of public research funds. The role of universities is regulated by an act formulating three major tasks including research, education, and knowledge dissemination. The university environment is made up by 12 universities where five combine several faculties, and other seven are specialized universities in for example technical and pharmaceutical issues. Universities are funded by a taximeter system, where the public allocation of funds is based on the numbers of students, and research projects are funded by Danish Research Councils, EU, and from commercial research. Sectoral research institutes play a major role in the Danish IS, as they serve the particular ministry with counselling and research. They are primarily public funded but some of their income comes from commercial activities. There are currently 12 sectoral research institutes, among others Risø-DTU, the Danish Building Research Institute *(Stat-*

ens Byggeforskningsinstitut), and the National Environmental Research Institute, *(Danmarks Miljøundersøgelser)* (Rogova & Toivonen, 2006; Lundvall, 2002).

So-called Technology Service Institutes (or GTS institutes) comprise another important part of the IS. They improve the interaction between public and private sectors and the commercialization of research results, and develop and sell technological services to private enterprises and public authorities on commercial basis in Denmark and abroad. Although being private and independent, they are non-profit organizations under the Ministry of Science, Technology and Innovation and authorized for 3-years periods. The GTS institutes collaborate closely with the Ministry of Science, Technology and Innovation on technology-based promotion of trade and industry with the purpose of increasing Denmark's international competitiveness. Basically, they are involved in independent development of know-how, participation in joint projects with public research institutions and private companies, and commercial activities. Today, the GTS institutes include nine consulting firms, among others Danish Technological Institute, (*Teknologisk Institut*), which will be further examined later on (Danish Technology Portal). The communication from technological institutes to firms is a very well functioning system, which conveys the newest technological insights on to the firms (Lundvall, 2002). The DISKO report from 1999 concludes that half of the Danish firms, who have had at least one product innovation within the last two years, have been collaborating with a GTS institute. Small firms are less likely to do so than larger firms, but the difference is not significant (Erhvervs Udviklings Rådet).

Another central part of the Danish IS is science-parks (Forskerparker). They are organized in Science Park Association in Denmark which is an association of science-parks and innovation milieus in Denmark. The association is a nationwide forum for the exchange of experience and opinion on innovation, entrepreneurship, technology transfer, capital, etc. It plays an active role in working to increase the public and private interaction, commercialise research and create new jobs (Science Park Association in Denmark). The science parks are designed to promote the formation and growth of knowledge-based or high value-added industries, with companies normally resident on site, and has a steady management team that seek to foster technology and business transfer to tenant organizations. Although science parks are normally independent and private companies, they are in some cases fully owned by universities, or they may be shareholders. There are seven science parks in Denmark, for example NOVI and Scion-DTU and seven innovation milieus, including Teknologisk Innovation A/S (Forskningsministeriet). They are partly funders of innovative incubators, for example through joint venture. The objective of the innovation incubators is to promote the commercialisation of R&D. Thus, they act in the sphere between public research institutions, the private sector, and venture capital, serving as a link between them that facilitates innovation. More specifically, they assist scientists and other entrepreneurs in the development of innovative projects and help remove barriers in connection with start-up firms by providing access to expert consultants, financial networks, and risk capital from the government. Furthermore, they provide consultancy, training, premises, and administrative services and cooperate with a broad spectrum of actors, e.g. universities, government research institutions, industrial enterprises, institutional investors, venture companies, business angels, and Vækstfonden[9] (Science Park Association in Denmark).

Lundvall (2002) points out two distinctive characteristics of the Danish IS. *First*, the Danish welfare model is built on social cohesion and trust, which are the bonds or "glue" that brings people together in society. Income is very equally distributed due to institutions like high taxes and a significant social awareness, which has furthermore been influenced by the presence of strong trade unions. In this respect the corporatist system of interactions between the state, the trade unions, and the employers has been a vital institution, which has initiated a Danish labour market characterized by a high degree of “flexicurity”[10], describing the special mix of flexibility in the labour market combined with social security and an active labour market with rights and obligations for the unemployed.

Second, the Danish “mode of innovation” is highly interactive, not science based and is primarily driven by local incremental innovations within SMEs that are considered low-tech but relatively innovative, based on strongly rooted institutions[11] that support learning by doing, using and interacting (DUI). Learning by interaction is particularly important in relation to inter-firm collaboration with costumers and suppliers, domestic as well as foreign. Firms’ competencies are determined by the presence of experienced labour from the “flexicurity” labour market and by the intensive interfirm cooperation[12] (Lundvall, 2002; Gregersen & Johnson, 1996). In this way human capital comprises a central part of the innovative resources.

Danish innovation policy was considerably changed in 2001 when the liberal conservative government took over. The Ministry of Science, Technology and Innovation was created and is now the government department, which is mainly responsible for innovation policy, where the agenda is

[9] Although there is no common adapted translation, it may be termed as The Fund of Growth.
[10] The term is thus a contraction of the words flexibility and security.
[11] E.g. high educational level, short hierarchical distance between employer and employee, different groups influence decision processes etc., which promote learning dynamics.
[12] There are exceptions in the food industry as well as within pharmaceuticals.

promotion of the interaction between business, industry, research, and education, as well as coordination between innovation and entrepreneurial policy measures. Furthermore, the government has launched several action plans[13] and strategies aiming at defining trends in national innovation policy development. National innovation policy seeks to strengthen the technology transfer and cooperation between public research institutes and the private sector and to increase commercialization of R&D results. Besides, there are different priorities relating to an increase of entrepreneurship and further investments in R&D, respectively (Rogova & Toivonen, 2006).

3.4 Sectoral Innovation Systems

Having presented the theories of National Innovation Systems and the concept's implications in Denmark, the next part is to present the Sectoral Innovation approach.

The economy may be classified into subdivisions called sectors or industries[14], which can be done in several ways[15] and, even further, sectors may also be subdivided into subsectors. When we talk about sectoral innovation systems (SIS) the geographical dimension is left out, i.e. sectoral systems are comprised only by a part of a regional, national or international system. A sector includes specific technological fields (generic technologies) or product areas (Edquist, 2005). Coherent with SIS there exist technological innovation systems, which we will describe later. The sectoral conception of an innovation and production system complements other concepts within the innovation system literature like national systems of innovation (Malerba, 2005).

According to Breschi & Malerba,

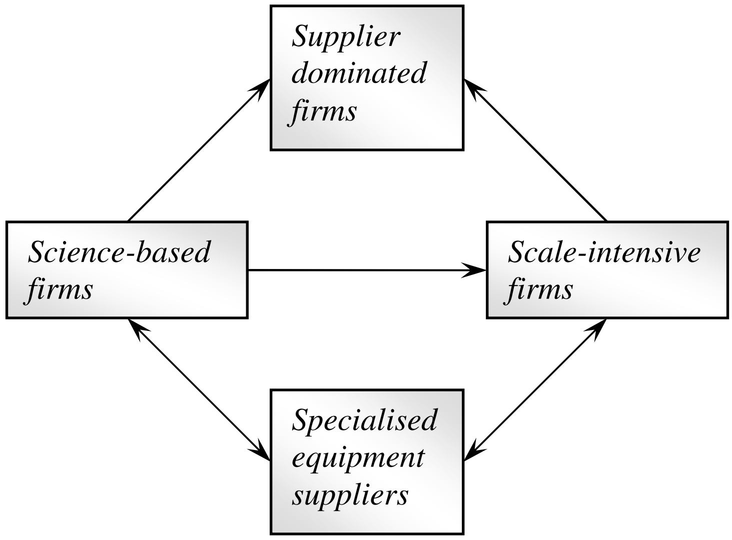
> "*a Sectoral Innovation System (SIS) can be defined as that system (group) of firms active in developing and making a sector's products and in generating and utilising a sector's technologies*" (Breschi & Malerba, 1997 p. 131).

This means that the actors within the sectoral system share some common knowledge and that the specific technologies or product areas can be used to define the boundaries of the SIS. Normally this is supplemented with a geographical delimitation, if it is not meant to be a global system analysis. The sectoral boundaries are not self-evident and must be explicitly constructed theoretically or socially, which may be reflected in the specific purpose of a study (Edquist, 2005).

[13] For example diverse growth strategies.
[14] There exists a lot of fuzz regarding the definition of sectors and industries, respectively. However, this thesis will not distinguish between them, as we argue that it is not important to thesis' main purpose.
[15] For example, some of the most disseminated models for classifying sectors are the *International Standard Industrial Classification of All Economic Activities* (ISIC) and the *Statistical Classification of Economic Activities in the European Community* (NACE). (United Nations Statistics Division)

There are significant differences in characteristics and performances of sectors, which can be referred to as *high* or *low R&D intensive*. Focusing on differences in market structure and industrial dynamics, sectors can be distinguished into the previously mentioned Schumpeter Mark I sectors that are characterised by "*creative destruction*", where technological barriers for entering are low. Schumpeter Mark II sectors are characterised by "*creative accumulation*", with significant barriers to entry and where large established firms prevail. The conditions for *appropriability* and *opportunity* also characterises a sector. If there are high technological opportunities these reflect a strong incentive for innovation activities. Appropriability is the probability of protecting innovations from imitation and of getting profits of innovative activities. So if there is high appropriability it is very likely that innovations will be successfully protected and make profits. *Cumulativeness* conditions describe whether innovative organisations are likely to follow specific technologies and trajectories when innovating, and if they do they are highly cumulative. The accumulated *technological knowledge* must also be characterised through various degrees of *specificity*, *tacitness*, *complementarity* and *independence*. Using these concepts, high technological opportunities, low appropriability, and low cumulativeness, leads to the Schumpeter Mark I sectoral pattern. Oppositely the Schumpeter Mark II pattern is connected with high appropriability and high cumulativeness. However in the industry lifecycle view a sector with a Schumpeter Mark I pattern can change over time into a pattern of Schumpeter Mark II (Malerba, 2005).

Figure 7: The main technological linkages amongst different categories of firms



Source: Pavitt, 1984

The Pavitt taxonomy can also be used for characterisation by distinguishing firms or specific parts of a supply chain into the 4 categories of firms, namely

(i) *supplier-dominated*,
(ii) *scale-intensive*,
(iii) *specialised equipment suppliers*
(iv) *science-based firms*.

(i) *Supplier-dominated* firms are very affected by developments in the other firm categories and distinguished by performing innovation embodied in new components through processes of learning by doing and using. (ii) *Scale-intensive* firms are affected by developments in especially "science-based" and "specialised equipment suppliers" categories and they focus on process innovation, which is based on both internal and external sources of knowledge, mainly a result of R&D and learning by doing. (iii) *Specialised equipment suppliers* focus on performance improvement, reliability, and customization in innovation and are stimulated through internal and external user-producer interaction learning. (iv) *Science based* firms are highly R&D intensive and induce many product and process innovations predominantly based on internal R&D (Pavitt, 1984; Malerba, 2005).

Besides these techniques, which can be used for characterising a sector, the three main dimensions of the methodology for the analysis of a sectoral system of innovation are (Malerba, 2005):

1. Knowledge and technological domain
2. Actors and networks
3. Institutions

These concepts are the most emphasised when describing a sector in terms of the systemic relations and their link to the drive of innovations. Hence, we will define and elaborate them in the following.

3.4.1 Knowledge[16] and Technological Domain

Knowledge and technological domain may be defined by the specific knowledge base, i.e. the basic knowledge required in the sector, because it differs greatly between sectors. The *sectoral boundaries*, which can change over time with the emergence of new technologies, become very important when focusing on knowledge and technological domain (Malerba, 2005).

When characterising knowledge at firm level it is highly idiosyncratic. Also it does not diffuse automatically and freely among firms – firms have to absorb it through their differential abilities, which accumulate over time. Knowledge and technology has a close relation because one knowledge domain refers to specific scientific and technological fields, which forms the basis for inventions and succeeding innovative activities. Knowledge also comprises selling skills, applications, user-specific, demand related issues, and so forth (Malerba, 2005).

Coming into the dimensions of knowledge, there is the degree of accessibility. Greater accessibility of knowledge can decrease industrial concentration. Greater accessibility may also imply lower appropriability in the internal dimension of the sector, which means that competitors can easier gain knowledge about new products and processes. Externally to the sector knowledge accessibility may be related to scientific sources and technological opportunities – human capital and organisations that contain and develop knowledge. Between sectors there can be large differences in the sources for technological opportunities, which is an important prerequisite for innovation. Opportunity conditions in sectors can be either related to scientific breakthroughs in knowledge institutions, advancements in R&D (like equipment & instrumentation), or external sources (like suppliers & users). Also the transformability conditions and social acceptance of the technological opportunities into concrete innovations plays a role, since the opportunities preferably should be demanded in the market to be profitable (Malerba, 2005).

Knowledge can be more or less cumulative in the way that new knowledge uses current knowledge as a basis for emergence. According to Malerba (2005) three sources of cumulativeness are identified:

1. Cognitive; knowledge and learning processes both constrain and generate new knowledge.
2. The firm and its organisational capabilities implicitly define path-dependency.
3. Feedbacks from the market; e.g. profits can be reinvested.

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[16] Knowledge is the result of learning and is not the same as data or information, though it is related to both (Davenport & Prusak, 1998). Knowledge in our definition does however include higher-order concepts like wisdom or insight and represents the unified effect of competences, skills and proficiency displayed by the agents of the IS.

There is an implicit connection between high cumulativeness leading to high appropriability of innovations. Knowledge spillovers will however occur in the system, and in high cumulativeness sectors they may play a role in diffusion of knowledge (Malerba, 2005). Other knowledge dimensions might be related to the degrees of tacitness, codificability, complexity and so on (Cowan, David & Foray, 1999).

3.4.2 Actors, Networks and Relationships

Actors and networks are the heterogeneous agents with *relationships* among them that form the system. The agents are distinguished into either organisations, which can be firms or non-firms (e.g. universities, agencies, associations), or individuals, such as entrepreneurs or scientists. Characterisation of the agents is done through specific learning processes, competencies, beliefs, objectives, organisational structures, and behaviours, which interact through processes of communication, exchange, cooperation, competition, and command (Malerba, 2005).

Firms are the key actors when generating, adopting and using new technologies and they can be characterised by specific beliefs, expectations, goals, competences and organisation (Teece & Pisano, 1994). Continuously firms engage in learning processes and accumulation of knowledge (Metcalfe, 1998). The degree of heterogeneity between sectors can vary through variety creation, replication, and selection.

Users and suppliers are types of actors, with more or less close relationships to producers and innovators, and are characterised by specific attributes, knowledge and competencies (Riggs & Von Hippel, 1994). Other agent types include non-firm organisations like universities, research institutes, financial organisations, government agencies, local authorities, and so on. These other agents can support innovation in various ways and not least technological diffusion and production by the firms. Universities can play a key role in some high technological sectors concerning basic research and the formation of human capital, and can even source start-ups and to an extent innovation. Financial organisations provide lighter constraints on finance for big firms in mature industries, while the start-ups in emerging and new high technology sectors must endure very high capital constraints (Malerba, 2005).

Regarding analysis of SIS the most appropriate units of analysis often can be individuals, subunits of firms, and associations of firms and not necessarily entire firms. As Malerba (2005) states, the emergence and transformation of the demand is a very important part in the dynamics and evolution of sectoral systems, and therefore there is a focal point on users, public agencies and consumers in the way that they redefine the boundaries of a SIS, stimulate innovation, and shape production activities.

Relations can be identified as formal or informal cooperation or interaction among firms, where networks emerge because agents are different, while having some of the same or overlapping interests or purposes. Consequently complementarities in knowledge, capabilities, and specialisation are integrated in networks. Firms' relationships with non-firm organisations (e.g. universities) can also be a source of innovation and change in a sectoral system of innovation (SSI) (Malerba, 2005).

3.4.3 Institutions

Institutions are the influences that shape the agents' cognition, actions, and interactions. These influences include norms, routines, common habits, established practices, rules, regulations, laws, standards etc., which is also the case within the NIS approach. The institutions can be distinguished as imposing enforcements or contrarily be created by the interactions among the system agents (e.g. contracts) through an assessment of how binding and formal they are. It is also interesting whether or not the institutions are national or sector specific (Malerba, 2005).

National institutions are e.g. the patent system, social rights, property rights, and antitrust regulations, which affect sectors, and might favour those that better fit the specificities of the national institutions and constrain other sectors' development. The interaction between sectoral and national institutions thus can mismatch or support sectors (Malerba, 2005).

3.4.4 The Sectoral System Dynamics

The ongoing interconnected interaction in the system between and through knowledge, technological domain, actors, networks, and institutions form and outline the dynamics and continuously transformation of sectoral systems. The evolutionary processes as variety creation, replication, and selection, which are present in a sector, make up the base of this (Malerba, 2005).

The processes concerned with variety creation deal with for example products, technologies, firms, institutions, and firm strategies. Creation of new agents (both firm and non-firm organisations) consequently plays a key role in the dynamics of a SSI. Selection processes occupy an imperative function that reduces heterogeneity among firms, which can eliminate those with inefficiency or reluctance to change. These processes are often path-dependent and can lead to inferior (caused by e.g. increasing returns) or superior (caused by e.g. exacting users) technologies. As the relationship between knowledge and evolution is close and two-way, changes in the learning processes and knowledge base can induce deep transformations in the agents' behaviour and the relationships among them (Malerba, 2005).

The co-evolutionary processes can for example be characterised by user-producer relationships, centralisation, or technological change and e.g. entail dominant firms, high entry of firms, divided technical leadership, and different other market structures. New clusters that emerge make out very relevant transformation processes (Malerba, 2005).

3.4.5 The SSI Relation to Policy

The purpose with the SIS approach is to identify the systemic dimensions that are missing, inappropriate, or not working, in order to specify a "problem". The systemic dimensions lay down the basis for the SIS efficiency and performance and it can pose a problem if the expected comparative performance is not met. The challenge is to find the cause behind a certain problem, which for example could be weak technological transfer between universities and the industry, which could be called a "system failure", when the cause behind a problem is found. An identification of this kind of problem should be supplemented with an analysis of its causes to facilitate proper guidance to policy makers in the design of sector specific innovation policies (Malerba, 2005).

Because of the major differences that exist among sectors, policies should not necessarily be horizontal across sectors but rather take the sectoral differences into account. Besides innovation and technology policies a wide range of other policies may be necessary to foster innovation, e.g. policies on science and competition. In order not to miss constraints or opportunities that influence innovative behaviour of organisations the policy maker also has to consider the coexistence of different geographical dimensions, e.g. local, national, regional, and global (Malerba, 2005).

Innovation policies could be tax breaks for innovative activities and public resources for RD&D, which however cannot stand alone. Innovation opportunities must be enhanced by improving the organisation of an innovation system to avoid diminishing returns and instead improve the complementary payoffs from public and private RD&D (Malerba, 2005). Having outlined the theoretical features of sectoral innovation systems, the next part takes the technological context into consideration.

3.5 Technological Innovation Systems

When studying the way technologies emerge, improve and diffuse within the innovation system it is relevant to apply the concept of technological innovation systems (TISs), which is defined as

> *"a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology"* (Carlsson and Stankiewicz, 1991 p. 93).

The TIS approach is a tool for analysing the process of the emergence, improvement and diffusion of a given technology, that is, the structure that surrounds the technology. A TIS can be considered as a technology-specific innovation system because of its emphasizing of innovation and diffusion processes as both an individual and collective act, like argued in the broader literature on innovation systems (Jacobsson & Bergek, 2004). Thus, the emergence of new technologies is assumed to take place through a process of interaction between firms and other organizations like universities, industrial societies and government bodies, in which the institutional set up is essential to the outcome of such processes. The concept is based on an assumption about the presence of various and different technological systems, each specific to their own capability to develop and diffuse technology (Jacobssen & Bergek 2004).

Instead of being based on flows of goods and services, TISs are defined by knowledge and competence flows, and networks, which may be transformed into so-called development blocks, i.e. synergistic clusters of firms and technologies within an industry or a group of industries, if the right conditions are present in the form of entrepreneurs and a sufficient critical mass[17]. Technological systems are not necessarily nationally bounded as it often goes beyond national borders, thus, sometimes technological systems are international, or even globally bounded. The boundaries depend on technological and market requirements, abilities of agents and the degree of interdependence among agents. A TIS may also be a sub-system of a SIS when focus is on the sector's products or when a knowledge field is exclusive to a sector. When the focus is more on generic knowledge, that is, knowledge that several sectors make use of, the TIS often cut across numerous sectors[18]. Sometimes, when TISs are defined by the national institutional infrastructure, they share a lot of common features with national innovation systems, but basically they are different given that the former refer to particular industrial areas while the latter covers all areas, and all national TISs, simultaneously.

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[17] The existence of a sufficient momentum in a social system such that the momentum becomes self-sustaining and promote further growth (Ball , 2006).

[18] Besides its close relationship with NIS and SIS, the TIS concept also comes close to the definition of technological clusters or regions when the TIS is highly regionally concentrated.

At the same time, the theory of TIS stresses to a higher degree adoption and utilization of technology instead of the generation and distribution of knowledge, as is the case with national innovation systems (Carlsson and Stankiewicz, 1991; Bergek et al., 2007).

3.5.1 Structural Elements

The key components in a TIS are the *actors* and their capabilities, knowledge and competence *networks,* and *institutions*, all influencing the innovation process for a particular technology[19]. These are presented more specifically below and adopted from Jacobsson & Bergek (2004) and Bergek et al. (2008).

Actors include firms and other organizations, for example users, suppliers and venture capitalists. Here, the role of the "prime mover" (or system builder) is very important. It is the actor(s) who posses strong enough technical, financial and political abilities to influence the development and diffusion of a given technology. Other actors include non-commercial organizations who act as proponents of a specific technology. When users and professionals operate within a (growing) TIS, they may over time recognize that they share some common interests that can be fulfilled by forming technical and professional organisations that are based on coalition building, voluntary associations and societal norms and customs. When they become powerful enough they will be able to lobby the political system in favour of a particular TIS.

Networks are essential to the transfer of tacit and explicit knowledge as they provide individual actors with the possibility to improve their own and gain access to other actor's knowledge bases. As learning networks are built around markets, the actors are able to jointly identify common problems and develop new techniques. However, there are often also non-market related networks that aim at a more general type of diffusion of information and an interest to influence the institutional setup. Actors' decisions are strongly influenced and guided by networks because of their ability to identify future interpretations of what is desirable and possible.

Like in the NIS and SIS approach, *institutions* are "the rules of the game" because they form the laws, rules and norms as well as regulating the interactions between actors. However, the set up and roles of institutions differ as some provides the role of connecting the segments in the system while others influence the incentives to for example innovation and demand (Edquist, 2005). Besides, institutions have a great influence on the rate of technological change making them very important for the path of technology.

[19] They may not always technology-specific given that they may be shared by various TIS (Bergek *et. al* (2008).

3.5.2 Functions

In order to identify the underlying mechanisms, it seems apparent to turn the attention on the functions that takes place within the TIS as they act as intermediaries between the components of the TIS and its performance. In order to promote industry growth, they must be in focus as a given technology is most beneficially investigated by means of its functional patterns, that is, in terms of the way that these functions are served. The basic *functions* include (Johnson, 1998; Jacobsson et al. 2004):

1) *Knowledge development and diffusion*
2) *Guiding the direction of search processes*
3) *Supply of resources*
4) *Creation of positive externalities*
5) *Formation of markets*

1) *Knowledge development and diffusion* is the core of TIS, as in the other branches of IS, being a determinant of the breadth and depth of the knowledge base, and concerned with the efficiency of knowledge[20] diffusion as well as how it is combined in the system. The creation of knowledge comes from academic and firm R&D but also through activities such as learning by doing, -using, and -interacting, and entrepreneurial experimentation, while the diffusion of knowledge takes place within different learning networks as stated above.

2) *Guiding the direction of the search process* for the users and suppliers is a prerequisite for the development of TIS. The reason is that there must be sufficient incentives or pressure for organizations to enter the system. This function includes guidance and legitimacy with respect to growth potential and the choice of design approaches, technologies, markets and business models.

3) *Supply of resources* of both competences, labour and financing. For example, competencies and capital are essential inputs to the activities within a TIS. Thus, it is important to recognize that a TIS should be able to mobilize human capital through for example education, entrepreneurship and management, and finance capital like venture capital and government funds for R&D and demonstration.

[20] The knowledge may not necessarily be genuinely new, given that innovations sometimes emerges by the combination of existing knowledge or by imitation.

4) *Creation of positive externalities*[21], market as well as non-market mediated. This value creation includes knowledge spillovers[22], reduction of both uncertainty and costs of information, as well as access to tacit knowledge, all of which are further increased by the number of new entrants. Other positive externalities are specialized labour markets, labour pooling and specialized suppliers, which are also often referred as Marshallian externalities (see e.g. Marshall, 1890). Physically, the externalities are present in the form of the establishment of supporting consultancy businesses, development of industrial structure and sub-supplier networks.

5) *Formation of markets.* When technologies develop, there are rarely initial markets ready for them, and therefore they need to be created or stimulated. This process is highly influenced by governmental intervention aiming at clearing legislative barriers, and different organizations' efforts to make the technology legitimate. It often includes the formation of niche markets.

These functions are interrelated as changes in one function may lead to changes in another; for example when the creation of new markets attracts new entrants, it might result in supply of new resources to the TIS.

By basing the analysis of the TIS on its functions and elements, it becomes possible to (1) identify the boundaries of the system by means of an investigation of the factors that promote and obstruct respectively the emergence of the functions, and (2) trace the way that the generation, diffusion and utilisation of a new technology is shaped by the interplay of different actors and the institutional set-up. The latter is based on the assumption that there is no system structure that clear and unambiguously relates to the performance of a TIS. This is more or less coped with by arranging empirical knowledge in terms of such functions (Jacobsson and Bergek 2004).

3.5.3 Emergence of a TIS

New TISs with strong functions should emerge around new technologies. For that reason it seems apparent to look at how they evolve. Jacobsson & Bergek (2004) identify two basic phases in the evolution of a TIS, namely a *formative* period and one of *market expansion*, respectively. Each phase is unique to its own characteristics in relation to the character of technical change, the patterns of entry/exit and the rate of market growth.

[21] Positive impacts on any actor not involved in a given economic transaction.
[22] Among connected (e.g. local) agents information about novelties can flow and offer opportunities and improved possibilities for diffusion.

The first, formative phase is characterized by a broad variety of competing designs, entry of several actors, emergence of small markets and significant uncertainty with respect to technologies, markets and regulation. In order to understand how the formative stage emerges, it is essential to identify the process of the constituent components' emergence as well as how the five functions begin to increase in importance. The process is made up by four elements of *market formation, entry of new firms* and other organizations, *institutional change*, and emergence of technology-specific networks (or *advocacy coalitions*), respectively (Jacobsson & Bergek, 2004).

Market formation consists of exploration of niche markets, that is, markets in which the new technology is by somehow superior to others. Such markets are sometimes referred to as "nursing markets" because of their involvement of government subsidies in order to protect the new technology. At this stage, the technology's price/performance ratio is improved, costumer preferences formed and learning processes begin to take place. This "protective" stage is not only destined for the first niche markets that emerge, as the diffusion of a new technology is considered as an exploration of series of niches before they penetrate mass markets. The intermediate level between niche markets and mass markets, so-called "bridging markets" is often required before the new technology gains the ability to become a commodity. Such markets promote larger volumes of production and act as a generator of space for the elements within the TIS in order to fall into place. These nursing markets attract new entrants into different parts of the value chain because of their propensity to guide the direction of search (Bergek et al., 2008).

In this way, *firm entry* gives rise to new TISs by means of the following factors. First, they provide the system with new knowledge and resources. Besides, new entrants extend the TIS by filling the gaps, for instance by becoming specialized suppliers, or by the development of new applications when they seek to meet novel demands. This process initiates positive externalities, as described above, where further knowledge is formed by specialization and accumulate skills as a consequence of a higher degree labour division. Finally, the externalities may give raise to selection processes and an increase in the returns for the following entrants by for example a higher flow of information and increased possibilities for firms to utilize complimentary resources. Associated with these are a greater availability of legal and accounting services, and a greater amount of venture capital, both encouraging other firms to enter, which are important for the legitimating[23] process of new fields (Carroll, 1997). The institutional framework is closely related to the legitimacy of new technologies and its actors, their access to resources, and the formation of markets. Therefore, important func-

[23] "Social taken-for-grantedness"

tions are in risk of being obstructed if the framework lacks alignment with the new technology (Jacobsson & Bergek, 2004).

For this reason, *institutional change*, (or alignment), is in the core of the process by which new technologies emerge, which takes different forms. When inducing the emergence of competing designs, new TIS and knowledge creation may be supported by redirecting both science and technology policy, sometimes even before market emergence. Institutional change also involves market regulation, tax policies, formation of standards etc. Firms within TISs do not only compete in the marketplace but also in order to affect the institutional framework, which sometimes takes place cooperatively when competing firms seek to influence the institutional setup in order to legitimize and make particular resources accessible (Jacobsson & Bergek, 2004).

Such cooperatives or *advocacy coalitions*[24] essentially consist of several actors that share some particular common perceptions while also competing to influence policy by means of their beliefs. For this reason, policy making takes place in such context. This is why technology specific coalitions often are formed with the purpose of influencing for instance institutions and consolidate institutional alignment in order to gain ground for a given technology. This necessitate political engagement in broader public debates and establishment of support among wider advocacy coalitions, or political networks, where a particular technology is regarded as a possible solution to broader public and policy concerns, for example with regard to solar cells and climate change. There are many types of actors and organizations within such coalitions including universities, private as well as non-commercial associations, media and politicians. Most significant, however, are the roles of individual firms and industry associations. Therefore, entry of new actors in the TIS might cause an increase in the formation and strengths of these coalitions, and the role of new entrants is thus also associated with stronger advocacy coalitions to provide a greater influence on the institutional set-up (Bergek et al., 2007).

Even though the time span associated with the formative phase may be very long, (often several decades), and considerable investments often are without success, at some point they have generated a large enough system that is able to begin to develop self-sustainingly where larger markets are formed in the <u>market expansion</u> phase. In order for this to take place, the systems have to connect with its underlying technological and market opportunities. Here, the causal interrelations between the elements and the functions of the TIS become parts of a larger chain reaction of positive feed-

[24] In the environmental field, advocacy coalitions actually existed before the emergence of specialised industries within e.g. wind turbines and solar cells.

back loops which give rise to circular linkages between the functions which in turn initiate a cumulative causation process. However, for cumulative causation to take place, a TIS has to go through the above-mentioned formative process (Jacobsson & Bergek, 2004).

3.6 Synopsis of the IS Approaches

There are significant overlaps and similarities between the IS approaches, but also some important differences. From the three branches presented above, it is clear that they all more or less point to structure as the basis for explanation, which consists of actors, institutions and the network of relations through which these are connected. These key concepts are defined very similarly, which we would consider justifiable to merge in an analytical framework. Differences come forward in the way of investigating the constituents of the systems. Especially the TIS approach stands out in as it puts higher emphasis on technological selection processes, diffusion processes with the important role of advocacy coalitions and prime movers, and not least puts forward the notion of functions within innovation systems. The functions seem to operationalise the approach but they also have a systemic nature of interconnectivity. Both the TIS and SIS approach can be used to investigate the PV Danish group of firms related to the PV technology but both approaches contain valuable insights into innovation and especially relevant studies about emerging energy technological systems have been made within the combined usage of the TIS and NIS approach (Jacobsson et al., 2004) and a seemingly complete merge of the TIS, SIS and NIS approach (ICCEPT/E4tech, 2003; Foxon et al., 2005), which we to draw upon in our analysis.

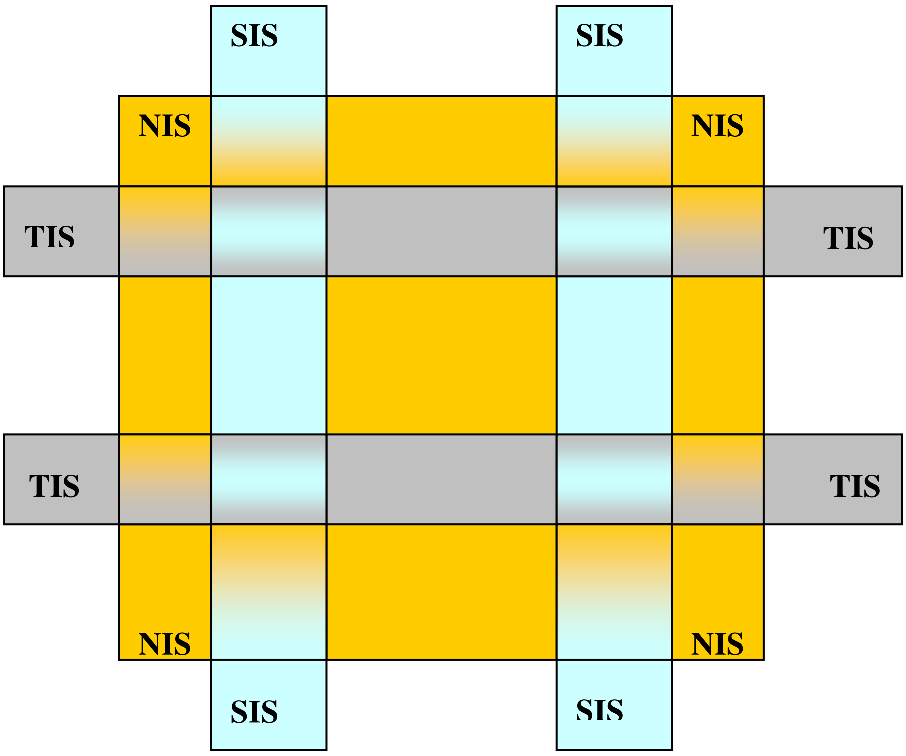
Therefore by the use of these approaches, (NIS, SIS and TIS), we generate a common, hybrid framework that include all vital components of the system of interest, referring to the problem formulation. In this respect, we will apply the SIS and TIS concept, while not forgetting the important repercussions of the NIS approach. The emerging PV technological system still though seems to have the potential to make out a much more essential part of the economy in the future. The NIS approach is toned down due to the fact that it covers the nation as a whole, and therefore includes a broad and rather complex range of actors, institutions and sectors, and thus does not provide deeper insight into the dynamics of specific sectors within the innovation system. On the other hand, however, the NIS approach forms the underlying basis for all innovation activity and is therefore essential to the overall national innovation performance, including the PV sector. Hence, this thesis proceeds with this important appreciation in mind; that is, even though the analysis is primarily based on SIS and TIS, we do keep the insights of the NIS approach in mind.

It was shown above that the SIS approach defines a sector by its technological domain and its knowledge base, which differs significantly between sectors, and for this reason the nature of innovation is also different between sectors. In this way, the sector is determined by specific technologies or product areas, but the sectoral boundaries are to a great extend much more theoretically grounded, and therefore it is still not clear what a sector really is, making it difficult to specify the sectoral boundaries. According to Malerba (2005 p. 402) sectoral systems often include more than one technology, while the same technology may exist in a number of different sectors.

By the latter, Malerba (2005) refers to the concept of TIS, where the knowledge and competence network dynamics of technology development is not seen as fully integrated in one particular NIS or SIS, but goes across, and beyond, national and sectoral borders. Often the TIS has both national and international dimensions, which is especially the case with scientific knowledge that is produced in different locations in the world. However, the technology in question often relate most significantly to one particular sector that is more important than others (Borup et al., 2007).

As we see it, the IS theories overlap in the following way:

Figure 8: Overlaps between NIS, SIS and TIS



The rationale behind the figure goes as follows: Within the NIS, there are several SISs (e.g. energy sectors) and TISs (e.g. types of renewable energy technologies), which each often goes beyond the national context, and therefore they are drawn beyond the borders of the NIS. Furthermore, there are several overlaps between TISs and SISs. For example, the PV technology is found within the energy sector as well as the building sector, and, conversely, there are several different technologies within e.g. the energy sector.

In our terminology a sector is defined as a socially or statistically constructed subdivision of an economy and may in some senses mean the same as the term industry. Oppositely technology can be perceived in the context of modern society as a consequence of useful inventions from the interplay between science and engineering. Coming back to the case for the PV technology it connects to the sectors of construction and semiconductor while its main feature as an energy providing technology makes it primarily embedded in the sector energy.

In the analytical framework we apply a hybrid approach, which both integrates elements of the SIS and TIS branches. In order to make this theoretical framework operational we are greatly inspired by ICCEPT/E4tech (2003), Foxon et al. (2005), and a paper by Jacobsson & Bergek (2004).

3.7 The Analytical Framework: An Innovation System Approach

According to the theoretical basis examined above, the framework for the analysis is divided into the concepts of SIS and TIS. The studies we will make use of are presented below.

OECD has in collaboration with IEA undertaken a case study of drivers and barriers to innovation within the energy sector in different countries. In this respect ICEPT and E4Tech (2003) have formed parts of the UK contribution to the project, where they analyse the UK innovation systems within a handful of renewable energy sectors. Here, the point of departure is taken in the TIS approach and the NIS approach, where the latter is related to the fact that it is a comparative study aimed at providing policy recommendations as well as insight to the differences between sectors of RE on a national basis. However, as the paper (ICEPT and E4Tech, 2003) analyses *"the innovation system for each sector"* (p.18), we argue that we can adopt the SIS methodology in order to make the SIS theory operational as well as the NIS and TIS. In the same way, Jacobsson & Bergek (2004, p. 211) have developed an analytical approach for technologies in renewable energy, which is on the other hand explicitly grounded in the TIS approach, and therefore we are also inspired by this framework in the composition of this paper's specific framework.

The next part will consequently integrate these approaches in a single analytical framework in order to provide the basis for the investigation. We take our point of departure in ICEPT/E4tech (2003), after which we relate to the key contributions from Jacobsson & Bergek (2004).

The ICEPT/E4tech (2003) work investigated the following key issues:

1. *The actors in the PV sector*
2. *Drivers of innovation*
3. *Creation and diffusion of knowledge*
4. *Innovation map*
5. *IPR*
6. *Public/private partnerships (PPP)*
7. *The international dimension of the IS*
8. *Other systemic influences on innovation*

Meanwhile, Jacobsson & Bergek (2004) emphasise three main elements within the TIS approach:

- *Actors*
- *Networks*

- *Institutions*

The first point is *actors*, whose definition is the same in both approaches. However, additionally, Jacobsson & Bergek (2004) stresses the role of so-called "prime movers" as well as organisations acting as proponents of specific technologies. Therefore, they will be included as a matter of investigation in the actor category below (1).

The *network* category is not explicitly mentioned in ICEPT and E4Tech (2003; Foxon et al., 2005), but is very similar to their category of *creation and diffusion of knowledge*. In order to make the importance of networks explicit, they are included in this category (3).

Besides, even though ICCEPT and E4Tech (2003) do not make explicit use of the concept of *institutions,* since they are more or less parts of all key issues. They make out the glue the binds the system together and result in e.g. drivers for innovation.

However, as *"five basic functions need to be served in a TIS"* (Jacobsson & Bergek, 2004), the following functions are essentially important to serve for the technology to mature:

a) *Creation and diffusion of new knowledge*
b) *Directing the search process (selection)*
c) *The supply of resources (e.g. capital and competencies)*
d) *Creation of positive externalities (market and non-market mediated)*
e) *Facilitation of the formation of markets*

The IS analysis covers the first four of these functions, while the *(e)* function is covered in the policy analysis.

Going on to the framework, the categories of *IPR* and *international dimension* will be treated as integrated parts of the other categories since we consider these to be justifiably covered. IPR can through patenting and licensing act as a driver for innovation and ways of knowledge diffusion and the degree of international dimension can be quite important as to how innovation is achieved.

Thus, the analysis is made up by the following issues:

1) Firstly, the key *actors* involved in the PV sector will initially be identified and characterized. These include those involved with creation and sharing of knowledge such as academic re-

searchers, technology developers, knowledge-sharing networks; project developers and end-users disseminating and using knowledge in the form of commercial products; and actors setting the framework conditions including government departments and regulators, research funders and financial investors. Furthermore, prime movers will be identified.

2) In this respect, the initial task is to identify the *drivers of innovation* and flows of influence within the PV sector, which includes a broad row of issues, including government policy and market forces in creating incentives for innovation, how policy drives the direction and timing of R&D, how actors are influenced by a long-term policy framework, and the significance of an early home market. Besides, the influence of some other institutions on innovation is investigated, which include the influence of societal concerns for example concerning the environment. Additionally, the relative importance of technology push drivers compared with demand pull drivers is addressed, where the former refers to basic and applied R&D, (both public and private), and the latter refers to the influence of energy distribution and users.

3) Then, the way knowledge is created, diffused and exploited is investigated by means of an identification of *key sources of new knowledge*, IP and new technologies. Referring to this, the means and importance of knowledge sharing between actors is examined and also exchange of (tacit) knowledge within networks, consulting and joint research project. During, there will be an identification of the key performers of R&D and innovation in the PV sector, followed by an assessment (of the balance) of how firms acquire knowledge, which can be internal, on contract or collaborative R&D, networking, and licensing. This area includes also an investigation of the way that research is carried out (relating to individuals, teams or research centres) and whether skilled labour is available.

4) Afterwards, an *innovation map* for the PV sector sums up the main systemic interactions between the actors, including the above innovation drivers and knowledge flows. It consists of the key actors and the flows of knowledge, influence and funding that take place between them. Furthermore, the main framework conditions will be examined as well as the position of PV technology on the innovation chain.

5) In order to investigate how public/private partnerships (PPP) influence and foster innovation, the forms and significance of these will then be assessed. Hence, the type and methods of

knowledge sharing within such partnerships is analyzed, where the type of knowledge can be either general or specialized and the methods formal or informal. In this respect, this part will examine the arrangements of PPP as well as how the results and property rights are managed and shared.

6) Finally, *other systemic influences* on innovation will be examined, which includes other *institutions* like market structures and government regulations that either give rise to or hinder technological innovation.

Thus, taking its departure in the IS approach, the analysis will identify the characteristics of the sector. The aim is to review resource potentials, technology options as well as technical and market status. Then the PV sector is recapitulated on the issues of drivers and barriers for innovation; knowledge creation and diffusion. In order to sum up the systemic relations between the actors, these flows are mapped in relation to influence, knowledge and funding. Any system failures that are found during the analysis will also be listed with the directions for further analysis and ultimate solving of the systemic problem.

3.7.1 Design of the Analysis

Summarizing from above, the structure of the analysis goes as follows:

1) *Main actors in the PV sector*
    a) What actors are present in the sector?

2) *Drivers for innovation*
    a) What are the primary drivers for innovation?
    b) What are the respective roles for government policy and market forces in creating incentives for innovation?
    c) How do the actors in the sector drive innovation?

3) *Knowledge creation and diffusion*
    a) Which are the key sources of knowledge and the means of sharing knowledge between actors?
    b) Which actors are the key funders and performers of R&D and innovation?
    c) In what ways do firms acquire new knowledge?
    d) How does knowledge creation lead to diffusion?

4) *Innovation map*

5) *Public/private partnerships (PPP)*
   a) What partnerships are present in the PV sector?
   b) How do they contribute to innovation?
   c) What funding and IPR sharing arrangements exist within the PPP?

6) *Other systemic influences on innovation*
   a) What other systemic factors (such as market or policy systems) promote or inhibit technological innovation?

When we finish off the IS analysis we sum up on the findings and make an assessment of the sector maturity.

Before turning to the analysis of the innovation system, to which this framework will by applied, the next part provides a review of the Danish PV sector, including sub-sectors, current resources, technologies and status. That is:

1) What are the PV technology characteristics?
2) What are the relevant sub-sectors within the PV sector?
3) What is its resources and potential?
4) Overview of technologies & developments.

4 Photovoltaics: An Introduction

Moving into our specific subject for this thesis we will start by introducing the technologies in order to provide the reader an acquaintance with the key concept and features of the area of solar energy.

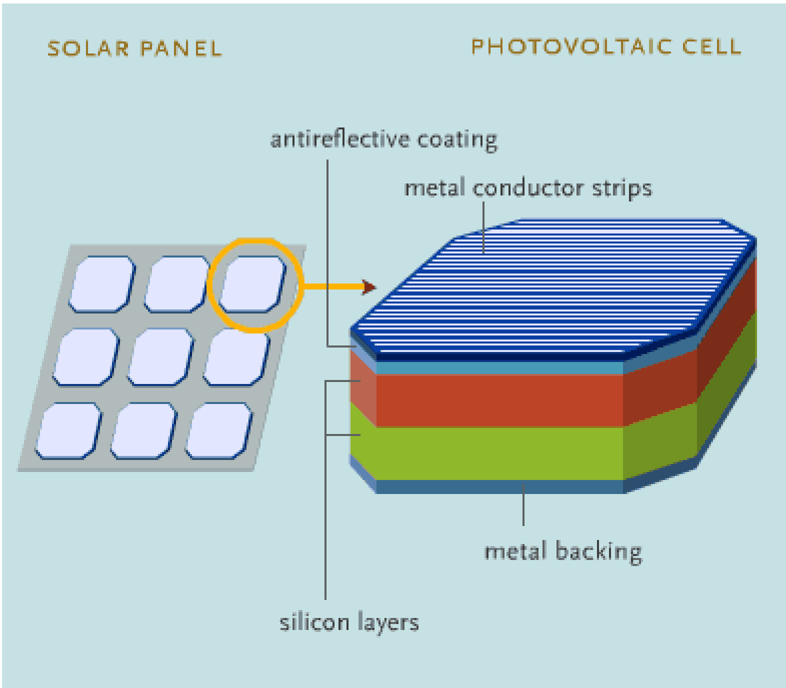
4.1 Solar Energy Technologies

Solar energy is divided into three main technology areas, which are (1) *photovoltaics (PV)*, (2) *solar thermal power* and (3) *solar heating and cooling*. In the presentation of these technologies we will follow the IEA (statistics) grouping definitions for convenience reasons. This study specifically concerns the photovoltaic technologies but other solar energy technologies also exist which should be clearly distinguished between. Therefore we provide a small guide to the area of solar energy.

4.1.1 Basics about Photovoltaics

Within photovoltaic electricity production there exist a wide range of technologies that we will come back to later in the report. Basically a solar cell or photovoltaic cell is a semiconductor device that converts light into electricity using the photoelectric effect[25]. Solar cells are a tough and reliable technology and also for this reason it has for a long time been used frequently in space travel missions (Energistyrelsen, 2005). PV installations are typically measured in kWp - an abbreviation for kilowatt-peak, a measure of the peak output of a photovoltaic system. *1st generation* photovoltaic cells are made of high efficiency silicon-based mono- or polycrystalline and is the dominant type of solar cells in the market. But even though producing costs keep falling and efficiencies keeps rising, the technology could be heading towards a peak in market share because of other emerging technologies. *2nd generation* technology are lower efficiency thin film cells typically based on amorphous silicon, which have a good market po-

Figure 9: A conventional silicon crystalline PV cell



Source: PBS

[25] Also known as the Hertz effect. Photons of light hit a metal or crystalline material and some of the energy is absorbed into electrons, thus giving some electrons enough energy to burst out of the material with a finite kinetic energy, thereby producing electric current.

tential because of lower producing costs and multiple niche application possibilities. However 2nd generation cells have lower durability and lifetime. *3rd generation* is completely new technologies with low output, e.g. PhotoElectro-Chemical (PEC) cells and polymer (plastic) solar cells, and some consider that these technologies have in perspective to develop the lowest manufacturing costs among the known technologies because of their simplicity and use of cheap materials (Katic, 2006; Borup et al., 2007).

Denmark has a relatively weak industry and international position within 1st and 2nd generation solar cells even though various Danish niche products like Building Integrated PV Systems (BIPV), inverters and crystalline silicon might do fine. Future perspectives are good though because Denmark have some market niche potentials in 3rd generation solar cells also, due to ongoing research activity on Danish universities, research institutes and technological institutes (Borup et al., 2007). The challenges for 3rd generation cells of demonstrating reliable field operation and commercialising the products lie ahead. For example, prototypes of small devices powered by dye-sensitised (PEC) PV cells have been developed (Solarbuzz A).

Some photovoltaic crystalline technologies can reach efficiencies up around 40% in lab conditions under concentrated sunlight and have perspectives of reaching 45-50% efficiencies, but still this technology have a key weakness because concentrators depend on direct sunlight, and thus might not have great relevance under cloudy weather conditions like the Danish (Solarbuzz A). Still photovoltaic electricity in private housing is more expensive than traditionally produced electricity from fossil sources. However, if the development continues like it has done until now, it is only a matter of time before solar photovoltaic electricity can begin to compete on price equivalent terms with other sources of electricity. The political determination seems also to be present in Europe and EU has accordingly formulated a goal for 2010 where photovoltaic electricity is to make up 1% of the total electricity supply and 20 % in 2020 for all renewable energy sources. In Denmark a grid-connected photovoltaic facility can produce 700-900 kWh per year for every kiloWatt (kW) installed effect, which is around the half of what facilities in Southern Europe can produce (Energistyrelsen, 2005).

Around 90 % of the market is made up of 1st generation crystalline solar cells and is considered as the reigning technology regime (Solarbuzz A, Energistyrelsen, 2005). Monocrystalline cells are still the most efficient with an average efficiency of 16 % in market products and a world market share of around 35 % in 2005. Monocrystalline PV cells can reach efficiencies of 22-24 %. Polycrystalline cells have an average of 13-15% functional efficiency and had a world market share of around 55 % in 2005 (Solarbuzz A & energistyrelsen, 2005). Higher lab efficiencies of PV cells are continuously developed and it is a central matter to bridge this gap between new high lab efficiencies and industrial solar cells (Hezel, 2004).

4.1.2 Solar Thermal Power

The main technology concerning solar thermal power (also called Concentrated Solar Power, CSP) works in the way that the solar light is concentrated through glorified mirrors in the shape of parabolic dishes (concentrators) directing the sunlight towards a tower, where the light energy is transformed into electricity[26].

Other technologies in solar thermal power are stand alone small power systems that use oil in hybrid systems with the solar energy (see e.g. NREL). Likewise there is also the larger parabolic trough meant to be connected to the electric grid. Concentration technologies from this field could be used in PV to enhance efficiencies.

4.1.3 Solar Heating and Cooling

Solar heating and cooling is made up of different technologies. *Solar heating* can be divided into active and passive systems. *Passive solar heating* relies on certain building principles for collecting, storing and distributing heat throughout a building and are accounted for under IEA's energy efficiency definition. Day lighting is another aspect of solar energy that IEA on the contrary does count in their statistics on solar heating. Day lighting is the practice of placing windows, or other transparent media and reflective surfaces, in order to let natural light provide effective internal illumination. However, the main technology within this category is active *solar heating*. Active solar heating facilities transform sunlight into heat which is provided through the use of a system that moves temperate air or liquid from the solar collector into e.g. a house. In Denmark and other Northern European countries, combined hot water and space heating systems are often seen, which at their best can provide up to 30-40 % of the annual consumption. Solar heating are usually, independent of facility, supplemented by other energy sources to compensate seasonal differences (Energistyrelsen 2005).

[26] The mirrors track the sun and the tower is heated up during sun shine. Inside the tower is a fluid with a very high specific heat capacity like water. Like in the industrial revolution a turbine is powered by steam and even if the sun doesn't shine the water stays hot for some time keeping on making power because of the high heat capacity. The use of solar thermal collectors in the US has risen since 2003 (EIA). Solar thermal power is mainly suitable for places where there are daily sun shine and high solar radiation like there are in deserts.

Solar cooling technologies are relatively new in terms of product to market and displays great global market and export potential because cooling takes up a larger amount of worldwide energy consumption than heating (Ahm, 2007). However in Denmark the need for cooling is limited to mainly refrigerating and approx 1-3 months air-conditioning in the summertime. There are three distributed technologies within solar cooling; absorption cooling, desiccant cooling and vapour compression cooling. The technologies can be used for air-conditioning and refrigeration. However products with vapour compression cooling are mainly used in larger applications for refrigerated warehouses (Canren).

The general impression of technologies in solar heating and cooling seems to be that they have a noteworthy connection with the building and construction industry, because of system installation issues. The PV technological domain does also have this connection, which encompasses niche applications termed BIPV. The heating or cooling technologies could be combined with PV to add value to innovations.

As this thesis is based around photovoltaics, the next chapter will provide a brief overview of the PV markets, first with a global approach and then in a Danish context. Then we characterise the industry.

4.2 The World PV Market

Like earlier stated, PV demand has risen considerably in recent years with about 30-40 %. As shown in the table below, according to Solarbuzz C, the corresponding yearly world aggregate PV installations where made.

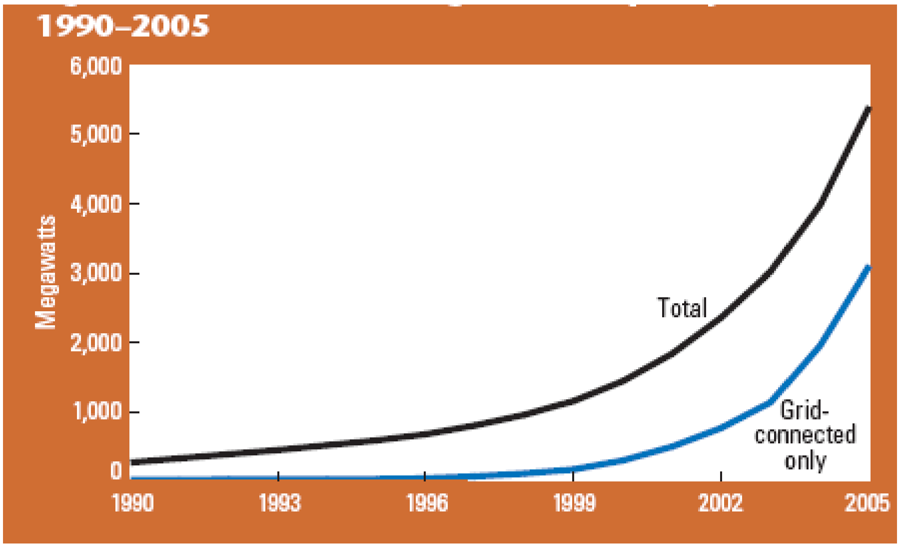
Table 4: The power capacity of world aggregate PV installations

Year	PV power capacity	Growth per year
2005	1460 MW	-
2006	1744 MW	19 %
2007	2826 MW	62 %

Source: Solarbuzz C

The growth of the PV market is obvious, even though it is not completely smooth. It could be discussed how the making up of these installations was made and whether or not it can be entirely trusted, however the picture remains of an industry in certain growth. Other sources like the "Renewables - Global Status Report" (REN21) also count stand-alone PV facilities in the statistics and seem to have a different way of making up the capacity:

Figure 10: Solar PV, The growth of world capacity



Source: REN21 (2006)

The graph above only goes to 2005 and keeping high growth rates in mind the installations would be significantly higher than the numbers from Solarbuzz. Either way of making up the installations there are sure signs of growth and in this respect it seems interesting to see how the PV markets are distributed worldwide. This can be seen in the world PV market distribution table below:

Table 5: World PV market distribution

Year\market	Germany	Spain	Rest of Europe	Japan	USA	Rest of World
2006	55 %	*	11 %	17 %	8 %	9 %
2007	47 %	23 %	6 %	8 %	8 %	8 %

*Note: *Spain is included in ROE number in 2006.*

Source: Solarbuzz C

These numbers show that four key nations with Germany in lead position drive the world market demand significantly. Going with the most recent numbers from Solarbuzz, in 2007 Germany made 47 % of the aggregated PV installations in the world, i.e. not less than 500 MWp. In other words Germany's PV demand made up over half of the world market in 2006 and almost half in 2007, so it seems like the favourable national PV policy of Germany have had a tremendous effect on the world market demand.

Germany – progressive environmental policies

The German EEG-law was launched in March 2000 and renewed in April 2004 and it fixes the prices that German electricity companies have to pay for electricity from renewable sources until 2020. The country has by far the highest nominal instalment of RE sources and has operated with feed in tariffs since 1990 (Lipp, 2007).

The German market has obviously constituted itself as the largest PV world market by the help of the "EEG-Law", while also the Spanish PV market grows enormously these years and displays a big share of world installations in 2007, with a growth of 480 % in market share compared to 2006. The Marketbuzz 2008 also reports (Solarbuzz C) that the PV industry globally generated US $ 17,2 billions in revenues in 2007. The Marketbuzz 2007 report (Solarbuzz B) predicted future PV industry revenues between US $ 18,6 billion and US $ 31,5 billion by year 2011.

The high growth is according to several sources (e.g. Jacobsson & Johnson, 2000; Jacobsson et al 2004; Lipp, 2007) driven by public support in different countries but the high demand has also implications for the supply and the prices. A number of countries have used feed in tariffs for some kind of renewable energy technology (EPIA, 2008) – in some instances successfully put together and in others unsuccessfully.

The following table shows the countries that have utilised feed in policies; however some of the countries do not use the policies anymore, including Denmark.

Figure 11: Cumulative numbers of Countries, states or provinces that has enabled feed in policies at some point

Year	Cumulative Number	Countries/States/Provinces Added That Year
1978	1	United States
1990	2	Germany
1991	3	Switzerland
1992	4	Italy
1993	6	Denmark, India
1994	8	Spain, Greece
1997	9	Sri Lanka
1998	10	Sweden
1999	13	Portugal, Norway, Slovenia
2000	14	Thailand
2001	16	France, Latvia
2002	20	Austria, Brazil, Czech Republic, Indonesia, Lithuania
2003	27	Cyprus, Estonia, Hungary, Korea, Slovak Republic, Maharashtra (India)
2004	33	Italy, Israel, Nicaragua, Prince Edward Island (Canada), Andhra Pradesh and Madhya Pradesh (India)
2005	40	Turkey, Washington (USA), Ireland, China, India (Karnataka, Uttaranchal, Uttar Pradesh)
2006	41	Ontario (Canada)

Note: Figure for 2006 is for early part of the year only.

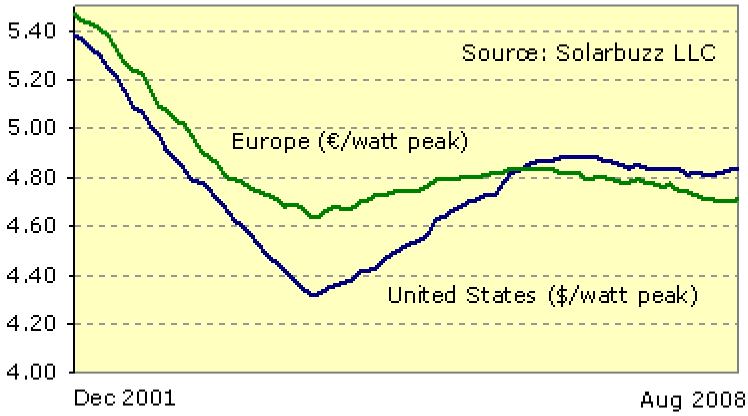
Source: REN21

The trend seems to be that more and more countries and states are enabling feed in policies. One consequence of this is that right now the PV supply cannot follow the demand, as one interviewee puts it, which is obvious in the shortage of silicon.

4.2.1 The Shortage of Silicon – a Conventional PV Sector Problem

A frequently mentioned problem in relation to the flow of commodities in the PV supply chain refers to the bottleneck in the production of pure silicon, where the rise in PV demand has had a notable effect on the price development. Silicon, though already expensive, has become a scarce resource because of bottle-neck difficulties in the production capacity which has resulted in high silicon prices, one of the most important raw materials in solar cell manufacturing. In 2001 the average price for silicon was US $ 20 /kilogram which rose to US $ 50 /kilogram in 2006 (Maycock & Bradford, 2006). In 2008 we still see the supply problem of pure silicon as the prices have reached levels of 100 US $ /kilogram in long term 10 year contracts (where the buyer is committed to buy a certain amount and are paid in advance per year) and spot market prices up over 400 US $ /kilogram, so overcoming the bottleneck is still an issue, even though past predictions had expected the investments in the silicon supply chain to have taken effect by now[27]. It is widely agreed in the PV industry that silicon prices are unsustainably high and that the lack of high-grade silicon is keeping back growth in the PV sector. To comply with this challenge on the international level EPIA could with the help of EU or other international financial actors set up a finance scheme for new silicon refinement facilities. One interviewee informs us that there are still many investments going on to expand capacity and build new production facilities and consequently the supply of silicon is expected by the international industry to catch up on demand and eliminate the supply shortage in the following years. The speed of the catching up could be expected to some degree to determine the speed of the international technology diffusion. Despite of the high silicon prices, still though the PV module price has been stabile as the following table shows.

Figure 12: Photovoltaic Module Survey Retail Prices (DEC 2001 - AUG 2008)



Source: Solarbuzz D

The graph displays that retail price of PV modules in Europe decreased considerably until around 2004 but has stayed at the same level during the last four years. This could be because of economics of scale, supply chain streamlining and improved production methods in other levels of the supply chain. The retail prices *on the standard module level* in Denmark are now around 50 DKK/Wp, which in terms of electricity price corresponds to 1.82 DKK per kW/h[28].

4.3 The Danish market

Having presented the world market main characteristics, the next part presents the Danish market, first with an overview of the PV development and then how the market looks today.

[27] There is a time lag from time of investment to realisation of production capacity of about 3 years, which makes it hard to predict the equilibrium of the market precisely.

[28] Own calculations based on a 150 Wp USL Solar module with 13 % efficiency in DK in a period of 30 years, the officially expected lifetime according to EPIA (calculator used on www.dansksolenergi.dk). Note that a PV output durability of 25 years is warranted and that 40 or 50 years is not unlikely.

4.3.1 Denmark in a historical context

Solar cells came on the political agenda for the first time in 1992 when the Danish Energy Agency issued the first Danish account of the solar cells in Denmark (PA Energy, 1992). It recommended a four-year prelude phase of technology supervision and knowledge obtaining in order to provide the basis for a multi-annual introduction- and demonstration phase (phase 1) followed by an actual dissemination phase (phase 2). The recommendations were followed and resulted in the three-year *Solar energy plans of action*[29] (Solenergihandlingsplaner) which the Danish Energy Agency and the *Solar energy committee* (Solenergiudvalg) composed in the period 1993-2000. These plans are also parts of other specific programs related to solar cells in the same period (PA energy, 2004).

The prelude phase was characterised by R&D projects, among others IEA-PVPS and smaller test plants, based on obtaining existing knowledge within the field of solar cells. The demonstration phase (phase 1) included major programs and projects on Danish technology development and demonstration, in particular *Sol-by*, *Sol 3000* and *SOL 1000*, which were implemented by EnCon/EnergiMidt (PA Energy, 2004). The dissemination phase (phase 2), which was initially scheduled to begin around 2004-2006, has never been fully implemented because of the closure of the "Solenergiudvalg" in the wake of the 2001 government change, one interviewee informed us. This could be a sign of a system failure.

PA energy concluded in their analysis of the PV sector in 2004 that Danish competences have increased on solar cells, including universities and institutes, consultant engineers and architects, electric companies, business communities and NGOs. Furthermore that in spite of high prices, there is considerable public interest in PV technology; not least Danish industry was showing increasing interest in the PV niche fields. Another interesting issue was that PV system prices had decreased in Denmark from 120 kr. /W in 1992 to approx 34 kr. /W in 2002 and that Technological Institute had established a public quality assurance system for photovoltaics.

4.3.2 The Danish PV Market Today

The applications for PV are divided into *grid-connected* PV applications and *stand-alone* PV applications. The latter includes traditional low-power niche applications such as signalling, week-end cottages, garden lights, telemetry & telecommunication and urban furniture such as parking meters and information displays, but stand-alone PV systems makes out a small and very limited part of the

[29] Plans about developing solar energy technologies that followed up where the other left off.

market segment since the electric grid already covers most of Denmark[30]. Contrarily, grid-connected PV systems are considered very promising, especially with respect to building integrated applications (BIPV), where public interest is increasing. In 2006 there was about 2.9 MW installed PV power in Denmark of which grid-connected distributed systems comprise about 90 %. It was an increase of approx 250 kW when compared to 2005, and more than a doubling since 2000 (PA Energy); however the installations show signs of a stagnating growth and it is an interesting question when it will increase as other markets have experienced.

Table 6: Installed PV power in Denmark

Sub-market/ appli-cation	31 Dec 1993 kW	31 Dec 1994 kW	31 Dec 1995 kW	31 Dec 1996 kW	31 Dec 1997 kW	31 Dec 1998 kW	31 Dec 1999 kW	31 Dec 2000 kW	31 Dec 2001 kW	31 Dec 2002 kW	31 Dec 2003 kW	31 Dec 2004 kW	31 Dec 2005 kW	31 Dec 2006 kW
off-grid domestic	10	10	15	20	25	35	40	50	50	50	55	65	70	80
off-grid non-domestic	70	75	85	120	125	140	150	155	160	165	170	190	225	255
grid-conn. distribut.	5	15	40	105	272	330	880	1 255	1 290	1 375	1 675	2 035	2 355	2 565
grid-conn. centraliz.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	85	100	140	245	422	505	1 070	1 460	1 500	1 600	1900	2290	2 650	2 900

Source: PA Energy, 2007 p. 10

Note: *- Off-grid ("stand-alone") domestic and non-domestic PV power system: System installed to provide power mainly to a household or village (domestic) or traffic signalling (non-domestic) not connected to the utility grid.*

- Grid-connected distributed PV power system: System installed to provide power to a grid connected customer or directly to the electricity.

- Grid-connected centralized PV power system: Power production system performing the function of a centralized power station.

As the table shows the segment of grid-connected and decentralised (distributed) facilities make up far most of the market. In many cases this would be BIPV facilities and the project could be developed and installed by a Danish company like EnergiMidt or Gaia Solar. Grid connected facilities supply the Danish utility grid with some of its produced power that is directed by dealers, i.e. electricity companies, which deal with all electricity made by different sources.

[30] In Greenland, however, stand-alone PV applications play a major role as power source for remote signalling and for the telecommunication network within the western coast line of more than 2,000 kilometres.

Denmark – the electricity system

The electricity supply consist of: 46,1 % coal, 24,7 % natural gas, 24,5 % renewables, 4,1 % energy from waste, 4 % oil. DK is one of the few countries in the world that actively and sustainably supported RE development from the late 1970's until present time (Lipp, 2007).

What certainly is remarkable about the Danish electricity supply is the high amount of renewable sources, mainly from wind. Next up the characteristics of the PV sector will be examined.

4.4 Industrial Characteristics

The characteristics of the PV sector are distinguished between conventional PV and novel PV. In both sectors R&D plays a key role but the focus is different.

4.4.1 Boundaries and Sub-sectors

There exist 3 technological generations of PV, which can be further categorised into the conventional PV, which currently are utilised by end-users, and the novel PV, which include technologies that are not yet utilised in a wide scale. In this respect, novel PV can be considered as a subsector to conventional PV. The distinctions are classified as follows (inspired by ICEPT and E4Tech, 2003 pp. 49-50):

- Conventional PV: 2 technologies are utilised in the market (also known as 1st G & 2nd G)
  - Crystalline silicon
  - Thin films
- Novel PV: Other PV technologies (or 3rd G)
  - E.g. PEC cells, organic cells, thermo-photovoltaics, quantum wells etc.
  - Concentration or multi-junction technologies

For each of these two categories we study those Danish organisations that are active in developing and making PV products and in generating and utilising PV technologies.

4.4.2 Industry Characterisation

Initial characterisation of the conventional sector points to high technological opportunities and high likelihood of profitability and growth in internationalised and dynamic companies. Also it seems that the technological opportunities have good prospects of IP protection. The appropriability conditions can therefore be said to be high. Sunsil, Photosolar and RAcell are examples of companies that are developing a product line in conventional PV and they all hold up secrecy about their production methods, R&D and partners. IPR consequently must be seen as a very critical point in innovation activities.

The sector shows trends of cumulativeness. The dominant technological path, polycrystalline silicon[31], is not the best for PV in terms of converting efficiency from the sun's radiance. CZ monocrystalline is better[32] and FZ monocrystalline[33] is the best in terms of efficiency. However polycrystalline is cheaper than both kinds of monocrystalline, which improves the key role of cost efficiency and thus makes this technology dominant in innovation activities; both monocrystalline technologies has possibilities of catching up though through new silicon factory investments, one interviewee could inform us. Regarding thin film technologies, there are no existing companies in Denmark but the dominant technology path is amorphous silicon.

The R&D for conventional technologies is less intensive than novel PV and is focused on continuously incremental cost efficiency improvements. Even though the technologies are rather new (within 40-50 years), they have been well proven, especially silicon crystalline ones. As we have stated, there is a connection with the semiconductor industry due to the common need for silicon wafers and similarities in technology, which makes the crystalline PV cell production quite dependant on developments in the much larger semiconductor industry with regards to different market related issues like human capital, production technology and silicon[34].

Even though much of the technology is well described and relatively easy accessible from scientific papers, establishing a company in the sector is quite capital demanding in some parts of the supply chain and can face challenges because of the immaturity of the sector. The easiest part of the supply chain for entry, where barriers are low, is the installation, which basically requires a common electrical craftsman education, an organisation and a talent for marketing. The further upstream the supply chain one comes, the higher the barriers become – and the barriers become very high in levels of cells and silicon crystallisation in terms of financial, equipment and human capital requirements. Topsil and other (int.) silicon crystallisation firms hold up great secrecy about their production methods, R&D and so forth. The barriers are also high in the supply chain levels of standard panel (e.g. Sunsil) and inverters (e.g. Danfoss).

[31] 15 % at best polycrystalline industry efficiency.
[32] 17-18 % at best CZ-crystalline industry efficiency.
[33] 20-21 % at best FZ-crystalline industry efficiency.
[34] For example, some semiconductors need certain types of crystalline Si, which could inflict on choice of Si type in the development of a solar cell.

According to theory this would label the overall sector as Schumpeter Mark II, where innovation is characterised as *creative accumulation*. The Mark II goes especially for the upstream part of the supply chain, where entry barriers are high. Installers and project developers would be characterised as Schumpeter Mark I, since they seem to have medium or low appropriability and cumulativeness of their innovations. Using the Pavitt taxonomy to characterise the sector, installers and project developers are relatively supplier dominated firms, whereas the upstream part of the supply chain in inverters, silicon, and cell development is science-based. Firms within panel and cell production would typically be scale intensive firms, and in the periphery of the sector specialised suppliers, in e.g. glass and batteries, would provide the rest of the needed features in a PV facility.

4.5 The Demand and Supply Chain Concept

In this section we go deeper into the technological domain of PV by investigating the different processes that goes on in the production of PV technology. Understanding the supply chain and the demand that drives the chain is an important part in any sectoral analysis. When the main processes and characteristics are found it is possible to investigate the mechanisms located in the links in the supply chain closer. In the mapping of the supply chain, we will characterise each of the chain links.

More generally a supply chain (or logistics network) are said to be the system of organisations, people, technology, activities, information and resources involved in the transformation of raw materials into a product that is demanded by users and consumers. The concept has been developed from the 1960's up till today and is linked to the concept of value chain used extensively in business management – one could say that the different organizational value chains are linked within supply chains in the transformation of basic resources into finished products for the consumer. In this way a supply chain is the meta-system of a value chain, described by Michael E. Porter (1985). Some products may in many cases re-enter a supply chain at any point where the residual value is useful and effective. The main purpose of a supply chain is to supply the demanded products and services.
We use the supply chain theory to get an insight in the sector where it is possible and a preliminary insight into some of the general systemic relations.

Strategic relations with interest parties such as customers, suppliers and knowledge institutions are generally perceived as essential for any firm with ambitions in the international market context. As we know from many situations in our everyday life, new products and services are launched daily. In this context technology diffusion can move quite fast and this has for some while been making strategic relations an important parameter in the competition between supply chains (Tang et al., 2008).

Supply chain theory generally argues in favour of more integration and information sharing between firms because of the market advantages of an agile and responsive supply chain (Tang et al., 2008) but also just as importantly to make the best use of resources, and thus create and deliver the highest levels of value and customer satisfaction. However as Handfield & Nichols (2002) puts it, more firm integration is not for the best in all situations and therefore every link between value chains in an industry should consequently be analysed separately to determine the optimum level of integration. Information technologies have made wide application possibilities for firm integration these days. Among the key benefits is the ability to make more precise demand forecasts and adjust the capacity accordingly, while increased user-producer interaction can also fasten incremental product improvements and lead to significant innovations (Handfield & Nichols, 2002).

4.5.1 Production Stages of Conventional PV

The sector is very far-reaching across different competing technologies and it is therefore almost impossible to cover all of these at once. Most solar cells on the market are made of poly-crystalline silicon, the dominant technology. These cells can be seen in panel systems e.g. on homes or boats, and typically have some colouring glance. The panels group together the individual cells and fit them for installation, usage and durability.

A PV device is manufactured in 3 main generic stages:

1. The production of the solar cell itself, i.e. solar cell production
2. Lamination (with low iron hardened glass or plastic) and framing, i.e. panel production
3. Installation (and battery/grid connection)

Preparation of the silicon is the first step in manufacturing a silicon crystalline solar cell. Most silicon are created using silicon dioxide (silica sand). Exposed to severe heat in a furnace purifies the silicon to 99%. Yet another purification process[35] results in 99.5% purity, which is needed to produce cells. The processed silicon must then go through crystallization[36], where the silicon is melted. During the melting, a p-type (or positive charged material) is added, which creates the electrical basis of the silicon, such as boron. The cooled down silicon crystal is then in the form of an ingot, which are cut in very thin (200-300 microns) wafers with computer guided machinery.

(1) Solar cell production: The crystalline silicon wafers are immersed in a negative charged fluid and afterwards an antireflective layer is applied, which makes the solar cells look dark. Silver or

[35] There are both several and alternative processes of purification, e.g. distillation and Chemical Vapor Deposition (CVD, or “Siemens”) process.
[36] There are three crystallization technologies; poly, CZ, and FZ.

aluminium conductors are then attached for the electricity to be conducted out of the cells. There is a very big variety among different cells' appearance with regards to aesthetics.
(2) Panel production: The solar are organised in rows on a sheet and connected. To protect them from whether conditions a sheet of hardened low iron glass is placed above and the panel edges are then framed and warrantied for up to 30 years.
(3) *Installation*: The panels can be mounted in a system array and are then connected through an inverter to the electric grid or to a battery to preserve the power (Professionals or DIY). Integration in buildings generally requires custom designed solutions that include specialist consultancy and architects.
(Chapo)

These three stages represent the core activities connected to the process of creating a PV facility, where a range of different technologies are present in each stage. However other processes and products are also important for the manufacturing of PV facilities (Maegaard, 2006), such as:

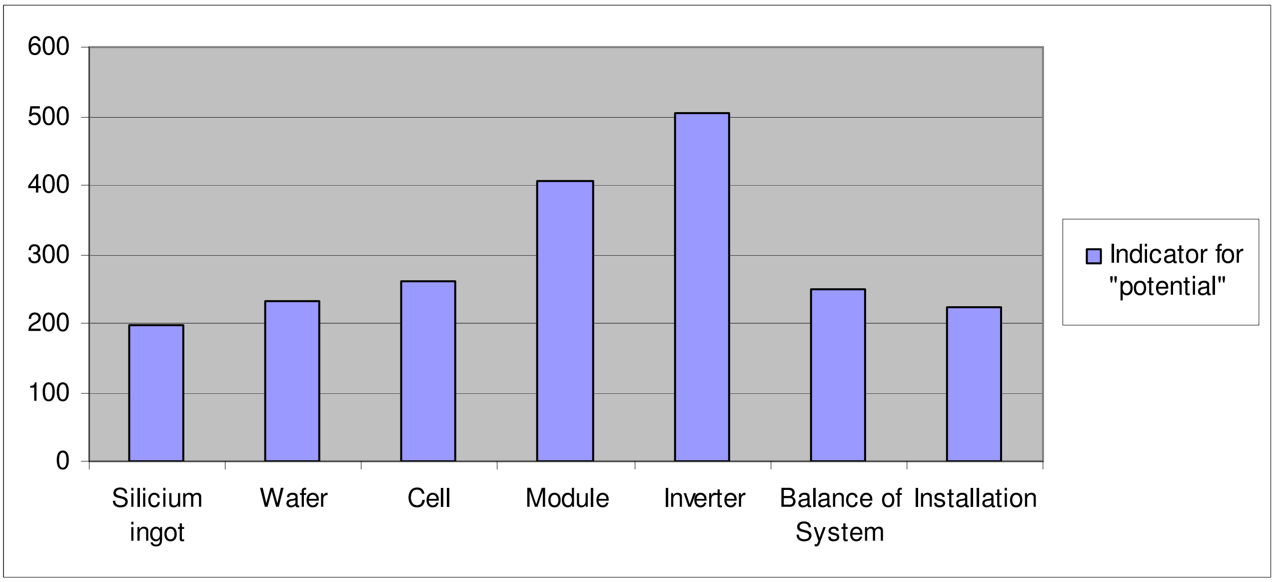
- Production of pure crystalline silicon wafers
- Inverters, which transform DC to AC current
- Mounting systems (application-oriented R&D)
- Factory facilities for production of solar cells
- Normal business procedures; e.g. exhibitions and media

4.5.2 The Danish BIPV Supply Chain

As some of the interviewees state Denmark has a market for BIPV that they expect to grow significantly in the future. This value chain is shown below and contains information about where the value added activities happen and to what degree[37].

[37] These numbers are from 2002 and might therefore be outdated because of the fast changing sector. The pattern would therefore be somewhat different today but it gives an indication of where the Danish innovation potential is.

Figure 13: Danish value adding processes for BIPV with indicators for innovation potential in 2002



Source: Own calculations based on numbers from PA Energy (2004) p. 16

The rationale behind the figure is based on PA Energy (2004) p. 16 who has analysed strengths and weaknesses in the Danish PV resource base, which ended up in a value attached to each element in the supply chain that displays the competence within each element, thus a unified value for competences within basic science, R&D, industry, counselling, and "other". Meanwhile, PA Energy (2004) p. 16 displays the supply chain for BIPV in EU with a relative value/weight of the significance of each part in the supply chain. We have followed the directions of the report and thus multiplied the relative value and the competence value, which has resulted in the figure above.

The figure reveals that Danish resource based competences is found especially within the value chain element of Inverter and Module. This picture is also what we believed it to be, because, as we will se later on, it is organisations within these before-mentioned fields that comprise the majority of the Danish PV sector.

The costs of a PV system also needs to be lower and in that regard Watanabe & Shum (2007) argue in favour of a far more standardised local model of solar photovoltaic deployment on the basis of their analysis of the PV innovation and learning conditions. They argue that the PV panel technical installation and Balance of Systems (BOS) could still have some significant cost reductions in sight and therefore state that more standardised end-product solutions in BIPV can make significant cost reductions. Examples of a more standardised BIPV model can be found in products from Photosolar and Skanska. One could imagine that increasing standardisation would create revenue and R&D resources for further technology drive. One way of reaching better end-product solutions could be for the downstream supply chain to be more integrated and in that way making customization possibilities. Meanwhile more standardisation could be reached through agreements towards worldwide product platforms. More cooperation between firms, national solar energy agencies and construction associations towards consensus in common product platforms could be the answer.

5 Applying the analytical framework

The next section makes up the IS analysis and thus applies the above-mentioned framework chronologically to our empirical data and interviews. Turning to the analytical design, we analyse the following:

1) *Main actors in the PV sector*
    a. What actors are present in the sector?

2) *Drivers for innovation*
    a. What are the primary drivers for innovation?
    b. What are the respective roles for government policy and market forces in creating incentives for innovation?
    c. How do the actors in the sector drive innovation?

3) *Knowledge creation and diffusion*
    a. Which are the key sources of knowledge and the means of sharing knowledge between actors?
    b. Which actors are the key funders and performers of R&D and innovation?
    c. In what ways do firms acquire new knowledge?
    d. How does knowledge creation lead to diffusion?

4) *Innovation system map*

5) *Public/private partnerships (PPPs)*
    a. What PPPs are present in the PV sector?
    b. How do they contribute to innovation?
    c. What funding and IPR sharing arrangements exist within the PPPs?

6) *Other systemic influences on innovation*
    a. What other systemic factors (such as market or policy systems) promote or inhibit technological innovation?

In the following analytical sections, the second numbers in the individual headlines corresponds to the numbered issues from the above analytical design. For example "*Main actors in the PV sector*" will be numbered *5.1*, while "*Drivers for innovation*" is numbered *5.2*, and so on.

5.1 Main Actors in the PV Sector

This part presents the actors within the Danish PV sector. When there is no source attached to a paragraph, it implies that the source is one of the anonymous interviewees. The first step for the analysis is to identify and characterize the actors in the sector. According to ICEPT & E4tech (2003), the PV sector is much internationalised with large international companies that play a critical role in the development. The picture seems to be the same in 2008. The scale of economics and the traditional learning curve of 20%[38] imply that large manufacturing companies will dominate the supply chain.

5.1.1 The Actors in Conventional Solar PV

Regarding industrial standards there are several international ones. The main Agencies and Codes that set standards of equipment performance, integrity and safety are located in Switzerland and USA. The strongest PV advocacy coalition EPIA – the European Photovoltaic Industry Association – is the largest industry organisation within PV and works within both national, European and worldwide levels to assist their members in developing business and markets.

There are also smaller and much less powerful advocacy coalitions in relation to PV in Denmark, like for example the Nordic Folkecenter for Renewable Energy (NFRE), which advocates RE in general. The RE expert, director of NFRE (and interviewee) Preben Maegaard has informed the Danish Parliament in a note (Maegaard, 2006) about the sectoral framework conditions of solar cells to the Energy Committee. In this note he advocates RE generally, encourages inspiration from the German EEG law, and directs attention to the growing PV sector. The industrial breakthrough in PV seems already to be a reality, and some traditional energy companies like Shell, RWE (Germany) have given up to follow the strong growth race and sectoral change pattern, while big Asian originated semiconductor companies like Sharp, Sanyo Electric, Mitsubishi Electric, and Kyocera have taking advantage of technological similarities to conventional PV and their existing organisation to form lead positions in the international PV sector. Also Intel (SpectraWatt Inc.) and IBM (collaboration with Tokyo Ohka Kogyo, Japan) have made investments into solar cell production to conquer market shares, both with ambitious goals on cost reduction and improving PV technology, IBM in

[38] Though delayed by increasing silicon prices.

thin film (Novel PV) and Intel in crystalline silicon PV. These examples imply strong linkages between the semiconductor industry and the PV sector.

However the conventional PV sector also is characterised by its own large companies such as Q-Cells, Solarworld, Sun Power, Suntech Power, Renewable Energy Corporation (REC), Isofoton, Yingli Green Energy, and Schott Solar[39]. The main national markets are also the main producers, e.g. Japan, Germany, USA, and Spain. Some of the large companies control the entire PV supply chain, while others focus on cell production (Maegaard, 2006; China Sourcing News; Earth Policy Institute). Top five PV producing countries are Japan, China, Germany, Taiwan, and the US. The Asian nations are racing forward in the manufacturing part of the supply chain and overtaking both US and with time probably also Germany (Earth Policy Institute). However until now it seems that proximity to markets has been a decisive factor in the set-up of companies within the PV sector, which is why some of the world's largest PV producers are localised in Germany, Japan, USA and Spain. All the PV industry leaders issue warranties with 20 years or more on the products with guarantee of power generation.

The picture of the PV industry is changing fast because of the high growth and technological opportunities, so the possibilities for PV companies to access risk willing investment capital seem to have a very big influence on where the future world leader of the PV market will be located. To give an example the US company OptiSolar announced plans in the spring 2008 to build the allegedly world's largest PV power plant of 550 MW in California, which will be able to power almost 200.000 homes (CNET).

In Norway the biggest listed company is a PV silicon, wafer, and cell production company called REC, which is the making of 2 entrepreneurs that have experienced tremendous growth in their organisation with revenues going from 100 million to 100 billion in the past 4 years, one interviewee emphasises. Entrepreneurial companies like this exist in other parts of the world as well, e.g. China. These success stories also affect Danish companies, entrepreneurs and financial investors and their expectations and ambitions.

5.1.2 Novel PV Actors

The subsector of novel PV is destined to take over for conventional PV at some point in time. Still though, many of the novel PV technologies struggle with durability and lifetime. Nanosolar is a

[39] Schott Solar was spun off from originally being a division within RWE, a large German energy company (Maegaard, 2006).

global leader of novel PV, which was founded in 2002 and is building the allegedly world's largest solar cell factory in California and the world's largest panel-assembly factory in Germany. They will be setting the standard of solar cell technology of significantly better cost efficiency, versatility, and ease of use (Nanosolar). Switzerland, USA, Germany, Australia, and Japan are leading countries in the field of novel PV (ICCEPT and E4tech, 2003).

5.1.3 The Danish Actors[40]

However, considering the internationalisation of the sector and even though Danish companies are not among the large international players, the Danish sector can still be said to be interesting because of the international high growth and because significant potentials can be found in niche areas of PV. BIPV is for example an area of the sector, where there exist a wide range of possible niche applications. Borup et al. (2007) have made an analysis of the Danish PV sector, where they have found 40-60 actors related to the overall technological domain of PV. However some of them might be peripherally related and may not be necessarily linked to the core processes of PV development, production or services, and also the picture could have changed a bit since then.

Initially we start off with the amount of work places within the main processes of the PV sector, which were distributed as follows in 2004 (PA Energy estimation):

a) Research and development (not including companies): 15

b) Manufacturing of PV system components, including company R&D: 150

c) All other, including within electricity companies, installation companies etc.: 20

It would seem plausible that the relative proportions are more or less the same still and could comprise an increase in numbers taking account for the growth in for example Gaia Solar, Photosolar and the increased publicly allocated funding for RD&D in PV (see section 6.5).

Coming back to the main organisations, the Danish main players of our perception in the PV field is generally:

- The energy system administrators and regulators (including the government).
- The PV industry, counting inverters, construction, electronics and systems, where several niches occur.

[40] It should be noted that it is almost impossible to map and identify the Danish actors by quantitative methods, as there are no adopted NACE codes for solar PV companies. Instead they should be found across several parts of the NACE system, which thus become a very time consuming task.

- Universities, schools, and research- and GTS institutes, carrying out a wide range of R&D activities related to both conventional solar technology and advanced novel technologies such as PEC cells and polymer cells.
- Electricity companies who have carried out projects including R&D and demonstration.
- Counselling service branches like engineers and architects who catalyze a broad spectrum of PV projects on to buyers and investors.
- NGOs that carry out public information, demonstration or other activities.
- Electricity consumers, who have shown both interest and willingness to invest in PV systems.

One of the most important actors is the government and its policy, which has for long time put great emphasis on result oriented research according to some interviewees. The policy is implemented through the *Danish Energy Agency* (Energistyrelsen) and *Energinet Danmark* (Energinet.dk), the nationally owned company, which owns and regulates the Danish electricity grid. Both of these function as key providers of public RD&D funding (e.g. EUDP, ForskEL, ForskVE). The government also has direct channels of R&D funding in the Strategic Research Counsel (*Det Strategiske Forskningsråd*). Not least there is the Danish National Advanced Technology Foundation (*Højteknologifonden*), which focus on developing technologies that create growth, opportunities and employment in Denmark with a total budget of 1,6 billion DKK (Danish National Advanced Technology Foundation). However the Danish laws and regulations are also affected by supranational agreements (e.g. UN Kyoto protocol) and EU decisions, directives, and regulations (e.g. CO2 quotas and energy objectives). The funding issues will be examined further in section 5.2 about the drivers of innovation.

Energy and environment is closely connected to PV through climate issues, which can have implications for the PV sector as a green energy technology. The fact that Bjørn Lomborg arranged Copenhagen Consensus[41] in Denmark this summer (2008) and that the Climate and Energy Ministry arrange the UN conference on climate change (*COP15*) in 2009 raises attention on energy technology and can have implications for the Danish PV sector as well as other subsectors of RE as a possibility to display products. The Association of the Danish Industry (*Dansk Industri*) and their energy section (*DI energibranchen*) are in this way also seen as actors. The influences of energy and environmental developments have linkages to many industrial sectors, among them the building sector. The Danish electricity sector is also paying attention to the PV field and studies and experiences (e.g. PA

[41] They allocated a sum of money to solve some of the world's biggest problems from a cost benefit point of view but did not find energy technology to give enough benefit as other fields.

Energy, 2003) show that solar cells fit well in the Danish electricity system. An ongoing EU project (PV-EC-NET) refers to the Danish electricity sector's involvement in solar cells as a national strength when compared to some of the other EU member states. Furthermore, a number of projects and studies reveal that the PV technology receives great interest from Danish electricity consumers (DEFU, 1998). Among Danish house owners with PV applications, reports have shown a saving of electricity of approximately 10% due to changes in behaviour, which is an effect of increased energy awareness (PA Energy, 2004).

The area of BIPV is also very influenced by the development in the building industry, which is dependant on knowledge institutes like the Danish Building Research Institute *(Statens Byggeforskningsinstitut, SBi)*, The Danish Construction Association *(Dansk Byggeri)*, and not least are EU and the government setting tougher standards for the building industry, which drives the progress (see section 5.2.1). In the building industry the development goes towards low energy housing with comprehensive collaborative projects involving many industrial agents for example like the *BOLIG+* concept, which is a project going on in the Danish building industry focused on making energy neutral buildings and homes that do not use more energy than produced of it selves (Bolig+). The Danish Construction Association in this way acknowledges their share of societal responsibility and is helping to realise the EU and Danish environmental goals. The industry ambitions are to integrate energy technologies efficiently, e.g. with up-to-date photovoltaics, to fulfil the goals of being able to build energy-producing and energy-saving homes that are affordable and aesthetically harmonic (Danish Construction Association). Another implied ambition is to establish Denmark as a global lead centre for development of such energy integrable product solutions for buildings. Many of the present end-product solutions in Building Integrated PV (BIPV) together with other technologies are not cost-competitive or flexible enough to meet the period depending[42] and differing energy needs of the consumers and therefore there is a need for holistic systems with supervision-, measuring- and need-driven operation capabilities (Bolig+). This is an interesting technological opportunity for Danish companies.

On the academic level, there are a number of knowledge institutes that possess knowledge, educate students and perform research within PV related areas. First there are the universities, of which the institutes shown in the table clearly have a relation to the PV industry.

[42] There are different energy needs for respectively summer, fall, spring and winter.

Table 7: University institutes within the PV sector

The Chemistry Institute, *Copenhagen University*	Research in PV systems
Nano-Science Center, *Copenhagen University*	Research in nanotechnology applications
Institute of Energy Technology, *Aalborg University*	Research in Power Electronics (Inverters)
Department of Development and Planning, *Aalborg University*	Research in energy systems and planning
DTU Nanotech (MIC), *Danish Technical University*	Research in closely related nanotechnological areas

Source: Interviews and university websites

Emphasised by the interviewees are the position of Aalborg and DTU universities – DTU, which formerly (in the 1990's) had a PV knowledge capacity in prof. emeritus Otto Leistiko (retired). Other institutes on the respective universities could also perform PV related research however we have not found explicit existing relations to PV. There are also departments working with nanotechnology in the universities of Aalborg, Aarhus, Roskilde and Southern Denmark, which can provide resources of competencies to the sector. According to one interviewee, the universities and knowledge institutes have the dogma that there have to be industrial finances involved in the research process to quickly get to public private collaborations, applied research funds and results.

A very important actor and key knowledge creator in Denmark is the sectoral research institute within energy in Denmark. Risø DTU (The National Laboratory for Sustainable Energy), performs research within all areas of energy and in relation to the PV sector they perform R&D in Novel PV technologies mainly within polymer solar cells.

Another very important actor is the Danish Technological Institute. They educate in installing of PV systems and other technical issues regarding PV quality standards and qualifications of technicians and promote mediation of technical information to the business community. This important work is done through the Solar Energy Centre *(SolEnergiCentret)*, which includes guidance to companies and quality assurance of the installed PV facilities. Also at Danish Technological Institute the PEC group research in new materials and technologies for PV. Some new companies like Photosolar spin-off from the ongoing technological research and can go into their innovation milieu Teknologisk Innovation A/S. The Technological Institute and Risø DTU could be characterised as key Danish knowledge creators and diffusers in both conventional and novel PV (see sections 5.3 & 5.4).

Besides the public institutes there is also a notable NGO grass root organisation, which works to influence the development in RE issues including PV. The Nordic Folkecenter for Renewable Energy

(NFRE) stems from the so called “68’s generation” work in alternative societal thinking and has had very close relations to the early development of the wind industry in Denmark (Ruby, 2006). The Folkecenter provides demonstration of RE technologies and other environmentally friendly technologies, which may display synergy effects in complementation. R&D are performed mainly in collaborations e.g. with companies or universities. The NFRE function as a knowledge creator and diffuser but also plays a role of an advocacy coalition for RE technologies.

5.1.4 Danish Companies

We have found that the depiction of Danish firms makes up a very fragmented part of PV development, supply and installation in the international context. The key companies of the sector are seen in the table below where their relation to the system of innovation is defined. Some of the key companies are developing different products and technologies with public funding from PSO including e.g. Photosolar, Racell Solar, and Gaia Solar (Energi 2008). In this section we define the roles played by each of the main actors, where some of the most significant are further described:

Table 8: PV related companies

Name	PV sector relation
Cenergia	Technical consultant (for BIPV)
Danfoss Solar Inverters	Production of inverters
DONG energy	ESCO* collaboration with Gaia
Esbensen	Technical consultant (for BIPV)
EnergiMidt	Electricity company; initiator of numerous demonstration projects
Gaia Solar	System developer and module manufacturer
Grundfos	Production of PV powered pumps
Dansk Solenergi RI	System developer and module manufacturer
Mekoprint	Working on a polymer solar cell commercialization project
Photosolar	Manifacturing and development of glass facade products
RAcell Solar	Processesing and manufacturing of semiconductor components
Skanska	Integration of PV in buildings
SunFlake	Developer of new PV material; nano-technology
SunSil	Developer of new system technology
Topsil	Refinement of silicon and sale of wafers
Velux	Development of harnessing of solar energy in the product range of roof windows

Danfoss Solar Inverters offers advanced grid-connected inverters for residential and commercial solar energy applications and solutions for monitoring solar systems in order to achieve optimal energy output. Inverting power is a key process in grid connected facilities, where the loss of power should be as little as possible. They are the biggest Danish company from the PV sector and one of the fastest growing and most successful companies that are very internationally oriented. They have developed their activities from selling only OEM to having both their own brand and OEM, and rumours tell that in the future they are planning to only sell products in their own brand name. Danfoss were involved from the start in 2002 but they were quickly spun off as formerly named *Powerlynx* and had reached 90 employees; however a supplier problem resulted in a bad year in 2006. Despite of this Powerlynx was acquired by Danfoss sooner than the bad result kicked in, which initially rescued the company from financial turmoil. Danfoss can be considered as a technology developer and prime mover within solar inverters.

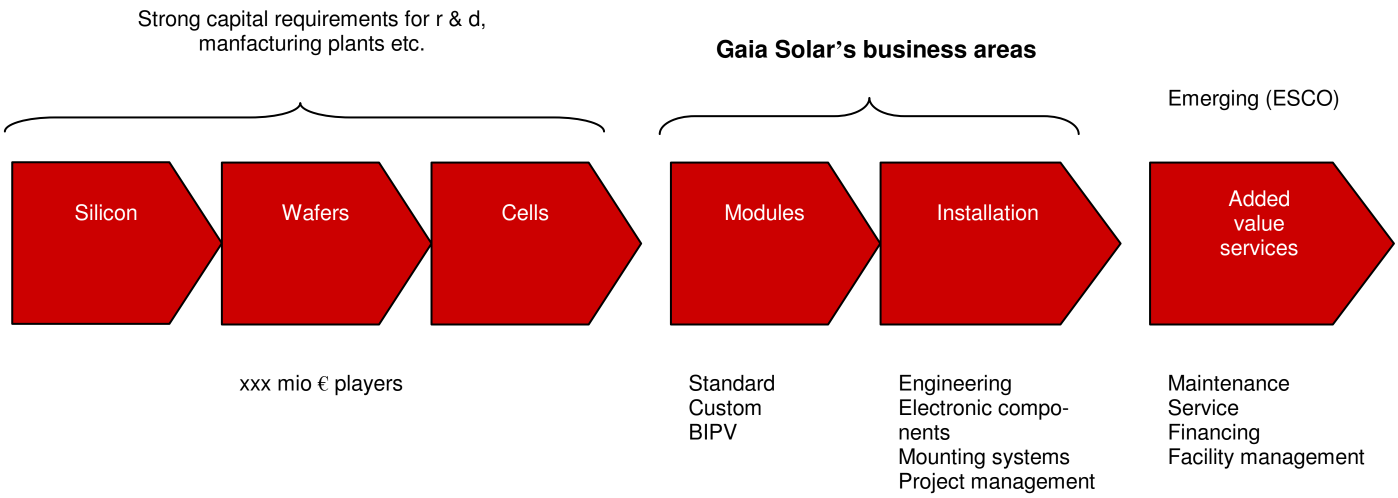
DONG energy is the biggest energy provider in DK and has been approved as an ESCO[43], which will provide PV power supply related services directly to consumers. Gaia Solar collaborates with them by providing the PV systems and uses the strategic relationship as a channel to reach the consumers.

[43] Energy Service Companies. There are considerable emerging opportunities in ESCO agreements for Danish companies to provide different services to consumers.

EnergiMidt is an example of a utility company that really has engaged itself in PV and has initiated several BIPV demonstration projects, e.g. sol 300 and sol 1000, which have received high consumer interest. They are right now active in several projects e.g. on education for public enlightenment and their own area-specific demonstration project. They function as a project developer and installer and have been one of the main advocators of PV.

Gaia Solar is the biggest Danish panel developer, producer and installer, who focus on custom designed BIPV and different standard or niche PV solutions. The company has implemented more than 300 PV facilities[44] and have recently grown from six to 18 employees in one year, and is expected to reach 50 employees within the next 1½ year. They have many orders in the pipeline to justify the expectations. Gaia Solar is a prime mover and was spun off in 1996 from a pioneer PV company, SolEL Energy that went bankrupt. Beneath is an example of the value chain from Gaia Solar's point of view, where they are placed according to their business areas:

Figure 14: The PV value chain from Gaia's point of view



Grundfos produces and sells pumps with PV power systems to niche export markets like Australia and USA, where they hold cattle in dry remote regions, but also to development countries, e.g. some nations in Africa, where they have subsidies for digging wells. The PV powered pumps are the result of a strategic relationship with the largest Thai producer of solar cells, Solartron Public Company Limited (Grundfos).

[44] A reference list with selected facilities can be downloaded from their homepage, www.gaiasolar.dk.

Mekoprint is collaborating with Risø-DTU on developing and commercialising a novel polymer PV technology in thin flexible film with printed circuits to be launched within several niche product areas. In general they produce components to the electronics industry.

Photosolar are developing a transparent window BIPV product with very promising market potentials, because it is also just as effective a sunshade as outdoor sunshades. They have one product on the market[45] and are expecting the main product in 2010. The company focus their efforts on R&D and networking and was spun off from activities in the PEC group (i.e. Technological Institute) in 2003 with the former head of the PEC research group as the director and founder.

RAcell Solar was founded in 2002 and are developing solar cells and modules. They have sold the allegedly largest Nordic BIPV system, which was integrated in the construction of the new HQ building for the national Danish TV-station, Danmarks Radio. RAcell was originally formed in 1989, which was the first real solar cell developer in Denmark and later spun off SolEL Energy and are thus considered a prime mover.

SunFlake is developing a new kind of solar cells based on a novel form of semiconductor nanostructures (*NanoFlakes*®). Their vision is to reach 30 % conversion efficiency of sunlight in the commercialised cells, which will have a significant cost reduction on the material side using less pure silicon. The IPR rights are secured and the market launch is not expected until 2010 or after. SunFlake was founded in 2007 (Sunflake) and is a spin off from the Nano-Science Center at Copenhagen University (KU). The company could be considered as prime movers of novel PV.

Sunsil are developing a new kind of PV module, which can be easier installed because the power inverter is build into the module, which can reduce installation costs (Energi 2008). They are in the process of securing IPR worldwide and are planning to build a new factory facility in Toftlund, Denmark. The investors will invest around 400 million DKK and expects to be ready in 2016. The finances include funds from EU 5 million DKK and PSO 7 million DKK (*see section 5.2*) (Electronic Supply). Sunsil are prime movers in the context of large scale production of standard modules in Denmark.

Topsil produce high purity FZ crystalline silicon of the finest quality, which can be used to manufacture the most efficient crystalline solar cells. However the ultrapure silicon is not used in solar

[45] Microshade®

cell production yet because of the relative high price and is for now only used in lab tests. Other processes than the FZ crystallisation is outsourced to subcontractors, and the final wafer product is sold in their name. They have initiated and completed several R&D projects and have interesting connections to large solar cell producers worldwide e.g. Q-cells and Sharp. Topsil are characterised as a technology developer and key knowledge holder in relation to silicon.

Velux are a very well known producer of roof light windows and is a big European player in solar heating systems and could seem to have a great deal of interest in the PV sector developments.

Cenergia are a technical consulting firm with expertise in rentable optimisation of energy savings and applications of solar energy in buildings (e.g. calculations of a building's energy consumption) and work on the Danish market (Cenergia). *Esbensen* are likewise a technical consulting firm and have expertise within building installations, electrical supply and have specialised competences in integrated energy design of buildings and low energy building designs (Esbensen). The technical consulting firms seem to contribute with knowledge creation and diffusion.

Danish Solar Energy Ltd (Dansk Solenergi RI) is pioneers of the Danish PV sector and often referred to as key agents. They started in 1993 and do PV related design/development, consultancy, project management and manufacture of modules, electronic hardware, and are also authorized distributors for a number of PV equipment producers like Siemens Solar, Solar World (former Shell), Uni Solar, MSK, GPV and Fromius. Their main markets are Scandinavia and projects in developing countries. Dansk Solenergi has developed a patented controller**,** which improves the efficiency of stand-alone generators. It also overall reduces losses and heat emitting from diodes up to 300 times. The patent improves the efficiency of stand-alone systems with at least 5%. Dansk Solenergi has also developed mobile solar/wind[46] generator systems. Based on the hybrid regulator the generator ensures DC and 230V AC supplies at remote locations (Danish Solar Energy). The production of electronic control systems is subcontracted to various manufacturers of electronic equipment. Danish Solar Energy Ltd can be characterised as technology developers, project developers and prime movers of the innovation system.

[46] The mobile solar/wind generator system were developed for mobile water supply and water cleaning systems, and is mounted into a solid state 80x100x120 cm standard container. The system is assembled and ready for operating in a few hours. The mobile solar/wind generator systems are produced on request and might be altered within the limits of the container to meet specific demands for other geographical locations

KeryChip and *Solkraft.dk* are examples of sales outlets to households of various imported PV products, including standard PV modules, thus being diffusers of the technology. On the BIPV side, *Oi-Electric* and *Persolit* are examples of installation companies that have experience from demonstration projects and collaboration with EnergiMidt.

Skanska Bolig is a construction company, which plan to do installation in homes in a larger scale by building standard houses with installed PV systems. The developing of the standard houses concept BoKlok is done in collaboration with EnergiMidt and Aarhus Architectural School and will be sold through IKEA's channels. Other Danish firms that have shown interest in the BIPV field are large firms like *Dansk Eternit* (producer of roof elements) and recently *Velfac* (producer of windows).

Recently the companies in the sector have established the *Danish Association for Solar Cells* (Dansk Solcelle Forening), by which they hope to influence the political establishment with joint statements and messages.

No larger solar cell manufacturers are present in Denmark, but Danish industry shows increasing interest in the field of PV technology. Danish niche product innovations seem to have considerable potentials. Especially the linkage between solar cells and buildings may imply that traditional Danish strengths such as system design are able to foster synergies by means of development of future building- components and systems.

Even though the Danish PV sector does not take up a lot of space in the business community, there are several actors of different kinds. Having presented these actors, the part below examines what we have found to be the drivers of innovation in the sector.

5.2 Drivers of Innovation

The innovation drivers in the Danish PV sector do not vary drastically between the two types of PV conventional and novel. However this part will take its departure in the first and finish off by relating it to novel PV.

Within conventional PV, it is niche possibilities for design system integration (BIPV) that drive the market and the innovation activity. Specifically there are a number of important drivers, which will be described in detail:

1) *Building regulation*

2) *Electricity prices*
3) *The net metering agreement "Nettomålingsordningen"*
4) *"Green branding" / energy awareness*
5) *Funding availability*
6) *Export markets*
7) *Market expectations*

5.2.1 The Building Regulation

One of the most important drivers is the energy frame[47] requirements within the 2008 *building regulation* (BR08), which specify certain regulations of what a building is allowed to use of electricity. In order to comply with the requirement, thus reducing the building's energy consumption, owners can on the one hand choose between for instance post insulating, exchanging old windows with new double-glazed windows, or on the other hand they can buy integrable renewable energy installations like BIPV products. If shares of the electricity consumption are produced by e.g. solar cells, the production will namely be deducted in the calculation of the energy frame. Buildings are consequently able to satisfy their energy demand with PV panels, thereby obtaining an energy consumption low enough to be approved under these standards or be classified as low-energy houses. Thus, by letting PV panels produce eco-friendly energy for housing, it is possible to work with large window areas, thinner walls and other architectural solutions that make the house more aesthetic. The negative energy impact of the construction is outweighed by the solar cells' environmentally friendly energy production, and often it is only minor PV systems that are decisive for the building permission. This applies not only for new buildings, but also when extending and rebuilding houses.

This significant importance to the success of solar sells is further intensified by future tightening of the building regulation. Hence, it appears from the energy agreement (2005) that the requirements of the building regulations are to be tightened by 25% in 2010 and further by 25% in 2015. According to one of the respondents, there is already a general assumption that the requirements will be tightened even more in the foreseeable future. The government has already, with reference to the Government Bill, stated that a strategy for energy saving housing will be developed, aiming at reducing the energy consumption in new buildings by 75% in 2020 (Økonomi- og Erhvervsministeriet). That is, down to 25% of what is allowed today. One of the respondent companies is already experiencing a significantly increasing costumer demand in the wake of the 2007 building regulation.

[47] The term energy frame is an expression of a building's needs for supplied (purchased) energy for heating, ventilation, cooling and hot water. The energy frame depends on the building's use and size.

The BIPV firms point out that the building regulation have a wide impact on a number of energy saving technological domains of buildings and this require development and use of new technologies, some of which does not exist on the market yet. The energy discount that PV power can grant to buildings through reduced electricity usage imply a good BIPV potential in the market, due to the fact that many new development projects of buildings now are seriously considering BIPV in the process of reaching the energy demands and still making a good investment in a long-lasting supplementary solution for energy. This trend is expected to amplify in the future with the mentioned coming tightening of the building regulations regarding the energy frame and boost the demand for BIPV.

The increasing demand for BIPV is to a very high degree regarded as critical to the future success of the conventional PV sector, inducing companies to do R&D in PV system solutions in buildings, including design (as probably the most important), production and product adjustment. Besides, some types of roof- and building facing, for example glass and natural stone, are often just as expensive as the PV system. At such, if there are to be implemented new roof or facade on a house, it may be a good investment to replace some of the materials with integrated PV modules.

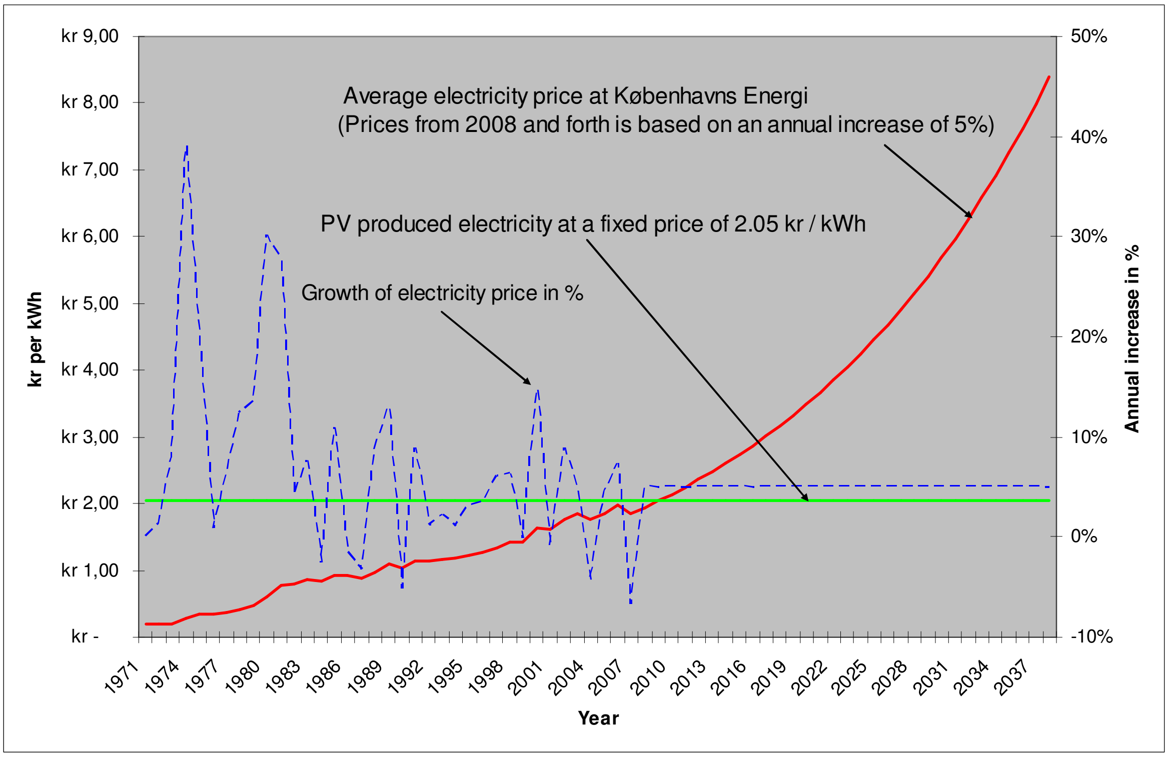
5.2.2 Electricity Prices

The *electricity price* is another important driver. Naturally, the higher electricity price, the higher benefits of PV electricity production, because the price per energy unit typically is fixed for the next 30 years. That is, by investing in solar PV the house owner is in a certain degree protected from increases in electricity prices, therefore it depends on the trends in electricity prices how beneficial investments in solar PV are. During the past 35 years the electricity price has on average increased by 7% per year (Københavns Energi; Data collected by respondent). Additionally the price of PV kW/h has decreased significantly in the same period and improved the cost efficiency due to more efficient solar cells and a learning curve rate of 20%[48]. The present costs of electricity from standard PV systems are around 2 DKK per kWh in Denmark[49], which can be reduced by increasing the PV efficiency further or by reducing the overall system costs. Both can be realized by further R&D in materials, processes and design, while growing production volumes also lead to falling prices, corresponding to the learning curve (Ahm, 2007).

[48] That is, a cost reduction of 20% every time the production volume is doubled. However, the last four years (2004-2008), the learning curve has slowed down due to scarcity of silicon but is expected to return to the former level in near future as a combination of reduced material (silicon) consumption and increases in silicon capacity.
[49] This is corresponding to the double of that for the best systems in southern Europe.

The following figure is based on a demonstration by an (anonymised) respondent within BIPV and displays the annual development in electricity price, in absolute figures (red line) as well as the growth rate (blue, scattered line), together with the cost of PV produced electricity (green line). The aim is to show costumers or business partners whether it pays to buy solar cells.

Figure 15: Does solar cells pay?



Source: Anonymised respondent

Although electricity prices have on average increased annually by 7% since 1971, in order to be on the safe side, the figure is extrapolating only by 5%[50]. On the other hand, however, conventional PV is among the respondents regarded as an established and proven technology, which entails that the price as well as its performance is known for at least the next 25 years, which is the guaranteed lifetime for most PV systems. In many calculations though (just like the above graph), 30 years are the expected minimum lifetime for a system. Therefore, the future PV electricity price is fixed as the green line in the figure, which is because of its aim at comparing a specific PV installation's expected lifetime and price with an estimated forecast on the general electricity price, and thereby not making the figure too complex and confusing. On the other hand, as the price of solar cell modules has been halved every 7 years since the beginning of the 1980's (Ahm, 2007), the overall generic price per PV energy unit is certainly expected to decrease rather than remain fixed. Thus, with this in mind, the green line should be decreasing since the beginning of 1980s, and past 2008 if the trend

[50] Actually, the creator believes that this growth number is significantly understated.

remains unchanged, which of course depends on the above-mentioned factors, including the learning curve (see figure 24).

The issue of whether or not to invest in PV systems depends most of all of the payback time, which is directly related to and depends, among other factors, on the facility's efficiency and price. The widespread belief of the respondents for a PV facility payback on investment time without subsidies is approx 20 years – everything after that period is pure profit. However, turning to the figure above one has to consider the entire period of which the investment concern, and when doing this the payback time in this example is much shorter: Based on a conservative electricity price extrapolation of 5%, the average price is around 4.10 DKK / kWh (during the PV system's minimum lifetime expectancy of 30 years). A price example is given by an interviewee: Together with a PV system price of 175,000 DKK and an efficiency of 3,100 kWh / year, the PV facility has a payback time of DKK 175,000 / 3,100 x 4,10 DKK / kWh = 13,8 years[51]. Of course, there are many different factors influencing the payback time, but the essence here is that the increasing electricity prices contributes considerably to keep it down. The argument of the company who has created the figure and the example is that others, who calculate with a payback time of approx 20 years, have not realized this major future increase, which is, apparently, the reason that they still regard PV electricity to be (too) expensive, especially without subsidies[52].

Thus, the payback time of a PV facility is therefore very much related to the price development of electricity. Because the payback time is one of the most important (if not the most important) factors when people buy PV facilities, the demand will increase when payback times get shorter, which naturally act as a major demand pull driver for firms to further innovate in new and improved methods of integrating the PV facility in buildings or improve the efficiency. That is, innovation is driven by expectations of larger markets.

5.2.3 The Net Metering Agreement "Nettomålingsordningen"

Highly related to the electricity price, another driver is the so-called *"Nettomålingsordningen"*, a grid control and net metering agreement that involves exemption from tax for PV facilities in order to cover the energy consumption for households. By this agreement, it is possible to "park" surplus electricity generation at the collective grid without individual metering and calculation, and then afterwards take it back without paying the ordinary taxes[53]. Quite simply, in this way the household

[51] Replacement of inverter every 15th year is not included in the calculation. (In principle the first years of PV electricity are very expensive and everything beyond 10-15 years is very cheap or free)
[52] Policy and subsidies implications will be discussed in the coming.
[53] Goes for private households, up to 6 kWp facilities, and providing that the sold power does not exceed consumption.

electricity meter runs backward or forward, depending on the PV electricity production and the current electricity consumption of the household. That is, households can sell their PV produced electricity for the same price that they buy electricity from the grid. This is driving innovation in small scale grid connected facilities and BIPV.

5.2.4 Energy Awareness

Another important driver is *energy awareness,* as the companies in the sector are committed to develop environmental energy technologies. In this respect, the growing public attention on the environment and the scarcity of fossil fuels has both had an important positive influence on the public perception of new energy technologies and the subsequent customer demand for PV. This is also positively affecting interest in PV facilities in public and private organisations that normally not have anything to do with the sector. This could be because of a desire to establish, or maintain, a green image to for example costumers, which involves BIPV in facades and office buildings. The "green branding" makes up a substantial potential market segment for companies involved with BIPV and a significant incentive to innovate in new and more aesthetic looking PV panels.

5.2.5 Funding Availability

By different means, *funding availability* is another driver of innovation, highly connected to policy issues. The latter will be discussed later, as this part is only to present the types of funding that presently have importance to companies' innovation activities. They are all aimed at promoting innovation by means of providing funding to specific areas of R&D. There are currently four Danish subsidy schemes aimed at research, development and demonstration of energy (Energistyrelsen):

- *The Energy Research Programme (ERP)* (Energiforskningsprogrammet, EFP) is administrated by The Danish Energy Authority. In 2007 approx 55 million DKK was available for project funding within a broad spectrum of new energy technologies. Funding is provided for RD&D concerning production, supply and effective application of energy. ERP is going to be replaced by *Programme for Energy Technology Development and Demonstration (EUDP) in 2008.*

- The Public Service Obligation *(PSO) agreement for environmental friendly production of electricity (often referred to as ForskEl)* has a foundation of 130 millions DKK in 2008 is administrated by the system responsible electrician company, Energinet.dk. (earlier Eltra og Elkraft System). The agreement grants funding for RD&D of environmentally friendly electricity production.

- The Public Service Obligation *(PSO) agreement for effective use of electricity (also named ForskVE)* allocates 25 million DKK in 2008 and another 25 million yearly for further three years for RD&D in smaller RE technologies, and is administrated by the Danish Energy Association, an association of electricity distribution companies. Common for the PSO agreements is that they are financed by the electricity consumers trough a obligatory donation via the electricity bill.

- *The Strategic Research Council* (Det Strategiske Forskningsråd) provides funding for energy research projects concerning renewable energy technologies and energy conservation for an amount of approx 105 million DKK in 2007, and managed by the Programme Commission on Sustainable Energy and Environment under Danish Agency for Science, Technology and Innovation.

Furthermore, the Danish *National Advanced Technology Foundation* (Højteknologifonden) has funded energy technology projects with approx. 50 million DKK, although the effort is normally on a broader basis, and there are row of requirements and relations to other technology areas for energy technology if they are to have hopes of getting funding.

Within PV, it is the PSO agreements that have constituted the most considerable source of subsidies from which several of the respondents have received funds in the million regions for R&D and demonstration projects[54] in new developing technologies. In the context of EU, funding from the Framework Programmes (FP) includes both R&D and demonstration. In the current FP6, PV is a prioritized area, with a funding frame of almost 300 million DKK. Relative to its size, Denmark has traditionally been able to make fine use of the FP system (PA Energy, 2003).

5.2.6 Exports Markets

The PV sector has an interesting export potential. Until now exports have mostly comprised minor PV systems mainly for use in developing countries and for the operation of "remote professional" facilities such as telecommunications and navigation, as well as expert- and counselling assistance in connection with PV projects. In the last years, new export opportunities have emerged for Danish industry, including crystalline silicon for the manufacturing of solar cells and inverters for connection of PV systems to the utility grid. Companies in the construction industry with established ex-

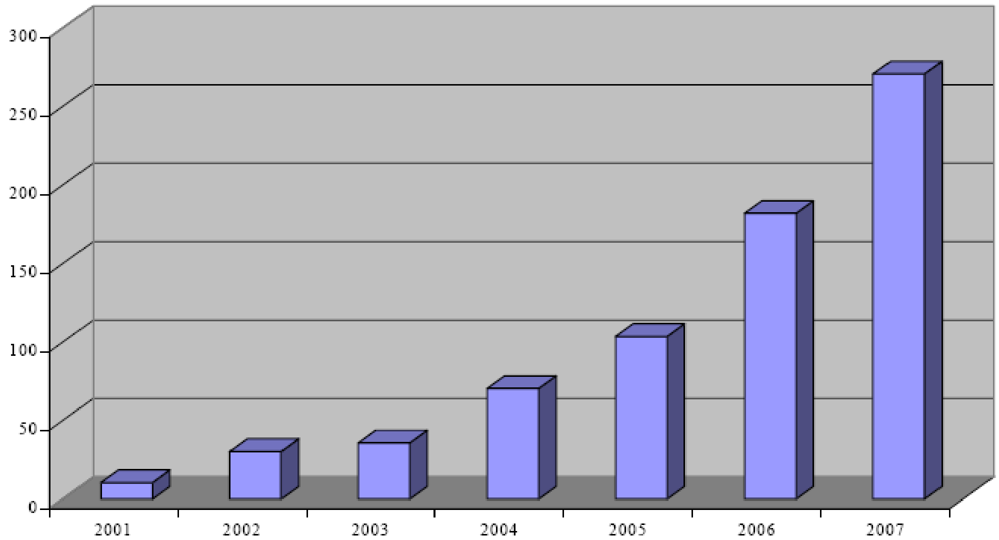
[54] Often demonstration projects act as a drivers themselves, as they generate attention to the product in question. For example, the Sol-300 and Sol-1000 projects attracted considerable attention among house owners and the public as a whole.

port markets have shown an increasing interest in developing new components and systems with integrated solar cells, and there seems to be significant opportunities for greater growth in the area (PA Energy, 2004).

For at least six of the Danish companies within the PV sector, *export markets* comprise a significant driver. So far, exports have mainly included smaller PV facilities for use in developing countries and the operation of "remote professional" facilities such as telecommunications and navigation, as well as consultancy in connection with PV projects. In recent years, however, new export fields have emerged, for example crystalline silicon for the manufacturing of solar cells and inverters for the network connection of solar PV. Furthermore, PV also seems to fit well into traditional Danish strength areas as energy (high) technology, industrial design and new combinations of existing technologies. Companies within the construction industry with well-developed exports have shown increasing interest in developing new components and systems with integrated solar cells, and there seems to be good opportunities for greater growth in this area (Ahm et al., 2005).

The Danish PV export companies have been able to increase growth in exports considerably during the period 2001-2005. The value of exports is thus factually increased tenfold in the period from approx over 10 million DKK in 2001 to about 100 million DKK in 2005, while the companies expect increasing exports value, noticeably in 2006 and 2007:

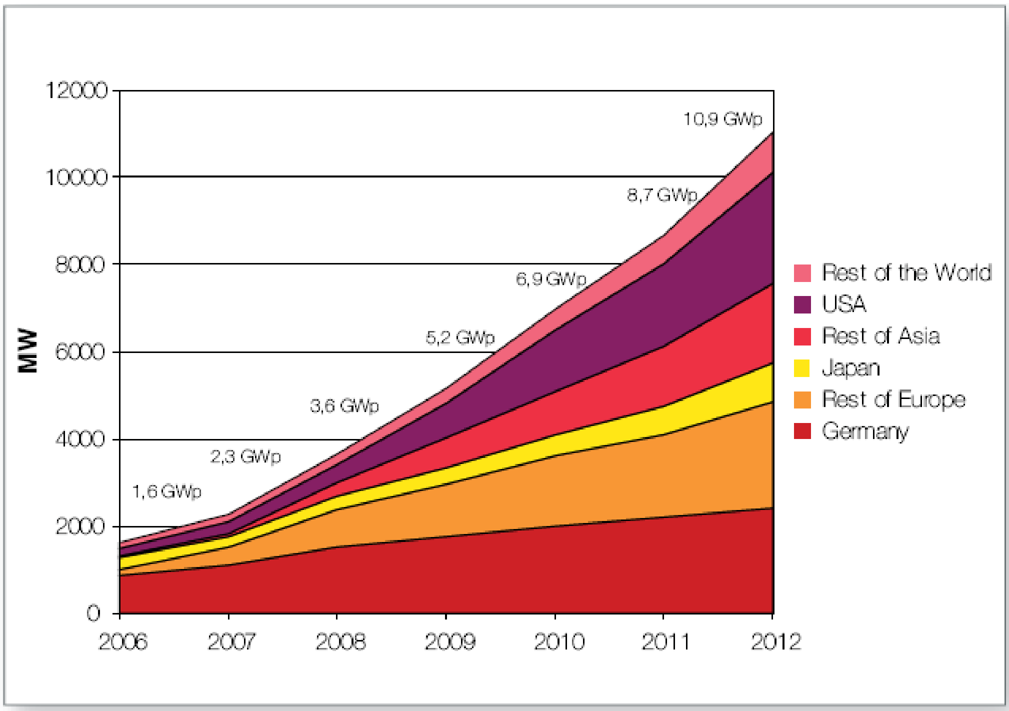
Figure 16: Actual and expected (2006 and 2007) development in Danish exports of PV-related equipment and technology (Million DKK)



Source: Ahm et al. (2005) p. 28

Interviewees express that standard modules are very easy to sell on most markets with feed-in tariffs – most of which go to PV power plant facilities on fields because they have much lower installation costs and thus the best cost efficiency conditions. However France has favoured BIPV in their feed-in tariffs and if other larger markets like Spain, which considers it, follow this trend it could imply a very big international driver for BIPV innovations, and thus Danish firms. Furthermore, the very positive market expectations shown in the graph assist in aspiring organisations to innovate.

Figure 17: The industry expectations to the regionally distributed global market demand



Source: EPIA 2008

Regarding BIPV, companies in the construction industry with established export markets have also shown an increasing interest in developing new components and systems with integrated solar cells, and there seems to be good opportunities for greater growth in the area.

5.2.7 Market Expectations

Market expectations act as an important driver, because the companies expect that foreign PV markets are to grow substantially as shown. But it should be emphasised that also within the Danish market, there are companies that expect significant growth. Interviewees argue from past experiences that the Danish people are very positive towards PV technology and also that they are similar to Germany as a market though without any kind of subsidies. Here, they also mention the overall economic prosperity of the nation to be a very important determinant for this to happen.

5.2.8 Summing Up on Conventional PV Drivers

To sum up, the drivers of innovation within the conventional PV sector are centred on different issues, some more important than others. Here, R&D funding are considered as being important to some of the respondents' future success, while others does not apply for funding at all – either because they simply do not need it, or because they consider the public funding system to be too politically controlled. Furthermore, the funding available is in most cases focused on emerging technologies that have obvious market potentials, and therefore funds are generally granted to technology developers like knowledge institutes or companies in the developing phase of a product. Besides the energy prices, the net metering agreement "Nettomålingsordningen" and the building regulations are vital to the market development within Denmark and future success for some companies within the sector, all acting as determinants of future demand for grid connected PV applications.

There is a general consensus among the interviewed actors that the future success for the present majority of Danish companies are within the field of building integrated photovoltaics *(BIPV)*, which is due to a number of different factors. First of all, the looks of traditional applications of PV panels on buildings have traditionally appeared rather doubtful, including both rooftop- and facade integrated PV, while the same concerns for example conventional sun shading. Seen from an architectonical perspective, the biggest challenge is to adapt the PV panels to the house so that they do not appear as foreign elements that reduce the building's architectural quality. For this reason, Danish companies have identified several niche applications. For example, one is specialized within complete turnkey systems that are custom designed for the client needs and fully integrated in the look of the building, while another has developed a new type of sun shading that consists of solar cells.

The main overall driver for innovation in Danish companies is the increasing international demand for grid connected PV facilities, which is driven by the incentive programmes[55] for diffusion in different countries like France, Germany, Greece, Italy, Portugal, Spain and so forth (EPIA). The Danish market is presently only interesting for a small number of companies due to the "missing link" of diffusion incentives and the main attention is accordingly headed outwards to the international scene. Companies like Danfoss and Sunsil are primarily driven by the international demand for export and Topsil is as well driven by this; however they still are unsuccessful in attracting PV investments. Photosolar and the novel PV companies are to some extent also driven by this demand though to a much slighter degree. The power from Photosolar's products will, because of the niche product features, not be able to contribute with much to the utility grid and so the schemes become a secondary priority for any buyer.

Conventional PV innovation activities are also now beginning to depend on the speed of developments in novel PV technology[56], which seem to close in on conventional but still though generally

[55] Mainly those build on the "German" model with guaranteed prices, feed in tariffs and long term policy. See e.g. the EPIA overview of support schemes: http://www.epia.org/index.php?id=18
[56] For example with the emergence of Nanosolar on the international scene.

have some R&D time left (5-10 years is expected) before competitive products to conventional PV are realistic (EUREC).

5.2.9 Drivers of Novel PV

The sector of novel PV shares some of its innovation drivers with those of conventional PV mainly that of future market and export expectations in relation with increasing energy prices. Funding availability and capital grants for R&D is also a considerably larger driving factor for novel than for conventional because of the R&D intensity. The environmental and societal needs for development of new and cleaner forms of energy also drive the companies to some degree to do R&D. However, it is future market expectations that comprise the largest incentive to innovate or entering into collaborations, which is more important here than with conventional PV because the novel PV companies in some cases will have to create the market themselves. There is a huge amount of possible applications of novel PV, for example within food, where solar cells can supply power to small microchips on for example a carton of milk, where the microchip can be able to tell if the milk has exceeded its shelf life. Besides, one company has successfully tested a PV-powered "radio-cap" in collaboration with DTU during a major music festival this year, which was handed out for marketing purposes. The Novel PV companies do not yet have ready products that can contribute to the power supply and it is right now unsure whether they will be able to within the time of the (int.) support schemes' horizon (until around 2020).

5.3 Knowledge Creation and Diffusion

The basic prerequisite for innovations is knowledge, which according to the theoretical framework has different characteristics that we will go into in this section for both conventional and novel PV.

5.3.1 Conventional PV

The message from the interviews is that innovation in the international arena has focused on standard modules and cells and incremental improvements of their cost efficiency, reliability, durability, and preliminary ease of installing. This means that innovation has been concentrated around the cell, standard panel and inverter levels for less costly and more efficient production methods and equipment and better technological output durability. The development has gone towards thinner silicon wafers and using lesser silicon per watt peak, which today is less than 10 grams. The initial success of this innovation has manifested itself further upstream the supply chain and has yielded a very increased focus on the silicon level of the supply chain, and the building of several new factory facilities for production of silicon has been initiated. The high and rapidly increasing demand for silicon has also given rise to a need for innovation on silicon that is optimised for PV, however investments on this level has very high capital requirements and other complex factors involved. Topsil is one out of five companies on a global scale, which can optimise silicon for PV.

Knowledge in the Danish sector is centred on optimisation of inverters (e.g. Danfoss, Aalborg University), BIPV (e.g. Gaia Solar, Photosolar, Skanska) and purification of silicon (Topsil). This knowledge is what determines further knowledge creation in the conventional sector. One interviewee points out that there is a possible PV cell developer and manufacturer in RAcell and Yakov Safir, who holds knowledge about how to start a cell production, one interviewee points out. Likewise also Topsil is a potential investment object (FDI) for foreign cell developer firms because they hold unique knowledge in the global context about the FZ crystallisation processes. Investment of this kind could entail a much larger production facility of the purest FZ silicon and very high revenues within a short term period, if financial investors are willing to raise the necessary investment capital.

In the supply chain levels of silicon crystallisation, inverters, cells, and standard panel production the knowledge is much codified and tacitness accordingly quite low. In custom panel production and building integration of PV some of the knowledge relates to experience and creative abilities, which in some cases can be characterised as non-codifiable and thus tacit knowledge. However as it shows from the interviews most companies can get by this hurdle and acquire some of this knowledge by networking and collaborating with other consultants, researchers, designers and architects that have the curiosity and valuable knowledge to use in the custom made PV facility field or share the interest of the PV facility developers.

Also downstream in panel development and installation there is an increased focus on learning DUI and organisational innovation with the scopes of improving marketing, product quality, individual selling skills, time consumption in projects, etc. For example in BIPV, which makes out the largest end-user market segment in DK, a company stresses the importance of understanding the building and construction sectoral system and their institutions, especially regarding the public procurement.

Innovation in the downstream supply chain is considerably user-driven and includes learning processes of user-producer interaction. For this reason knowledge networks that include developers, designers and architects seem important in the downstream processes of BIPV product development. Besides, another important knowledge network is combined by PV technology developers and product developers, who holds know-who and know-why knowledge related to technology usage, market needs, and product attributes, and OEMs that have know-how about production processes – knowledge flows go back and forth in these networks. The role of knowledge creation is vital for the growth of the Danish sector and can entail new actors, both key individuals and firms e.g. Photosolar and novel PV firms. The role of knowledge institutes is very central in all the knowledge networks. There is still an architectural challenge for BIPV and therefore BIPV is very dependant on the architectural schools and more gifted architects and designers that are interested in using and integrating PV in their plans and designs.

A lot of the existing knowledge about conventional PV was created in relation to the two large demonstration projects, "Sol-300" and "Sol-1000", initiated by some of the Danish electricity companies and involved some Danish PV firms. EnergiMidt led the demonstration projects and was one of the main knowledge creators and diffusers together with the other actors involved. Another actor, which has had, and still has, a very central position in knowledge sharing networks in the conventional PV sector, is the Technological Institute, which play an important role as a mediating link between the other knowledge institutes, technology developers, installers, consultants, architects and others.

The knowledge creation especially depends on the policy strategies for energy technology development, where PV has been a low priority area for number of years compared with other energy technologies, which in the past has hindered Danish knowledge creation in the high growth PV sector. As a result some Danish firms in conventional PV cannot find adequate knowledge within Danish borders and are consequently forced to build knowledge networks with foreign knowledge institutes if they wish to develop a product with the latest state-of-the art technology. The relation the firms have to Danish universities goes both ways – the Danish sector is very small in size, and as we know the universities need applied research funds and collaborations with companies, which means that there is an institutional barrier in the process of knowledge creation for new technologies. According to one interviewee, the relatively small or non existing PV firms make the area significantly less interesting for the universities and knowledge creators. That model is self-reinforcing because Denmark gets more knowledge creation in those fields, where there are existing knowledge and companies, which means that the institutions for knowledge creation imply technological path dependency.

Learning by DUI is also generally done by the Danish PV firms in relation to the market, in some cases Denmark is used as a test market, while the real market is abroad in for example Germany.

One interviewee emphasises a problem concerning inadequate knowledge about development phases in product development, like product testing, within Danish private financial investors and instead recommend German or Swiss investors.

Many companies traditionally try to avoid IP protection because of the difficulty and time lasting process. Companies would in many cases rather keep their knowledge secret if possible to save time and money. Collaborative research partnerships with other organisations can raise a problem of complexity, when sharing IP (ICEPT and E4tech, 2003). The impression from the interviews is that this also goes for the Danish sector. Key knowledge in the upstream part of the supply chain is to be able to see through the value chains of silicon purification and wafer production and understand the mechanisms. Aalborg University and Danfoss knows a great deal about inverter technology, how to test and optimize them to PV power and could be considered as key knowledge holders – also in the international arena.

The interviewees express that knowledge networks and corresponding flows are not confined within DK but rather goes across borders to other European countries, especially Germany, where they have specialised knowledge institutes and many major PV firms. The networks seem to emerge either in the R&D phase of a product or in connection with marketing of developed products, e.g. on the big international trade fairs or exhibitions like *Intersolar 2008* in Munich, Germany, or *The 23rd European Photovoltaic Solar Energy Conference* (in short EU PVSEC) in Valencia, Spain.

The European industry (EPIA) has developed R&D strategies and technological roadmaps to mature the technologies:

Table 9: Industry roadmap for PV Technology

Topic	Time	Goals	Action Items/Actors
Wafer	2010 (2020)	**Halving the materials consumption** for Cz-Si and mc-Si per Wp **Thinner ribbons** **Thinner wafers** **Decreasing kerf loss**	**Development of new wire saws** for Cz and mc-Si *Equipment manufacturers and material suppliers* **Improvement of material quality** *Wafer makers and Research Institute* **Productivity increase** *Wafer makers and in-house producers, Research Institutes* **Reduce cost of consumables** *Wafer makers and in-house producers*
Solar cells	2010 (2020)	**Crystalline Cz efficiency increase** to 20% (continuing to 22%) **Crystalline Mc efficiency increase** to 18% (continuing to 20%)	**Develop new processes and cell concepts** *Research Institute and Solar Cell Industry* **Material and consumables cost reduction** *Equipment manufacturers, material suppliers and cell makers, Research Institutes.* **Decrease processing time** and increase area per cell. *Automation industry and cell makers*
Modules	2010	**Expand life time expectancy to 35 years**, **Interconnect technology**, e.g. back-contacted solar cells	**Develop new processes and concepts** *Research Institute, equipment and module industry* **Material and consumables cost reduction** *Equipment manufacturers, Research Institutes, material suppliers and module makers*
Thin film	2010 (2020)	**Larger process area** to $3m^2$ (continuing to $9m^2$) **2 routes:** Higher efficiencies, at least 10-12% (aSi/µcSi, CIS and CdS/CdTe) or Price reduction of 50%	**Improvement of the TCO**[57] *Research Institutes, equipment and thin film industry* **Improve stability** *Research Institutes and thin film makers* **Develop new processes and cell concepts** *Research Institutes and thin film industry* **Increase the deposition area** *Building sector, equipment and thin film industry*
Novel PV	2010	**First production plant** for dye-sensitised (PEC) solar cells, piloting organic and other novelties	**R&D to create a range of colours of dye-sensitised modules with sufficient outdoor life:** *Research Institutes (with Industry involvement).* **Pilot plant followed by a first production plant for dye-sensitised cells:** *Research Institutes and PV Industry.* **R&D for organic and novelties:** *Research Institutes, Industry.* **New materials and cell concepts above 40% efficiency:** *Research Institutes.*

Source: EPIA Roadmap (2004)

While some of the goals for R&D need to be revised, the table gives a good picture of what aims and focus the R&D efforts for PV technology have. Besides the different technological goals there were also goals for the systems. Just to mention the main ones R&D in hydrogen and fuel cells will become important in the system for the storage of PV produced power and also the work on standards are imperative to introduce new definitions and improvements in components and systems. In

[57] TCO: Transparent Conductive Oxide layers

BIPV a goal is that modules will go into a new building as a standard component and in order to do this standardisation of PV products inside the building sectors are important (EPIA, 2004).

5.3.2 Novel PV

There are very wide varieties of new types of technologies that can make PV cheaper, more efficient, and more applicable. Examples of the emerging technologies that can improve PV cost efficiency are shown in the following overview of cell technologies. These are radical innovations that need some period of R&D before it is ready to market, however market readiness and competitiveness are realistic within 5-10 years.

Table 10: Emerging novel PV technologies

Technology type	Technology	State-of-the art	Efficiency potential	Potential for cost reduction
Novel Inorganic thin-film technologies	Spheral CIS solar cells	6% solar cells on small area	14-16% CuInSe2	Cost well below 1 Euro/Wp seems feasible with an efficiency of 12%
	Polycrystalline Si thin-film solar cells	6% solar cells on small area First modules are 7x7 cm2	12-14%	Cost well below 1 Euro/Wp is feasible with a certain layer thickness efficiency of 12%
Organic thin-film technologies	PEC solar cells (Dye, Graetzel-cell)	11% on small area 15% in combination with inorganic thin-film cell	15% is achievable A multi-junction approach could further enhance this	An efficiency of 10% is necessary to reach the goal of 0.5 Euro/Wp Presently the estimated cost is rather around 1.5-2 Euro/Wp
	Organic polymer solar cells (bulk-donor-acceptor heterojunction)	5% on small area Printing on larger areas has been demonstrated	7-8 % is achievable – A multijunction approach could enhance this to 10-15%	An efficiency of 10% is necessary to reach the goal of 0.5 Euro/Wp
Thermo-Photovoltaics	Different cell technologies	First demonstration systems (JX Crystals, ISE, PSI)	System efficiency depends on cell technology: 1-20%	For solar TPV systems a goal of 5-30 €cent/kWh can be expected

Source: EUREC (2006)

Learning in novel PV technologies mainly goes on within organisations through R&D but also knowledge networks and collaborations play important roles that give rise to knowledge transfers. Risø DTU holds key knowledge about polymer cells, while the Technological Institute is the Danish knowledge centre for PEC. Nanotechnology institutes on universities focus broadly on application of nanotechnology in PV and other areas. The knowledge created in the institutes is essential for innovation. Spin off innovation activities from the main knowledge institutes are a key part in the building of the sector. The key knowledge carriers can create knowledge entrepreneurs that can turn into system builders (e.g. SunFlake).

Between the many competing technologies the role of R&D is to invent and prove that the new technologies are usable, efficient, and especially durable enough to compete with the conventional PV technologies and eventually conventional energy technologies. There are high expectations from some scientific circles and nation leaders to the novel PV technologies, which can be produced much more efficiently, with cheaper materials and even some with higher efficiencies than conventional ones. Financial investors (mostly public) are beginning to realise the potentials for the energy supply and thus are ready to make investments in RD&D. Also besides this there is a technology race going on that amplifies the intensity of R&D and implies approaching selection processes.

We have categorised the competing and complementing technological domains of new cell technologies in 3 types of R&D areas, which have different scopes compared to conventional PV:

1. Focus on use of cheap materials, more efficient production methods and expanding application use.
2. Focus on enhancing cell efficiencies on the material side e.g. through nanotech (e.g. SunFlake's Nanoflakes®).
3. Concentration or multi-junction technologies, which can enhance cell efficiencies significantly (up to 60-70 % in long term) (EUREC, 2006).

Within the concentration and multi-junction technologies there are no organisations in Denmark and it is an interesting question whether there is any existing knowledge potential to build on. However in the two first types of PV technological domains there is some noteworthy potential for Danish companies and products. SunFlake is an example of no. 2 type company working with nanotechnology, whereas the collaboration between Mekoprint and Risø is an example of no. 1 type that commercialise novel polymer PV technology.

Knowledge in Danish novel PV is centred on PEC, polymer, and use of nanotech in different aspects of PV power generation. This knowledge together with conventional PV knowledge complements each other in the way that the different knowledge institutes use each others knowledge to build on and in collaborations with firms the knowledge flow back and forth, which can stimulate and improve innovations. Knowledge creation in one knowledge institute, such as Aalborg University, can sometimes have the purpose of helping R&D in another knowledge institute, such as the Technological Institute.

Some of the novel PV technologies follow the path of conventional PV and improve it through nanotechnology (e.g. SunFlake, Copenhagen University), while others (e.g. Mekoprint, Risø, Technological Institute) follow new technological paths like the PEC or polymer.

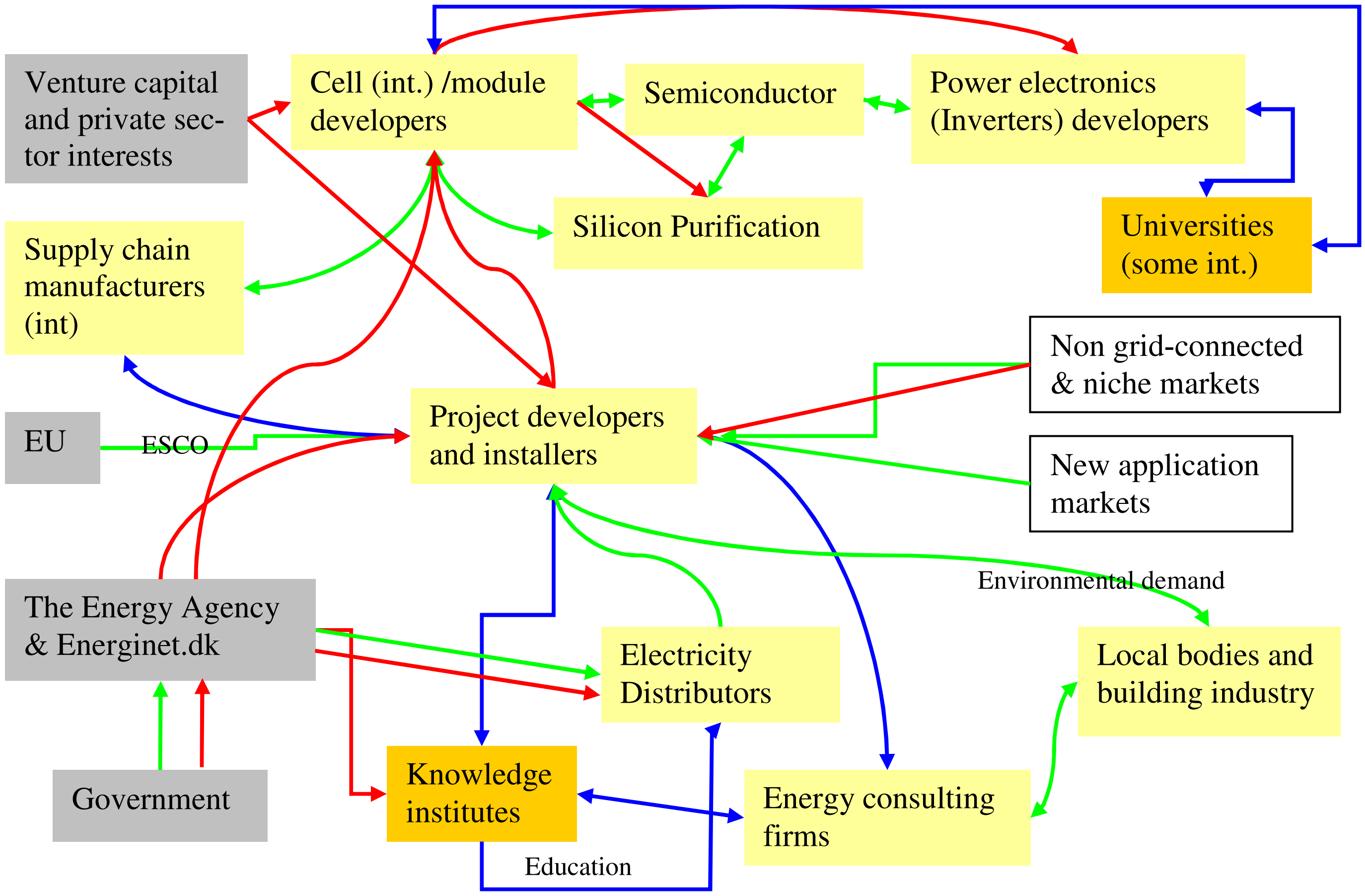
In the commercialisation process of the novel technologies important aspects are to investigate the market potentials for new applications as well as adapt the technologies to existing production technology. If possible, firms try not to invent new production methods that better fit the technologies rather than doing the opposite because it is less costly. The high technology PV firms are very interested in knowledge creation in the universities, and the educated Ph.D's, in for instance PV inverters or nanotech, are in demand in both Danish and international organisations. Regarding IPR, most companies in novel PV are doing IP protection, which gives an indication that they prefer to publish their ideas and main results in order to maintain competitive.

What goes for conventional PV in relation to networks and knowledge flows also applies for novel PV with the additional remarks that academic networks play a much larger role in the intensified need for R&D, and also that the networks are much more confined within Danish national borders. All the novel PV technologies can spin off science based firms and these can choose to outsource the scale-intensive manufacturing activities to other firms, as in the case of one interviewee.

5.4 Innovation System Maps

This part is to figurative sum up the flows of knowledge, funding and influences presented in the previous parts, first according to conventional PV and then for novel PV.

Figure 18: Conventional PV innovation system



Each colour corresponds to a particular type of actor:

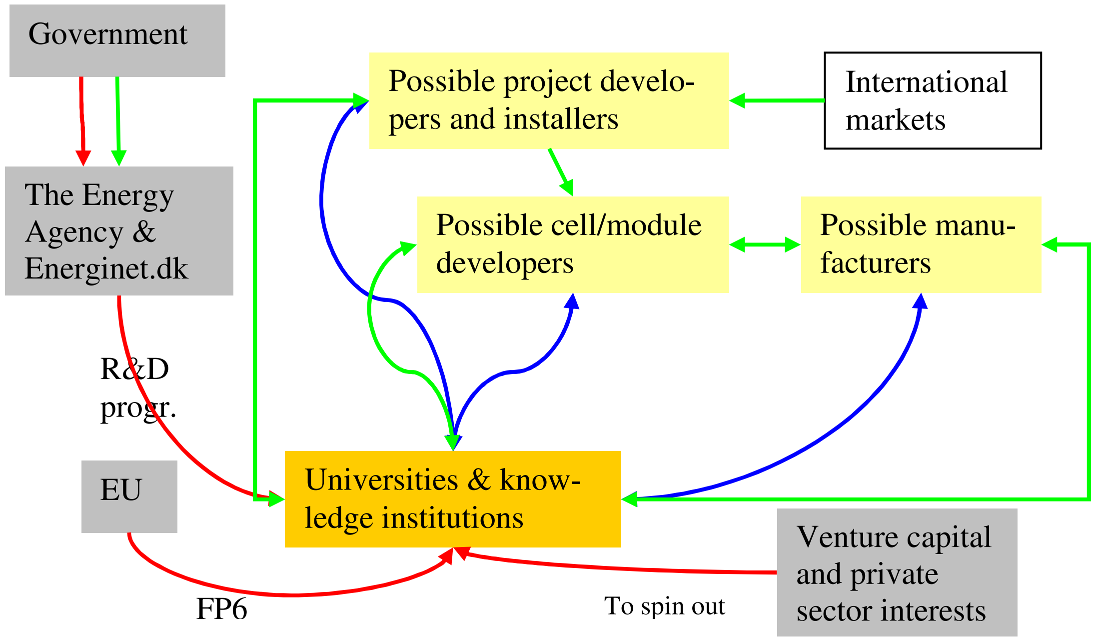
Grey:	Public authorities
Orange:	Knowledge institutes
Light yellow:	Companies

Likewise, the colour of the arrows corresponds to a particular type of flow:

Green:	Influence
Red:	Funding
Blue:	Knowledge

The above system relations of innovation are how we have managed to understand the system through the analysis of our collected information, where innovation clearly centres around *project developers and installers*, and *cell and module developers*. However it is important to keep in mind the very small size of the sector and that there are overlapping roles between *electricity distributors* *and project developers*, and also between *module developers and project developers*. Also the importance of the international dimension can seem understated – the big international trade fairs and exhibitions mean a lot for Danish conventional PV innovation.

Figure 19: Novel PV innovation system



Likewise, each colour corresponds to a particular type of actor:

Public authorities:	Grey
Knowledge institutes:	Orange
Companies:	Yellow

The colour of the arrows corresponds to a particular type of flow:

Green:	Influence
Red:	Funding
Blue:	Knowledge

The innovation chain is centred around the universities and knowledge institutes in this R&D intensive phase of the technology development. Processes of knowledge transfers from knowledge institutes to companies are decisive for Novel PV in the initial commercialisation processes.

5.5 Private/Public Partnerships (PPPs)

Some of the R&D is carried out in collaboration with companies within so-called Public/private partnerships (PPPs). For example, a promising BIPV company in the product development phase has collaborated with Risø-DTU and Aarhus School of Architecture, while another has cooperated with Nordic Folkecenter for Renewable Energy about development of a BIPV tile.

Another company has made some interesting experiences regarding partnership circumstances with Danish universities. There is namely a kind of "duck pund" elimination race atmosphere when projects are put together and applications for funds are made. That is, certain actors prefer specific partners, and when actors have made alliances to one side, then they are reluctant to collaborate with others, i.e. it is somewhat very politically controlled who does what and why. This is one major reason why the company in question prefers to cooperate with foreign universities, in which such "control" does not take place. Another reason why the company often turn to foreign universities is that it considers Danish universities to lack the skills within the company's field. However, despite of the political "duck pund" example, companies do not recognize any particular barriers for project collaboration and knowledge sharing. Accordingly, this is because of the fact that it is relatively easy to access the right people.

Often, there is a conflict of interest in collaborations between public and private partners, where the public partners are interested in publishing results, and oppositely the private partners are interested in keeping the knowledge creation as a secret. Some firms can get offended and resist from further collaboration if public partners want to publish some results that the firms do not want published, so clear agreements in collaborations on what parts of the knowledge creation can be published and how are quite important. Generally though, most collaboration with firms is kept confidential by the universities and other knowledge institutes.

Also the IPR aspect of partnerships can pose a problem if there are not any clear agreement about who the rights belong to if anything new should turn up in a collaboration that can be patented. In most cases of PPP the property rights will go to the knowledge institute in return for the demanded secrecy. To give an example, Aalborg University has a standard collaboration agreement, which can be adapted to different collaborations. This standard agreement always gives the patent rights to the university and in return the companies always have the right of being the first offered the rights to buy for a reduced price. Also in some cases the rights are transferred to the firm in return for a compensation or share or alternatively the firm can buy the exclusive rights for a substantially larger amount.

5.6 Other Systemic Influences

First of all, there is the case of the market behavioural institution, which determines that the entire Danish industrial business community will not invest in PV facilities unless important branding issues imply it. Interviewees agree that businesses, in the case of energy, are very focused on the bottom line for income, so therefore if there are not added value to a PV facility, no business are interested in buying it unless it is economically rationale, i.e. the cheapest form of energy available. Another regulatory institution that amplifies this effect is that companies are partly exempted from environmental energy taxes. It applies to all the market that lack of widely and well known PV related actors in Denmark imply that buyers have very limited possibilities of acquiring PV facilities and that competition still is too modest to create any market synergies.

Regarding some niche applications, there seem to be some barriers like cronyism and lack of economic rationality inhibiting innovation in the established systems, where the established way of doing things sometimes succeeds in resisting technological and organisational change. To give an example there are possibilities of increased effectiveness of public resources in both lighthouse applications in the Danish Waters Directorate (Farvandsvæsenet) and speed measuring facilities in the National Road Directorate (Vejdirektoratet), where companies fruitlessly have offered their products and services, which accordingly should be more cost effective[58] for the public sector directorates than having a continuously battery service for all the facilities. Companies point out that the resistance seem to be incorporated in the organisations and in some instances the same person does not hold responsibility for both the facility budget and the operating budget, which create conflicting interests within the organisation.

In relation to the power supply, all of the interviewed actors feel that there are very long perspectives to realise novel PV technologies' and that only conventional PV seem relevant for the regular power supply. In this respect, solar PV is also dependant on the complementary effects from other new energy technologies and it would be wise to keep exploring synergies in the energy systemic context between the emerging technologies (Ahm, 2006).

No compatibility problems have been experienced with the utility grid from the demonstration projects. However the consumers do not have rights to be grid-connected, which has not posed a problem yet but electricity companies could refuse to connect households if they want. Nobody knows how the electricity companies would react in a situation with massive expansion of grid-connected PV facility demand. Conversely, the interviewees generally do not expect any problems in relation to PV grid-connection. However one emphasise that discussing this subject seriously would imply the process of going from a few hundred facilities to 100.000 facilities and how to optimise the management of that process. A coherent policy design would be needed for this that would enhance

[58] With budget savings of up to 150 million DKK annually.

market creation by creating incentives and removing barriers like different regulations that inhibit innovation. For example it is possible and without risk to plug in small DIY PV facilities, beneath 500 Wp, directly into the power socket like they do in the Netherlands but it is not allowed in Denmark – The Danish Energy Agency have been against it.

In relation to growth the interviewees agree that the most interesting areas of PV are in niche applications, such as BIPV. There are some complicated institutions regarding BIPV, but one main is that architects in Denmark have great decision-making authority in the construction project, and it is still very few architects in Denmark, who has the experience and competences to integrate it aesthetically. In this respect it is emphasised that a coupling of architect and engineer interests would help push PV and other building integrable energy solutions forward. The historic absence of a PV advocacy coalition has furthermore surely not improved the PV sectors' position in relation to other energy technologies. The formation of the new Danish PV industry association will probably be a big step towards a better approach to influence the political system and advocate for better suited policy frameworks. According to one interviewee, a serious barrier for innovation in relation to larger BIPV facilities (over 6 kW) for blocks of flats, is that the present regulations prevent the separate flats in a block in converting the unified power production of the facility to power contributions from the separate flat owners' or leasers' settlement of electricity accounts. Thus the net metering agreement scheme "Nettomålingsordningen" cannot be applied, which entails a bad deficit investment for facility users and owners. This eliminates a part of the Danish market segment for the innovators in BIPV. One interviewee emphasises that what Denmark need to get the PV sector going could be a producer of a niche product that goes well with the Danish building sector.

The general discussion in scientific and political circles about how Denmark's future energy supply should be put together in the future by different energy sources also has a huge overall effect on the energy sector and the alternative technologies. Some are firm believers in nuclear power, others in wind power and so forth. The essential basis for the discussion is the increasing scarcity of natural fossil resources and abundance of energy found elsewhere through relatively new technology. The eventual readjustment of the energy system to other energy sources than fossil is as a point of departure imperative and therefore the political decisions about how to manage this transition become very central. In this respect, RE and PV have an advantage according to a RE expert because the energy sources are unlimited and the energy production units smaller size means that they can be produced with economies of scale as opposed to for example big centralised coal fired power plants.

Repeatedly it is emphasised by the interviewees that a seal of approval for the RE technologies in general from the government and long term stability in policy framework is vital, which they do not think is the case for Denmark in the recent years. Here most also lay emphasis on the importance of a proactive, barrier braking and to some degree favourable policy, which is reasonable in the light of other EU countries' efforts and experiences on the energy area. Some interviewees underline the importance of a policy system that covers all the new alternative energy technologies and does not obviously favour one technology on behalf of the other. Widely in the sector it is believed that the governmental signals of indifference to RE and reticence to acknowledge the sector potentials and build supporting policy systems was, in the period of 2002-2005 and in slow change onwards, a major reason to why the Danish PV sector has not developed further than it is.

The political signals and priorities from EU likewise play a very important systemic role, for example the EU energy goals has affected the Danish energy policy and also the EU court of law has given priority to RE over the inner market in a verdict from 2001. This way the EU sets a great deal of the framework conditions like standards and regulations, which the energy agencies and authorities carry out in practice, for example all the publicly funded R&D projects need EU approval. It is widely agreed that PV and other RE technologies need support for development of the technology in order to reach the phase of maturity and be fully commercially competitive.

Another important role in the energy political arena is that of IEA, which by some interviewees are assessed as setting up a barrier for RE development. They are the only energy agency that to a certain degree can be considered neutral on the international level, and their predictions seem to constantly overestimate the fossil energy sector and underestimate the RE sector in terms of price development and other central issues, all of which has implications for the PV sector.

5.7 Technology and Sector Status

In this section we conclude our analysis of the Danish PV innovation system by summing up on our main findings and assessing the maturity of the sector. These concise conclusions about the system could have policy implications that we will go into in the final part of the master thesis.

5.7.1 Main Findings from the IS Analysis

We can subsequently derive the following conclusions about the studied innovation system on the basis of our analysis. The Danish innovation system for PV is centred on two broad areas: conventional PV, with companies related to crystalline silicon, and novel PV, based on novel materials and systems. The innovation system within conventional PV is characterized by optimisation of inverters, BIPV and purification of silicon. Innovation in the downstream supply chain is mainly user-driven and includes learning processes of user-producer interaction. For this reason knowledge networks that include developers, designers and architects seem important in the downstream processes of BIPV product development. The knowledge creation especially depends on the policy strategies for energy technology development, where PV has been a low priority area for number of years compared with other energy technologies. The R&D for conventional technologies is less intensive than novel PV and is focused on continuously incremental cost efficiency improvements. In the longer term, R&D may lead to improvement of the price/performance ratio through the development of new types of PV technologies, including PEC cells and polymer solar cells, which are areas where Danish R&D institutes contribute. Also the linkage between solar cells and buildings may imply that traditional Danish strength positions like design and system development are able to foster synergies together with PV by means of development of future building- components and systems.

The innovation system within novel PV is yet at an infant stage. Different R&D institutes are doing research in new types of solar cells, for example PEC types and polymeric types, which in the long term may result in more commercial opportunities. Learning in novel PV technologies mainly goes on in house by R&D but also knowledge networks and collaborations play important roles. In the commercialisation process of the novel technologies important aspects are to investigate the market potentials for new applications as well as adapt the technologies to existing production technology.

It is also possible to point out a few barriers for innovation, which is where the innovation system can be improved by removing or minimising those barriers. A main barrier in the system is the lacking knowledge about phases in PV product development at most venture capital investors. Another sector barrier for innovation in Denmark is that there is a lack of knowledge about conventional PV in the Danish universities even though they have had competences within the field in the past, one interviewee informs. This is where international relations and the resulting knowledge flows become essential for Danish firms and the development of the Novel PV subsector, which has prospering knowledge creation and could be successfully developed with entailing innovations by means of a focused RD&D strategy for public funding. To optimize the innovation system it seems that also a promising opportunity could be to stimulate knowledge creation further within novel PV and conventional PV around the BIPV, module developer and inverter levels.

In terms of policy, a main barrier will be to convert the former political reluctance to PV and convince politicians to create a supporting policy system that will help the maturing of the Danish sector. The European PV sector emphasise the significance of supporting policy systems if growth rates of 30 % per annum or more should be maintained, which according to them is necessary in order to mature the technology and industrial sector within a reasonable horizon (EPIA). In this work a stronger advocacy coalition is certainly needed and the initiation of the Danish Solar Cell Association (Dansk Solcelle Forening) and an eventual admission to The Danish Industry Association (Dansk Industry) can be a great help to articulate and facilitate united sector messages that can accomplish this. The European PV sector is developing fast and, in order to hang on and take part in the industrial development, Danish policy should be supporting the growing Danish part of the sector[59], so it can catch a stronger foothold within national borders.

5.7.2 Maturity

If it is acknowledged that a national energy system is a public matter and responsibility then it would also be logical to recognise the role of the public sector as one that determines what path the nation should take in order to secure energy for the people and organisations now as well as in future generations. In assessment of which scope the energy technology policy should have, a stage or phase approach can be applied to the current development and used to weight up pros and cons in the maturity of technologies. The stages are accordingly (Foxon et al., 2005):

- *Basic and applied R&D* that comprises fundamental research and engineering/ application focused research. Both university and industry R&D are included in this.
- *Demonstration* which consist of early prototypes and is intended to introduce new technology in single units or small numbers and by the means of public finance help to overcome the difficult development stage of introducing the first products and stimulate product development. Small spin outs or research subsidiaries often perform the demonstration.
- *Pre-commercial* captures a quite wide phase of development - here many units of previously demonstration-stage technologies are installed for the first time, also the first few systems might move to much larger scale installation. Larger companies also initiate move in or spin outs have to grow rapidly, thus at this stage the financial investment risks are high.
- *Supported commercial* encompass the stage where technologies develop competitiveness and, on the basis of generic renewables support procedures, are produced and installed in substantial numbers by commercially oriented companies.

[59] By means of political messages and economical incentives, and also likewise with other RE technologies, according to our interviewees.

- *Commercial* technologies can fully compete on commercialized markets and are unsupported, within the broad regulatory framework.

Given the above energy technology stage approach for maturity, conventional PV is in the supported commercial stage since we have moved through the pre-commercial stage in Denmark, which included the sol300 and sol1000 demonstration projects[60]. However there is no Danish system of diffusion support for PV in the *supported commercial* stage but nonetheless many other countries than DK support PV with feed in tariffs or other diffusion inducing mechanisms and this is the only reason why Danish companies within conventional PV still exist. The lacks of a support system for diffusion prompt that we must characterise the innovation system to have a failure in the policy framework conditions, given the above approach. As we know, the companies have survived mainly on foreign public support-driven export until now, while they also still indeed have high expectations to the Danish market in the commercial stage.

Novel PV has moved into the demonstration stage and is past some of the first working prototypes. The main problem in relation to first PV cells has been their short lifetimes, which are under intense RD&D to prolong.

The overall PV sector is still at a relatively immature stage compared to the established energy sectors within for example oil (cash-cow) but are experiencing fast increasing maturity, which also seems necessary if the technology, within the next 30 years, should develop to one of the main components of the power supply. EPIA expects PV power to contribute with 1 % of the accumulated power supply in 2020 and 26 % of the supply in 2040 in a supported policy scenario[61] (EPIA, 2004).

In the next chapter we go further into the analysis of the system failure of no public support in the stage of developing competitive energy technologies. We will try to answer how Denmark should solve the system failure in relation to how new energy technology sectors emerge, using the exemplified case of PV technology and evidence from the Danish PV sector.

[60] These projects included Danish firms, however some modules and PV cells where imported, one interviewee informs.
[61] With feed-in tariffs, guaranteed for a number of years, focused RD&D programmes and export promotions assistance.

6 Science, Technology and Innovation Policy

This part will present the features, and connections between, science-, technology-, and innovation (STI) policy according to the definitions by Lundvall & Borrás (2005). Although each of these are distinct policy fields, they have certain characteristics in common, and each does not belong to a specific period in modern history. While widely present on today's policy agendas, the main aspects of these policies date back to the last centuries.

6.1 Science Policy

Science policy is usually considered the art of justifying, managing and prioritizing support of scientific R&D. In an IS perspective, it has three major venues: educational institutions, research- and technological institutes, and R&D laboratories. Science policy is aimed at regulating these parts of the IS as well as their links to the environment, especially regarding government and industry. As many political issues include a scientific component, science policy may to some extend be regarded as the intersection between scientific research and public policy. The main issues in science policy are about allocating resources to science and distribute them between activities, while making sure that they are used as efficient as possible and contribute positively to society. One ongoing debate within the science policy community is the degree to which science should serve the state and capital on one hand, and whether it should be autonomous on the other hand. Advocates of the latter, for instance university researchers and scholars, claim that research independence is important for two reasons: First, they argue, basic research should be left independent in order to let it move along specific trajectories. In the long run, the result may be unsuspected new avenues for applied research and technical solutions. This is also referred to as the concept of serendipity - or a so-called fortuitous discovery. The second reason refers to the importance of critical science to modern democracy, as scientific knowledge from independent sources is argued to be essential in order to maintain open and apparent decision making of the political level. However, on the one hand, completely free science might be a delusion, but, on the other hand, when subordination of science goes too far in the interests of politics and economics, the contribution to society and economy may be undermined in the long-run.

At first glance it seems obvious that the central policy actors are ministries and councils in charge of education and research. However, science policy covers a far much broader part of the public sector given that ministries relating to health, defense, energy, transport, and environment play a role because they manage their own research and account for a significant majority of the public R&D spending. Meanwhile, ministries of finance, and ultimately parliaments, have an influence when deciding R&D budgets and organizations of consumers and citizens play a critical role if political decisions become too biased in favor of commercial interests. Policy actors use budgetary decisions as instruments when allocating funds to public research institutions and tax reliefs or subsidies for private companies. In order to find means of allocating public money and create incentives for institutions and scholars to become more effective, an important policy tool is to evaluate public funded R&D while making sure that review procedures take place within the scientific community. However, the ongoing evaluation criteria are very often maintained internally within the particular academic apartments. In this respect, there is an ongoing debate concerning the degree of internal evaluation; that is, whether in certain circumstances it is too slack. On the other hand, if external authorities impose too exhaustive reporting systems, the result might be unfavorable discontent and time waste among scholars and researchers and, at worst case, end up being a nuisance to the entire innovation system.

Another important issue regarding science policy is the question whether "good" research always should be equated with "useful" research. Thus, in these circumstances, it would be obvious to leave some of the allocation authority to the academic communities themselves. However, the issue whether there is a relationship between prestigious academic publishing and innovation success is not clear, instead it seems partially to dependent on the particular sector in which scientists do research. In this respect, Zucker & Darby (1998) show that star scientists are important to the growth of firms within biotechnology, while Gittelman & Kogut, contrary, demonstrate no obvious relationship between prominent publishing and major innovations. Apparently, the longer the distance between scientific discoveries and innovations, the more severe requirements in the domain between doing outstanding research and creating highly applicable technology. The degree to which science should be generated by means of interaction with its users is another interesting subject, where Lundvall and Borras argue for a science system containing several layers and career shifts among scientists. In this way, some research is carried out in a non-applicable context only within a specific discipline, other focus on user-needs, and some operate within the sphere in-between. The "new social contract of basic science" has been introduced as a term covering the fact that basic science since the early nineties has been continually pushed by politicians in order to show its social and economic usability, in this way avoiding an unfavorable "no value for money" syndrome among voters. However, this attitude is claimed to undermine important features of science policy, for example the *development of knowledge abilities* within areas with high uncertainty about effective exploitation.

6.2 Technology Policy

When focusing policies on specific technologies and sectors, the term technology policy is introduced. It concerns primarily science-based technologies, which are often regarded as being key drivers of economic growth. This is the case with nuclear power, computers, drugs, and genetic engineering, among others. One of reasons for their importance is their capability to open up new commercial opportunities, while being characterized by high rates of innovation often aimed at high growing markets. Technology policy is often used as a strategic tool for defining those technologies and sectors where attention should be directed. Often, the rationale for technology policy initiatives is based on national, political and economic interests, for instance US space technology during the Cold War and the export embargo of computer technology in France in light of the dominance of American multinational firms. However, in Asia the motivation is different. Here, the driving force behind technology policy has often been national strategies aimed at modernization and catching up based on imitation of Western technology.

Nevertheless, a number of essential issues concerning technology policy remain open. That is, whether the state should only intervene in favor of national interests, and to what extend technology policy should be implemented for commercials reasons. Besides, the task of picking out those technologies that ought to be supported remains unclear - for example, whether high-tech and science-based sectors always should be given first priority or attention should to be focused on modernization of traditional industries. Finally, finding the optimal balance between public support and competition may be difficult, for example "picking the winners" on the one hand and "controlled" competition on the other.

Science- and technology policy are both ideal types of policies that facilitate broader analytical objectives. However, policy focus, instruments and actors are rarely capable of being grouped exclusively within one of these categories. In this respect, the next part will deal with innovation policy in which broader policy issues play a much more significant role.

6.3 Innovation Policy

There are two different versions of innovation policy. The first one is the laissez-faire version, as it is based on an idea that emphasis should be on framework conditions instead of specific sectors and technologies. Therefore, no direct government interventions are carried out. Instead, basic research, general education, and intellectual property rights protection are considered the only legitimate kinds of public activities and regulation. However, in other more moderate versions, initiatives are carried out aiming at fostering entrepreneurship and promoting a positive attitude to science and technology in the population.

The other version of innovation policy is based on a systemic approach and refers to the concept of Innovation Systems given that all major policy fields are considered in an innovation context and how the linkages within the system should be managed. While the laissez-faire approach is based on the standard economic assumption that firms always have the ability to know how they should act in order to optimize their achievements, the systemic version take into account the fact that firm capabilities are not equally distributed. Therefore, potential new and improved ways to develop, absorb and apply new technology are not diffused among firms instantly. Furthermore, firms do not only face neoclassical market failures, as in the laissez-faire version, but they also have to deal with coordination failures among institutes in order to link or address different systemic needs.

Both approaches shares the feature that they take into account all aspects of the innovation process, that is diffusion, marketing and use of new technologies, which are all parts of a broader economic policy context. They both focus primarily on innovation rather than allocation of resources, while they consider institutions more important than organizations, which is not the case with science and technology policy. However, in the laissez-faire version, *market dominance and competition are regarded as the only determinants* for innovation, which is why institutional policy design recommendations do not vary across countries. In the systemic approach, competition plays a smaller, though still important, role. At the same time, *vertical collaboration* between users and producers as well as *horizontal cooperation* between competitors is pointed out as a central driver of generic technology development. Unlike the laissez-faire approach, the systemic approach recognizes the fact that institutional characteristics differ across countries, and therefore policy makers must acquire deep insight in the institutional set-up when designing and implementing a proper innovation policy. These two versions of innovation policy are building upon two very different foundations. While the laissez-faire approach is based on standard neoclassical economics of innovation, the systems approach considers innovation policy as a long-term result of innovation research, underpinned by institutional and evolutionary economics.

The rationale behind policy should be found in the economic growth deceleration around 1970, which was claimed to be a result of a slow-down in Total Factor Productivity[62]. A considerable fear

[62] Total Factor Productivity is an expression of the part of economic growth that can not be explained by measurable variables such as physical capital and labour. This means that changes in TFP might have many explanations, including

of inflation dominated the political agendas, which made it especially important to discover new instruments in order to promote growth from the supply side. At such, the key object of innovation policy is the creation of economic wealth, and, in certain contexts, “social cohesion” and equality.

When implementing innovation policy, policy makers use regulation of intellectual property rights and access to venture capital as instruments. Innovation policy can both be considered as initiatives promoting innovation within the institutional context as well as programmes aiming at changing the institutional context itself in order to establish the right setting for innovation. As the former method shares its instruments with those of science and technology policy, the latter makes use of more specific reforms of educations institutes, labour and capital markets, as well as competition laws and regulation of industries. At first sight, it seems obvious that ministries of economic affairs are the major coordinators of innovation policy, which is also true. However, most ministries have some sort of influence on the National Innovation System because of the importance of establishing a broader forum in which interaction and dialogue on policy design and implementation can takes place between different actors. These may be government institutions on one hand and business communities, trade unions and knowledge institutions on the other.

increased knowledge of production and technological progress, which is not directly observable. TFP is also known as the Solow residual and is considered an essential expression of growth.

6.4 Relationship between STI Policies

The figure displays the relationship between science, technology, and innovation policy.

Figure 20: Relationship between science, technology, and innovation policy

Science Policy

Focus: Production of scientific knowledge

Instruments:

- Public research funds granted in competition
- (semi-) Public research institutions (i.e.: laboratories, universities, research centers…)
- Tax incentives to firms
- High education
- Intellectual Property Rights

Technology Policy

Focus: Advancement and commercialization of sectorial technical knowledge

Instruments:

- Public procurement
- Public aid to strategic sectors
- Bridging institutions (between research world and industry)
- Labour force training and improvement of technical skills
- Standardization
- Technological forecasting
- Benchmarking industrial sectors

Innovation Policy

Focus: Overall innovation performance of the economy

Instruments:

- Improving individual skills and learning abilities (through general education system and labour training)
- Improving organisational performance and learning (i.e.: ISO 9000 standards, quality, control, etc.)
- Improving access to information: information society
- Environmental regulation
- Bioethical regulation
- Corporate law
- Competition regulation
- Consumer protection
- Improving social capital for regional development: Clusters and industrial districts
- Intelligent bench marking
- Intelligent, reflexive and democratic forecasting

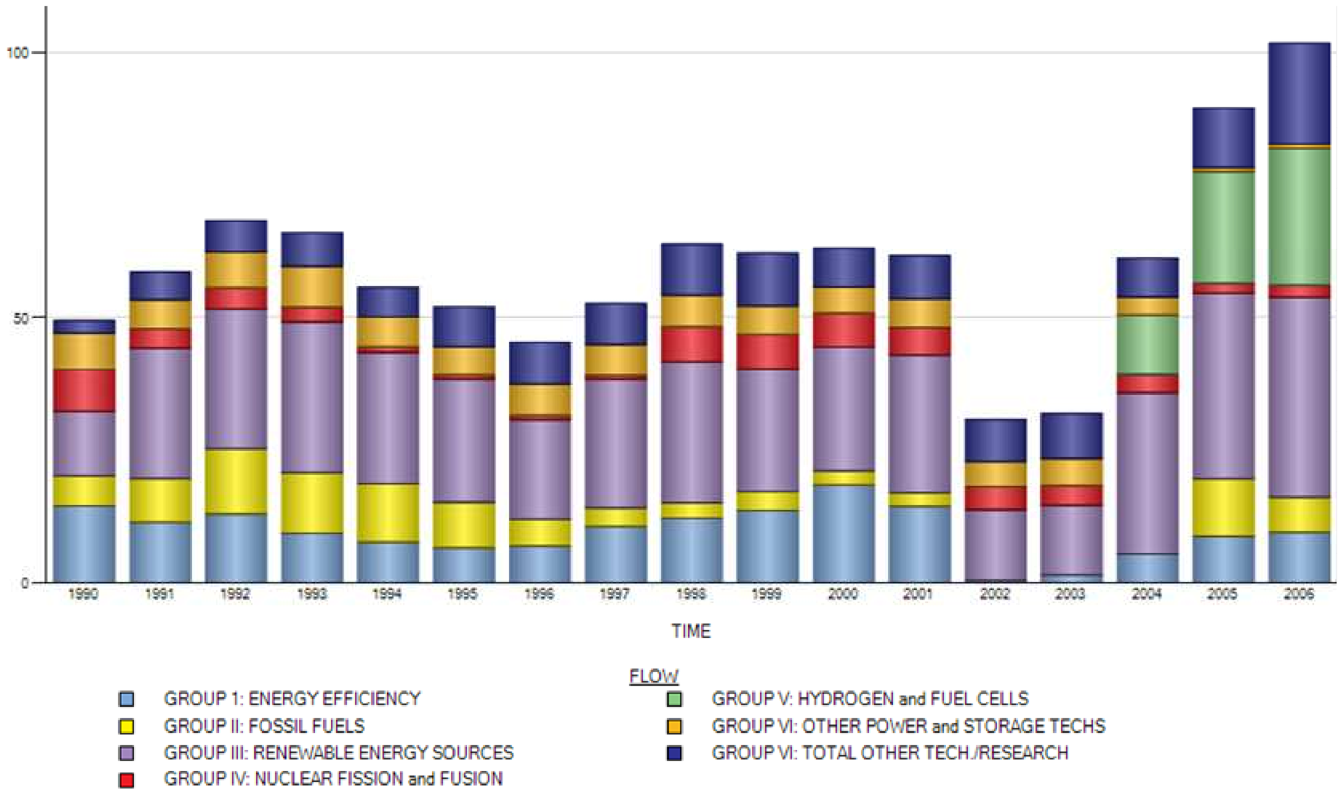
Source: Lundvall & Borrás (2004) p. 615

While science policy and technology policy primarily takes universities and technological sectors into account, the attention of innovation policy takes a step further, as it moves to a broader context including all parts of the economy that influence innovation. This is the reason why innovation policy instruments are the same as those associated with science and technology policy. The aim of innovation policy is to recognize innovation as a social and complex process, emphasizing the importance of institutional and organizational dimensions as well as competence building and organizational performance in the innovation system.

6.5 Danish Policy

This part will present the components of Danish policy in relation to PV. First, in order to get an overview of the development in public PV funding, the section below displays presents figures of RD&D support since 1990. It will initially present the funding for general energy technologies, where after the development in RE technologies is displayed, and finally the specific funding development for PV. Afterwards, the implications following the 2001 government change will be examined, and Danish policy will be discussed by taking the approach in the former presented theory about innovation, science and technology policy. Finally, we will seek to find policy implications that sustainably promote the growth of PV.

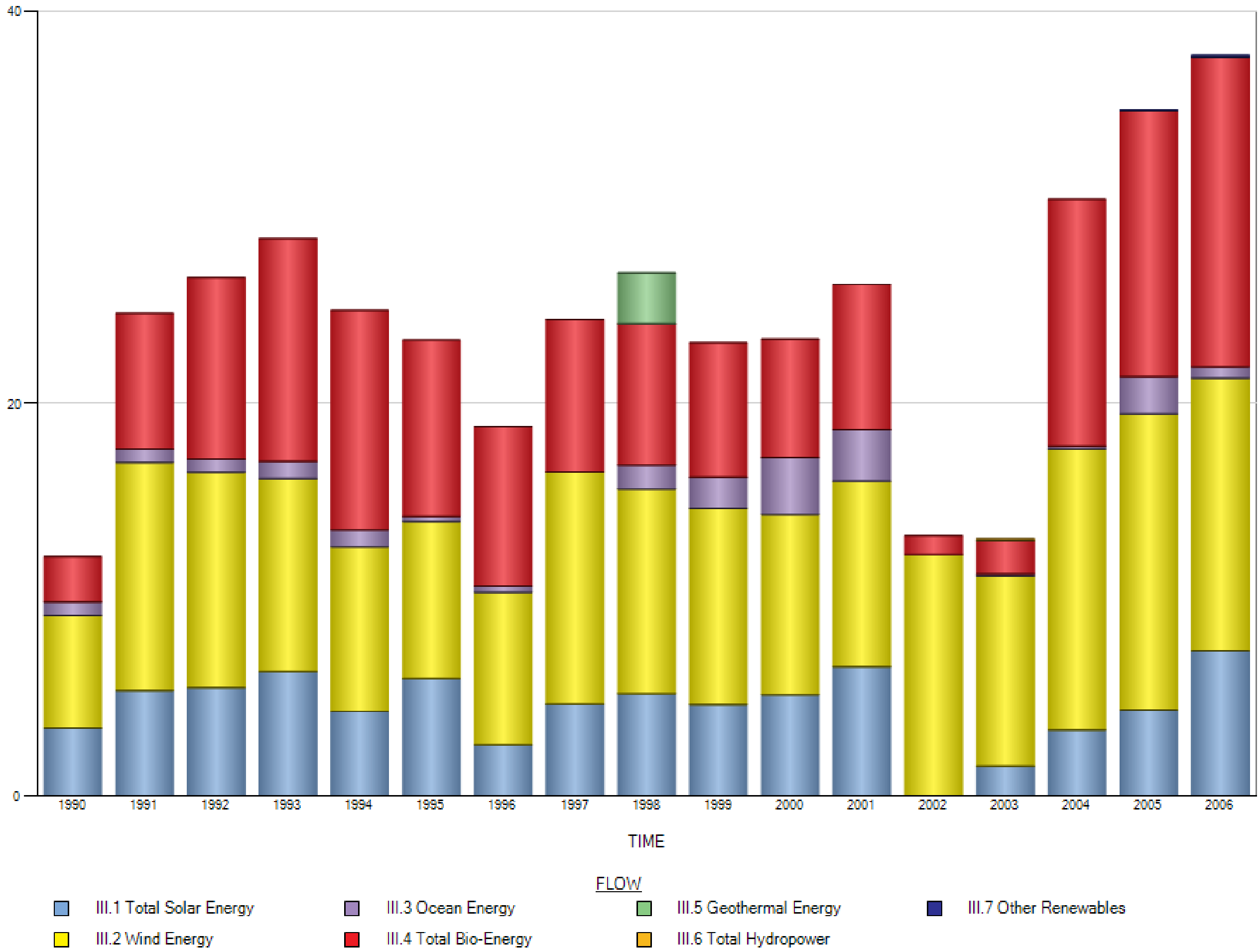
Figure 21: Public RD&D support for energy technologies (Million USD, 2006 prices)



Source: IEA statistics

In the figure above we can see that in the decade of the 1990's there are fluent fluctuations which continue until 2002, where a sudden drop in RD&D resources can be observed. However the following increases in 2004 and 2005 kicks in just as suddenly as the decline in 2002. Another thing worth noticing is the growth in RD&D resource inflow in the new technology field of hydrogen and fuel cells beginning in 2004, which is significantly higher percentagewise to the total than the IEA member countries and countries we normally compare ourselves with (e.g. Germany, Sweden).

Figure 22: Public RD&D support for renewable energy (Million USD, 2006 prices)

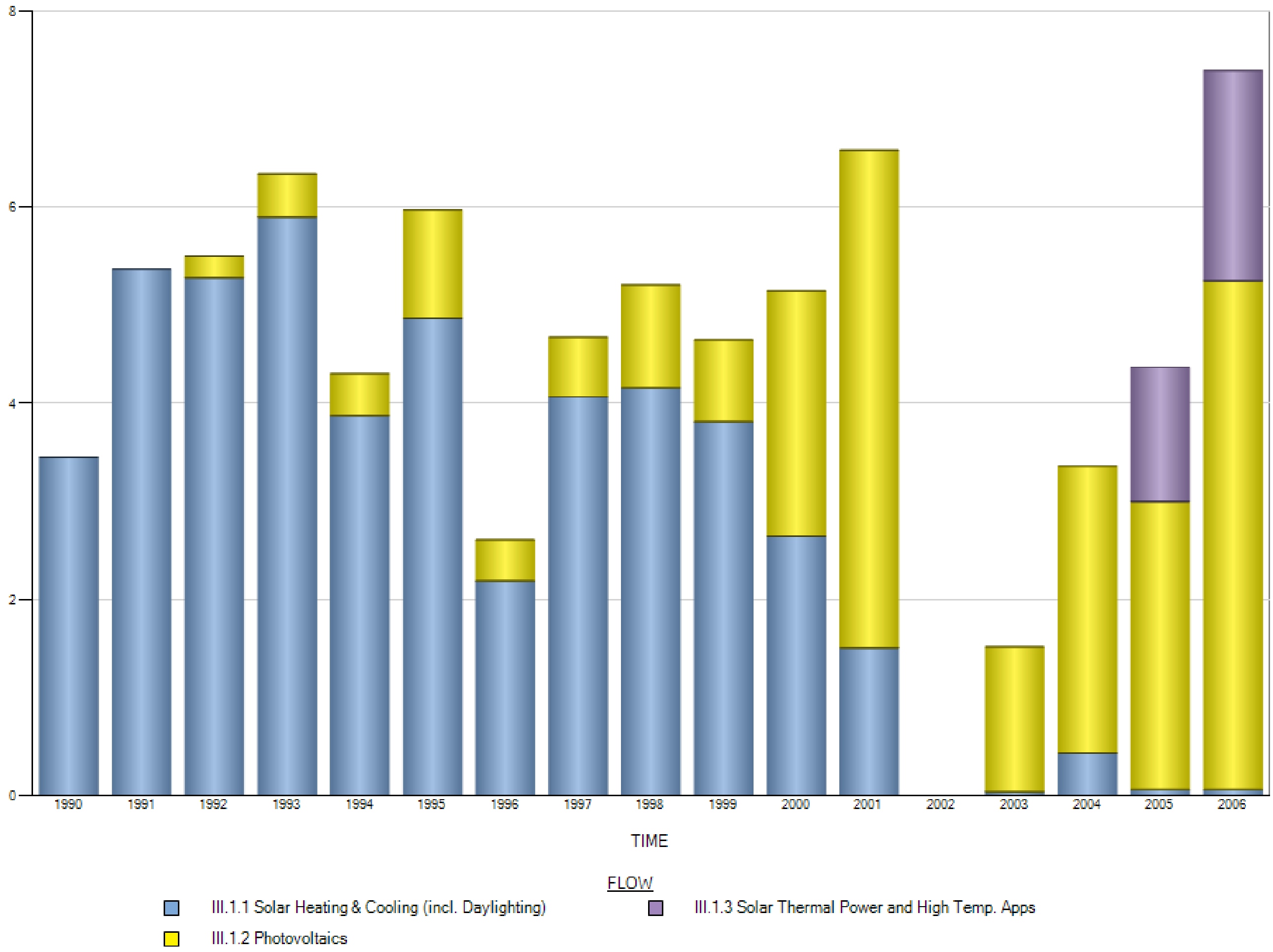


Source: IEA statistics

What is interesting in the above figure is to compare solar energy (the bottom blue column) with the other renewable energy sources. It is apparent that wind energy (yellow column) is the primary subject of RD&D funding focus, however followed closely by bio-energy (red column). It seems that solar energy comes in third place of focus. The government has explicitly stated that wind and bio-energy is official focus areas in the political energy agreement (*Aftale om den danske energipolitik i 2008-2011*); however this is not the case for solar energy.

The figure below displays the development in Danish public support for solar energy RD&D.

Figure 23: Public RD&D support for solar energy (Million USD (2006 prices)



Source: IEA statistics

The figure suggests what has been prioritised from the government. It shows how solar heating and cooling RD&D has been a focus area in the past and how it gradually has been lower prioritised and dramatically almost disappeared in the start of the new decade and millennium. Meanwhile, the area of PV came into the funding context in the beginning of the nineties and increased in public RD&D support until 2001, with major increases in 2000 and 2001. The missing column in 2002 is not due to missing data but should be seen in the political context in the end of 2001, where an election resulted in a change in government, and the consequent political ideology and strategy. In the following, the implications of the 2001 government change will be examined on the basis of the interviews, which to a high degree attribute today's climate around PV to this government change.

The liberal-conservative government took over in 2001, and there is a wide consensus that attention to RE was significantly scaled down almost overnight while a "most value (i.e. energy) for the money" agenda was initiated. In this respect, an atmosphere was created saying that renewable energies does not have a future, and it was clearly politically announced that RE would be de-emphasized. Instead, and according to the "most value for money" approach, the aim was to reduce the electricity price, and thereby RE was left out due to the fact that RE cannot decrease the electricity on the short term contrary to a more established and known technology such as coal. Some argue that it was a matter of "ideological crusade" against the former social democratic government, while others points out (highly related to this) the ideological regime shift as the main reason, that is, that the liberal way of thinking generally neglects government support, which entails that energy technologies should be based on market terms instead. Meanwhile, industry experts within the RE field as well as the chairman of Danish National Advanced Technology Foundation warned against this tendency (Dansk Fjernvarme, 2005). This would imply that the liberal conservative government introduced a laissez-faire version of innovation policy to this area.

Funding for RE was generally cut down, which also included the PV field. All 9 renewable energy committees (including that of PV) were thus removed. 100 people then made up the back bone of the PV innovation, but they moved into other branches together with their competences. This induced that all promising RE opportunities, which were the result of decades of previous research, disappeared. In January 2002, Danish Folkecenter for renewable energy received the message from a political spokesman of one of the government parties, that there were no longer funds available for development projects as the knowledge of RE apparently was sufficient, and that there was not need for further development within the area. Thus, the organization was obliged to dismiss five employees and live on its own means and finances for a period. This had serious implications for the knowledge diffusion and sharing in the context of smaller niche development projects within e.g. PV, which are the central points of the organization's unique strengths. Meanwhile, one of the most important knowledge institutes, Technological Institute, was forced to dismiss not less than 15 employees, which reduced its impact on Danish innovation within PV drastically.

However, RE has returned on the political agenda during the past 3-4 years mainly because of a growing public attention on CO2 emissions and probably also the acknowledgement of peak oil issues (Hirsch et al., 2005), not least in pressure from the political opposition. These factors more or less forced the government to reconsider its approach, and consequently it initiated a more RE focused policy which was further encouraged by the instalment of a new Minister for Energy in 2007. Today, public funding for PV technology development and promotion is comprised of various subsidy agreements, while several technical universities and research institutes carry out R&D of its own appropriation with an energy aim. There can through various schemes be funding granted to all links in the value chain from basic R&D to product maturing for commercial development and production. The present implementation of the policy through Danish Energy Agency is based on the idea that basic R&D is generally risky and the need for support is accordingly greatest in the initial stages of the development procedure (PA Energy, 2004).

In the report *Solar cells: Introduction to a national strategy for research, development and demonstration (Solceller: Oplæg til en national strategi for forskning, udvikling og demonstration)* (PA Energy, 2004) the Energy Agency presents a recommendation for a national PV strategy. Overall, the objective of the strategy is to support the Danish energy policy and to ensure and develop Danish competences that can arise in relation to other countries, especially within EU. The efforts in research, development and demonstration of PV seek to increase the efficiency and durability of PV facilities, and reduce cost of production of components and systems. This is in order to improve the PV facilities' competitiveness compared to other kinds of electricity generation aiming at making installation of PV systems economically and consumer attractive, both in Denmark and internationally: In order to promote the PV sector, the strategy recommends that the following areas should be in focus:[63]

- *Silicium "feedstock" (or raw materials)*
- *New advanced (novel) solar cell types such as PEC and polymer cells.*
- *Effect-converting – Alternating current converter technology.*
- *System technology, for example adaptation to the grid*
- *Building integrated solar cells (BIPV).*
- *Design & aesthetics, particularly relating to multifunctional building components.*
- *Demonstration activities.*
- *International cooperation.*

Thus, the strategy takes into consideration that Denmark has already lagged behind in 1st and 2nd generation solar cell technology, and therefore points out niche-areas as focus within conventional PV. Conversely, it emphasizes that there are Danish possible strengths within novel PV.

[63] EU is working on a so-called *"Road Map"* to which the Danish strategy is recommended to be adapted when it emerges.

The government (Transport- og Energiministeriet) focuses on a fully liberalized energy market, complemented by a framework that can ensure effective protection of consumers and the environment, energy savings, a limited increase in energy prices and not least ensuring the security of supply. According to the government, these energy terms are best handled through proper functioning markets and market-oriented instruments and through R&D in new efficient energy technologies. Furthermore, it is emphasized that the challenge is also to contribute to growth and business development through competitive energy prices and further development of Danish energy technology strengths (Ahm et al., 2005). It is worth noticing that PV technologies are not mentioned in this context. The actual agreement on energy policy (*Aftale om den danske energipolitik i 2008-2011*) was adopted in February 2008. Within RE, it stresses to a high degree wind mills and bio mass, whereas PV is categorized as a *"minor RE technology"* together with wave power. In this respect, 25 DKK is allocated yearly over four years. The agreement suggests explicitly that the means, which is PSO-financed (ForskVE), can be used for e.g. BIPV.

Besides the above-mentioned, there are other policy factors of importance - thus, recalling from the "driver" chapter, there are following drivers related to policy which contribute directly or indirectly to the innovative activities within PV:

- *The building regulation,*
- *The Net Metering Agreement "Nettomålingsordning",*
- *and funding availability, including:*
    - *The Energy Research Programme (ERP)* (Energiforskningsprogrammet, EFP)
    - The *PSO agreement for environmental friendly production of electricity (ForskEl)*
    - The *PSO agreement for effective use of electricity (ForskVE)*
    - *The Strategic Research Council* (Det Strategiske Forskningsråd)
    - *National Advanced Technology Foundation* (Højteknologifonden)

Turning to the theoretical section above concerning STI policies, a number of different and interesting issues can be identified. First of all, it seems interesting to examine to which extent that PV related policies can be related to the theories.

The issue from the theoretical part regarding science policy whether science should serve the state and capital on one hand, and whether it should be autonomous on the other hand, is very interesting. The reason is that one of the companies we have interviewed do not apply for funding anymore because is does not want to be politically controlled. Thus, the company has experienced that funding agreements are made by politicians and thus made up of too much objectives and declarations of intent. Therefore the statement is that it does not want to be subject to political decisions, as, the company argues, valuable freedom will be lost. Besides, there is apparently too much review and revision associated with funding agreements. Although the company in question is one of the largest and most significant within the Danish PV sector, and therefore the need for funding is not as substantial as in the case of smaller, infant firms, the issue is important. The reason is that if science is too much influenced and controlled by the state, (thus, not letting research move along its independent specific trajectories), there is a risk of obstructing possible serendipities[64], that is, unsuspected new avenues for applied research and technical solutions. On the other hand, if research is leaved completely autonomous in the arms of researchers, science may become too much based on coincidences and researchers' own interests in favour of the nation's interest as a whole. Furthermore, the government and its agencies are able to regard science in a much broader context to which research should be aimed in order to accommodate certain macro-level goals. Thus, often it is necessary to coordinate science within different technologies and sectors in order to comply with a goal on a much broader national level. Therefore, there is a very fine line between autonomous science on one hand and government-controlled science on the other, which public authorities have to recognize. In our view, this is also the case of Danish funding means, which outline the context in which research should be conducted – for example, the PSO agreements define the boundaries such as *"environmentally friendly electricity production"* and *"smaller RE technologies"* without a more specific aim, but enough in order to pursue a coherent overall national policy.

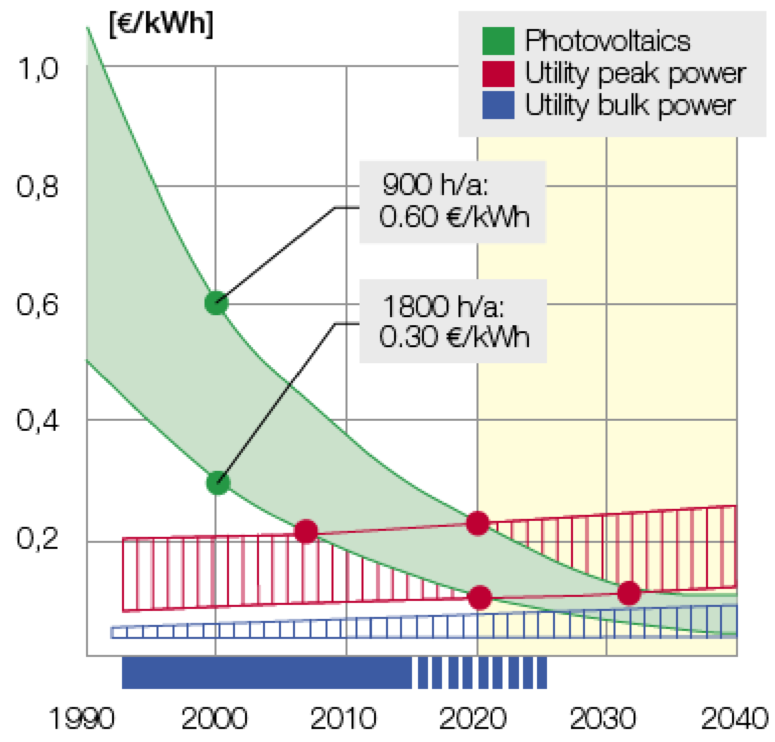
Another interesting point is the issue that politicians seek to avoid the "no value for money" syndrome, which somehow seems to be the case in the Danish context according to some of the interviewees. The argument takes its point of departure in the above-mentioned "most energy for the money" approach adopted by the government in 2001. That is, in order to show the public (and indeed voters), economic and social usability, the focus is aimed at solutions that display a rapid positive effect, rather than letting knowledge abilities develop within areas characterized by high uncertainty about effective exploitation, such as particular types of RE technologies such as PV. This tendency can also be recognized in the government's Energy agreement proposal from 2007 (Transport- og Energiministeriet), in which *"most energy for the money"* is a repeated concept of policy, which is also one of the reasons that well-developed RE technologies like wind mills and biomass are both stressed as important parts of the Energy Agreement. In this respect, there is no technology

[64] "Lucky coincidences"

policy explicitly aimed at the PV sector and/or technology, which, on the other hand, seems to be the case with biomass and wind energy.

Danish innovation policy has gradually moved in direction of the NIS characteristics in the recent years but the innovation policy does not yet take the form of the systemic approach. That is, Danish innovation policy does not fully recognise the importance of institutions and knowledge flows. The *"most energy for the money"* concept is not especially conducive for innovation of new kinds of RE energies, because types of RE that are cheap and well-established will always be preferred over new technologies. In this case, the interviewees call for more significant home market in order to develop and innovate in new technologies. On the basis of this it is not clear which innovation policy approach is used, though the evidence points to a moderate version, where other political and economic interests play a decisive role, meaning that optimum economic benefits of the PV innovation system cannot be reached currently.

Figure 24: Expectations to grid parity



Note: The blue band indicates that market support programmes will be necessary until about 2020 in some markets.

Source: EPIA & Greenpeace (2007)

The above graph suggests that support programmes will be necessary in some countries until around 2020. The green band between the bottom and top green line shows the scenario from southern

Europe to northern Germany and Denmark, which thus follows the top green line scenario for PV power generation prices. The red and blue line scenarios build on data from IEA statistics. The implications of the above displayed development graph is that southern Europe countries will have competitive PV power within the next few years and that PV power in Denmark and neighbouring countries will be fully commercially competitive with conventional fossil energy technologies from around 2018-2020.

6.6 Discussion of Policy Issues on the Basis of Interviews

The subject of policy is one that all the interviewees naturally have opinions about. Before we undertook the study we expected to find very similar opinions about policy, however this has not proven to be the case, rather it is the opposite way around. Interviewees have very different priorities and suggestions to how the policy framework should be composed. These views will be presented in the following.

In this section we will try to present the different opinions in a discussion about the policy framework so that one gets an impression of how the different priorities in the sector stand out. To start out the discussion a general impression one gets from the interviews can be said to be that the public sector, as a result of government policy, does not care particularly about developing new technologies that can utilise renewable sources of energy because the technologies in many cases not will provide cheap power within a short term time period. Cost effectiveness for the final energy price is crucial in this discussion for the ruling government. Some of the interviewees emphasise that this have the effect of *deselecting* the emerging energy technologies for further development. Some point out that if the supplies are to satisfy the future demand for energy then it does not make sense only to set off with one new technology that will prove to be insufficient, furthermore since there can be synergies between different technologies. To create optimised policy framework conditions most interviewees believe that one needs to think in long term scenarios rather than in what works best right now. The "stop-go" policy is rather inhibiting than promoting innovation, some of the interviewees argue. In this respect, it is also important not only to pay attention to the traditional Danish industries, which argue in favour for the ruling government's policy, if the purpose of policy also should be to attract and develop new high technology industries with high potentials.

Development commonly requires investment of some resources, and a focused effort in the energy innovation system is necessary, as a point of departure[65]. In this process it will be an advantage to

[65] Marion King Hubbert and Colin Campbell are known scientists that have demonstrated that the Earth's endowment of crude oil is finite, that the rate of oil production reaches a maximum (i.e., peaks) when approximately half of the original

build a system that can reproduce itself as opposed to the fossil energy system. The transition within energy technologies does not only have implications for the energy policy but also for employment and economic growth in a society. The RE expert Preben Maegaard from the Nordic Folkecenter for RE, whom we interviewed for this thesis, argues:

> "If we really want something serious with renewable energy, and for this there are a variety of good reasons, one needs to look at the area with industrial policy eyes, rather than energy policy. … Of crucial importance is the fact that it (feed in tariffs, *red.*) guarantees the price over 20 years, so investors are assured a return which is used for research and development, as the technological skills will be built up and follow-industries arise." (Preben Maegaard in Mandag Morgen, 2008)

It is a clear statement that PV as a renewable energy source should be given good framework conditions to develop – not only for the sake of CO2 reduction and to future-proof energy sources but just as well because of the arise of new industries and employment. Derived from this is the argument of support for development in energy technologies that seems as a small investment compared to the possibilities that arise for those countries who invest at the right time with the right form of policy design. When the competences are there it is important to "jump on the wagon" when the industrialisation starts rolling and it seems in some way that Denmark is left behind regarding conventional PV, one interviewee says. However it is emphasised that this only goes for the main links of the supply chain, i.e. standard modules and cell development. Other interviewees can however still see possibilities in those phases of the supply chain because of the rapid growth of the international sector. All agree that there are still good niche possibilities for Danish actors, which could be developed further. The PV solar cells can give added value if they are fitted to apply in new contexts or products, e.g. a refrigerator.

The mood seems more positive when talking about novel PV, where there are promising technological opportunities. There is a good deal of public R&D funding for novel PV technology however this fact alone does not lead to an expansive sector. It is emphasised that it is the diffusion of new energy technologies that is inhibited, and that this is an imperative process to bring down the prices for the technologies. According to an expert, one has to clarify where the specific technology is in the course of development, i.e. maturity, and assess if the technology has a future potential for the

resource remains, and after that goes into irreversible decline. Also they have tried to predict these peaks, while emphasising the important societal implications of the long irreversible decline, i.e. implications for energy and innovation policy.

energy supply. The role of the public sector is to take the primary risk before the private sector will dare to engage with investments. The R&D and demonstration support programmes seem to function well for novel PV, though the long term predictability of policy still lacks. One interviewee encourages to focus wider on more R&D projects with good concepts and engagement and also not to avoid overlapping of projects, which can create competition and positive synergy effects. A well functioning home market would be of great use for the innovators but it would have to be done in a sustainable way but also require willingness to invest a great sum of money.

In the discussion of central vs. decentralised energy facilities some argue that there are more advantages in decentralised production units because of the proximity to consumers and to take advantages of economies of scale. Oppositely others feel that centralised PV facilities are just as important to develop, which for example could be an integrated facility in noise shields along the highway nearby the biggest residential areas, e.g. from Roskilde to Copenhagen. Generally it is agreed that larger PV facilities (over 6 kW) should be promoted more than the case is now in Denmark to stimulate innovation for those facilities because they quite simply are a bad investment for now. One thinks that an elegant solution would be to make a standard subsidy scheme for larger or centralised PV power facilities.

Addressing the question of support it is important to have a versatile comprehension of the energy sector and other sectors. As one points out, a technology is not inferior because it needs public support to develop proper competitiveness with other mature technologies, which in time will become antiquated. To ask the question if new energy technologies should be given public support or not is in some way the same as asking if the public sector has a responsibility in providing energy security and energy affordability for future generations. As economical development depends on reliable sources of energy it becomes the main responsibility of the public sector to drive the development of energy technologies. Other sectors like the farming sector have also received financial support for years with very few seriously questioning the sustainability in that system. Some of the interviewees highlight the importance of better finance opportunities in the framework because of the sector's high capital intensity and suggest guaranteed loans from the state as a solution. It is argued that diffusion support would create a more substantial PV market in Denmark and that it would imply significant synergy effects for knowledge creation and learning possibilities for companies. Regarding diffusion of PV most interviewees refer to the German model as the benchmark model, which could be refined for Danish purposes – meaning that a kind of feed in tariffs scheme is what Denmark need to introduce to get the Danish sector going. Also one point out that starting a PV company in

Denmark is way too much up hill compared with other countries. One electricity company, EnergiMidt, actually has initiated their own diffusion scheme for PV targeted to their own costumers. It is accentuated that in order to drive a potential new major Danish company in energy technology forward it is essential to facilitate the creation of a market through some kind of a support scheme. Another aspect of policy could be in the area of public procurement, where one suggests rules that would impose PV or other building integrable RE technologies to the new buildings of the public sector.

The question of time is also of significant importance because efforts to support the rise of national industry should not be done prematurely or too late. In this respect, failed attempts can cause more damage than good; however the worst is not to invest in diffusion support in any form of new energy technology at all. Most of the interviewees actually feel that it is already too late to support diffusion in Denmark, even though the PV energy technology has a very great potential, because of the other emerging technologies, where Denmark has better opportunities of catching a strong industry foothold. However seen in the light of the peak oil issues, CO2 reduction and strong world PV expansion it is not to know whether or not Denmark has a choice of PV or no PV – the technology will surely develop to be competitive within 10-15 years if other economies like Germany, Japan, Spain, Portugal and USA carry on with their focused efforts. Some argue that Danish policy should join this effort to boost the Danish PV sector in those areas, where they have competences and companies within.

The question of why Denmark has no diffusion support for RE and PV power technologies could be the result of many complex matters. Some point out that the established energy sector has strong interest groups, i.e. advocacy coalitions, and very highly regarded leaders, for whom the political system has great respect for. Some of the interviewees feel that the high respect and acknowledgement from leading politicians to the established energy companies could yield unrealistic conceptions and expectations about their capabilities and engagement in the area of new energy technologies. One interviewee points out that Denmark and Japan seems to be the only markets left with no support for diffusion of PV and that when the competitiveness (i.e. grid parity) of PV closes in on the established power technologies there will be a catch-up effect and a big boost in the Danish PV market. Already now the leading companies are under pressure for supplying the increasing demand of PV. The Danish part of the supply chain is not yet mature or comprehensive enough to make habitual business procedures work – bigger firms are needed for this.

In the area of knowledge creation, education and public awareness some of the interviewees agree that it is an area, which should be developed further by PV imposing teaching methods in public schools, universities etc. Thus, this will increase public awareness and establish the basic demand and motivational measures for focused knowledge creation.

6.7 Facilitation of a Market

In this section we outline some suggestions for further development of policy processes to facilitate improved market diffusion, which would in the best of our abilities and intentions consist of sustainable innovation policy processes. In alignment with the IS approach we argue that a systemic approach to innovation policy should be used.

As we know from the IS analysis PV innovation does not flourish in Denmark because of the small and fragmented industrial sector. The actors are certainly differentiated and connected, which could enhance innovation; however the national market is too small to really set them off flying internationally. It was argued by Bergek & Jacobsson (2004) that a larger market demand is needed in order to facilitate the development of new energy technologies, who suggested a form of capital grant scheme for pioneering users. As we know, the interviewees all agree that Denmark certainly will develop a market for PV at some point in time but then it may be too late for any of the Danish firms to maintain a competitive innovation performance due to internationalised pressure.

According to Bergek & Jacobsson (2004) one addresses the matter of market formation correctly by developing technology specific pricing policy of PV that is predictable and persistent. The pricing policy should be powerful since the aim of this is to ensure rapid and sustained diffusion. This could be done in an assessment of how much the consumers are willing to pay, while at the same time considering the benefits and potential of the particular technology. Some interviewees expect a rapid diffusion when a pay back time beneath 10 years for PV is reached. In order to attract entrepreneurs and investors to drive the innovation the Danish PV sector need a home market – it is important to remember that RE markets are government induced and investors accordingly do not want to be trapped with investments in markets that could change with the political context (Stenzel & Frenzel, 2008). A weakness in general for the Danish sector is that advocacy coalitions and interest groups are very weak as opposed to Germany, for which it is by some argued compellingly that the advocacy coalitions had a very big influence in imposing the feed in tariffs (Bergek & Jacobsson, 2004; Jacobsson et al., 2004). Jacobsson et al. (2004) and also they argue that it could take up to 20 years for a considerable sector to build up from scratch, as the case was for Germany. The message here is that development and innovation takes time and the results do not kick in within short term periods.

The motivations and objectives for RE policy have been strikingly similar to that of Germany's, so there are good grounds for comparison. Actually Denmark has had feed in tariffs before, which got the Danish windmill sector going by the formation of a home market. The utility companies were obligated to purchase wind power at a rate of 85 % of the consumer price (Lipp, 2007)

RE technologies like PV face various barriers for their technological diffusion and widespread adoption of products. Aside from technical and cost issues, renewable technologies have to overcome the so-called *carbon lock-in* effects. This refers to the technological institutional complex associated with the fossil-fuel based centralized generation regime that presently dominates energy production and use (Shum & Watanabe, 2006). In order to make it to competitiveness in the fully commercialised stage, the PV sector and their technologies must overcome these barriers, which relates to the structurally disruptive nature of RE technologies (Foxon et al. 2005). Policy efforts thus should take consideration to this; Stenzel & Frenzel (2008) argue that with the right policy and strategy approach incumbent electric utility companies can drive transformations and develop to major players in RE e.g. PV.

PV is an important technology in microgeneration of power, i.e. the generation of electricity and/or heat within the home. Particularly research has suggested that these technologies encourage changes in household energy consumption, as well as providing renewable energy. Keirstead (2007) has suggested in the context of the UK energy system that the full benefits of microgeneration can only be realised if households are encompassed within the PV supportive schemes and government frameworks (Keirstead, 2007). In other words some kind of market support that embraces consumers is necessary if the purpose with the policy framework should be to enhance PV deployment in residential areas and improve chances of gaining competitiveness, which also could secure mitigation of both global warming effects and peak oil implications – it will ease the transition from incumbent energy technologies and maybe even in long term scenarios lead to better cost effective forms of energy. Here it seems that PV technology has a significant future potential.

Diffusion of PV could be approached in two basically different models of deployment according to Shum & Watanabe (2006) – those by respectively Japan and USA. The *first* deployment model (Japan) operates with solar PV as a manufactured technology with least customization and achievement of massive deployment. The *second* deployment model (USA) leverages upon PV to focus on user oriented customization to achieve deployment. The different models have different implications to the PV system engineering aspect. A *focus* upon the standard grid-connected distributed category in the residential setting avoids the heavy customized engineering associated with many off-grid and unique type projects (Shum & Watanabe, 2006). The implications of the study by Shum & Watanabe suggest that the most effective generic model for diffusion would be that, which has focus on decentralised grid connected facilities, which to some degree includes BIPV. The often referred to German model resembles the Japanese deployment model and was to some degree inspired from this, one interviewee informed us.

In this context it is specifically recommended by some that demand should be used as an innovation policy tool. The demand side of the market seems in some ways to have been neglected recently when it comes to Danish RE policy. Edler & Georghiou (2007) argue that demand side should be seen as one of the main policy areas which can facilitate and source innovation. Furthermore they emphasise the important role of public procurement as a demand oriented policy tool. Demand for a product can expand to incorporate demand for innovation in that particular product's technological domain. Public procurement can in this way target innovative products and services within the PV sector by sharing technological risk with the suppliers, which could push development forward towards the commercial phase and contribute to achieve the public mission of CO2 reduction and global warming mitigation through innovation (Edler & Georghiou, 2007).

The advantage with public procurement is that it is more controllable than other policy instruments like feed in tariffs. It is to some degree possible to control by whom the procurer buy from and could be better targeted towards certain focus areas such as different kinds of BIPV for example. Oppositely public procurement must be financed by the state, which is not required for feed in tariffs that is usually consumer financed through the electricity price.

Addressing the discussion of green certificate markets against feed in tariffs it has been argued that these approaches should be seen as complementary regulatory instruments to each other, which could target succeeding steps in the product cycle. Both instruments are necessary in the maturing and formation of RE markets (Midttun & Gautesen, 2007).

As a conclusion of our analysis on policy we have to acknowledge the crucial importance of diffusion inducing mechanisms such as feed in tariffs or other forms of supportive schemes for the PV sectoral innovation system, and that it seems to apply to other RE technologies as well. We will refrain ourselves from giving precise guidance as to how the policy framework should be designed, although call attention to the crucial importance of well developed policy design encompassing the technological development in the innovation system holistically if support measures should function as intended. In developing the policy design it is possible to take on an investor perspective to assess the potential for success and profitability of a supportive scheme, which could be recommended in the context of the late start of the Danish PV market compared to other nations (Dinica, 2006).

Investment in knowledge creation for novel PV will certainly not be in vain since conventional PV will clear the way for novel PV technologies. Still though, considering this it would be an advantage for the Danish PV innovators to have a driving market force within national borders.

7 Conclusion

Turning to the problem formulation, this thesis has investigated

> ***the Danish solar photovoltaic sector characteristics and dynamics seen in an innovation system perspective***

In this respect, the conclusion is divided in three parts, each providing the answers to the particular questions within the problem formulation. First, an initial overview of the sector's characteristics and dynamics will be presented.

On the basis of the initial characterisation of the sector we found two categories of technologies, *conventional* and *novel PV*, where conventional PV is the technologies presently dominating the market, namely crystalline silicon and thin film technologies. Most of the technologies within the subsector of novel PV are not present in the consumer market. The generic processes in production of PV equipment include the solar cell, lamination and framing, and installation. Regarding PV installations there was evidence indicating a stagnating growth in the Danish market, while oppositely the foreign markets within the European Union with emphasis on especially Germany and Spain seem to display very high growth rates. We identified prime movers and system builders of the conventional PV sector in Denmark as *Danfoss* (*Powerlynx)*, *Gaia Solar*, *RAcell Solar*, *Danish Solar Energy Ltd*, *EnergiMidt*, *Grundfos*, and recently *Sunsil* and *Photosolar*. The prime movers in relation to BIPV are *Gaia Solar*, *RAcell Solar*, *Danish Solar Energy*, *EnergiMidt* and *Photosolar*. In novel PV the prime movers and system builders seem to be *Mekoprint* and *SunFlake* supported by the strong knowledge base in the main knowledge institutes, i.e. Risø DTU, the Technological Institute and the nanotech-departments in the universities. The unified sector seems to be strengthened with the foundation of the new Danish Association for Solar Cells *(Dansk Solcelle Forening)*, which can function as a prime advocacy coalition and help enhance the development of the Danish PV sector.

The high technological opportunities and high appropriability conditions points to an industrial pattern of Schumpeter Mark II. The dominant technological path in conventional PV polycrystalline silicon however seems likely to be overtaken by better cost efficient monocrystalline or novel technologies in the near future. The small size of the sector both nationally and internationally still means that developments in other sectors can affect the PV sector to a large extent and risks for investors are accordingly still high but falling along with the sustained growth.

Turning to the first question within the problem formulation, thus:

> ***What synergies and dys-functionalities for innovation are present in the form of drivers, barriers and system failures?***

The main *driver* for innovation is the increasing international demand for grid connected PV facilities, which has emerged because of a focused effort for diffusion with incentive programmes in different countries, with Germany as the main initiator of this increasing demand. Furthermore there is an increasing focus on BIPV from both existing and rising markets. BIPV is a niche market, where Danish companies hold potential to contribute with significant innovations. Companies could emerge given the right framework conditions that would enhance innovation. The high future market expectations are also closely linked to this increasing demand for PV.

Building on this we found that the innovation system is very linked to developments in the international arena especially with regards to the increasingly rapid diffusion process led on by support schemes in many countries with Germany and Spain standing out as the main markets. Large international manufacturing firms dominate the supply chain in the levels of especially cell and panel production.

Another important driver in Denmark for BIPV, the most important Danish market segment, is the building regulation, which is fundamentally driven by environmental demands to better energy efficiency of buildings and energy awareness. In this context the building industry and the Danish Construction Association (Dansk Byggeri) play a key role in the coordination and facilitation of a market. Engagement from designers and architects is an imperative resource for innovation in BIPV and could in some instances be mediated to project developers for the enhancement of the innovation process. It may be necessary to enhance promotion of solar cells and PV to the designers and architects to form the basic interest. A project like *BOLIG+* seems to be a step in the right direction for this. The coming tightening of the regulations will enhance innovation.

Other important drivers are the electricity price and the grid control agreement "Nettomålingsordningen", which has removed some tax and regulatory barriers for PV. The growth in electricity price determines basically the benefits of investing in PV and thus will not be a driver before competitiveness is reached, i.e. grid parity. The expected time of the emerging grid parity is a subject to different opinions and depends to a large extent on developments in the electricity price but will probably emerge within the next 10-15 years. RD&D funding programmes drives the progressing processes of knowledge creation and diffusion, which again forms a basis for innovation. Knowledge diffusion is driven by collaborations in R&D projects.

Innovation activities in the conventional PV sector are focused on incremental improvements of standard modules and inverters, development of BIPV and attracting investments to purification of silicon. Knowledge creation and diffusion is mainly done through collaborations and projects concerning demonstration and diffusion of the technology. Also learning modes of doing, using and interacting (DUI) play a central role in knowledge creation, especially with relation to new markets. Innovation in the downstream supply chain is much user-driven and includes learning processes of user-producer interaction, which is the most important learning mode since knowledge networks have an essential part in all processes of knowledge creation and diffusion. Knowledge networks often go beyond national borders and could involve foreign universities because of the relatively few knowledge capacities in Denmark. Knowledge is in most parts of the supply chain very codified and tacitness seems to concern only some architectural or aesthetic matters, why architects are an important knowledge resource for BIPV. In BIPV it is essential to understand the building industry and their institutions, especially concerning public procurement. The policy strategies have not been focused on knowledge creation in conventional PV in a number of years, which has kept it from developing faster.

Collaborations between universities and firms are rarely seen because they suffer under an institutional barrier that implies larger industries to catch the interest of the universities. Thus the collaborative institutions imply path dependency for different technologies and conventional PV is not a path that is pursued. A very central role in knowledge diffusion is played by the Technological Institute, which function as a link between the different agents in the system. Entrepreneurs can have a hard time raising capital to the required processes of product development because of the inadequate sector specific knowledge at Danish private financial investors. The roadmaps from the European PV industry (EPIA) give the impression that many incremental improvements in PV technology continuously will be introduced in the coming years.

The “disruptive” subsector of *novel PV* is starting to emerge in the market with the first new big actors like Nanosolar with the largest plants for PV yet to be seen. And many more actors are likely to come forward in the following years on the international scene. The knowledge creation and diffusion in novel PV are mainly done by the relevant knowledge institutes, namely Risø DTU, Technological Institute, and the universities, which are essential sources of innovation. Focus of innovation in the novel technologies is pointed at the use of cheaper materials that fit to existing and more efficient production methods, enhancement of cell efficiencies and expanding application use. PEC and polymer technologies seem the first to be commercialised within the next couple of years, while other nanotech PV cells are also emerging fast. Given the right conditions and if no sudden barriers arise the potential for Danish companies in novel PV is considerable and should give some opportunities for the companies to mingle in the international arena.

The innovation system maps look very different for conventional and novel technologies. Where the conventional sector is a motley picture centred on the *project developers & installers* and *cell / module developers* the map is somewhat clearer in the case for novel PV that is in the early phase of demonstrations, where all activity is centred on knowledge transfers from knowledge institutes to emerging manufacturers and developers.

Interestingly we found out concerning partnerships that collaborations and projects within Danish borders are very politically influenced, i.e. who wants to work with whom. Also we learned that most collaboration is formally initiated with contracts.

There seems to be a system failure in moving along with the innovation chain when going from the stage of *pre-commercial* into the *supported commercial* stage. The conventional PV sector in Denmark has been stuck at the pre-commercial stage for 3-4 years but is beginning to see light at the end of the tunnel with the tightening of the building energy regulations. Most markets in this stage are created by policy mechanisms. The expectations and perseverance of the political environment and a sufficiently long time frame of stability in policy are important. This is however a learning opportunity for policy makers and advocacy coalitions and could entail the development of a shared vision between government, industry and research community, which is important for the sector as a whole. The importance of policy incentives to overcome barriers or create early niche markets is reinforced.

Turning to the second research question:

> ***What are the market potentials, possibilities and future perspectives for the photovoltaic sector in Denmark?***

We have found that the future of the Danish PV sector seems to lie mainly within Building Integrated PV and novel PV with high expectations about exports markets. The coming tightening of the building regulations is very likely to boost the demand for innovations in BIPV, which is also further increased significantly as the payback times get shorter. This naturally acts as a major demand pull driver for firms to innovate in improved methods of integrating the PV facility in buildings and improve the efficiency. Additionally, the "green branding" effect is likely to be one of the most important drivers of near-future demand and innovation due to the rapidly increasing attention to environmental issues like global warming. In this connection, the 2009 climate summit conference in Copenhagen could pose possibilities to reinforce the growing environmental attention substantially, which may prompt a value adding factor on (ordinary) Danish companies' marketing and supply opportunities, triggering an increasing demand for environmental products like BIPV.

Exports markets comprise an important driver as the home market is by comparison very small. The companies often only use the home market for testing and user-producer innovation in order to go into export markets later. Besides, solar cells seem to fit well into traditional Danish strength areas like industrial design and new combinations of existing technologies. Future market expectations, comprising the largest incentive to innovate or entering into collaborations, is more important to novel PV than to conventional PV because the novel PV companies in some cases will have to create the market themselves.

And what policy implications can be stated following the analysis?

The main message from the analysis of the IS was that the government should issue a seal of approval to all forms of RE in general and keep a *stabile* and *predictable* policy that should intend to remove barriers for innovation in PV. Linked with this is the theoretical reasoning from ICEPT & E4tech (2003) about maturity stages of energy technologies that imply the technologies need for diffusion support as the conventional PV sector is in the *supported commercial* stage without any significant Danish support whereas novel PV is in the *demonstration* stage, where there are support programmes for RD&D.

The policy implications concerning the Danish PV field and what supportive mechanisms that ought to be used are central matters of discussion. Several interviewees call for more supportive mechanisms as they argue that the PV technology is not ready yet to be based on fully commercial market terms. Contrarily, some state that it is too late for more supportive mechanisms and that the electricity prices seem to increase systematically and in a near future reach the point of grid parity and thus in itself develop competitiveness. Another central issue is also whether Denmark should focus intensively on specific RE technologies to which all funding and policy designs should be directed, or whether funding and support should be given to a broader variety of different technologies, which lets the technologies compete on equivalent terms to enhance the possibilities for the best technologies. The PV technology is still facing a major obstacle in connection with the reigning policy approach i.e. here-and-now most energy and CO2 reductions for the money, which points attention away from emerging technologies and to the established sources of energy that by definition always will be able to provide the best short-term cost efficiency.

Danish policy makers should by now have learnt from the past successful experiences with innovation and diffusion of windmills and realised that it does pay off to address a focused policy mix for innovation to new emerging energy technologies. Oppositely the policy mix has in the case of PV not been focused in any particular way in taking account for the development after 2001 with political insecurity. The novel PV subsector still though has significant commercial potentials and if a focused innovation policy mix is explicitly developed and maintained persistently in a long term period then the sector would seem to possess what it takes to grow to fully commercialised maturity. Furthermore, market formation should be promoted by developing technology specific pricing policy of PV that is predictable and persistent.

What policy makers should be aware of in the process of developing a focused policy mix is that an overall policy approach could benefit from taking account for other emerging energy technologies as well. The potentials and position in maturity phases are different for each technological domain and it is therefore an essential subject of judgement to predict which one of these that demonstrates the best possibilities, which is why policy designs should follow traditional risk management and bet on several “horses” rather than one.

7.1 Reflections on the Study

Reflecting on possible further work in the wake of this master thesis study, it would be very interesting to work more in depth with the different market developing mechanisms, and in particular how to improve the transitions between the different technological development phases by means of a phase differentiated holistic policy design. Thus it would have been interesting to investigate the possibilities for different policy approaches for innovation and compose recommendations for a policy framework in which initiatives could be examined and supplemented with a discussion of how they should be implemented. This does not necessarily have to include directly supportive policy instruments only but also a broad variety of other means of influence on the PV sector, such as electricity price characteristics, building regulations and public procurement.

The results seem to implicate that in order to overcome the challenges of for example global warming and peak oil another policy approach to innovation and energy than the current is needed. The approach should lay emphasis on more than market dominance and competition by embracing the importance of certain sectors, knowledge flows and institutions to economic development. This would be a holistic approach to innovation policy of energy technology.

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Abbreviations & Acronyms

In favour of clarity, there are certain words and technical explanations that are abbreviated in the thesis, which include:

AC: Alternating Current

BOS: Balance of System

DC: Direct Current

DK: Denmark

DUI: Learning by Doing, Using & Interacting

EC: European Commission

EU: European Union

EU-15: Denmark, France, Belgium, Netherlands, Luxembourg, Germany, UK, Ireland, Sweden, Greece, Italy, Austria, Spain, Portugal, Malta.

IEA: The International Energy Agency

IEA-PVPS: The Photovoltaic Power Systems Programme by IEA

OECD: Organisation for Economic Cooperation and Development

OPEC: Organisation of Petroleum Exporting Countries

PV: Photovoltaics

RE: Renewable Energy

R&D: Research and Development

RD&D: Research, Development and Demonstration

SE: Solar Energy

Si: Silicon

UCTE: Union for the Co-ordination of Transmission of Electricity

W: Watt (Joule/second)

Wp: Watt peak (the peak effect of a PV system)

List of Figures

List of Tables

Appendix 1 – Interview Guide:

(in Danish)
Spørgeramme: (Solstrøm)

1. **Om arbejdet**
   - Kort om historien, udviklingen
   - Hvem er de primære samarbejdspartnere
   - Et typisk innovationsprojekt (idé, proces, formidling)

2. **Aktører på sol**
   - Primære aktører, drivende aktørkoalitioner
   - Andre aktører
   - Forskellige aktørtyper og deres roller ifbm. teknologiområdet

3. **Læringssamspil – integration imellem behov og muligheder**

3A Eksperimentering og entreprenante udviklingsaktiviteter

- Hovedelementer i udviklingsaktiviteterne på området – kort om de væsentligste
  – anvendelsesorienterede; forøget anvendelse, udvidelse i anvendelsesmåde, nye produkter og processer, løsninger på problemer
  – demonstration
  – forskning og undersøgelse af principielle muligheder
  – bagvedliggende og supplerende vidensopbygning
  - udviklingsprogrammer (F&U programmer, indsats ca. 2000-2007)

3B Markedsdannelser

- markedsanvendelser og markedsområder
  - nicher såvel som evt. rolle på bredere energimarkeder
- markedsformning, markedsbaserede policyindsatser
- standardisering, certificeringsordninger
- relaterede netværksudviklinger og aspekter af integration
  - i energiforbrugs- og energiproduktionssystemerne (energianvendelse, energiproduktion, energinet/infrastruktur; den løbende, alm. energiplanlægning)
  - i industrielle områder og vidensområder

3C Guidning – visioner, strategier

- visioner og forventninger blandt de drivende aktører
- behov og problemer udtrykt af forskellige aktørgrupper
- policies og nationale strategier samt evt. internationale policies og strategier

- Diskussions fora, debatter og netværk for den visions diskussion og strategiudvikling
- Legitimering, bredt set og blandt mere specifikke aktørgrupper

3D Vidensproduktion, uddannelse og oplysning

- Formel vidensproduktion på universiteter, forskningsinstitutioner mv.
  - Centrale vidensområder og væsentlige nye områder
  - Supplerende vidensområder, støttende såvel som perspektiverende/kritiske
- Uddannelser og efteruddannelser
- Oplysningsaktiviteter

3E Positiv ekstern økonomi – dannelse af nye aktivitets- og forretningsområder

- netværksudviklinger og aspekter af integration
  - i industrielle områder og vidensområder
  - i energiforbrugs- og energiproduktionssystemerne (energianvendelse, energiproduktion, energinet/infrastruktur; den løbende, alm. energiplanlægning)

3F National og international samspil

- Sammenholdning af interne danske og internationale samspil, vigtigste samarbejdspartnere
  - Anvendelses-/markedsmæssige, Industrielle netværk
  - Vidennetværk
  - Behovs og visionsnetværk

4. **Synergi i det systemiske læringssamspil – diskussion**

- Styrker, barrierer/mangler i det systemiske samspil
- Integration og sammenhænge med eksisterende aktivitets- og vidensområder
  - Graden af integration i energianvendelsen, energiproduktionen og energinet/infrastruktur, energiplanlægningen
  - Modenheden/helstøbtheden i industrielle netværk (cluster tendenser)
- Samspil ml. behovsformulerende aktører og udviklere af teknologiske muligheder og løsninger
- Samspil ml. markedsmæssige og ikke-markedsmæssige dynamikker?
- Overlap og afvigelser fra det bredere innovationssystem - i energisektoren, og generelt nationalt IS

5. Ideelle rammebetingelser for styrkelse af sol

- Finansiering (herunder offentlige tilskud)
- Forskning
- Uddannelse

- Demonstrationsprojekter