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Photovoltaic Power Systems in Denmark

Drivers, barriers and policies for diffusion

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Batch 13! So happy I've come to know you and I really hope we'll keep in touch. Who would have thought you could be so abroad just an hour from home…

Abstract

The objective of this thesis is to analyze the development and diffusion of Photovoltaic Power Systems (PVPS') in Denmark, identify drivers and barriers for further dissemination, and explore how the policy framework supports the diffusion of PVPS" and thus contribute to learning within this field. The focus is on grid-connected PVPS', which are either used as an "add-on" device or integrated into the buildings.

The high cost of the PVPS', and consequently the high cost of the generated electricity together with a complex innovation system with many different actors, were identified to be the major barriers to a wider diffusion of the technology. Policy support is therefore needed to support involvement and commitment of many actors and support learning that can lead to a reduction in cost.

This thesis applies a system approach to investigate the characteristics of the Danish PV system. The actors active today are identified and their involvement investigated. Moreover, the study approaches the potential for further cost reductions. To do so the distribution of cost is analyzed. It is assumed that the cost attributed to the PV module could be reduced due to learning and experience in producing PVs worldwide. It is also assumed that cost attributed to the implementation of PVPS' will, to a larger extent, rely on experience in the implementation of PVPS' in Denmark.

The findings of this thesis show that the involvement of actors has developed over time in Denmark, however, further dissemination requires further development of knowledge. The analysis also shows large variations in cost distribution of costs related to the module and the implementation of the module. The cost related to implementation varies between app. 15 - 50%; the higher figures relating to the building of integrated PVPS'. The results indicate that a relatively large part of future cost reductions will rely on learning related to implementation and learning processes within Denmark. This then indicates a need of national policy support.

The findings further show that the current policy framework does support diffusion of PV, but also that none of the policy instruments are targeting building integrated PVPS' specifically. This may cause potential barriers for dissemination of PVs in the future as integrated PVs may be a very important driver for PVs in the future to reach high acceptability. Moreover, PVs do not need to be more expensive than other types of innovative materials for facades. The research highlights the need for policy intervention related to the implementation of PVs, in order to support further cost reductions. Further research is needed to both to investigate this issue fully, and to define how different policy instruments can be applied to support the learning needed.

Executive Summary

Photovoltaic solar cells (PVs) are an emerging technology that can contribute to a more sustainable future energy system. The technology is growing in installed capacity and is showing considerable cost reduction potentials. However, due to the high investment cost, e.g. the cost of generated electricity, it is still not competitive with other energy sources. In addition to cost identified as a major barrier for further disseminations, is the complex innovation system and the need of many different actors to be involved in the development and diffusion of PVs. To bridge this gap policy intervention is needed. A general assumption of this thesis is that policies can't be made in a vacuum. The aim of this research is therefore, to investigate some of the prerequisites for policy making, with Denmark as the scope of analysis. The research is guided by the following research questions:

1. What are the characteristics of the Danish innovation system for grid-connected Photovoltaic Power Systems (PVPS')?
2. a) How are the estimated costs distributed along the value chain of a PV's system?
   b) Where are the sources of cost and the Danish cost reduction potentials?
3. How do the different current policy instruments support the diffusion of PV in DK?

The analytical approach of the thesis is inspired by theoretical work within innovation systems analysis, with focus on the actors and end-users involved in the context of the energy sector and governmental institutions, as well as the networks where the mentioned groups interact. Another part of the analytical structure is inspired by the theoretical understanding surrounding the "need of learning", where learning from practical experience with a technology will further improve production and use of a technology and also drive down the cost. In this thesis it is suggested that the learning connected to production of the PV technology, e.g. the PV modules, is taking place in an international arena, whereas the learning connected to implementation is to a larger extent, if not totally, governed by national conditions such as regulatory and economical frameworks, a qualified workforce, building culture.

This research identifies a complex net of actors, end-users and networks that has emerged as the DK PV innovation system. In the PV business (i.e., actors commercially involved in PVPS') the agents work primarily within implementation, but a few have also specialized themselves in customized module production and power electronics. It is a characteristic for the engaged actors that none of them make their business from Danish PV projects solely due to the limited national market. These actors either have projects abroad or they have PV projects as a part of a broader business portfolio. An interesting finding from this work is also a change in attitude among the actors in the projecting link, that is, engineers and architects who previously has showed a rather negative attitude towards PVPS'. A large driver for this change is identified as the increased attention on energy and climate issues from the public, which have created a market for "climate projects". There are, however, indications of a lack of knowledge and experience on PVPS from these new entrants in the innovation system, which can become of importance to the cost.

The increased attention towards climate and energy also appears to drive new segments of end-users in the innovation system. The traditional end-users have been private households, but now also businesses and the public sector are identified to be emerging end-users. For all end-users the high investment costs are perceived to be the primary barrier to implementation, even though the magnitude of this barrier varies. The energy sector is somewhat divided in

their attitude towards PVPS. From a pure production perspective the cost of PV power is too high to be of interest. The companies with utility services see the potential of PVPS' in terms of improved customer relations and special PV power products. The energy sector has been part of former research on PV implementation, and the engagement of actors within this sector must be perceived to be a strength in the Danish PV innovation system.

The PV businesses have so far been characterized by a somewhat contradicting situation. Agents have interacted in various development and demonstration projects, but their branch on the other hand didn't have any official organization for media contact or political influence. This situation is however expected to change with the newly initiated business focused trade organization: the Danish Photovoltaic association. There are several other NGO's of importance to the cooperation and diffusion of PVPS', where especially Solar City Copenhagen seems to be a current forum. Organizations with a broader energy and sustainability focus are also present in the innovation system.

As a base for discussions on policy intervention this research is based on an assessment of data on various cost distributions of PVPS, concluding that there is a large degree of variation in the share of the cost of the different elements in the value chain. Another important conclusion is that even though the PV modules contribute to a large share of total cost, a considerable share of the costs can still be found within the implementation of the PVPS, and thus where a cost reduction requires learning in the national setting.

The type of PVPS (standard add-on versus building integrated) and the implementation process (retro fit on existing building versus new build or comprehensive renovation) are general factors influencing the system cost and the distribution of costs. This research suggests that the cost related to building integrated PVPS' should be perceived more broadly than for add-on systems. The broader perception of cost is relevant because the integrated systems can substitute traditional building solutions, thereby acting as an alternative roof or façade building material, but also because of the opportunity of double functions such as sunscreens, noise control etc. The integrated systems also offers communicational properties in relation to architecture and image branding, which seems to have increased in value with the growing climate concern in society.

The Danish reduction possibilities should be found in the implementation of PVPS'. In this regard, the primary sources of cost is a lack of experience among the actors, especially the new entrants, due to the small volume of projects, the lengthy building chain and the complicated communication and coordination process of the involved actors. Suggestions for national industrial development perspectives based on design, standardization and integration with building materials are presented in a short discussion at the end of this thesis.

The last section of the research addresses the Danish policies, which influences the diffusion of PVPS'. The net-meter scheme is perceived to be of great importance to private households and public institutions, but it is not enough to contribute to a payback time acceptable for most households. The building codes are currently the biggest drivers for implementation, especially for the commercial sector, who are not entitled to the net-meter scheme and have advantageous low electricity retail prices. Another interesting issue related to the building codes, is how the municipalities have started to use them in a rather pro-active way in the context of spatial planning and internal guidelines. This thesis also draws attention to the fact that none of the current policy instruments are targeting building integrated systems directly, even though these systems are perceived to have the largest cost reduction potential when it comes to national learning, due to the relatively higher implementation costs. Moreover, building integrated PVPS' may be a very important driver for PVs in the future to reach high acceptability. Aesthetics and design issues may be a critical aspect for dissemination in the future. Aesthetic PV systems may not be so easy to develop applying an add-on concept. In addition, PVPS' do not need be more expensive than other types of innovative materials for facades.

A brief analysis of the research policy shows that the focus of the governmental funding is spread to both the PV technology itself and the implementation of it. The new governmental program ForskVE, which is targeting diffusion of small scale renewable energy technologies including PV's, must be assumed to support cooperation among the actors and the learning related to implementation, and might also create some push for integrated PVPS'. Assessments of the currently granted R&D projects shows that much research is carried out by actors in the PV business, which indicates a rather market oriented focus of research. Only few of the granted research projects involve both traditional research institutions and the PV businesses, which is a low percentage compared to projects on other developing technologies such as wind and bio energy. This indicates a cooperation gap, which probably exists because most of the research carried out in the traditional research institutions is related to development of new generations of PV technology, which are not ready for commercial applications for the time being.

The results of the thesis show that there is a need for continuous support for the implementation of PVs in Denmark. This is to support further development of the innovation system, the involvement and commitment of actors, further knowledge development and learning that can support further cost reductions related to implementation.

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1 Energy for sustainable development

The world of today faces severe challenges related to energy and climate change. Reports from IPCC (see for example (Metz, Davidson, Bosch, Dave, & Meyer, 2007) and IEA (see for example (IEA, 2007) present numerous examples while mass media is showing images such as people suffering under extraordinary weather conditions and Greenland's melting glaciers. There is a widespread scientific agreement that such changes have a strong correlation with the human release of greenhouse gases, such as CO_2 emissions from combustion of fossil fuels. Another important aspect is the use of depletable fossil fuels and the rapid increase in worldwide energy consumption. To ensure energy security both end-use efficiency and a diversification of energy sources is required (UNDP, UNDESA, & WEC, 2000, p. 27).

For a more sustainable energy future a range of technologies are needed, many of which are already available today or close to commercialization. The analysis of the Energy Technology Perspectives from the International Energy Agency stresses that for these technologies to reach market adoption, a substantial effort from both public and private sector is needed, both in terms of R&D, demonstration and deployment, but also with clear and continuous incentives for diverse energy sources and low carbon options (OECD/IEA, 2006). According to The European Renewable Energy Council and Greenpeace, 35% of the worlds total energy use could be covered with renewable sources in 2030, if sufficient political will and energy efficiency measures were present. They estimate the share of total energy demand covered by renewable sources today to be 13% (Teske, Zervos, & Schäfer, 2007, 5ff).

An increase in political attention and will towards renewable energy sources is for example reflected in the new proposal for a EU directive on promotion of the use of energy from renewable sources released in the beginning of 2008 (Commission Proposal {COM(2008) 30 final}, 2008). Here specific targets for the relative share of renewable energy are presented for each member state. A range of eligible technologies are available to fulfill these targets of 20% renewable energy by 2020, all with different strengths and weaknesses at different stages of development. Some of the large scale and mature technologies, such as the large hydro and biomass fired CHP plants, are already competitive in the energy market, alongside newer technologies within special settings (e.g. optimal location or remote areas without grid connection). There is however still a large share of renewable energy technologies with a slower deployment, which need political support in order to develop and overcome marked based and social barriers (Sims et al., 2007, p. 272).

Photovoltaic power systems (PVPS'), or solar cell systems as they are popularly called, are one available technology for the production of renewable electricity, already cost competitive in remote areas without grid connection. When it comes to the grid connected PVPS', the technology is less mature and cost competitive. The expectations to the potential of PVPS is however large, as is the yearly growth in installed capacity.

The growth has already contributed to significant cost reductions as a result of increased experience. This is illustrated in the figure 1-2 which shows how the accumulated installed capacity has contributed to considerable cost reduction of the technologies.

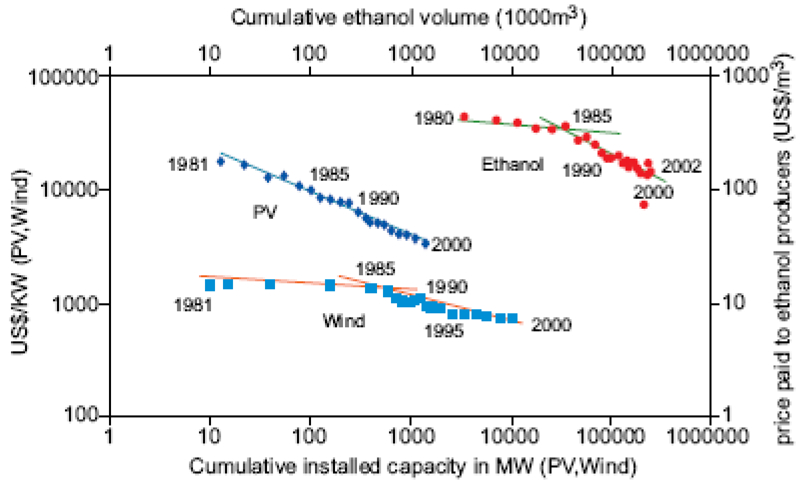

Figure 1-2 Price development of PVs, wind turbines and bio ethanol in relation to installed capacity
Source: From (Sims et al., 2007, p. 272)

In spite of the promising development the cost of PV Power systems (PVPS') is still high and if the technology is to contribute to the development of a more sustainable energy system in the future, possibilities for utilizing and integrating PVPS' as part of the existing energy system should be explored. Practical experience with the technology is needed and while the technology is developing it will take some policy support to bridge the gap to the market. This means that even though PVPS' are not competitive now or in the short run, policy makers will be influential in maturing the technology to enable it to become a competitive renewable energy source. Long term strategies and policy support for innovation should be considered now.

1.1 Objective of the research

The overall objective of this thesis to is gain insights on how to design policy instruments to support the diffusion of PV Power Systems in Denmark. Two major barriers to the diffusion were identified in the literature: the high investment cost and the complex innovation systems around the technology. Policy instruments are needed to overcome these barriers, and this thesis aims at providing a basis for the discussion of such policy making.

This objective is broken down into three **research questions**:

1. What are the characteristics of the Danish innovation system for grid-connected Photovoltaic Power Systems (PVPS')?
2. a) How are the estimated costs distributed along the value chain of a PV's system?
   b) Where are the sources of cost and the Danish cost reduction potentials?
3. How do the different current policy instruments support the diffusion of PV in DK?

The first research question is related to the innovation system of PVs and the identification of important actors, institutions, polices and networks of importance to the development and application of PVPS'. In order to develop relevant policy instruments, It is important to identify which actors and institutions need to be included in a process of change and which actors and institutions actually are active and committed.

The second research question relates to the high cost and the need of further cost reductions through learning and experience. The aim is to analyze the cost distribution in the value chain of grid connected systems and the Danish possibilities for cost reduction within different parts of the value chain. The hypothesis is that learning and cost reductions are related to both the technology in itself and its implementation. Considerable research has been carried out on development, learning potential and cost reductions related to the technology itself (e.g., the PV modules). This thesis will primarily focus on the implementation of the modules.

The third and last research question relates to the policy instruments which are used to support the diffusion of PV in DK, and this research question also will build upon the findings from the two former research questions (i.e., the characteristics of the technology specific innovation system and the identified possibilities for cost reduction). In this thesis, experience in DK will be highlighted and suggestions on targets areas for future policy developments put forward.

1.2 Scope and boundaries

As stated in the objective the scope of this thesis is the *current Danish PV innovation system* limited to the part related to *grid-connected systems*. This limit the focus of this thesis to Danish actors, networks, NGO's, public institutions and policies active in the current innovation system. Due to time constraint it was decided to leave the dynamics and impact of the financial sector outside the scope.

When it comes to the cost distribution and reduction potentials, price development of the PV cell itself and standard PV modules are issues, which are often analyzed when it comes to a discussion of the potential of PVPS' in the energy system and the probable cost reductions. This is however, outside the scope of this thesis and the same is the case for the discussion on the potentials and expected breakthrough of new generations of PV technology. In the same way the scope of the research is limited to the development, generation and utilization of PVPS, which means that issues related to the eventual dismantle and end-of life treatment is outside the scope.

The primary scope of the research question 3 is also limited to the Danish policies, even though the development in PV policy internationally must be considered to be of influence on the Danish PV innovation system, due to a large international market. Within the Danish polices it's prioritized to address the policies affecting directly and indirectly in the way they either push or constrain the implementation of PVPS' in Denmark. Outside this scope are policies of influence for other renewable energy technologies and conventional electricity production, which could affect the relative competitiveness of PVPS as an energy technology.

1.3 Methodology

In this section the methodological framework of the thesis is presented.

1.3.1 Research structure

The timeframe for the research has been rather short. In the preparation phase, it was realized that not much literature was available on the specific topic, and that the research therefore, would be dependent on getting suitable interviews from actors engaged in the PV innovation system. Consequently, the interview phase was started early in the research period to ensure adequate data before the potential interviewees left for summer holiday. Therefore, the interview phase and the assessment of background information and literature were carried out in parallel. This gave opportunity to ask the interviewees about credible sources for detailed information and written sources elaborating on the issues discussed. The disadvantage of that approach was naturally that some interview time was used on rather basic issues, which could most possibly have been minimized in the case that a more extensive literature review was conducted before the interviews were initiated. In the last phase of the research the data from interviews and literature were categorized and analyzed within the chosen themes relating to the research questions.

1.3.2 Data collection

The origin of the data used varies in the different sections. The type of data varies within the different sections of the research based on suitability and availability of primary data. Chapter 2, assessing the role and potential of PVPS' in the current and future energy system, as well as the identified drivers and barriers, is mainly based on literature review, and so is the theoretical framework in chapter 3. Chapter 4 on the Danish PV innovation system is primarily based on the first hand data from qualitative interviews. The data for chapter 5 on cost distribution and reduction potential are also based on primary data from the interviews, complemented with findings from previous studies on the topic. The final chapter 6 on the Danish policies is primarily based on second hand sources, but also includes inputs from the interviews.

1.3.2.1 Primary data

The primary data in the thesis are based on 19 interviews, which were conducted with actors from the Danish PV innovation system, as well as on information from an interview made in connection with recent research on the innovation system for renewable energy in Denmark carried out by the author of this thesis.

It has been the intention to cover a wide range of the stakeholders in the innovation system, thus including actors from industry (suppliers of raw materials, sub components and PV modules and their network), a number of actors within the projecting link, as well from NGOs connected to the end users. Interviews were also conducted with actors from the two major energy companies and from the Danish Energy Agency. The selection of interviewees has partly been based on research of actors active within the field and partly on the "snowball method", where the interviewees recommend other potential actors for interviews. All interviews were semi-structured and open-ended in their phrasing, and the interviews were to a large degree, structured after the themes of the research questions. The interviews were recorded and categorized afterwards. A list of the basic questions guiding the interview and discussions is presented in appendix 1. The interviews were all carried out in Danish, which means language barriers were avoided.

1.3.2.2 Secondary data

The secondary data used in this thesis is from reports, presentations and evaluations conducted and/or provided by the interviewees, institutions and secretariats working with renewable energy in general and PVs specifically such as the Danish Energy Agency, The Photovoltaic Power System Group under the International Energy Agency (IEA PVPS) and the EU PV Policy Group.

Scientific publications from research institutions and cooperatives such as RISØ, The Swedish Elforsk program and research projects supported by the European Union was also used, as well as articles from peer reviewed scientific journals.

1.4 Outline of the thesis

The chapters of the thesis are structured in the following way:

Chapter 2 provides the reader with a background on PVPS and the major drivers and barriers for the technology identified in the literature.

Chapter 3 outlines the analytical and theoretical framework and defines the two central concepts; The Danish PV innovation system and systems of learning.

In **chapter 4** the innovation system for PVs in DK is identified, including the various sorts of implicated actors, for example businesses directly involved in the production and implementation of PVPS' in Denmark, NGOs, the end-users and the energy companies. The networks of importance that exist between actors and the groups of actors will also be assessed.

Chapter 5 deals with the cost distribution of PV systems in DK as well as some general determinants of cost and identifies where the Danish sources of cost is found. An important part of this chapter is the difference between standard add-on PVPS' and Building integrated PVPS' (BIPVPS') with regard to cost and cost perception.

The scope of **chapter 6** is the policy framework of the innovation system and the political attitude towards PVPS' in Denmark. The chapter begins with a short description of the policy program history in the field of PVPS´ followed by an assessment of the current policies targeting PVs including both direct and indirect policies, which are of importance to the implementation of PVPS'. Afterwards a minor section will present the public research priorities in the area and the coordination of actors in the research projects.

Chapter 7 presents the conclusions on the thesis based on the findings and concluding remarks of chapter 4, 5 and 6. In addition, some cross cutting discussions in relation to the findings, such as DK potentials for cost reduction and industrial development, are presented in this chapter.

In **chapter 8** the main message from the thesis is summed up and a short section with recommendations for further research is presented.

2 Photovoltaic power systems (PVPS')

Photovoltaic Power Systems (PVPS')' is not a new technology. The basic principles of the technology was discovered in the 19th century. However, it was not until the 1950- 1960 that the technology was used for electricity generation (EU PV Technology Platform, 2007, p. 7), where at the outset, it was mostly applied in the space industry. This section will provide a quick general overview of PV power systems in terms of the state of implementation, the technical and environmental characteristics as well as an introduction to the industry. Finally, the chapter will provide a presentation of the primary barriers and drivers to the further diffusion of PVPS'.

2.1 State of diffusion

The market for PVPS is the fastest growing for renewable energy technologies, as well as one of the fastest growing industries worldwide in general (EU PV Policy Group, 2007, p. 3), due to an average growth of 25% over the last two decades and with as much as almost a 50% rate in the last 5 years (EU PV Technology Platform, 2007, p. 9) The total accumulated installed capacity still however, is way below for example wind power, which by the end of 2006 reached above 74 GW capacity (GWEC, 2007). By the end of 2006 accumulated installed capacity within the IEA countries was 5.7 GWp[1] and about 1.5 GWp of these were installed during 2006, where 82% of this new capacity was in Germany and Japan (PVPS (IEA), 2007). The figures below show the global trends in cumulative capacity and annual installation.

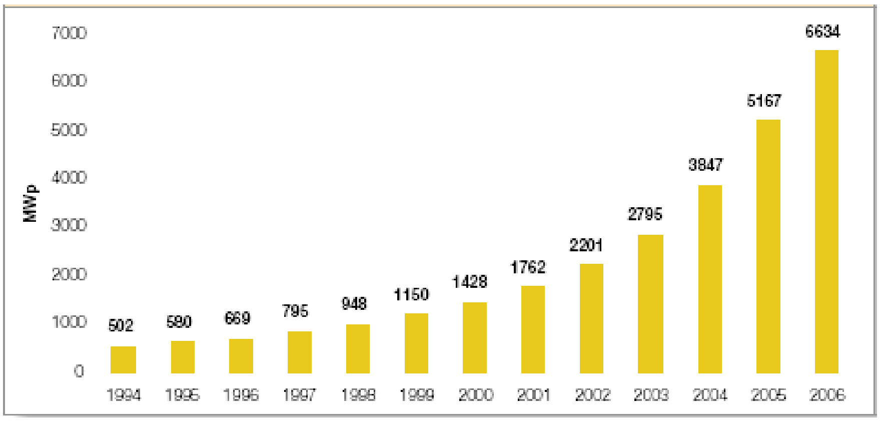

Figure 2-1 Global cumulative installed PVPS capacity
Source: From (EPIA & Greenpeace, 2007, p. 24)

[1] Installed capacity of PVPS' is measured in Wp (Watt peak) or peak power. This is the power delivered from a PVPS under standard test conditions (STC), which is a temperature of 25 degrees Celsius and a solar irradiance of 1000W/m2 (IEA PVPS, 2002).

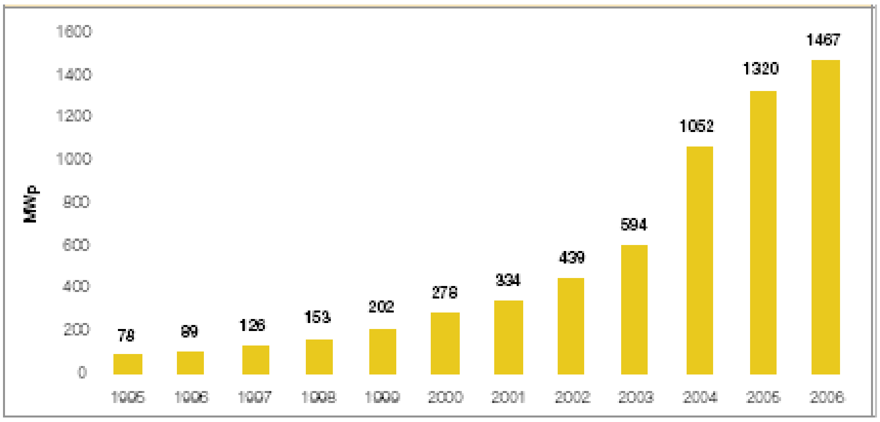

Figure 2-2 Global annual PVPS installation
Source: From (EPIA & Greenpeace, 2007, p. 25)

Taking a European perspective, the installed capacity accounted for 2.9 GWp, also with the main part distributed over relatively few countries. Again Germany was the main actor, with 85% of European capacity in 2005 followed by only eight countries, with more than 10 MWp installed capacity each (EU PV Policy Group, 2007, p. 3). The EU commission's goal, set in 1997, was 3GWp installed capacity by 2010. However, according to the European Photovoltaic Industry Association (EPIA) 2.9GWp was installed already by 2006, and by 2010 about 5 GWp is expected (EU PV Technology Platform, 2007, p. 12).

The rapid growth in the sector has created substantial economic value. Europe was estimated to account for approximately 40,000 jobs related to the PV industry in 2006. The majority is located in Germany, who experienced an increase from 1,500 to 30.000 employees within the last 8 years, and Spain, where around 6,300 jobs were created by the end of 2005 (EU PV Technology Platform, 2007, p. 9). IEA PVPS reports a total value of 10 billion USD within their member countries[2] in 2006 and a total direct employment of 70,000 persons distributed within research, development, manufacturing and installation (PVPS (IEA), 2007, p. 27).

2.2 Technical characteristics

The PV cells can be divided into 3 generations; 1st generation PVs are the crystalline silicium cells, which currently dominate the market with a share of approximately 90%. The 2nd generation cells are made with thin-film technology and are increasing their share of the market, whereas the 3rd generation includes organics and semiconductors for dye-sensitized solar cells (also known ad PECs) and polymer solar cells(Larsen & Pedersen, 2007, p. 44ff).

With regard to applications, there are three major groups of PV power systems; *Grid-connected distributed PV systems*, which provides electricity to a grid-connected customer or directly to the grid as a small distributed source. These systems are typically installed on the roofs or surfaces of buildings. When discussing the grid-connected distributed systems another differentiation is important: 1) the building mounted systems and 2) the buildings integrated systems. The first type is also referred to as standard add-on-systems and are systems applied on top of the roof or outside the surface with mounting structure and bands. The Building Integrated PV (BIPV) systems are installed as an integrated part of the house, thus substituting for a given surface material. As defined in the previous chapter it is this type of PVPS' that will be the focus of this thesis. Then there is the *Grid-connected centralized PV systems,* which performs in the same way as any other centralized energy production system e.g. not connected to any specific consumer. These are typical power parks or free field systems mounted directly on the ground. The last category is the *Off-grid Domestic and Off-grid non-domestic PV systems***,** where the first typically are installed to supply electricity to houses that are not connected to the electricity grid and the last is utilized to power applications located at isolated settings for example telecommunication and water pumping. The IEA Photovoltaic Power Systems Program reports that 4% of the 63MW capacity installed during 2006 in the reporting countries was off-grid applications (PVPS (IEA), 2007, p. 6)

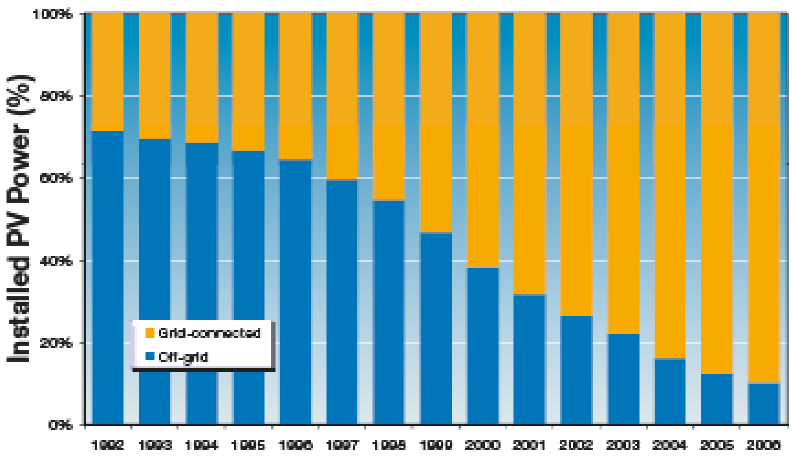

Figure 2-3 Development in distribution of PV power system types in IEA PVPS countries[3]
Source: From (PVPS (IEA), 2007, p. 6)

As can be seen in the figure 2-3 there is a trend in system type towards a rapid increasing share of grid-connected system.

2.3 Environmental characteristics

As addressed in section 1.1 one of the main arguments for renewable energy sources for power production in general, is the increasing environmental problems related to CO_2 emissions from fossil fuels. In the discussions on the potentials of PV Power systems, the energy payback time (EPBT) of the system has been argued to be considerably high compared to other RES-E technologies. Larsen & Pedersen (2007) report that Europe (without specification) will take between two and five years (depending on location) for a PV installation to produce the amount of energy it consumes during its production. The European PV trade association EPIA and Greenpeace suggest a similar timeframe, between one and 3½ years for EPBT, with the lowest example being thin-film systems in southern Europe and the highest being mono-crystalline applications in northern Europe (EPIA & Greenpeace, 2007, p. 51).

[3] Reporting member countries of the IEA PVPS group are: Austria, Australia, Canada, Czech Republic, Denmark, Germany, Spain, Finland, France, Great Brittan, Israel, Italy, Japan, Korea, Mexico, The Netherlands, Norway, Portugal, Sweden and the US. Hence should it be noticed that upcoming nations such as China is not represented in these numbers.

The CO_2 savings associated with applications of the PV systems are dependent on which source of energy it is substituting. EPIA has in cooperation with Greenpeace made estimations which suggest that the deployed amount of PV's in 2020 will create a CO_2 reduction equivalent to the amount emitted by 75 average-sized coal fired power plants or 45 million cars (EU PV Technology Platform, 2007, p. 9). The CO_2 emissions associated with the PVPS' as such, the great majority from the production of the technology, are estimated to account for approximately 21-65 grams/kWh depending on the technology, lifetime and location of the specific PVPS' (EPIA & Greenpeace, 2007, p. 52).

An interesting aspect associated with the implementation of PVPS' is the indirect behavioral effect that the domestic applications have on the consumers. An evaluation of the participants in the Danish PV demonstration project SOL 1000 showed that the general awareness of energy consumption increased among half of the participants. Results from this project showed that 25% directly changed behavior and electrical appliances, all of which resulted in a reduction in the total electricity consumption among two thirds of the participants. According to the project evaluation the reason for these still relatively moderate numbers is that the participants already had an extraordinary focus on these issues, which was what motivated them to participate in the project in the first place (EnergiMidt A/S, p. 29). Also the previous SOL 300 project showed an average reduction in total electricity consumption of 11-12 % per household and similar figures have been found in studies in Germany, Switzerland and the Netherlands (Ahm, 2008). Thus it seems that the PVPS' represent an added environmental value besides substituting electricity produced from fossil fuels. By increasing the cautiousness of personal energy use, the PVPS can then lead to a direct decrease in total electricity consumption.

2.4 The Photovoltaic Power System

A grid connected PVPS will in this thesis be defined as consisting of; **1)** the *PV module*, which converts the solar radiation to direct current (DC), **2)** the *inverter*, which converts direct current to alternating current (AC) to feed into the grid and **3)** the *Balance of System (BOS),* which then includes the associated cables, mounting structure, components for monitoring/metering and grid connection. This differentiation is important for the understanding of the cost distribution of the final PVPS. In analysis of the PVPS' it is widely used to break down the system in such sub systems. Some focus only on the potentials of the PV modules and others include the PV modules and BOS as two separate systems of analysis. Still within this subsystem a variety of definitions are present. Some define BOS as all the components besides the module (se for example (Frankl, Menichetti, & Raugei, 2006, p. 3) and (Shum & Watanabe, 2008)) thus limiting the BOS to the additional physical artifacts. Others use a broader definition of BOS, where also the site preparation, projecting and practical installation ect is included (see (Neij, 2008) and (Schaeffer et al., 2004). The PVPS is broken down in even more detailed sub systems in this thesis, as is showed in figure 2-4 below. This is done in order to increase the understanding of the value chain, but also to be able to do a more detailed discussion on how the learning related to production and the learning related to implementation (see chapter 3) affects the Danish possibilities for cost reduction (see chapter 5).

2.5 The value chain –Production and installation of PVPS'

As for any other technology, the industry around PVPS' has its specific value chain and the different links with their characteristics. The figure below shows the value chain of a PVPS[4].

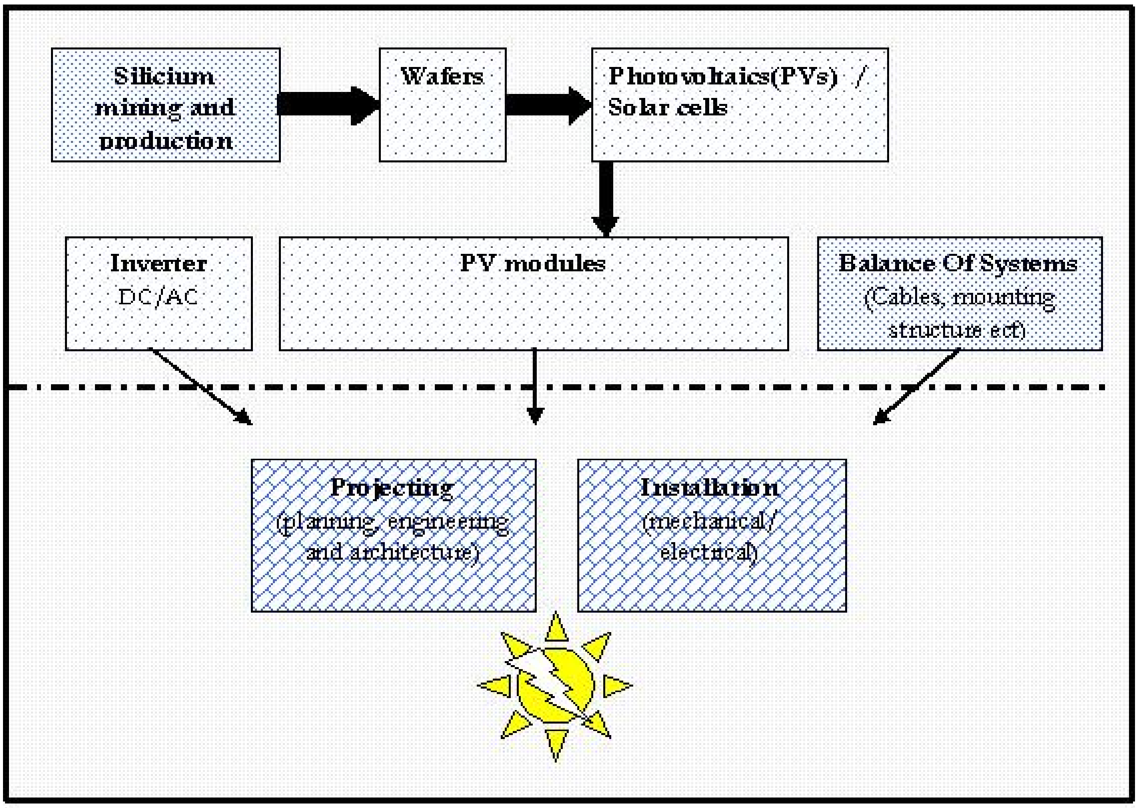

Figure 2-4 The value chain of a PV power system.
Source: Authors design

Figure 2-4 shows the technical elements in the value chain of a PVPS in the upper part of the box ; the elements with little dot density are those, which are specific to the PV industry and the densely dotted the technical elements of which only some of the element is specifically targeting the PV industry. The boxes patterned with squares in the lower part of the figure are the elements in the value chain where the added value consists of man power.

The first two links of the value chain, the **silicon and wafer production**, are very cost intensive both in terms of energy use and when it comes to capital investments, which are in the range of 2-3 billion DKK when starting up a production (Aarø, 2008a). Major producers of Solar photovoltaic grade silicon for crystalline based PVs are the Japanese Tokuyama, the German company Wacker, Hemlock Semiconductor Cooperation from the US and REC Solar Grade silicon from Norway, which together had 60% of the feedstock used in the industry in 2006 (PVPS (IEA), 2007, p. 21).

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[4] Naturally this model could easily be expanded to include a number of additional sub suppliers, especially when it comes to the part of the model representing the technical artefacts, which all have a chain of sub suppliers connected. It is, however, outside the scope of this thesis to go into these next tiers of the PVPS business.

Production of the PV cells themselves is not as capital intensive as the raw material production, but still requires considerable capital investments in the range of 500 million DKK (≈66 million €[5]) to start up a business (Aarø, 2008a).

The fabrication of the **modules** is considerably less technologically and capital intensive than the upstream links, and thus makes small scale production possible. There is, however a strongly consolidated industry present with mass production standard modules, where a few major companies dominate the world market (Bødker, 2008). Japan was the most dominant producer country on the market in 2006 with a share respectively of 48% of the PV cells and 39% of the modules followed by Germany and the USA. But also countries in East Asia, with China as the main driver, are rapidly increasing their industry (PVPS (IEA), 2007, p. 21).

Also around the **inverters** a large manufacturing industry has emerged in connection to the growth in the market for grid connected systems. The more established producing countries in Europe are Austria, Germany, Denmark, the Netherlands and Switzerland and outside Europe: Japan, USA and Canada host the leading actors (PVPS (IEA), 2007, p. 24).

The projecting and installation in the value chain are foremost related to the specific national setting depending on where the PVPS is implemented. The characteristics of Denmark in that respect are presented in chapter 4.

2.6 Drivers and barriers for PVPS' as a RES-E technology

As briefly mentioned in section 1.1 a range of various drivers are present for the implementation of renewable energy in general for example the climate change issues, security of supply and the increasing oil prices. PV power systems show indications of being a viable solution to these energy dilemmas, with the back up of a rather consolidated and growing industry. The accumulated installed capacity is however lagging behind compared to the magnitude of alternative RES-E technologies. This section will address some of the major barriers to an increased diffusion of PV power systems, as well as elaborate on the drivers for this RES-E technology.

The main barrier to the diffusion of PVPS' is the *high investment cost* (Frankl et al., 2006, p. 9). The primary function of a PVPS is to produce electricity, foremost to the end-user and secondary to feed into the grid. Hence the system output competes with the electricity provided by the grid, where around 70% of the Danish production comes from fossil fuels (EC D.G. Energy and Transport, 2008)[6]. The high costs of the PVPS', thus makes the price of the generated electricity less competitive compared to other RES-E technologies. The issue of cost reduction and distribution will be addressed in chapter 5.

Another barrier to the diffusion of PVPS is the *complexity of the innovation system* that, (as will be assessed for the DK case in chapter 4), includes a great variety of involved actors, networks, research areas and cross cutting policy frameworks. A related aspect is the *complex pattern of interactions* between different agents, which can hinder the implementation in similar ways, as what has been seen for energy efficient buildings in the construction sector. These complexities originate from the large degree of fragmentation within the different steps of the

[5] Exchange rate used: 1€ = 7.6 DKK

[6] The wholesale in Denmark is however part of the Nordic power market, which means that this mix changes slightly depending on the prices in Norway, Sweden and Finland.

building chain and the very little integration between the actors, as well as the management discontinuities throughout the process, characteristic for the commercial building market. The developers of new building projects and the capital providers of the project, such as investors, are usually only interested in the short term value of the building, which will get them their money back. This means that energy saving efforts in the building process only will be prioritized, if the effort is expected to be of importance in the sale of the building (WBCSD, 2007, p. 14).

A picture of the complex patterns of interactions in a PVPS project is illustrated below. The amount of actors and the degree of necessary coordination and interaction is, however, larger in case of new buildings with PVPS' than with retro-fit systems, where the amount of participating actors is less.

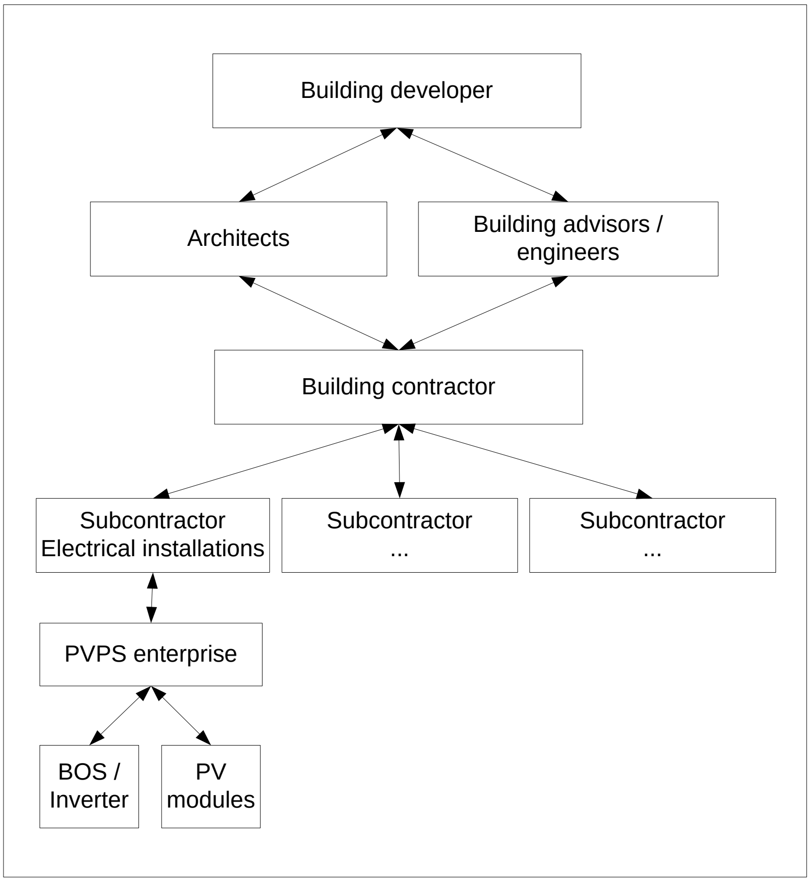

Figure 2-5 The actors engaged in a PVPS building chain (new build)
Source: Based on (Aarø, 2008a)

Figure 2-5 shows the complex process of a PVPS installation project. Outside this figure are other actors such as future building owners and users (in case these are not the same). When these are not directly included in the picture, it is because these actors usually have limited influence on the decisions in the building process in case of new build, unless the project already has an owner in the construction phase, or that the demands of the future customers are so well articulated in the market that the building developer finds the inclusion of a PVPS necessary to sell the building. As will be addressed in chapter 4, this is not the case at the moment. Building authorities are naturally also a part of the various interactions in the process. Their role is discussed in the section on cost reduction and policies. The complexity of the innovation system can also be of influence to the primary barrier; where the traditional building enterprise structure can be of influence to the cost of the PVPS.

Another identified barrier is the *low energy density of the technology*, due to the relatively low efficiency of modules and the consequently large demand for space (Frankl et al., 2006, p. 9). This issue should however, not be considered as a primary barrier, when taking into concern the expectations on technological development and the potential area for building applications, as assessed below. Still it's important to keep in mind, the high price of the electricity not only relates to the high cost of the PVPS, but also to the low efficiency of the system in general and over its life time.

An ambivalent characteristic of PV's is the variations in the electricity production. In the NEEDS project this is considered a drawback of the technology, as the production naturally depends on sunlight and that backup capacity thus is necessary when the production goes down at night time or on cloudy days. They also stress the potential problem of intermittent sources in the electricity grid. Still this not expected to be problematic before PV electricity constitutes 15-20% of the total amount in the electricity grid (Frankl et al., 2006, p. 9). A more positive interpretation of the production profile of PVPS is that it can be considered advantageous when it comes to day rhythm, because the primary production takes place during the day, where the overall electricity consumption and thus the spot price of electricity usually peaks. Also it is rather easy to forecast and thus manage compared to a RES-E source such as wind power (Nielsen, 2008). A small amount of PV power in the electricity mix is actually experienced to have a positive effect on the grid (Ahm, Frederiksen, Morthorst, & Holst-Nielsen, 2006, p. 21).

In contrast to the barriers above, the PVPS' have some basic characteristics that are fortunate for integration in the energy system as it is today, as well as in the future. In the NEEDS project several drivers for PVPS' were identified. Foremost the technology shows a *considerable cost reduction potential* of 20% each time the production of the technology doubles (Neij, Borup, Blesl, & Mayer-Spohn, 2006, p. 50) and also the *potential technological improvements* with regard to increased efficiency is assumed to be significant. The technology has no moving parts, which minimizes the need for maintenance and at the same time the sun is the *most abundant primary energy* source (Frankl et al., 2006, p. 12).

When it comes to the spatial planning PVPS' differentiate from other RES-E technologies in the way it easily can be *integrated in or mounted on buildings* in a rather discrete way. This makes it very *suitable for production in cities*, where the electricity consumption is most intense. In Denmark alone the potential space for PVPS is suggested to be of 87.98 Km^2 on roofs and 32.99Km^2 on facades, with the main part on residential buildings (Eiffert, 2003, p. 16) This characteristic should be seen in contrast to windmills, where proactive RES-E nations, such as Denmark and The United Kingdom, to an increasing degree are facing public resistance to new windmill projects on shore with complaints about noise and visual pollution (Buch, 2008a).

Figure 2-6 Examples of Danish PV Power systems
Source: (Berg et al., 2005)(Gaia Solar A/S, 2008a)(Gaia Solar A/S, 2008b)

The discreteness of PV power systems also originate from their multi function abilities, where the technology can substitute conventional building elements in facades, and climate shades. This at the same time brings in a substitution effect that can influence the cost of the system positively, as will be addressed more in detail later.

Another advantage by using a distributed energy source such as PVPS' is that *losses are avoided* in the transformation, transmission and distribution, which usually takes place in the transport of centralized production. In 2005 the transmission losses in the western part of Denmark of 2.3% and the distribution losses of approximately 5 % (Ahm et al., 2006, p. 22).

3 Theoretical framework – describing PVPS' in terms of innovation and learning

The purpose of this chapter is to introduce the reader some of the theoretical groundwork behind the analytical approach of this thesis. The work in this thesis is inspired by theoretical work related to innovation and learning. The first research question focuses upon *identification of the influential actors, networks and policies,* where the inspiration can be found within the branch of work on (technological) innovation systems. The second research question relates to the potentials to *cost distribution and cost reductions* and the theoretical inspiration of this part is dealing with technological learning systems.

3.1 Innovation systems

In order to understand how policies can be developed to support the diffusion of PV power systems in Denmark, it's important to broaden the perspective from the technology itself to the whole system in which it's developed, applied and utilized. The diffusion of PVPS' will require development, not only for the technology, but for the whole system around it. To support this development it's important to collect knowledge of this surrounding system. The idea of viewing technological development and diffusion in systems is far from new and draws on an extensive theoretical work, some of which briefly mentioned below.

This thesis draws on the general assumption that innovation and learning is taking place in systems (Smit , Junginger, & Smits, 2007, p. 6432) Innovation systems in general are made up from components, relationships and attributes in what system engineers define as a number of interrelated components working towards a common goal (Carlsson, Jacobsson , Holmen , & Rickne, 2002, p. 234). Within the area of innovation theory several authors have systems as the scope of their work, all with different angles and foci.

The idea of incorporating the social dimension of a technology and thinking of technological development processes as large and *complex socio-technical systems* was conceptualized in Bijker, Huges, & Pinch (1987) where also the interdependency of the components in the system and the interaction with, and adaptation to, the surrounding environment was addressed (Huges, 1987, p. 51).

A geographical approach to the innovation systems is found in Lundvall (1992), who emphasizes the importance of *National Systems of Innovation*, which are systems of innovation located or rooted within a given national state, and where the primary factors of investigation are the macro structures such as the institutional structure, the industrial characteristics and the regulation. Another focus of innovation theory is on specific technologies. The *Technological Innovation System*, is by Carlsson & Steinkiewicz (1991) understood as a network of actors within a specific of technological area, who operates under a specific institutional infrastructure and are involved in the generation, diffusion and utilization of the technology (Carlsson & Stankiewicz, 1991, p. 111). This approach to systems is also called a *Technology Specific Innovation System (TSIS)* (Smit et al., 2007, p. 6432). Characteristic for this approach is consequently, that the connection to the technology defines the boundaries of the system.

The analytical approach of the present research was thus inspired by elements from both of these theoretical traditions. The scope is specifically on grid connected PV power systems and the networks of actors engaged in this generation, diffusion and utilization of this technology.

At the same time the analytical framework is limited to the PVPS innovation system of a specific nationality. Elements of a broader national innovation system approach are included in order to understand the institutional setup both in form of governmental institutions and policies of importance, as well as the attitude of the energy industry, which forms the sector (or context) for PVPS.

3.2 Systems of learning

The major current barrier to diffusion of PVPS is that the costs of the PVPS and thus the cost of the produced electricity is too high, not only compared to conventionally produced electricity from fossil fuels, but also in comparison with other RES-E technologies. Consequently, a cost reduction on the final PVPS' is crucial to diffusion and of utmost importance from a policy perspective. In order to obtain the desired cost reduction on a still not widely applied technology, learning is a central issue. Aside from cost reduction, learning can lead to improved technology, higher production output and increased size and character of markets (Langniss & Neij, 2004, p. 176) all of which improve the conditions for diffusion.

As for the innovation systems, learning in relation to cost reduction of technologies has been approached in various ways in the literature. One type of learning called *Learning by Searching* is the typical R&D approach which for example takes place in universities or in development projects in the private businesses. This, to some degree, contrasts with *Learning by Doing* as described in Arrow (1962) which assessed the learning gained in the actual production of the technology (e.g. the industrial production processes) (Smit et al., 2007, p. 6432). This, in the context of this thesis, is the first link in the value chain described in section 1.2.2. The learning in the next links is conceptualized by Rosenberg (1982) and is called *Learning by using* (Langniss & Neij, 2004, p. 176) or *Learning by utilization* (Smit et al., 2007, p. 6432) both of which refers to the improvements and cost reduction obtained when the technology is implemented in a real world setting. A forth kind of learning is described as *Learning by interacting* by Lundvall (1992). This is not directly linked to the value chain of the technology, but does instead take place between the different parties who are somehow involved in the goods and services connected to the technology (Lundvall, 1988, p. 362), for example the actors in the technological innovation system.

In connection to the value chain of a PV power system, the learning by doing takes place from the module production and upstream along the chain, as well as for the inverter and the BOS as defined in 2.4, whereas the projecting and installation are the major contributors of the learning by using for PVPS'. The learning-by- interacting on the other hand can be present among all actors along the value chain, but where special emphasis can be put on the user-producer interaction and hence the end-user link of the value chain. Consequently it's important to emphasize that when it comes to learning and an associated reduction in costs, the scope of learning is not limited to the technology itself, but should include the learning connected to the planning and practical implementation of the systems, as well as the feedback from the end-users. In that way, the learning process could be divided into *learning connected to production of the technology* and *learning connected to implementation of the technology*. Going back to the value chain of a PV Power system, several subsystems are present, all of which have learning processes and thus reduction potentials. The learning connected to implementation is then linked to projecting and installation, whereas the learning connected to production takes place in the links of raw materials, PV's and modules, as well as the inverter.

It's important to recognize the difference in the spatial focus of these two types of learning. This is in order to understand which part of the PVPS' the learning, and thus cost reduction, primarily is determined by national factors and development, and where the processes of international knowledge spillover is governing the cost reduction. As described in section 2.5, the production of PV modules, as well as the links up stream in the value chain (and thus the part characterized by learning connected to production), constitutes a highly internationalized market with a few giant companies producing and supplying to the world markets. The result of this is then a fairly equal price on the world market, which is outside the control of a national policy program (Shum & Watanabe, 2008, p. 510). The same is true for the inverters and the other generic technical artifacts such as cables, which are produced to fit generic standards on the international market. This means that the learning and thus the potential cost reduction is developed in an international context, but also that national policy efforts related to learning related to the modules might contribute to a reduction of the cost but not in the price, as this is determined on the international market (this issue is also touched upon in chapter 7). In the downstream parts of the value chain (e.g., the links governed by learning connected to implementation), the context of the development is suggested to have a more national character as it to a large degree is determined by national factors. For wind power, such conditions are mentioned to be specific geographical characteristics, legal and economical frameworks (Langniss & Neij, 2004, p. 177). These nationally determined circumstances require the learning processes to take place within the national innovation system, and this author suggests the same to be the case for PV power systems. This is supported by Shum & Watanabe (2008), although they only differentiate between two subsystems: the PV modules and the BOS, who in their definition includes all the rest of the costs of a final system.

It should, however, be noted that there could be some parts of the learning connected to implementation that could benefit from international knowledge spillover, for example, when it comes to countries with similar building traditions and weather conditions. In this manner, portions of international experience could be used in the national implementation of the technology for example by the Danish actors operating abroad. In the same way there is a share of national characteristics involved in the modules, for the part that is related to the specially customized ones, which are produced to fit specific demands for size and visual appearance. A visual display of this understanding PVPS' is presented in figure 3-1.

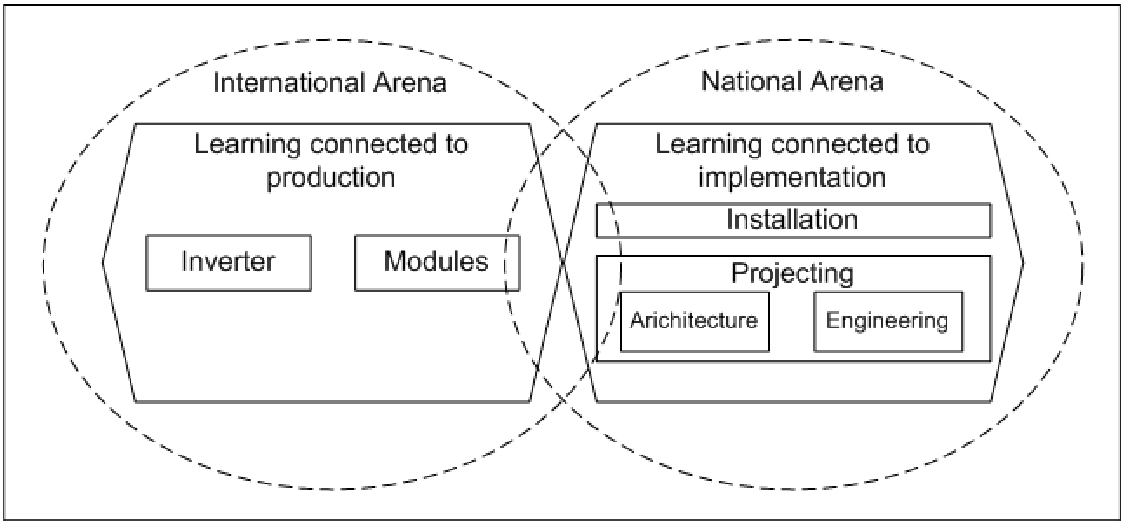

Figure 3-1 The scope of learning for a PV Power System
Source: Authors design

In this thesis both learning connected to the production and the implementation will be considered to be of importance in order to manage the important challenge of achieving cost reductions of PVPS. Due to scope on the Danish PV innovation system and the characteristics of this, most emphasis will be put on the learning connected to implementation.

Another widely used way of describing cost reduction and learning, when it comes to new technologies is via construction of *experience curves,* which assess the relationship between the accumulated capacity of a technology and the cost reduction, as for example done in (Neij, Andersen, Durstewitz, Hoppe-Klipper, & Morthorst, 2003) where windmills were used as case. For PV's specifically, experience curves were developed in the Photex project (Schaeffer et al., 2004). Also in the NEEDS project (Neij et al., 2006) the cost development of PV's have been assessed with experience curves, however in combination with a complementary bottom up analysis of the cost reduction potentials and development potentials. This thesis will not go more into the potentials, complications and findings related to this method.

4 The Danish PV innovation system

The latest publicly available data on installed Danish capacity[7] is from the end of 2006 and shows about 2.9 MWp, equivalent to 0.5 Wp per inhabitant. From this number 90% is made up from grid connected distributed systems and the rest is represented by low power niche systems such as parking meters, telecommunication, information displays, etc. However, on Greenland stand-alone applications are used widely to power remote signaling and the telecommunication network, where electrical grids are unfeasible (Ahm, 2007, p. 9).

An optimally placed 1kWp system generates on average 850kWh a year with the solar radiance in Denmark (compared to a production of 1800 kWh for a similar system in southern Europe (Larsen & Pedersen, 2007, p. 44). For production in Denmark with a typical electricity consumption of a household (between 4000-5000 kWh/year) an optimally placed PVPS will be able to supply about 20% of the total electricity consumption on a system of approximately 10 m^2 (Katic, 2006, p. 3). Most systematically collected knowledge from Danish experience is collected via the three governmentally supported demonstration program Sol-by (start 1996), Sol 300(start 1998) and Sol 1000 (start 2001) where respectively 60 kWp, 700kWp and 600 kWp were installed (Kristensen, 2006, p. 3). More details on the structure and design of these programs are given in section 6.1 on previous Danish policies.

This chapter will address research question 1 on the characteristics of the PV innovation system, and thus explore which actors that are active and committed in the diffusion of PVPS' in Denmark, and how they are networking. Another important point is to identify the drivers and barriers for implementation of PVPS' in the different segments of end-users.

4.1 Overview of the PVPS innovation system

As described in the previous chapter the innovation system consists of the actors, networks, and institutions that influence the development and diffusion of the technology. The Danish innovation system surrounding PV's thus consists of the actors and networks directly implicated in the PVPS business; raw material and module producers, subcomponent producers, project developers in connected building sector (e.g. involved architects), building advisors and electricians. Another part is the energy industry, for example production and utility companies and the grid operator. A group of actors of special importance for the PVPS innovation system is the end-users of the PVPS and related NGO's, as they play a crucial role in the diffusion of the technology due to the distribution way the PV energy enters the energy system. Also international networks on PVPS implementation and industrial development, where Danish actors are engaged, are a part of the Danish innovation system for PVPS'. It's important to recognize, that innovation systems are continuously changing and developing over time, with the change in actors, polices, and markets. This chapter presents a picture of the current Danish PVPS innovation system. Some historical aspects will however be added in the chapter to increase the understanding of the PVPS innovation system of today. Trends and potentials for future development will also be discussed in chapter 7.

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[7] Including capacity installed on Greenland

4.1.1 The PVPS Business

This section identifies the groups of actors in the Danish PVPS innovation system, which are active in the commercial PVPS business through direct involvement in the production, projecting, installation of PVPS, as well as the networks and trade associations they participate in.

4.1.1.1 Raw materials / feed stock

Recalling figure 2-4, which showed the different sub-industries of the PV industry, there are at the moment no Danish actors dealing with the very first part of the chain; the silicon mining. However one single company; *Topsil Pure Silicon***,** is producing mono-crystalline silicon and wafers. Especially during the years 2000 - 2005, the company was active in the PV industry, with contracts to several PV producers, mostly abroad. Their silicium is of very fine quality, most suitable for high efficiency PV's (efficiencies above 20%). It is too expensive to use as raw material for mass production of PV cells, (with the current efficiency of 11-16% (Solarbuzz, 2008)) because of higher costs for production and raw materials. Consequently, Topsil Pure Silicon is only active in the part of the innovation system that concerns research institutions, and a large share of their products still goes to export.

4.1.1.2 Modules and inverters

The next step of the value chain where actors are represented in the Danish PVPS innovation system is module production. A small number of companies work with a dual business model, where they partly work as project developers/advisors, and partly as module producers. They produce special size modules for some of their projects and the rest is purchased as standard modules from international producers such as GPV (Gällivare PhotoVoltaic) and the Sharp Cooperation. The most dominant firms within the category are *Gaia Solar, Racell* and *Dansk Solenergi,* each with different niche markets. They are all three focusing on specially designed modules, customization and building integration, but the latter, Dansk Solenergi, has the main part of its business on stand alone systems in the developing countries and free field plants and power parks in southern Europe. They all, however, have the characteristic in common, that they do the main part of their projects abroad in spite of their Danish location, due to the limited demand from their home market. Gaia Solar estimate that they do around 80% of their sales abroad with grid connected systems in Sweden and Germany being the primary market (Aarø, 2008a). Dansk Solenergi do as much as 95% of their work abroad, with countries such as Afghanistan, Senegal and Greenland requiring most of the stand-alone systems and Spain, Portugal and Italy being the primary locations for the power parks (Marker, 2008). An interesting issue relating to these actors is their interest and work with developing new PV products to the market. They have the similar goal of making the systems simpler and bringing down costs of the PVPS', by developing building elements including PVPS' and simple all-in-one mounting systems. In spite of these initiatives in the module production link of the value chain, the main part of the installed modules is imported. As an example Gaia Solar estimates, that only around 400kWp of the more than 1MWp, they installed last year (2007), were produced by themselves, even though it was a year of relatively high production (Aarø, 2008a). There are however indications, that this link will develop in the future, as Dansk Solenergi, by the time this thesis was conducted, was in the final negotiations with the municipality of Lolland about starting up a production line of about 10-15 MWp. A dual focus of production is expected, including both standard modules for power parks aimed for the export market and further development and production of a PV building element suitable for the Danish market (Marker, 2008).

Another group of actors in the value chain is the PVPS subcomponent producers, which in the Danish innovation system primarily is represented by the company **Danfoss Solar Inverters** (Previously known as Powerlynx). They produce the inverters for PVPS' (device for transformation of the direct current from the PV's into alternating current, suitable to feed into the electricity grid). Their product is applicable in 16 countries, but the primary market in Germany followed by Spain, Italy and France (Raunkjær, 2008).

4.1.1.3 PVPS Projecting

Going to the next link in the value chain, two main groups of actors are present, when it comes to the design and related implementation of the PVPS', whereas some of the important ones, as mentioned above, also produce and purchase modules. There are, however, a range of consultant companies such as **building advisors and consulting engineers**, which do the projecting and calculations of new buildings, restoration or re-design. Of actors with a special interest and knowledge of PVPS *Esbensen Rådgivende Ingeniører* and *Cenergia Energy Consulting* were frequently mentioned during the interviews. Also the utility company *EnergiMidt A/S* and the Energy and utility company *DONG Energy*, do PV projects including installation (these will be addressed in section 4.1.3 on the "energy sector"). None of the companies work exclusively with PV projects, but have the competences on the technology as a part of a company profile related to energy efficient and environmentally sound buildings in general. Besides there are few companies with knowledge and experience within PVPS in buildings, it is the impression of Pedersen (2008) that the building advisor trade is rather conservative, and that the hard competition in the business minimizes the number of hours available for the building projects. Thus they are very skeptical of projects bringing in new or unknown techniques and technologies. This constitutes an important barrier for bringing in PVPS' in the building process, as it is not a standard application. It is on standard projects, that these actors make the most profit. Hence it usually takes a very persistent building owner, not to be talked out of an initial idea of using PVPS' in a new building.

On the other hand most advisors have recently included PVPS' as a part of their portfolio, as the general focus in society regarding climate change has increased, and more customers ask for possibilities of "climate friendly projects". However, due to the lack of projects very few of them have a solid experience. This usually causes larger time consumption and also problems with the suggested placing and angle on the systems in the projects, -failures all of which increase the costs of the projects (Pedersen, 2008) (Marker, 2008) (Maegaard, 2008).

As was the case for the building advisors, there are a number of actors in the **Architect** business, which have specialized themselves in PVPS and sustainable buildings in general. *Arkitema* and *Rubow Arkitekter* are mentioned to be companies, which have worked a lot with PVPS' and solar energy in general, but also companies such as *Domus Arkitekter A/S, Dissing+Weitling, Henning Larsen architects* and *Entasis* have carried out projects with PV's (Kappel, 2008a). Another interesting and important actor, when it comes to this part of the Danish PV innovation system is *The School of Architecture* in Århus, in relation to which several projects and publication on PVPS' and architecture have been carried out. Hansen (2008) sees a clear change in the way architects perceive PVPS' now compared to just a few years ago. Previously no architects were interested in working with PVPS', which were considered technical and uninspiring. As the case with the building advisors, the increase of climate issues on the public agenda has made these sorts of "climate friendly" projects interesting as showcases, and today many companies claim to have knowledge on the issue in spite of very few specific projects. This change of interest is also showing among the students at The School of Architecture, who in general seems less frightened of working with technology as a part of the architecture, than the batches a few years ago. A change which fits very well with the increasing demand for people with skills in the area from the architect companies (Hansen, 2008). In spite of this changed attitude Hansen (2008), doesn't find it likely, that the architect companies themselves will suggest or push for PVPS' in building projects. The technology is still perceived to be something, that takes extra time and brings up the costs of the project, and which most possibly will be removed for cost savings in the end.

Another barrier for architects can be identified, when it comes to involving the innovation system more actively and push for increased implementation. The cooperation with the module producers and retailers is perceived to be difficult for architects, because the retailers only deliver certain formats and colors and don't need to adapt to their customers, due to the beneficial situation on the market at the moment, where the demand for modules is very high. At the same time it is difficult for the architects to get an overview of which possibilities are available, to what price and when (Hansen, 2008). These challenges are closely connected to the building chain problems, which will be addressed further in chapter 5.

4.1.1.4 Installation

As it was the case with the advisors and architects, there are no actors in the Danish PV innovation which makes a business solely from electrical and mechanical installation of PVPS'. Up to 2002 people had to have a certified electrician (as well as quality assured modules) to put up the systems in order to get the governmental subsidy available at that time. (Poulsen, 2008). Solenergicenteret (*The Solar Energy Center)* was in charge of this special education, that was required to get the certification, and approximately 50 electricians were certified. However, the demand for certification was abolished when the public investment subsidy was withdrawn and the large project developer in the public SOL 300+1000 had their own electricians, so the certified ones never got to do many projects (Windeleff, 2008). These days a new initiative is coming up from the EU level regarding a mandatory cross cutting PV electrician certification (Marker, 2008). This might benefit this group of already certified actors and build up more national experience. On the other hand it could also be the case that none of the Danish actors will bother to invest in the international certification, due to the small national market, and that future installations consequently will be carried out by specialized PVPS electricians from outside Denmark, for example from Germany. The task might however be more difficult for foreigners without knowledge of the Danish conditions until experience of the setting is built up.

4.1.1.5 Trade associations and networks

By the end of April 2008 a new trade association for actors in the Danish PVPS business was started. The purpose of the *Dansk Solcelleforening (Danish Solar Cell Association*) is to support initiatives, that can increase the demand for PV's in Denmark, communicate the possibilities of PV's to the politicians and push for political prioritization of PVPS' in the policy making. The target members of the organization are hence actors in the PV business, who want to improve the institutional conditions for PV's in Denmark. Public communication and information work is for the time being considered to be a job for the individual businesses or the public authorities (Raunkjær, 2008).

The interest of the participating companies differs depending on their position in the innovation system. Naturally the actors specialized in PVPS' in the projecting and installation part of the value chain have a great interest in increasing the amount of PV projects and hence enlarge the market for their businesses. For the few companies engaged in the development and production of the PV technology, a developed home market would increase the possibilities of testing their products, as they already base their business on export markets. But also from a recruiting point of view, the PV business could benefit from an increased domestic growth because the association believes this would cause an increased focus on the technology at the educational institutions as well (Raunkjær, 2008).

Besides this new, formally organized network the actors in the PV business reports on national *temporary ad hoc networks* related to specific R&D projects, for example as was the case with the previous governmental demonstration projects.

Because the Danish PV industry is highly oriented towards the various international export markets, participation in international networks is also influential on the Danish PVPS innovation system. The big industrial sub supplier Danfoss Solar Inverters is a member of the *EPIA (European Photovoltaic Industry Association*), which is the largest industrial association for promotion of PVs in the world (EPIA, 2008) The company perceives the network to be of outermost importance and they believe that they gain from being a part of the international promotion of the technology and thus a lobby, which affects the export markets. As the director of Danfoss Solar inverters also is the representative for the new Danish Solar cell association, they expect to be able to use the extensive material produced by EPIA as background for their national work (Raunkjær, 2008),

The players in the commercial business also keep track on what is going on in the German trade association: Deutsche Solar Gesellschaft**,** as Germany is the leading market in the word and most of the Danish actors export to or work there (Ahm, 2008).

Another interesting emerging international network for the industry is the voluntary *PV Cycle*, where on EU level has been taken initiative to an organized way to deal with recycling of the modules and eventually end of life treatment, even though not many systems have come to that state yet. There are two German factories working with the issue on a pilot level today. In the long run this could also be of interest to actors in the Danish context (Ahm, 2008).

4.1.2 End-users

The end-users in the Danish innovation system for PVPS' can be differentiated into two major categories; *private households*, and the *public sector* - all of which have different approaches and incentives to implement PVPS'. A potential future category of end-users is emerging: the pre-fab house business, which is discussed in the end of this chapter. In general, the interviewees experience an increasing interest in PVs as a RES-E technology - a trend that is seen as an effect of the increased focus on energy and climate present on the public agenda at the moment. Even earlier there have also been indications of a positive attitude towards PVPS', for example when the SOL1000 Project (2001-2006) was carried out. When the project was announced through different media channels, the secretariat received more than 10000 enquiries from interested house owners out of which 5000 ended up applying for a system (EnergiMidt A/S, p. 19). The goodwill towards the technology is also reflected in Eurobarometer survey from the European Commission in which Denmark is on top of the ranking, when it comes to solar energy in general with 95% in favor and the last 5% with only balanced views on the technology. This first ranking is however similar in case of wind and wave power (Directorate-General for Research Sustainable Energy Systems, 2006, p. 36) which indicates a more cross cutting attitude in favor of renewable energy technologies in general.

In spite of the positive attitude, it seems like the actual knowledge on PVs and PVPS' is limited and/or flawed. The lack of knowledge is in many cases as basic as a lack of knowledge of the actual function of the systems and a confusion of PVPS' and the more widely deployed thermal solar installations (Poulsen, 2008). This issue is exemplified by Nielsen (2008) from DONG Energy, who almost every time he starts up a project with potential customers, has to present all the basic information on the technology (its function, viability etc.), before they can start talking about the specific project opportunities. Also the rather bad reputation of the thermal solar systems for water heating, which were installed in large numbers without considerations for architecture, seems to create a bit of a negative heritage for the PV systems to struggle with. This relates to points from several of the interviewees, who stress the PVPS' need to have a somewhat aesthetic appearance to be acceptable in the Danish context.

The PV technology is something that is rarely present in the general media picture and is not really mentioned in the debate about the future energy supply challenge. However more narrow newspapers and journals, such as *Ingeniøren ("The Engineer")* do occasionally publish articles about the state of the technology on a general level (prices, installed capacity, effects ect) or reports on new findings within the research on PV cells (Beuse, 2008).

4.1.2.1 Private households

The largest group of end-users is represented by private *single family households* (Marker, 2008)(Nielsen, 2008)(Aarø, 2008a). The typical representative for this group was according to the evaluation of the SOL1000 project, a man over 45 years, who is aware of his impact on the environment and tries to optimize the energy consumption of his house in general (EnergiMidt A/S, p. 36). This picture of the private end-user is very much the same, as the one reflected by the comments from the interviewees, who also pointed to the fact that the general economic growth in Denmark has created some economic surplus for the house owners, which they like to invest in a sustainable way (Nielsen, 2008). Another group of private end-users are several family houses and housing cooperatives in general, which are interested in implementing a PVPS on their common roof. This group has so far faced more challenges when it comes to using the net-metering scheme available for private users. This might, as will be addressed in section 6.2, change in the future due to a new verdict from the Parliaments Tax Committee.

An interesting case in the category of private end-users is *Københavns Solcellelaug (PV cooperative of Copenhagen)* The idea of the cooperative is to increase the knowledge and use of PV's in Denmark after the same model of organization that started the expansion of the windmills (KBH Solcellelaug, 2008). The Cooperation has 440 shares of 3000 DKK (≈ 400 €) divided on 40 kWp placed on two roof locations available by the Municipality of Copenhagen (Christensen, 2005, p. 5). By the end of 2007 the cooperation had 28 shareholders. For comparison approximately 125.000 Danish households have a share in a windmill (Meyer, 2007, p. 267). This type of organized end-users seems rather interesting especially in the case of a changing attitude towards PV power from the energy companies.

Regarding general attitude from the population, two groups can be found in each end of the spectrum. The pessimistic group is of the opinion that the systems will never pay back economically, and that the energy payback time for the systems is so big that PV's image as a sustainable energy source can be questioned (Frederiksen, 2008). At the other end of the spectra is what can be conceptualized as the super optimistic group. They basically believe that they can be self-sufficient in energy supply and almost save money from day one and get disappointed when they hear about the price and properties of the system (Nielsen, 2008). Between these two extremes is a larger group of people, who are fascinated by the logic of the technology and the idea of having their own little power plant, while contributing to reducing climate impacts. Here the issue of the initial cost and long payback time is the serious barrier for acquiring a system themselves. In that way PVPS' has to be a good private business to be of interest to private households (Beuse, 2008). On the other hand the increasing prices on oil and an expectance of this development to continue has helped to set the prices of the systems in another perspective. This was also shown from the SOL 1000 project, where a group of middle aged people saw the investment in a PV system as a strategic investment, which could decrease their budget for electricity by the time of their retirement, as the installation typically will work 10 years after it is paid back (Windeleff, 2008).

4.1.2.2 The commercial sector

The other group of end-users of PV systems is the commercial sector, although its implementation of the technology historically has been marginal. The main barrier to this group of potential end-users is foremost the investment cost, thus the payback time of the system. This will be longer than for private house owners, because they pay less for the electricity from the grid, and this makes the electricity from PVPS' relatively more expensive for this group (Poulsen, 2008). Also for this group of end-users is the acceptable payback time, in general considerably lower than for the private investors, despite that they have the possibility to write off the physical investments. The project developers report on sessions with several interested companies, but almost all of them back out, when they hear about the price (Nielsen, 2008). This indicates for this group as well, that the pure economic payback is the context in which the PVPS' are evaluated. The commercial sector is also not entitled to use the net-metering scheme. A main challenge to an increased implementation for this group of end-users thus seems to be moving the framing of the PV systems towards their perception of nice architecture, design furniture and sponsorships, all of which mainly represent a PR/brand value and CSR perspective to society and possibly an added symbol value and statement toward the employees. It is the impression, that the Danish commercial sector historically has been less aware of this way of using PVPS' than for example Germany, Switzerland and The Netherlands. However, also for this group of actors, there are now indications, that the growing focus on climate and energy issues has created an emerging interest for the technology for branding reasons. At the moment, some of the chains of large retail stores are looking into the possibilities for PV applications (Ahm, 2008). It's also the impression, that the UNCCC conference in Copenhagen in December 2009 has increased the attention from companies, who want the installations as showcases for the event and all the associated conferences (Aarø, 2008a).

Another interesting field when it comes to the commercial sector as end-users is related to the indirect policy driver for PVPS'; The Building Codes, which will be addressed further in section 6.3. The strict demands to high energy efficiency of new buildings can change the attitude of the PVPS from being an additional investment, which has to pay back within a short time, to one of the opportunities available to comply with the building codes. This is especially relevant for luxurious buildings such as hotels, prestigious headquarters and new office domiciles in general, where the style of architecture for a while has been promoting large front areas of glass – a choice which also means increased demands for air conditioning in the summer, and where a PVPS can help decreasing the electricity demand per m^2 in order to meet the standards (Marker, 2008). The same can be the case for building development companies erecting new luxury one family houses for private people, where for example the window area is large compared to the volume of the house (Beuse, 2008). It is however not the impression of Poulsen (2008), that the influence on new buildings for private use is considerable yet. A reason for this are the earlier addressed building sector problems for energy efficient buildings in general. The problem is, that an actual articulated demand from the final end-users; the buyers, isn't present yet, which means that the building developers are able to sell the houses as long as they just comply with minimum standards (Poulsen, 2008). The influence of the building regulation is addressed in detail in chapter 6.

In case of continuously increasing energy prices a potential end-user group could emerge among the companies, which would make a business from building office buildings and renting them out. However, at the moment the energy prices are so advantageous for commercial sector, that low energy consumption doesn't have an especially high priority when choosing locality (Aarø, 2008a).

4.1.2.3 The public sector

On the surface it seems like the public sector would be an obvious end-user for the diffusion of PV power systems. Public procurement has before been seen as a way of pushing new technologies, and because of the profile of consumption (a large share of public institutions like schools and offices are only open at day time), this sector could potentially be of great interest in the diffusion of the technology. Also since many public buildings will have to be renovated comprehensively the coming years, and then comply with the tighter building codes (Marker, 2008). The high initial investments costs associated with the PV systems are again perceived to be the main barrier for the segment, even though it on the other hand seems to have extra strong drivers for such an investment for educational reasons. Interestingly enough, this end-user segment also seems to be influenced by the general climate agenda in the public debate. Solar City Copenhagen experiences an increasing number of inquires from municipalities, which are interested in starting up PVPS projects as a part of broader goals, such as being "The greenest municipality", "Renewable energy municipality", "CO_2 neutral municipality", etc. The organization is thus expecting the segment to grow considerably in the future as a part of this more general increased focus on branding and initiatives within climate and energy (Kappel, 2008b).

A barrier to the utilization of PVPS in the public sector is the somewhat divided administration and budget process between the construction and building costs and the operational costs. Buildings usually have a long lifetime and more than 80% of its total energy use cost occurs during its operation (WBCSD, 2007, p. 11). A higher investment in the construction phase will therefore often pay back in the long run, as it minimizes the operational costs. However, if two different departments and budgets administrating the construction and the operations, the first have very little incentive not to minimize the costs as much as possible in the construction phase, even though it would save costs during the operation phase. This means, that the idea of PVPS is likely to be discharged because of the high initial costs (Aarø, 2008a). A possible potential to overcome this barrier is the idea of Energy Service Companies (ESCO), which could have PVPS as a part of their portfolio of energy saving solutions. In that way, a given public institution contracts their energy needs (e.g., temperature, light, etc.) for a fixed price. The ESCO company is then free to decide how to fulfill this via the most energy efficient mix of supply and energy savings. ESCOs are not a widespread phenomenon in Denmark so far, but the large industrial concern Danfoss, has already by the Danfoss Solutions Department been providing energy saving services successfully (Elforsk, p. 2).

In case PVPS' were managed and installed by experienced ESCOs a number of the building chain problems mentioned for other end-users could be avoided, as well as the cost issues related to mass purchase of modules and experience of the involved actors (these issues are further addressed in chapter 5). It is however, outside the scope of this thesis to evaluate the

Danish ESCO potential, and to what degree an expansion of this concept will affect the diffusion of PVPS'.

Also for this end-user segment, the building codes represent a strong indirect driver for the implementation of PV power systems, and this can be enhanced by policy of the municipal governments. In the Municipality of Copenhagen there are specific municipal requirements for the energy use of public buildings, which demand new buildings to comply with the class II requirements. This is especially interesting as many new buildings within the public sector are based on pre-fabricated standard house elements, as they provide a low cost opportunity for municipalities with tight budgets. These elements are, however, often produced to comply with the standard class and a PVPS then becomes a possibility to comply with the specific municipal requirements (Aarø, 2008a).

4.1.2.4 Product group - Pre-fabricated houses

A not yet present but still potential end-user for PVPS is the industry for pre-fabricated houses. At the moment projects are carried out by for example Skanska, who in cooperation with EnergiMidt A/S works with integration on IKEAs pre-fab houses (Frederiksen, 2008). Another example is Gaia Solar, who has carried out projects on 24 pre-fab houses in the Kyoto project in Borup at Sjælland. Again the building codes are an important driver for the companies developing these initiatives, as projects had demands for a class II energy use from the municipal regulation. By using a PVPS the consumers avoided using district heating, which else would have been mandatory to comply with the standard (Aarø, 2008a). Another interesting project, although not yet in production, is "SOLTAG" (*The solar roof)*, developed by a team of architects, sustainable building consultants, a window producer and a renovation company. SOLTAG is a complete and sustainable roof element, which is self-sufficient in energy use and can be added on top of various types of buildings. In this element PVPS are used to power heat pumps ventilation systems and is thus an integrated part of the roof (Rubow, Pedersen, Klint, & Ellersgaard, 2008)

An interesting aspect of the pre-fabricated houses and elements is that when using this building approach for PV systems, most of the actors shown in figure 2-5 of the building chain could be excluded. Hence are architects, building advisors and all of the other links complicating the process and increasing the cost of the system not necessary except an electrician for the final connections (Aarø, 2008a).

4.1.3 The energy sector

The energy industry consists of the energy producers, the energy utility companies (energy sales) and the grid transmission operator, of which the two first functions for example in case of Dong energy are managed by the same company. The energy industry's position towards PVPS' is naturally of importance to the development and diffusion of the technology as they generally speaking produce the current alternative to PV power systems: grid distributed electricity. In relation to renewable energy in general, the big energy companies have an interesting role, as they are the major investors in renewable production capacity, but at the same time, they are also the producers of conventionally produced electricity from fossil fuels. In general, it's up to the producers to promote renewable energy, but it's the impression of Buch (2008), that the large energy companies will increase their investments in renewable electricity (RES-E). An expected driver for investments in RES-E in general, is the increasing demand for CO_2 reductions, where the energy companies are the primary actors in focus, and there are expectations of raising quota prices on the market. Still it doesn't seem likely, that these drivers will be enough to make the big energy producers engage in PVPS', as their investments are targeting big scale and commercially durable RES-E production, which at the moment favors investments in offshore wind parks

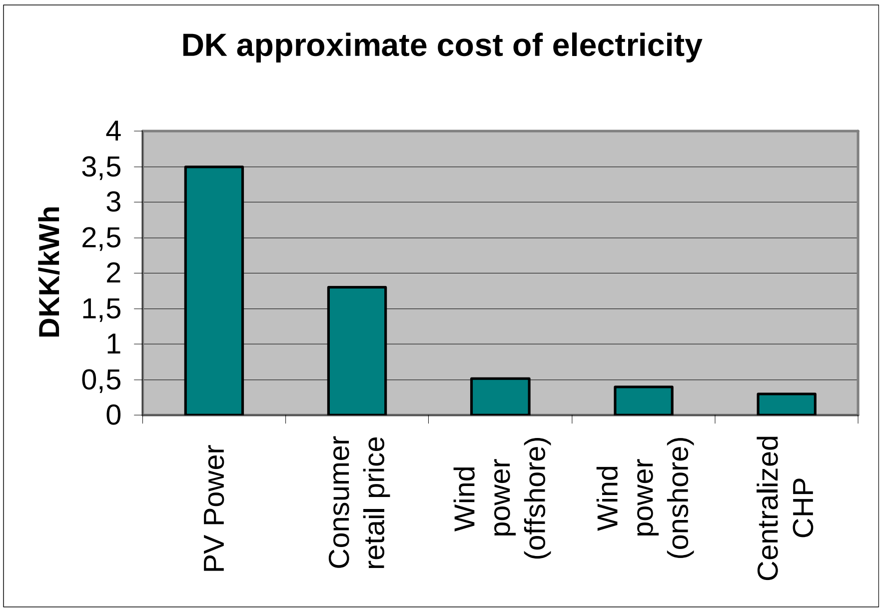

Figure 4-1 Approximate Danish costs of electricity generation from different sources
Source: Based on (P. Nielsen, 2006, p. 1)[8] and (Martini, 2008).

Another identified driver for investments in RES-E in general for the energy sector is the image motives relating to the general climate awareness among politicians and the customers, as well as to spread their portfolio (Buch, 2008b). Especially these motives seem interesting in relation to PVPS' for the companies selling utility services, hence having the customer contact. This point is also stressed in the Swedish Elforsk report on the competitiveness of grid connected PVPS' in Sweden, which points to the potential of PVPS' in the new role of the utility companies, which includes various energy services as well as customized energy mixes. (Carlstedt, Karlsson, Kjellsson, Neij, & Samuelsson, 2008, p. 45) The energy production industry in Denmark is traditionally dominated by the formerly state owned Dong Energy, but with an increasing share going to big foreign companies such as Vattenfall and E.ON.

4.1.3.1 Vattenfall

Vattenfall currently possess about 1/3 of the Danish market for energy supply and do not have any activities related to production from PVPS' in their Danish or Swedish departments. The cost of PV power is perceived to be too high for the company to run it commercially at the moment, and it is viewed that the role of the PVPS producers/ distributors is to break down those barriers. Nor either in the research department of the company is there any activities directly connected to PVPS', as short timeframe research priorities have been put on carbon capture and storage (CCS) and utilizing current knowledge on power plant technologies. On the research projects with a longer time horizon wave power has been

[8] For wind power the estimations are based on a payback time of 15 years (typical investor time frame). There was no information of this for the other technologies.

selected, and where it's expected to draw on already existing knowledge on offshore installation from experience with offshore wind power (Fock, 2008). The company has some experience with distributed production from projects with small scale gas turbines, but the organization is constructed for centralized power plant production, with a very limited contact to the end-users, as they have no electricity sales or distribution in Denmark, which they find to be a barrier to engage in distributed production.

Consequently, it does not seem likely with the current priorities, that Vattenfall will contribute more to the development and diffusion of PVPS' in Denmark. For that to be the case it would demand a combination of strong political pressure and fortunate financing/subsidies, as was the case with the introduction of co-firing with biofuels and development of decentralized CHP production (Fock, 2008). However as was the case with research priorities, this was a change or development of existing technology, where PV power production would demand fundamentally different methods and organizational structure.

4.1.3.2 DONG Energy

DONG Energy still posses the largest share of the Danish energy production and have in recent years expanded and taken over several central energy utility companies such as Københavns Energi (KE) and Frederiksberg Forsyningen. KE have had some experience with PVPS' via the *Solstrøm (Solar power)* project, where the customers could choose to buy a certain amount of electricity, which was produced on PVs for a higher price. KE did not have any PV systems themselves, but bought it via a bidding round from Københavns Solcellelaug (Copenhagen PV cooperative), all of which resulted in a consumer price of approximately 7.5 DKK/kWh (≈ 1 €) sold in packages of for example 500 DKK PV electricity. The initiative was only communicated through the webpage and the internal magazine and had about 200 customers at most; in spite of the fact that an internal survey showed that only 2% of the company's customers had knowledge about the special PV product. Today the company is considering re-launching the Solstrøm product, likely already from the autumn 2008, but with the possible difference, that the company is considering to start its own production in order compete with in the biddings (Nielsen, 2008). This decision will naturally also be of high importance to the PV cooperatives.

As mentioned in section 4.1.1.3 DONG Energy today also have a department for PV projects, where they have worked as either project developers or sub entrepreneurs and advisors. Also at this part of the business there are indications of an upcoming focus with plans on developing an all-in-one concept for the customers, in cooperation with Gaia Solar, who will do the practical installation, whereas Dong Energy will be in charge of the distribution and customer contact as well as marketing and even financing of the systems. The financing part is expected to work in the way, that the customers order a full functional PVPS to their building, and then decide themselves over how long a time span, they want to pay it off ex. 20 years (Aarø, 2008a). This unusual move is rather interesting strategically, as it could help Dong Energy keep its customers in an electricity market with increasing competition.

Naturally an increase in PV electricity can be said to create competition to the conventionally produced electricity of which DONG Energy produces by far the most, but at the moment the PV power production is so marginal, that it doesn't represent any threat to the other business areas of the company. At the same time the production profile of the PV systems is advantageous, as they produce the most in the summer time, where the efficiency of the CHPs is smaller, because they can't get rid of the heat. At the same time the production is, as put forward in section 2.5, quite stable and easy to forecast, which puts less demands for backup capacity than for a renewable energy source such as wind power, which is the primary renewable electricity source at DONG Energy (Nielsen, 2008).

4.1.3.3 EnergiMidt A/S

An important actor for the knowledge on and diffusion of PVPS in Denmark is the utility company *EnergyMidt A/S*, located in the central Jutland. The company started their work with PV's in 1993, where they were in charge of the first Danish grid connected system. Since then, they have been managing several demonstration projects in cooperation with the Energy Agency (see section 6.1.), with focus on how the systems affected the grid and the consumer behavior, application on different house types and use of different systems as well as on obtaining the cheapest possible system prices. Except some few exceptions standard add-on roof top systems have been used in these projects. Today the company runs its own subsidy systems, where the customers can get 50% coverage of the system costs. This in practice sums up to 30-50 systems/year depending on the size of the systems applied for. The company is very engaged in the different Danish networks and also represents Denmark in the working group in the IEA's PVPS task 10 on Urban Scaling and Application. Internationally they carry out projects with energy efficient buildings in Uganda and Thailand, where the application of PVPS' are a part of most concepts (Frederiksen, 2008)

4.1.4 Networks and Non-Governmental Organizations (NGOs)

There are several networks and NGOs related to the end-user part of the Danish PV innovation system. Specifically engaged in the promotion and diffusion of PV power systems is *Solar City Copenhagen*, which works on turning Copenhagen into a development and demonstration area in the field of solar energy. The organization started as a cooperation between the municipality of Copenhagen and a small number of dedicated actors. Today the members count the Municipality of Copenhagen (which provides the location and a large share of the funding), private business, private people, public institutions and a number of other municipalities located in the greater Copenhagen area. The association has its main strategic activities in a project related to the possibilities for solar energy in context of the building codes and has some responsibilities in a project on developing a *Solar City Horsens* in Jutland. This project is carried out under the energy research program EFP and with the utility company EnergiMidt A/S and the municipality of Horsens and the city renovation company Kuben. Both Solar City sections have facilitating activities for people interested in acquiring PVPS', in the form of projects with subsidized projecting of PVPS[9]. For SSC, commercial businesses, building cooperatives, several family houses and institutions are eligible to apply for the projects (e.g. not single family houses). Another criteria is that the building must be located in the area of greater Copenhagen. Previously there has been a fair correlation between the eligible projects applying and the pool of money available, but recently the association has experienced an increasing amount of requisitions. When they now have to start choosing between the various projects, the association will prioritize projects with emphasis on the architectural elements, which can work as showcases (Kappel, 2008b).

Two other relevant organizations are *Foreningen for Bæredygtige Byer og Bygninger (FBBB)* (*Association for Sustainable Cities and Buildings)* and *Organisation for Vedvarende Energi (OVE)* (*Organisation for Renewable Energy*). *FBBB* works with a rather broad perspective on cross cutting issues within sustainable buildings, energy use, construction, architecture, etc.. Many of the

[9] SCC has in total 14 projects available for co-funding of fixed projects of 8500 + VAT, where the customer fund 2500 DKK+VAT . SCH offers projecting of approximately 10.000 DKK, where they pay 70%

members are also represented in Solar City Copenhagen and some of the activities (e.g. seminars and study trips), are carried out in cooperation. The member base of the association is broader than SCC and includes various types of municipalities, architects, commercial businesses and private persons located all over the country. *OVE* is working on extending the knowledge of and application of small scale RE-technologies in general and thus also with PVPS', although there, within the category of solar power, traditionally has been much more focus on thermal solar systems. The organization also has an international department which carries out a number of energy projects in developing countries like Thailand and Malaysia, where PVPS' are a part of the portfolio and is also represented in the Energy Agency's Solar cell group, but are not currently directly engaged in Danish PVPS projects at the moment (Beuse, 2008).

There is no coordinated strategy for information on PVPS' to the potential end-users. Besides the organizations mentioned above, a number of NGO's and grassroots are dealing with energy issues in general for example *Energitjenesten* (*The Energy service)*, which are local offices, where the schools, privates, craftsman businesses and service businesses can get advice on energy saving issues and thus also PVPS' (Energitjenesten, 2008a). The service is operated by OVE and the local *Environment and Energy Offices*. Besides these wide scoped NGO's it's the impression of Solar City Copenhagen, that interested citizens take contact to EnergiMidt if located in Jutland or DONG energy if they live at Sjælland (Seeland)(Kappel, 2008b).

The energy companies also have a trade association; *Dansk Energi (Danish Energy) and* is represented in the Danish confederation of industries as *Energiindustrien (The Energy Industry).* Both forums work to improve the condition for the industry in general and are rather present on the political agenda. When it comes to renewable energy these organisations play a double role, as they represent both the fossil fuels based and the renewable production. Small scale technologies are however rarely present in the discussions, most probably due to lack of cost competitiveness and strong industries with high employment. On the other hand Dansk Energi funds the ELFORSK program with 25 million DKK (≈ 3.3 million €) a year. The program is targeting energy efficient building, industrial processes, and power electronics and projects close to market commercialization and employment creation in the industry is prioritized (Dansk Energi, 2008a). PVPS' can possibly be a part of these projects.

4.1.5 Governmental institutions

A number of governmental institutions are of importance to the Danish PV innovation system. Today the area politically sorts under the *Ministry of Climate and Energy* and associated policies are administrated by *The Energy Agency*. Previously it was also the EA which administrated the governmental R&D funding available through the EFP (*energy research program*). In parallel, there was PSO-funding[10] eligible for various energy R&D projects administrated by the state owned transmission system operator: *Energinet.dk*, which has the responsibility for the Danish grid infrastructure and transmission of electricity and natural gas (Energinet.dk, 2008c). By a recent rearrangement Energinet.dk got the responsibility of the small scale energy technologies, thus also PVs as a part of the former EFP, which was renamed to EUDP (*Energy development and demonstration program)*, whereas the Energy Agency got the responsibility of the large scale technologies (Ahm, 2008). A specific strategy or a revision of the Solar Cell Strategy, developed with the coordination of the Energy Agency, has not been carried out with the change of responsible institution; however Energinet.dk has

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[10] Public Service Obligation, where the money comes from the electricity taxes paid by the customers

pointed out some focus areas for example education on PVPS' and is currently assessing the experience from other countries (Windeleff, 2008).

Solenergicenteret (The Solar Energy Centre) is a small secretariat located at the Technological Institute. They do cross cutting information activities for solar energy in general, advise inventors and businesses and give presentations on economy and technical issues to advisors in the building sectors. Under the previous policy schemes they ran a quality assurance program for modules in the subsidies projects and coordinated the education of electricians and the certification scheme (Poulsen, 2008). The Technological Institute also have an independent research section on the next generation of PEC (photo-electro chemical)/ Dye Sensitised PV cells.

Another interesting organization is *Nordisk Folkecenter for Vedvarende Energi (Nordic Folkcenter for Renewable Energy)*, which carries out research and demonstration within a range of renewable energy technologies such as biofuels, wave power and small scale windmills. The center carries out various information activities and has many visitors (Nordisk Folkecenter for Vedvarende Energi, 2008). The organization has also previously been engaged in development projects with regard to deployment, where they have constructed PV glass and sun screens in cooperation with private companies. These projects didn't, however, result in market penetration for the developed products (Maegaard, 2008).

Other relevant actors are naturally the local governments (e.g. the 98 *municipalities*), which already have been touched upon, via their role as potential end-users. Their importance in relation to special planning policies will be addressed in section 6.3.

4.1.5.1 Research Institutions

Only a few institutions are engaged in the research on PVPS' in Denmark. The primary objective of the research carried out is the next generation of PV technologies, with a research cluster on polymer cells located on *Risø/DTU* and a section on PEC at the *Technological Institute*. Furthermore there is research carried out by the Department of Power Electronics at *Aalborg University,* as well as at the Department of Applied Electronics at *DTU*. As mentioned in the section on projecting agents, there is also a cluster on the *School of Architecture, Århus*, which is researching on the architectural aspects of PVPS' and sustainable buildings in general. A new crossover of research has recently appeared, most possibly in line with the increased focus on climate issues and future energy supply, as scientists within nanotechnology and material physics at *Copenhagen University* have started taking interest in the potentials for PV improvement based in their respective fields (Borup, 2008a). An assessment of R&D funding and cooperation patterns in the projects are provided in section 6.4.

4.1.5.2 Governmental Networks and forums

Within the governmental part of the system, the most important Danish network for PVPS has been the *Energy Agency's advising Solar cell group*, which since 1992 has been a network of actors within the field, and the majority of which is now starting up the trade association: Danish Solar Cell Association. In connection to the Energy Agency's primary group is *The Dialog group*, which has a broader character of various stakeholders from businesses, organizations and institutions, and this group was used, when the focal group wanted broader opinions on their work. The primary outcome from the network has been the Danish PV strategy from 2004, which presented guidelines and focus areas for the development of PVs in Denmark (Energistyrelsen, Elkraft system, & Eltra, 2003). The group was supposed to update the strategy in 2007, but with the redistribution of the R&D funding to the resort of

Energinet.dk, the work of the group has been on low power (Windeleff, 2008), which probably is one of the drivers behind the newly established trade network (Beuse, 2008).

On an international level, Denmark participates in the IEA PVPS, which is the Photovoltaic Power System Group within the International Energy Agency**.** In the continuous work carried out by the group, Denmark is currently involved in task 1 (exchange of information) and task 9 (PV services for developing countries) represented by PA Energy A/S (Peter Ahm) and by EnergiMidt A/S (Kenn Frederiksen) in task 10 on urban scale applications (PVPS(IEA), 2008). When it comes to the IEA PVPS forum Denmark contributes little, when it comes to new knowledge on the development of the technology on the production level, because the Danish actors first enter the value chain in, or for a large share after, the module production link. Thus the contributions in these international forums are connected to the implementation, except when it comes to development of emerging generations, where Danish research institutions as mentioned carry out work. To talk about contributions on implementation might seem strange, taking into account the low installed capacity in the country and the modest home market experienced by the businesses. On the other hand is it unusual, that such a large share of the implementation of PVPS has been planned, followed and evaluated so closely, as was the case of the different SOL projects, and in the same way was the inclusion and coordination of various actors and interests very high (Frederiksen, 2008). The contributions have thus primarily been connected to the "softer" findings from the projects (e.g. consumer attitude and behavior, pay back acceptance, social acceptability etc.), but also in variations in house types, architectural opportunities for both add-on and integrated systems effects on the transmission grid. The projects contributed to new knowledge and Denmark is now perceived to have a more passive role in the network, as the experience and evaluation of the Danish implementation has been modest the last years.

Denmark, via the state owned transmission operation company Energinet.dk, is also a part of *PV-ERA-NET,* which is a network of European institutions funding and managing R&D programs for PV technology. The purpose of the network is to coordinate some of the research activities in the field and the participating countries are together in putting forward the POLYMOL program for research on 3rd generation technologies (Energinet.dk, 2008a). PA Energy is hired as permanent consultant to participate in the work of the network (Ahm, 2008).

Around the public research institutions and universities **research networks** do mostly occur between Technological Institute, Risø/DTU, Aarhus and Ålborg University. The trends in cooperation structure within the research section 6.5.

4.2 Concluding remarks

As can be seen from the analysis, the PV innovation system is rather complex with a range of different actors distributed over a long value chain running from the mining of raw materials over the production of the PV technology and the projecting and implementation to the various types of end-users. In the Danish system a number of actors have developed over time, and these are primarily represented within the area of implementation of the technology even though also a small number of actors related to the production of PVPS technology and power electronics are represented. The businesses are operating in a setting with a limited home market, which previously primarily has been driven by demonstration projects, but where the political support has been modest the last years. As a consequence of the limited Danish market the actors involved in the industrial part of the value chain (e.g. the inverters) and the little amount of customized modules primarily produce for export markets in

Germany, Spain and Italy, as well as Sweden. The same conditions are present in the projecting link, where the few specialized companies have the main part of their projects abroad or have PVPS as a part of broader portfolio. An interesting finding relating to the projecting part is a change in attitude among the two groups of actors within this category e.g. the building advisors and the architects. Both groups, except for some few specialists, have been quite negatively positioned towards working with PVPS' previously. This has recently changed, as the technology has been framed in the general climate debate present in Denmark and all respected consultancies and architect businesses now have "climate projects" including PVPS projects as a part of their portfolio. There are however indications, that the level of experience of PVPS projecting within the more broad consultancy arena still is relatively limited.

Several segments of end-users are present within the system, and there is a positive attitude towards solar power and renewable energy among the Danes in general. Interestingly enough, despite this there is a rather low level of knowledge on the basic functions and properties of the technology, which often is confused with thermal solar power. This mistake also adds some drawback to perception of the technology, because the thermal solar systems traditionally have been implemented without much consideration for architecture and thus is considered to be ugly and non-aesthetic among the potential end-users. For all groups of end-users the cost of the PVPS' are considered to be the primary barrier to implementation, but the relative size of this barrier varies among the groups. The private, primarily single family, households constitute by far the largest share of the total group of end-users, and this group has been pushed by the previous SOL demonstration programs. The deployment by this group has however decreased since the public co-funding was withdrawn. An interesting sub segment in this category is the PVPS cooperatives in line with the organization form known from the development of wind power. The interest and implementation by the commercial sector has traditionally been marginal, as the cost of the produced electricity is relatively higher, due to the lower purchase price of grid electricity, and the fact that they are not entitled to the net metering scheme. There are however incipient indications of an increasing interest for branding reasons or in order to comply with tightening of the building codes, whereas the electricity production of the PVPS thus becomes secondary. A potential, but yet small group of end-users is the public sector, where the profile of consumption, the building codes and the educational elements should be considered strong drivers. The tight budgets of the municipalities (the investment costs and the fragmented administrative processes) constitute the major barriers to this segment. An increasing interest from this group is however experienced, also partly as a component in a more general climate and energy effort of some municipalities. A future end-user within pre-fab housing industry is identified, but there is not yet an established market for these solutions.

Being the market context and producer and retailer of the typical benchmark (grid electricity), the energy sector is interesting from an end-user perspective. The companies dealing exclusively with energy production have very little incentive to implement PVPS' at the moment due the high electricity costs, where the PV-power needs to compare with the pure production price of the grid electricity (without the taxes). The utility companies (and the energy producer having this as a part its business) on the other hand have other incentives to engage in PVPS. An important part of this is the potential for improved customer relationships, which has been seen both in a model of direct investment subsidies for customers acquiring PVPS' and as PV-power packages sold to conscious customers and as well as a possible model of projecting and financing contracts. Inclusion as a part of ESCO services could also be a future opportunity.

A simplified overview of the Danish innovation system for PVPS' is pictured below.

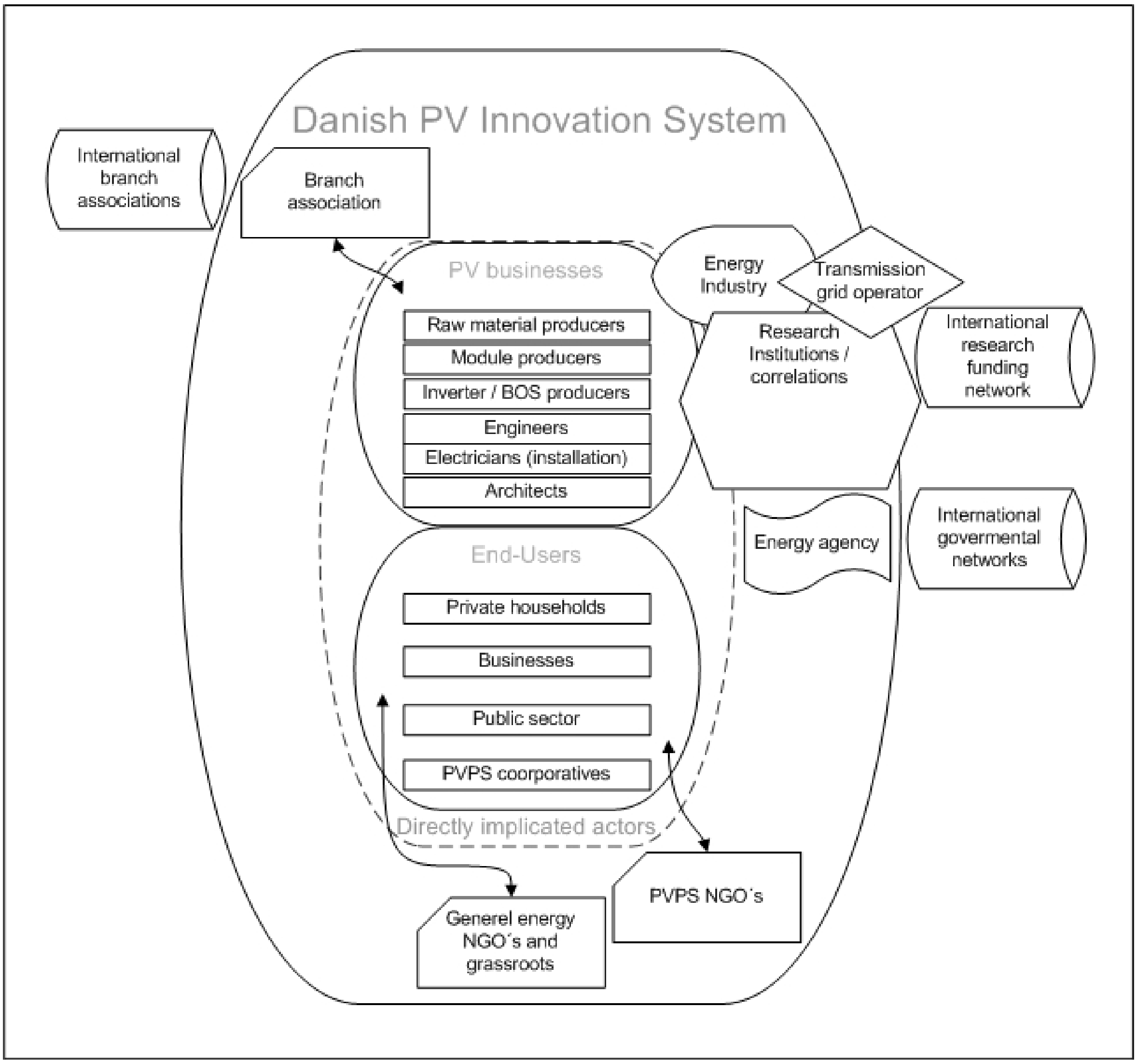

Figure 4-2: The Danish innovation system for PV Power System
Source: Authors design

It thus appears, that there are potentials for a wider diffusion of PVPS in Denmark with an innovation system including a number of specialized businesses, but even more important a positive change in attitude among previously critical actors, as well as an increasing interest among the variety of potential end-users. The system, however, still struggles with the high cost of the PVPS' being the primary barrier to a further and increased diffusion, but also the implementation is constrained by the limited knowledge. There is thus a need for learning, both among the increasing amount of interested actors within the parts of the PVPS value chain connected to implementation and among the potential end-users. As identified in the chapter 3 is the learning connected to implementation primarily taking place nationally or in settings with highly similar characteristics, and there is thus a need to support this learning and knowledge diffusion connected to the implementation of PVPS' in Denmark. An analysis of the cost distribution and Danish cost reduction potentials is presented in the following chapter and an assessment of the current supporting policies and the properties of these, is discussed in chapter 6.

5 Cost distribution and reduction potentials

As identified in the literature and within the Danish PV innovation system, the high cost of the electricity produced relative to conventional and other RES-E technologies is one of biggest barriers against diffusion of PVPS'. According to national reporting to the IEA from May 2007, the current turnkey price[11] was in the range of 40-90 DDK (≈5.3-11.8 €)/Wp. It should however be noted that this is based primarily on the SOL projects, but also that the prices are somewhat higher than in 2004-2005, because of the world prices on silicium and thus modules. As will be stressed in this chapter, there is considerably variation in the cost of PVPS' due to a number of factors, and the lowest reported numbers above must be assumed to be for the add-on and retro-fit systems of the SOL program. An estimation of the value of solar electricity from Ahm et al. (Ahm et al., 2006) suggests the estimated value to be of 0.34 DKK(≈0.045 €) /kWh, which is 0.07 DKK more than the average spot price may 2006[12], because the main part of the production occurs during peak hours, where the spot price is above average. When it comes to the price of the electricity from the PVPS, it is hard to suggest proper estimations. This is foremost because the price for the end-user will depend on various factors. This is both the turnkey price of the system, the expected lifetime of the system (currently, most producers provide a 25 year guarantee of a certain efficiency, but the PVPS' are expected to function longer than that), the term of financing (will the end-user have to borrow the money in a bank?, is it savings that are invested?), the owners tax issues but also external factors such as the spot price of grid electricity (which determines the net meter tariff for the private end-users) are important factors, when the actual price of the PV electricity is determined. In the same way all these issues should be taken into account, when issues such as pay back time for private users are discussed. In a current newspaper article the cost of PV electricity was suggested to be 3.50-4.00 DKK(≈ 0.46- 0.57€)/kWh[13], which is approximately double the retail price of grid power (Martini, 2008). The estimated production cost from the Sol 1000 demonstration project is 3.50 DKK/kWh (Windeleff, 2008).

Consequently, a cost reduction in the system price seems to be a crucial factor for a wider diffusion of PVPS' in Denmark. This chapter will assess research question 2 on how costs are distributed along the value chain of a PV system and which Danish cost reduction potentials can be identified. The cost related to the production of PVPS' is difficult to affect by Danish policies, so it is important to know how large a share of the total price the Danish end-user is facing, which is related to the implementation. The next step is then to look into the reduction potentials of this part. The first part of this chapter present a number of estimations on the cost distributions in order to show the different elements of cost reduction potentials in a PVPS. Then some general factors influencing the cost of implementation are discussed. The last part of this chapter focuses on the sources of costs specifically connected to implementation.

[11] Price of the installed PVPS, but without VAT. In Denmark the VAT constitutes 25% of the sales price for private consumers

[12] based on a 1kWp PVPS with a south orientation may 2006.

[13] Without any specification on the applied assumptions

5.1 Cost distribution in the value chain

The cost distribution among the different links in the value chain is a central aspect of this research and a key question for all interviewees has therefore surrounded how they perceive the distribution of the total cost among the different elements in the value chain of a PVPS. For simplicity the PVPS can be divided between the costs of technology itself (the PV modules) and the costs of implementing the technology (the rest of the PVPS). An important finding in that respect is then the general point, that the cost distribution varies considerably from project to project, and that there are several issues influencing the final outcome. Three different groups of data are presented: Table 5-1 presents the distribution of standard add-on roof mounted systems without any size specifications, where the data are the general estimates of the interviewees[14]. Table 5-2 shows the cost distribution on a number of specific systems, and table 5-3 shows cost distribution data found in the literature on PVPS'., which unfortunately didn't specify the type of grid connected system.

Table 5-1 Estimated cost distribution from the interviewees

	Cost of technology itself	**Cost related to implementation**		
PVPS element	**Module**	**Invertors**	**BOS/mounting systems**	**projecting /Installation**
EnergiMidt A/S #1	**60%**	**15%**	**10%**	**15%**
Solenergicenteret #2	With reference to Novak (2005) **68%**	**11%**	**8%**	**2%** Projecting **11%** Installation:
DONG Energy #3	**75%**	**8%**	**8%** (incl. installation)	**10%** Projecting and administration
Dansk Solenergi #4	**68%**	**8%**	**4%%**	**20%**
Gaia Solar #5 NB. Integrated system	**58%**	**10%**	**13%**	Projecting/admin **6%** Installation **21 %**

Sources: #1(Frederiksen, 2008),#2 (Poulsen, 2008),#3 (Nielsen, 2008),#4 (Marker, 2008) and 5# (Aarø, 2008a)

[14] the data showed in this matrix is from the interviewees who are working with or in close cooperation with the practical installation of PV systems. The rest of the interviewees provided looser estimations without useable specifications differentiations between the elements.

Table 5-2 Cost distribution of specific PVPS projects

	Cost of technology itself	Cost related to implementation		
PVPS element	**Modules**	**Inverter**	**BOS /mounting system**	**Projecting /installation**
OFFROT Sweden 2008 (average distribution)#1	**75%** for "materials"	Included in materials	Included in materials	**5,5**% for projecting **19%** installation
UK DTI 2008#2	**60%**	**7%**	Not reported (possibly included in installation costs)	**10%** projecting **23 %** installation
Malmö technical museum #3	**84%**	**8,5%**	**3,7%**	**3,7%**
Gasværksvej, CPH #5	**51%**	**7%**	**7%**	**18%** projecting **17%** installation
Victoriagade, CHP #6	**67%**	**7%**	**11%**	**8%** projecting **7%** installation

Sources:#1: Based on 97 installed systems – of these were 24 BIPV systems. The system sizes varied from 0.25- 161 kWp. (Nilsson, Ridell, & Ekdahl, 2008, p. 20)

#2: 6 examined BIPV projects (Teknologisk Institut, 2006, p. 4) based on (Davies & Munzinger, 2003, p. 32)

3: 64 kWp building mounted ad-on system.(Carlstedt et al., 2008, p. 23)

#5: 7,5 kWp BIPV system (Aarø, 2008b)

#6: 8,6 kWp BIPV system (Aarø, 2008b)

Table 5-3 Cost distribution from literature

	Cost of technology itself	Cost related to implementation		
PVPS element	**Modules**	**Inverter**	**BOS/mounting system**	**Projecting / installation**
EFP05 (2006) #1 Danish assumption	65%	Collected under the	common category 35%	BOS
Photex (2004) #2 Germany 2kWp (2002)	68%	11%	8%	2% Projecting and administration 11% Installation
Photex (2004) #3 Germany	71%	Collected under the →	common category 29%	BOS ←
The Netherlands	66%	→	34%	←
Italy	56%	→	44%	←
France	54 %	→	46%	←
PVPS (2007) #4	55%	10%	Collected under the 35%	Common category BOS ←
EU PV Policy Group (2006) #5	70%	8%	7%	15% Installation

Sources: #1:(Ahm et al., 2006, p. 37),#2: (Schaeffer et al., 2004, p. 44),#3: (Schaeffer et al., 2004, p. 54),#4:(Clavadetscher & Nordmann, 2007, p. 8)and #5: (Weiss, Stierstorfer, Orthen, & Gisler, 2006, p. 87)

The findings and estimates of the cost distributions are not intended to be representative for grid connected PV power systems or specific groups of these sizes. The information for the main part is not detailed enough to conclude anything about the reason behind the exact distribution. An interesting point, which can be seen from the matrixes is that the distribution of costs varies considerably. As identified in the literature and in the interviews the modules represent a major share of the total cost , but still the size of this part varies considerably for PVPS' , for example from 84 - 55% as presented here. When it comes to the rest of the systems, it is equally interesting how much of the costs connected to the implementation and projecting varies, keeping in mind that much research within this area usually only divides the costs in the modules and the BOS, which then becomes a common category for the rest of the system, thus compiling supporting hardware and electronics, projecting and installation in the same category. The more detailed presented distribution in the matrix above shows that the projecting and installation part in the given examples together varies within a range between 3.7% and 35% in the specific projects, where both were carried out in the Øresunds region. The importance of other factors than the modules for the system price is supported by the evaluation of the Swedish OFFORT program, where according to Ekdal (2008) there is little variation in the price of the standard modules and the variation in price thus was to be found in the rest of the projects.

These findings do consequently mean, that even though the modules have been the scope of the great majority of the discussions on development, costs and cost reduction potentials, the variety of their share in the examples and thus the share of other elements suggests that factors in the PV system outside the modules should be of interest, when it comes to cost reduction and policy making for diffusion of PVPS.

5.2 Factors influencing system costs

Apart from these general perspectives illustrating the importance of looking into costs outside the modules of the PVPS, a number of factors influencing the costs of the systems have been identified through interviews and review of literature. The first sets of determinants of cost differences can be found in the form of application (add-on or integrated PVPS') and the building of application (retro-fit or new build/renovation), as well as the combination of these choices.

When implementing a PVPS on an existing building by retro-fit, the standard add-on system is the cheapest solution (Ekdahl, 2008)(Nielsen, 2008)(Frederiksen, 2008)(Beuse, 2008), as they consist of standard mass produced modules and mounting structure. As was the case with the Sol demonstration projects, the modules can be purchased in bulk to help keep down the price, and at the same time the demands to projecting and architecture are minimized for these standardized projects. On this type of project, the BIPVs come out as a more expensive solution because it puts higher demands to the projecting part and retro fitting in the roof and often includes customized modules due to a lack of standardized modules and mounting systems and/or high architectural demands, which increases the cost of a BIPV systems.

When it comes to new build or renovation, integration can come out as an equally priced or even cheaper solution (Aarø, 2008a),(Beuse, 2008),(Hansen, 2008). This is both due to practical issues, such as the fact that the building will be prepared for the system, which makes it easier to install and also because the time used for projecting for example roof calculation is minimized, as it is already known in the general calculations (Marker, 2008). A matter of importance mentioned by the practitioners is when and how the system comes into the building process, for example, if the preconditions are planned and settled with all actors in the building chain. This is both in order to avoid extra work and failures, but also to save additional materials, that the PVPS can substitute.

The multi functions and substitution potentials of the PV technology is a very special feature, which deserves increased attention in the assessment of PVPS as an energy technology. This means that the PV power system adds more value to the system, than the electricity produced and should be accounted for when discussing the cost issues. As described, the properties of the technology make it suitable for various sizing, as well as integration into buildings. This gives architectural opportunities for double functions of the technology for example as sun screen, for indoor climate and noise control as well as for architectural communication. These matters have not been very much in focus. The narrow perception of the value of the PV power systems exclusively based on the payback time and electricity production, is according to Hansen (2008), constituting a serious barrier to the diffusion of PVPS' both for the matter of price perception and for the attitude among the end-users and the architects and consultants. For the price perception it is rarely that one would do a payback time calculation with ordinary bricks or expensive facade materials such as marble as seen in prestige headquarters. As seen in the figure 5-1 below, the cost of PVPS as façade material is positioned within the range of several other building materials. The materials presented range in the more exclusive end of the spectra, but it should be noticed that the income produced by the PVPS is not subtracted the price.

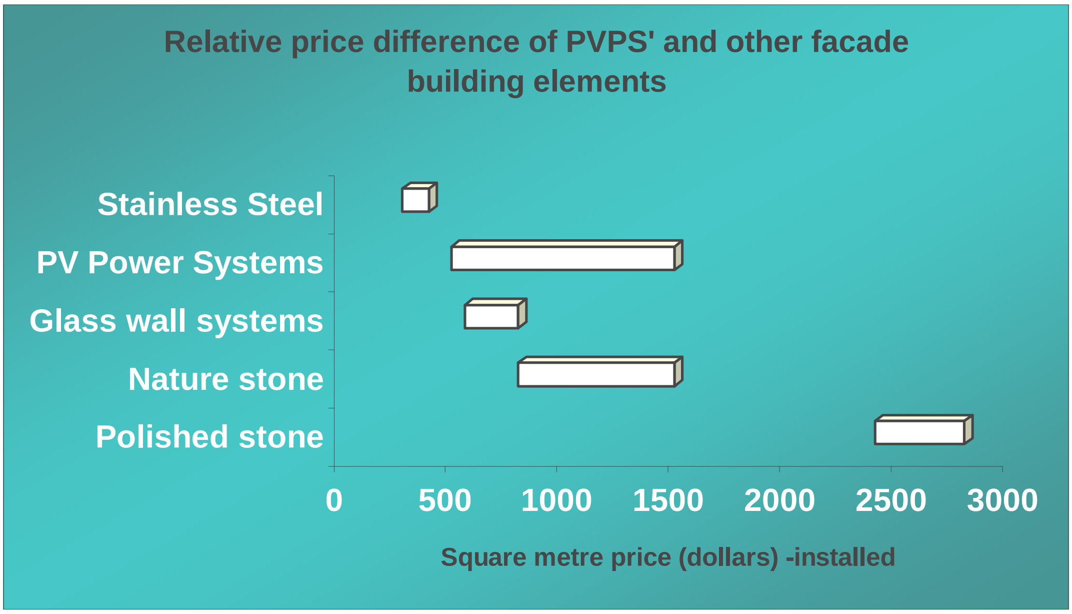

Figure 5-1 The relative price difference between integrated PVPS' and other substitutable building materials. Source: Based on data from (Eiffert & PVPS countries, 2002, p. 35)

The substitution effect naturally depends on which surface or roof material is substituted and as mentioned in the section above, is the case for new buildings or renovation works, where new materials are required anyway. By this kind of material substitution Gaia Solar state to have delivered systems, where the PV electricity production costs are down to approximately 2 DKK (≈ 0.26€)/kWh[15](Jensen & Lind, 2008, p. 36) Another more artistic, perspective influencing the perception of the substitution cost of the system is by subtracting the general

[15] Based on a 30 year lifetime of the system and inclusive VAT.

building infrastructure such as staging and mounting systems of an alternative roof or sunscreen from the system price (Aarø, 2008a).

The multi functionality of the technology is also of importance, because it is an opportunity to add value to the systems by substituting ordinary building materials and construction, as is the case with sunscreens, which often conventionally have been managed by adding an extra layer of silk printed glass to limit the light and heat in entering the building (Hansen, 2008). As mentioned in section 4.1.1.3, working with PVs is still a relatively new thing for many architects and engineers and this seems to create a barrier in the form of negative attitude. Some work has however been done in Denmark to attract attention to the architectural and functional possibilities of the PV systems, both with the focus on various cases PVPS applied or integrated into buildings and the potentials for different types of buildings (see for example (Berg et al., 2005) and (Wittchen & Svensson, 2002)) and a new initiative addressing the architectural potentials of transparent PVs (thin film cells) with regard to climate and light regulation and aesthetic communication (see (Hansen, Hilbert, & Munk, 2008).

When discussing these additional values of PV systems, it is important to be conscious about the tradeoff between electricity production, cost and architectural demands dependent of the primary function of the system. For example does the additional function in a climate screen prescribe an installation, that is not necessarily the most suitable for optimization of the electricity production, or that architectural demands for a showcase business head quarter require non-standard modules and mounting structure for communication purpose, which then increases the system price. It is the impression from the interviewees, that architectural demands range the highest on the prestige installation, whereas the production is the main focus of private households, who have calculated their investment based on the income from production and just want "*a system being the least ugly possible"* (Hansen, 2008)

5.2.1 Sources of cost connected to implementation

For PVPS', most research on cost issues emphasize the cost reduction potentials of the modules, due to their large share of the final cost and the expected technical improvement, Among the Danish interviewees the modules are considered to have the largest reduction potential. However, a look at the cost distribution matrixes (figure 5-1 to 5-3) also showed that the relative contribution from the modules to the final system costs varies considerably among the presented estimations, specific projects and data from literature, which suggests that the reduction potentials outside the modules are of importance as well. At the same time it can be concluded from the analysis of the Danish PV innovation system, that the production of modules in Denmark is minimal and at the moment restricted to niche customization. The combination of these two findings thus advocates for a more in depth assessment of the determinants of cost and potentials of cost reduction connected to the implementation and thus the national context, which according to the definitions in chapter 3 are the links downstream the PV modules in the value chain (e.g. the barriers and potentials related to projecting and installation). As could be seen in the matrix and the discussion above, these parts of the system contribute to a relatively higher share of the total cost for BIPV systems, and the issues below are consequently of highest importance to this type of systems.

A main determinant of time use and thus final cost identified is the experience of the actors involved in the process. As was pictured in fig. 2-5 the building chain is complex with several actors involved all of which have various backgrounds and experiences. In general, a lengthy chain (the amount of involved actors), drives up the total cost of the system, as all actors will earn profits on their work (Aarø, 2008a). In the same way the length of the chain complicates the communication process for the actors, architects for example, seldom have direct contact with module supplier (Hansen, 2008).

When it comes to the projecting link, the analysis of the innovation system indicated a relatively limited experience on working with PVPS among architects and consulting engineers, with the exception of the few specialized actors. This experience gap can mostly be said to exist due to the limited amount of national projects, but also from the previous hesitation to work with the technology from the advisors' side. In the same way, the knowledge of the building developers is perceived to be shallow, a factor which can influence the cost negatively by complicating the coordination and create insecurity of demands and wishes for the PVPS. As discussed in the section above, high architectural demands usually drive up the total cost, if it demands special designed modules or assembly systems, as well as the architectural design work naturally adds cost in itself. According to the architects interviewed for this thesis working with PVPS is actually not that complicated or technical as assumed by many of the new actors, but naturally it takes a little extra time, to get to know the material just as for any other new building material.

Another factor is that if architects have PVPS' as part of the bidding process for a project, they tend to go for new and extraordinary applications of PVPS' to differentiate from the competition. This then puts even higher demands to special design and customization of the PVPS and this consequently increases the cost (Aarø, 2008a). For the architects specifically, the lack of visibility on the market, for especially BIPV modules, was perceived to be troublesome and time consuming, because it requires assistance from experts with knowledge of the possibilities and availability on the market at the given moment, which was perceived to change rather often (Hansen, 2008) and consequently a matter that can drive up the final cost or simply hinder them in considering the use of PVPS. The focus to decrease the barriers for this link is thus both related to actual experience with projects and visibility in the market.

The wide range of cost difference determined by factors outside the modules are illustrated by the determinants of cost and the distribution from the two different BIPV projects: Gasværksvej and Victoriagade (distribution presented in table 5-2), where both were carried out by the same project developer in the same geographical area. Victoriagade (8.6 kWp) was carried out to a price of approximately 55 DKR/Wp, where the project was characterized by using a cheap mounting structure/system, having limited architectural demands, a team of advisors with experience in PVPS', one of the certified (KSC) installers/electricians, a challenging cabling and few actors in the building chain. The Gasværksvej project (7.5 kWp) on the other hand had a price of approximately 125 DKR/Wp and this project was, as for Victoriagade, characterized by difficult cabling. Issues that drove up the price for this specific project was stated to be: the use of an unknown mounting system, high architectural demands, lack of knowledge and experience by the advisors and the installers/ electricians and a long building chain with many links involved (Aarø, 2008b). The examples are naturally not representative for all DK projects and there are no specifications of the relative importance of the different factors to the final costs, but are from Gaia Solar examples on the cost difference of a smooth and a complicated project process. Other interviewees within the projecting link also stress the importance of a smooth and coordinated building process with a high degree of communication and experience among the actors in order to avoid bad solutions and failures, which have to be corrected and consequently will have either an influence on the performance of the system, the system cost or both (Pedersen, 2008)(Marker, 2008). The experience of the actors has also been considered to be of importance from the Swedish perspective based on the governmental OFFORT program. Here the great majority of the PVPS' were carried out as "all in one" projects ("total enterprise"), where only 4-5 companies specialized in PV systems managed the whole project, thus minimizing the number of actors engaged in the building chain. This is considered to be an important factor in keeping down the total system cost (Ekdahl, 2008). Another finding from the Swedish program is a difference in the time consumption for meetings in order to coordinate the projects and get permission from authorities. An interesting error in the data from the Swedish project is that some PVPS owners didn't include their own time use in the cost evaluation, even though it in some cases must be perceived to be considerable, whereas some included everything in the reporting. This does however not disturb the general impression from the projects, and Ekdahl (2008) believes that the time consumption for these coordinating meetings would be dramatically decreased if the participating companies or municipalities should carry out more similar projects in the future, due to the increased experience by both themselves and permission given authorities.

5.3 Concluding remarks

An important finding of this chapter is that the cost distribution within the different elements of the value chain of a PVPS varies considerably over the examples presented from interviewees, specific projects and literature. Even though a large share of the total cost is connected to the PV modules, the part related to implementation is also of great importance, not at least because it is within this category that the national opportunities for learning, hence cost reduction is present. Some general factors that influence the cost of a system is the type, for example add-on standard applications or building integrated systems, and the condition of the building on which it's carried out, for example retro-fit versus new build or renovating. For retro-fit projects the add-on applications are perceived to be the least costly solution, whereas for new build /renovating the integrated systems can turn out equally costly or even cheaper. This is due to the need for less calculations, but also the possibility of substituting roof or façade material on the building, which would have been needed otherwise. An important point from this chapter is thus that cost of the PVPS can be perceived differently depending on how the values additional to the electricity production of the PVPS are conceived. This is not only regarding substitution of alternative building materials, where cost can be considerable, but also the possible double effects of the PVPS' in terms of sunscreen, noise protection and architectural communication, where especially the last factor seems to have increased in value along with the increased attention to climate issues.

When it comes to the national sources related to the implementation, the major determinants of cost are identified to be the experience of the involved actors (both in terms of experience with the technology, but also with the project process), the length of the building chain (which increases the actors gaining profit and the need for coordination) and the process of interaction of the actors (which can cause failures, that need to be corrected or bad solutions). Learning and simplification thus seem to be important to reduce the cost related to the implementation. This issue will be stressed further in the final conclusion and discussion on the Danish possibilities for cost reduction and industrial development.

6 Policies for PV power systems

This chapter addresses the policies of importance to the deployment of PVPS' in Denmark within the last 15 years (1992-2008), naturally with an emphasis on the policies currently in force.

6.1 Highlights of historical PVPS' policies

A large share of the deployment of PVPS' in Denmark has traditionally been driven by governmentally funded demonstration projects. The first of its kind was the SOLBY project, which ran from 1993-1997(1999[16]), and was managed by EnCon (now EnergiMidt A/S) with contributions from the Energy Agency, the grid operators, PA Energy and an observer group of stakeholders within industry, energy NGO's and knowledge institutions. The scope of the project was to gain basic knowledge on the viability of the technology in a Danish context, but also to test how the production would affect the balance of the grid and quality of the power, when a number of systems were installed in the same local area. Furthermore the project set sub-goals of gaining knowledge of practical mounting and integration possibilities, social acceptance of the systems and effect on behavior. For this project 29 installations of a total effect of 60kWp were installed (Kristensen & Frederiksen, 1999, p. 3). The prices of the system was approximately 50DKR/kWp installed and the house owners only carried 15% of the total costs (Kristensen, Kristensen, & Frederiksen, 2004, p. 3).

The next demonstration project was SOL300, carried out between 1998 and 2002(2004), which in many ways was an extension of the SOLBY project. Based on the findings from the previous project the scope was however somewhat different with a focus on various PV applications, house types and geographical areas, as well as technological and architectural improvements and price reductions. The main actors involved were almost the same except for a number of architects, but the observer group was expanded considerably. The project included 8 different utility companies and had 750kWp installed on approximately 300 houses (primarily one family type). In comparison to SOLBY the house owners carried 25% of the costs and the price was brought down to 40Dkr/kWp installed (Kristensen et al., 2004, p. 3).

Until now, the last comprehensive demonstration project was SOL1000, again with EnergiMidt as the primary project manager. The scope of this project was to increase the implementation of PVPS' in order to reduce the system price and the amount of investment subsidy needed. Furthermore the project should contribute to initiate demonstration facilities and create and sustain a Danish knowledge in the field and the system of actors emerging in the industry (EnergiMidt A/S, p. 5f). The project was suspended when the government changed in 2001, and it ended up implementing approximately 600 systems with a total capacity of 600 kWp(Ken Frederiksen, 2008). The owner share of the costs was increased to 60% and the turn key price reduced to about 35 DKR/kWp.

A fourth project was planned, but because that project was characterized as diffusion and not demonstration, there was no money available from public funding at the time, and since 2000 it has been the experience of Frederiksen (2008) that it has been very difficult to get funding for PV projects The might however change now with the initiation of the ForskVE program in 2008, where some funding is available for diffusion projects. This will be described later in this chapter.

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[16] The year of final reporting on the project.

Other previous policies include a small BIPV program, which ran from the middle to the end of the 1990's, as well as the previously mentioned subsidy program for energy efficiency in the commercial sector, also in the 90's, where the participants got 40% of their investment costs refunded. The program was unfortunately not really a success in a PVPS context in contrast to similar programs in other European countries. The limited success of the program was according to several interviewees due to a lack of information on the program and the branding possibilities of PVPS', as well as the long pay back time of the PVPS' compared to other energy saving investments.

In the period 2004-2005 a national PV strategy was carried out with the Energy Agency as the coordinator. The strategy assessed the state of the implementation, R&D and the PV businesses in Denmark and pointed to areas of prioritization and public funding. No specific goals on development or implementation were adopted. The strategy was supposed to be updated by the end of 2007, but that didn't happen due to organizational changes in the responsible research secretariat.

6.2 Direct current policies (2008)

There are no specific national targets for PVPS' in Denmark, even though deployment naturally must be considered to be a part of the general Danish EU goals of achieving 30% of the total energy consumption from renewable energy sources in 2030(Commission Proposal {COM(2008) 30 final}, 2008, p. 47) and the 10% share of RES-E demanded by 2010(EC D.G. Energy and Transport, 2008).

The most influential direct policy is the "Net meter scheme". This was made permanent with § 2 stk. e in the Law on Electricity Taxes in 2007 after a trial period starting in 1998. The scheme dictates that private producers of electricity with maximum 6 kWp installed capacity can "park" their PV electricity in the grid, and sell surplus production at the same price as they buy electricity from the utilities (Skatteministeriet, 2006), for the price including tax - approx. 1.80 DKK/kWh depending on the district. The scheme also applies to buildings, which are not used for commercial purpose (such as public institutions) where 100 m^2 build area, according to the preliminary documents of the law, equals one private household. Very strictly interpreted this can be considered a subsidy policy, as the producers are excluded from paying the taxes and fees of the electricity, they buy back from the grid. The electricity is sold back to the purchase price even though the price of the kWh only represents approximately 33% of the total price (Dong Energy, 2008). The Net Metering Scheme is specifically for PVs, but it might need to include all types of distributed production later (Windeleff, 2008). The main part of the interviewees is under the impression that the economic incentive in the scheme is too weak to create a direct driver for PV installations in itself. With a production price for kWh solar electricity around 3.5 DKK/kWh, the payback time for the most buyers is higher than the 20-25 years, which is considered to be the time limit for private consumers. This limit of payback time today could be reached with an estimated investment subsidy which starts at 25% and then gradually decreases (Ahm et al., 2006, p. 43). The importance of the Net Metering Scheme should however not be underestimated, as it still represents some incentive for the PVPS owners in terms of sold production. This should be seen in contrast to the other Scandinavian countries, where there are no such compensation schemes (Malm & Stolt, 2007, p. 21)(Bugge & Salvesen, 2007, p. 21). As mentioned in the section on the private end-users the net meter system also adds an additional energy saving benefit, as the owners become more aware of their energy use and competitive in making energy savings in order to be able to sell more to the grid.

In spite of the schemes feature good facets, some criticism and problems have risen with the interpretation from the Tax Agency, who administrate the scheme. Until recently, several family houses/housing cooperatives have had problems with being accepted for the scheme, because there were demands to, that each connected household had a separate meter (accounting for maximum the allowed 6 kWp). This made it troublesome, inconvenient and expensive for building cooperatives and other residential building blocks to use the scheme. This then has worked directly contrary to the advantageous properties of PVPS, which particularly allows electricity production in the densely built cities. There are however recent indications that these troubles will disappear in the future. Based on an inquiry from a project developer, the Parliaments Tax Committee published a settlement in June 2008, which stated that a future project with 424 apartments/households could install a common 565 kWp PVPS and have the production accounted for from a common meter, as the average production per household will be 1.3kWp and thus far below the upper limit of the net meter scheme (SKAT, 2008). This settlement must be expected to be of highest influence on the future administration of the scheme.

Unfortunately, the law also causes some confusion, when it comes to the legal interpretation of the parties entitled to be a part of the scheme. A current case has been the Municipality of Copenhagen. They wanted to put up an installation on their property managed by the Department of Technical and Environmental services, where they among other activities were running a landfill. Due to these commercial activities the municipality is VAT (value added tax) registered and is in the juridical interpretation of the law categorized as a commercial business and hence not entitled to the scheme. This strict interpretation is according to Windeleff (2008), not in line with the original intentions of the law, where the commercial sector was excluded, because they are getting other advantages, such as a cheaper electricity prices and the possibility to write off their physical investments. A more correct interpretation would be to assess whether the institution has the privileges of the commercial sector. This was not the case with the municipality in spite of the fact that it was VAT registered. Such administrative barriers for the scheme should preferably have been sorted out during the latest Energy Agreement, but that wasn't a part of the discussions (Windeleff, 2008).

Besides the Net Meter Scheme a parallel scheme is running, which is based on the new additions to the Tax Law § 57c. This scheme is eligible for all solar energy, wave power, and small scale hydro and biomass producers. In this scheme the producer can sell the PV electricity to the grid at a price of 0.60 DDK/kWh for the first 10 years of production. Thereafter the price drops to 0.40 DKR/kWh for the following ten years (Klima- og Energiministeriet, 2008). This policy is therefore a feed-inn tariff, and it is the existing possibility for businesses, which are not eligible for the net metering scheme. This group has, as mentioned, special favorable purchasing prices for electricity. This means, that even though a feed-in-tariff definitely must be perceived as an incentive, it can not be considered to be an efficient driver for this group, because the production price of the PV power is competing with grid electricity even cheaper than electricity for private households. It is therefore also the impression that the scheme only includes very few PVPS' (Windeleff, 2008).

6.3 Indirect current policies (2008)

Another policy of great influence to the diffusion of PVPS' is the new and stricter building codes based in the EU Directive on Energy Performance of Buildings (EC, 2002) and it's this policy, which has been perceived by the interviewees to be the primary policy driver for implementation of PVPS' at the moment. The building codes and their energy Framework is a measure for a buildings demand of supplied energy for heating, cooling, ventilation and heated water as well as basic lighting for non-residential buildings. Factors of influence are among others the size, direction and location of the building, the climate screen, the utilized heat and hot water source. In the rather complex calculations PV power is multiplied by a factor 2½ and subtracted from the total energy use. This gives the building constructors the opportunity to raise the allowed energy framework of a building (Energitjenesten, 2008b, p. 1). This is especially relevant for luxury houses or houses with large window areas, such as hotels, where a PVPS can come in as an appendix, which keep a building project inside the energy framework and where the alternative otherwise would be to increase the amount of insulation, and decrease the window surface (Kappel, 2008b).

The revised building codes went into force by April 2006 (with a complete up date of the building regulation in February 2008) and presented in the tables below.

Table 6-1 Building codes for private households, hotels, dorms

Minimum standard of compliance with BR08	(**70+** 2200/(area in m2)kWh/m2 per year
Low Energy **Class II**	(**50+** 1600/(area in m2)kWh/m2 per year
Low Energy **Class I**	(**35+** 1100/(area in m2)kWh/m2 per year

Source: Based on (Erhvervs- og Byggestyrelsen, 2008)

Table 6-2 Building codes for industry, schools, offices

Minimum standard of compliance with BR08	(**95+** 2200/(area in m2)kWh/m2 per year
Low Energy **Class II**	(**70+** 1600/(area in m2)kWh/m2 per year
Low Energy **Class I**	(**50+** 1100/(area in m2)kWh/m2 per year (kWh/year)

Source: (Erhvervs- og Byggestyrelsen, 2008)

The minimum standards above represent the mandatory standard of compliance for all new buildings and buildings renovated to above the limit of 25% of the envelope or in a way that increases the public real estate valuation more than 25%. It should be noted that single family houses are excluded from the renovation rules, unless it a case of complete renovation (Erhvervs- og Byggestyrelsen, 2008, p. 7.4.2). The codes are to be tightened by 2010 and it is expected that Class II will be the mandatory standard by then (Energitjenesten, 2008b, p. 2). Furthe more it is expected that the standards will be tightened again with about 25% in 2015.

Even though the building codes are an indirect policy, it is considered to be the policy of outermost importance for the implementation of PVPS' in Denmark at the moment. The figure below is from the Danish Enterprise and Construction Authority and shows the history and expected future development of the regulatory demands to buildings.

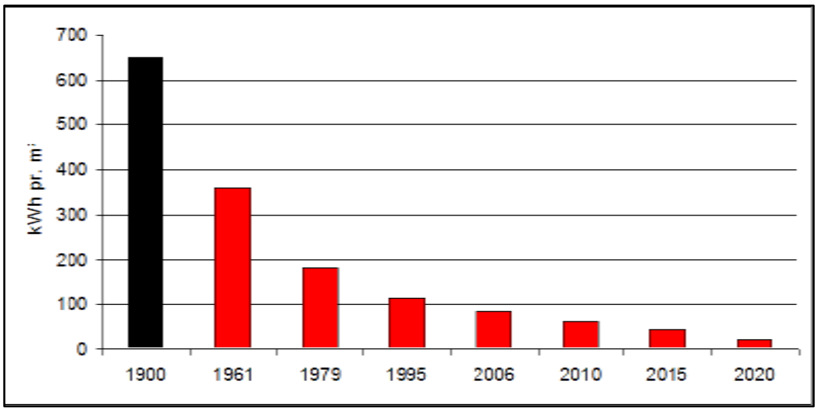

Figure 6-1 Historical and expected development of the Danish building codes
Source: from (Lauritzen, 2008, p. 7)

A comparison with the codes in other countries made by the Enterprise and Construction Authority underlines the ambitiousness of this regulation. In the example of a 150m² one family house, the Danish standard code demands a maximum consumption of 85 kWh/m² The Swedish equivalent is 110-130 kWh/m² and the German 122/Kwh/m², whereas Norway has an energy framework of 136 kWh/m² (Lauritzen, 2008, p. 6).

On the municipal level there are a number of potential policy drivers and barriers present, all of which are regarding spatial planning regulation. A change in the Spatial Planning Act in June 2007, made it, with the inclusion of § 17 stk.22 and §21a, possible for the municipalities to lay down demands to low energy buildings e.g. class I or class II buildings, in certain areas defined the district plan (Miljøministeriet, 2007). In that way the special planning can be a part of the municipal sustainable development or climate strategy. The Municipality of Egedal and the Municipality of Køge are both good examples with large areas on the district plan determined for both class I and class II buildings (S. R. Andersen, 2007). It is however not possible to plan for the use of PVPS' specifically, and is therefore up to the building developers, which measures they want to use to comply with the building codes.

On the contrary, the municipal planning can also create barriers to the diffusion of PVPS', because it can put restrictive covenants on the roof tops of certain housing areas. These can for example demand certain properties for the roofs; color, material etc. Or they can ban changes on preserved buildings. This is especially a problem in central Copenhagen, where the city architecture is rather restrictive with regards to changes on the buildings. However, for most cases with residential houses, the issues can be solved by placing the PVPS on smaller adjoining buildings with flat roofs, such as carports (Windeleff, 2008).

In spite of these special cases, the Danish policies related to PVPS' are considered to be rather flexible, when it comes to integration in buildings and access to grid. Especially the last issue is considered to be a barrier in for example Sweden, where the connection fee itself exceeds the relatively low income from the production (Carlstedt et al., 2008, p. 78). The changes of meters in relation to the Net Metering Scheme are also free at the great majority of the utility companies, even though they are legally allowed to charge a fee. Few cases with conservative companies occurred when the scheme was enforced, but today this is considered to be marginal problem (Beuse, 2008).

6.4 R&D and D funding

The public funding of the research, development and demonstration within the field of energy is coordinated and administrated by various institutions and through a number of programs. PVPS' are politically perceived to be interesting primarily in the long timeframe. It is simply too expensive now, because the current focus is to fulfill the RES-E goals as cost effective as possible (Windeleff, 2008). The focus on research funding is addressed in this section.

6.4.1 ForskVE

As already mentioned in section 4.1.5 the main part of funding available for PV Power systems are administrated through Energinet.dk. With the new Energy Agreement this is primarily done in the ForskVE program, which distributes 25mio DKK/year in 2008-2012 for projects for *diffusion* of PVs, wave power and bio gas[17]. The program is funded via the PSO scheme, where the money collected via a 0.07 DDK/kWh fee, paid by the electricity consumers (Energinet.dk, 2008b).

Guidelines for prioritising between projects have been developed for all included technologies and these are important when directing of development of each technology. For PVs specifically, the following conditions are expected to be op importance in the selection of projects (Benkhe, 2008, p. 10): **1)** Large projects with BIPV systems. **2)** The subsidized systems shall be BIPVs or in other ways have considerable additional value, including energy savings. **3)** No support is given to projects with subsidies of PV products, unless these provide considerable additional value. **4)** Preferably syndicates, which will cooperate on improved market diffusion. **5)** Campaigns which will make house owners invest in PV power systems. **6)** Use of the Net Meter Scheme for private households. **7)** Preferably large business owned systems and the possibility for support of the operation/production. **8)** Prioritizing of outstanding projects as show cases, with demands of grid connection and large production.

So far it has not been determined how much money is reserved to which technologies but all the interviewees are expecting that the program will be of considerable importance to the diffusion of PVs in Denmark, even though there yet not is any specification of how the distribution of money between the different technologies will be.

6.4.2 ForskEL, DSF-EnMi, EUDP(EFP) and Højteknologifonden

In all existing energy research support programs, solar energy as such received about 14.6 out of the total funding of 382.6 mio DKK in 2007(Energinet.dk, Energistyrelsen, Dansk Energi, Det strategiske forskningsråds programkomité for energi og miljø, & Højteknologifonden, 2007, p. 23). When it comes to solar energy the ForskEL is primarily targeting the general development of the different elements in the PVPS. DSF-EnMi is supporting the more strategic ground research in the next generation PV cells, whereas the scope of the EFP (EUDP) program is more on application and integration in buildings and cities (Energinet.dk et al., 2007, p. 23). The **ForskEL** program is, as the upcoming ForskVE, funded by the PSO scheme (tariff financed) and originally restricted to research and development; however since 2007, an extra pool of 30 mio DKK was included for demonstration projects. In 2007 10% of the funding was targeting solar energy as such (no specifications for PV) (Energinet.dk et al., 2007, p. 23). In the tax financed **EFP(now EUDP)** program, a number of projects in relation

[17] Even though the law was finally adopted by the parliament in June 2008, reservations should be made that the support program is not yet notified by the European Commission. This is however expected to happen during the autumn 2008.

to PVs were also granted. In 2007 about 15 mio DKK was distributed to solar energy (as such), which is a considerable increase from 2004-2006, where about 3-5 mio was allocated to solar energy (Energinet.dk et al., 2007, p. 23). In the **DSF-EnMi** program 7.5 mio DKK was allocated to solar energy in the period 2004-2006 (Energinet.dk et al., 2007, p. 23). **Højteknologifonden** did not support any projects on PVs in 2007. Furthermore Dansk Energi (the trade association of Danish energy companies) has the **ELFORSK** program, which is a 25 mio /year fund allocated to energy efficiency projects in for example industrial processes, ventilation and buildings (Dansk Energi, 2008b), where PVs can be a part of the initiatives.

The projects commissioned for PVs varies in scope. A simplified categorization of the scope of the projects which where granted and are still running and ended in 2007, is shown in the matrix below. It should however be noticed, that this does not reflect the distribution of the actual amount commissioned to the different categories and a project on translating a book on architecture and a large ground research on next generation PVs is therefore considered equally.

Table 6-3 PV projects categorized after focus of research

	Developments of the PV technology	Developments connected to the implementation of PVPS'			
Scope of project /research program	PV cells	PV integration (building elements)	Associated electronics e.g. inverter /BOS	Architecture	Others ex. conditions for diffusions and information
ForskEL (granted)	1	1			1[18]
ForskEL (running & ended projects)	7	4	3	1	1
EFP (EUDP)		3	2	2	7[19]
DFS –EnMi	3				
Total, project	11	8	5	3	9
Total, tech. vs Implementation	11		25		

Source: Based on (Energinet.dk et al., 2007)

The table shows that the research projects prioritized, varies considerably in their scope, but that the largest individual category is to be found within the research connected to the development of next generation PV technology. On the other hand there is almost the same amount of projects related to research in integration of PVPS' of other cross cutting projects aiming at increasing the performance and learning in the areas related to the implementation of PV power systems rather than research into the technology itself. Even though this simple overview does not show the actual amount of research money granted for the different categories, it is positive that the prioritization is fairly distributed within the different aspects

[18] This project is funded through the demonstration pool and focus on production of architectural suitable and cost efficient silicium PVPS.

[19] This category includes support for participation in international knowledge networks, educational material, calculation software, PV application catalogue ect

of the technology, because the national potential for learning and thus cost reduction is related to the implementation of PVPS' as discussed in the previous chapter.

The cooperation structure on the R&D level of the current innovation system has been assessed in a conference paper by (Borup et al., 2007), where the governmental R&D spending and actor cooperation within five specific energy technology areas were analysed. An interesting finding from the project is that within the field of PVs, the universities and research institutions do not have a large presence, as they are only involved in 39% of the research projects in the public funded R&D and D programmes. This is less than what is seen in for example the research area of hydrogen and fuel cells (61%) energy efficiency (63%) and bio fuel (58%). Also when it comes to projects with cooperation between research institutions and businesses, the number is small compared to other the technologies. For PVs both actor groups only cooperate in 26% of the projects compared to 40% for bio energy, 52% for energy efficiency and 57% for wind power (Borup et al., 2007, p. 21). It therefore seems like a cooperation gap exists, when it comes to the research and development carried out by the actors in the PVPS business (e.g. the directly implicated actors and the research going on at the research institutions). On the other hand the assessment of the PV innovation system showed that the main part of the research carried out at the research institutions and universities is related to new generation PV cells, which are not mature for the commercial market. The work related to applications carried out by the businesses is on the contrary focused on the generations of the technology already availably, where the silicium cells dominate. The focus of the two groups is therefore different and this could to some degree explain the lack of cooperation between the groups.

6.5 Concluding remarks

This chapter has presented a number of policies of importance to the implementation of PVPS'. When reflecting on the policy framework of the identified Danish PV innovation system it seems clear that both the current direct and indirect policies are targeting the end-users of the technology. For this group both encouraging "carrot policy" and forcing "whip policy" drivers were identified, however not equally strong for all end-user segments. The primary carrot policy is the Net Meter Scheme, which is acknowledged to be of considerable importance by the interviewees from the innovation system, even though it is criticized of being too low to reduce the pay back time of a PVPS to a level, which is acceptable for most private households, which is the segment that traditionally has been the primary end-user segment.

The same can be said about the feed-in tariff, which is the direct policy driver for the commercial sector. Even though it must be considered to be positive, the timeframe of the tariff is long term. For example, it is difficult for potential producers to count on a certain tariff for the first 20 years, as it does not provide a sufficient incentive as PV power is relatively more expensive to the businesses, due to their advantageous electricity retail prices.

An interesting finding in the analysis of the Danish PV innovation system was that the policy, which is considered as being the strongest driver for PVPS' at the moment, is not targeting implementation of the technology specifically. For all end-user segments the building codes are considered to be a major driver for implementation of PVPS'. The driver is expected to be strengthened even more, as the standards are expected to be tightened further in the coming years. They will therefore constitute an indirect whip policy for PVPS', even though it probably was not its initial purpose. It should however be emphasized, that at the moment this driver, primarily affects luxury buildings with a high energy consumption or building projects in areas with special energy consumption demands determined in the municipal policies such as the spatial planning policies. Another reservation to make for this driver is that it only targets new build and buildings renovated beyond 25 %, and that the renovation rule does not apply to single family households unless in the case of complete renovation. A further discussion on the implications of the building codes is presented in chapter 7.

A further issue of importance when discussing supporting policies is whether they support coordination and interaction of the different actors (e.g. what was conceptualized as the learning by interaction in the innovation system in chapter 3). The previous SOL demonstration programs seem to have implied a high degree of cooperation of various actors in the innovation system and resulted in knowledge which has been useable for many links in the value chain, and where many of the issues and barriers related to implementation have been addressed. A recent review of the cooperation structure at the R&D and D level would on the other hand suggest a gap between the research carried out in the research institutions and among the PV businesses, because the amount of projects with participation of both type of actors is low compared to other research areas within energy. This is possibly due to the focus on new generations of PV cells.

This also links to the important question regarding which scope of learning the R&D policies support. The research carried out at the traditional research institutions is to a large degree focused on the PV cells and thus where the learning is connected to the PV technology itself (e.g. *learning connected to production)*. The same must be assumed for the power electronics even though these are a part of the implementation of the PVPS, and this could suggest a problematic prioritization and development, now the biggest national learning potentials and thus cost reductions were identified to be within the implementation part of the value chain. Nevertheless Table 6-3 showed, that a large part of the total funded R&D projects is focused on issues related to the implementation of the PVPS', such as building elements and architecture, which suggest a positive drive for *learning connected to implementation*. At the same time the high degree of business involvement in the R&D could suggest a rather market orientated focus with a strong connection to the real life implementation.

When viewing the policies in the context of the innovation system it seems like there is a need for policy support to encourage actor involvement. Even though there is a good base of committed companies, where many are also active at the research level, it seems like they need support to create a home market to test these new projects. This is especially true for initiatives within BIPVPS', which as described in chapter 5, are facing the largest potential for learning related to implementation. Furthermore is it important to note, that the current policy drivers do not differentiate between the types of systems, which again suggests a more focused policy intervention for the BIPV systems.

An often used method of political support is targetting the end-users. It is outside the scope of this thesis to recommend specific policy instruments, but before getting into that discussion, policy makers should consider which end-user segments to support (e.g. what are the advantages and disadvantages of supporting the different end-user segments and how are they supported by the current policies). To reiterate: if you want to break down the barriers to increased diffusion for the end-users, where would it make the most sense to put effort?

The private end-users segment is, as mentioned, supported by the net-meter scheme, which is important because it increases the market value of the PV power to the price of the electricity purchased from the grid. This is really important because this end-user segment doesn't benefit from the branding value of a PVPS' as opposed to the two other end-user segments (primary the commercial, but also the public sector). This end-user group is also less targeted by the building codes, as they are excluded from the 25% renovation limit which else makes the new stricter building codes apply to existing buildings, and thus can push for implementation of PVPS'.

This means that the payback time becomes very important for this group, and with the current PVPS costs and grid electricity tariff, there is a gap of approximately 25% between the current payback time and an acceptable payback time for this group (Ahm et al., 2006, p. 43). One of the general issues is that the consumption profile of this group is less advantageous, because the production primarily happens during the daytime, whereas the consumption peaks at night when people come home from work and cook, do laundry, and shower. This is obviously not a problem for the end-users, because of the Net Meter Scheme, which figuratively speaking allow them to "park" their PV production in the grid, but it minimizes the positive characteristic of the distributed production. On the other hand the behavioral impact of the PVPS' observed from this end-user segment could be viewed in line with other energy saving initiatives, and it must be assumed that this behavioral change is closely related to the fiscal saving effect. Considering the new ForskVE program this group will possibly not gain a lot, when looking on the intermediate guidelines for funding, unless they get into large coordinated projects.

The commercial sector was identified to be an emerging end-user for PVPS, not due to the direct policy, but because of the building codes and the increased branding drive from the increased climate concern. Contrary to the private sector, this group will be very difficult to support in relation to payback time, because they have the advantageous electricity prices and in general are used to investments with considerably shorter payback time. Still the commercial sector has as end-users, a consumption profile which is a good match for the PVPS' electricity production. This is especially for modern office buildings where architecture dominated by large glass facades faces increased electricity use for air condition at the time where PVPS production peaks.

It could be argued that the commercial sector would have some buildings for applications where the esthetical appearance was unimportant (factory buildings), and it therefore would be possible to obtain lower kWh prices with large standard PV systems. This would nevertheless require an enhanced feed in tariff to make an economic incentive for this group of end-users, which would not be a very political feasible solution with the current political setting. On the other hand the currently emerging branding drive behind commercially deployed PVPS' suggests prioritization of BIPVs, where the need for learning as concluded is largest. On the contrary to the private end-users it looks like the commercial sector could gain from the support of the new ForskVE program, as both large commercial application (even with possibility of subsidies for operation and production) and BIPV show cases are stated to be prioritized.

The public sector is the last end-user segment and it is supported by both the net-meter scheme up to 6kWp and the stricter building codes. This end-user segment is however still facing special economical and procedural barriers in form of tight budgets, division between construction and operation departments, as well as a general larger degree of time consuming and complicating administrative management. On the other hand the opinion of this author is that this end-user segment should be a future target of policy support because of its multiple benefits from the diffusion of PVPS'. As is the case for the commercial sector consumption profile of many public buildings (e.g, kindergartens and schools) is matching the production from the PVPS with peak consumption during daytime, and little consumption in evening and night. At the same time many of these public buildings (constructed by the expansion of the public sector in the beginning of the 70's) is about to go through a comprehensive renovation, which would be a good occasion to integrate PVPS' in the building projects and take advantage of the substitution and multi function possibilities of the systems. That being said, support to break down the barrier of budget division would most possible be for the benefit of the public sector in the long run, as the investment would save money for electricity on the operation budget for a timeframe of the 25 years a PVPS is expected to work.

A somewhat softer and more ideological perspective is connected to the pedagogical aspects related to implementation in the public sector. Deployment at schools for example would make it possible to increase the knowledge of and interest in the technology (e.g., displays in the aula showing production and CO_2 savings and by integrating it into the teaching). In that way support of the public end-users might be a way to deal with the lack of knowledge identified in the innovation system. Support for the public end-users would thus both be an opportunity to increase the knowledge and interest of PVPS' in the population, support the actors in the PV business with a national home market and increase the learning connected to implementation to drive down the cost.

7 Conclusions and discussion

The aim of this thesis has been to contribute to the understanding of the complex PV innovation system in Denmark, with the goal of identifying the characteristics and the primary drivers and barriers for diffusion that the actors are facing. The high cost of the PVPS', and consequently the high cost of the generated power, is acknowledged to be the major barrier for diffusion of the technology. An important part of the work has therefore been to assess how the total end-user cost of the final system is distributed between the different links in the value chain. This has been done in order to understand which elements that are within the scope of learning, and thus where the cost reduction potential is connected to the production of PV modules, as well as where the cost reduction potential is connected to the implementation process. This chapter draws up the major conclusions and findings related to the research questions. It is based on the concluding remarks of the different chapters. Under each of these sections there will be cross cutting discussions with perspectives on the knowledge level in the DK PV innovation system, the identified sources of and the DK potentials for business development, as well as on the identified policy instruments.

7.1 The Danish PV innovation system

This section relates to the first research question - What are the characteristics of the Danish innovation system for grid-connected Photovoltaic Power Systems (PVPS')? The major findings on characteristics of the Danish innovation system for PVPS' are;

- The PV innovation system in Denmark is emerging and many groups of actors are involved. The market is growing with new segments of end-users in parallel with a general climate concern in society, but at the same time there are indications of a lack of knowledge and experience within the group of entering actors in the PV business, which mainly is in the projecting link.

- A number of businesses have emerged in the Danish innovation system – most related to the implementation of the PVPS. The national market is still limited and the specialized actors either do a major part of their work abroad or have PVPS as a part of broader sustainable building portfolio.

- The energy sector is somewhat divided in their dedication. PVPS' are uninteresting due to the high production cost, but PVPS' are on the other hand interesting from a customer relation point of view and possibly as a part of an ESCO business model.

- The system is characterised by a combination of a "small world" where the actors know each other from projects and a lack of organized cooperation and communication between these actors.

- The high cost is the major barrier for all segments. In particular for the businesses due to their advantageous electricity prices and exclusion from the Net-meter scheme, but also for the public sector due to the fragmentation in their administration and the tight budgets of the municipalities in general.

- A number of NGOs are present in the innovation system, but there's no specific communication or coordination strategy.

7.1.1 Knowledge and attitude

This thesis has showed a growing number of end-user segments that are emerging in the Danish PV innovation system, as a result of the building code, spatial planning and a general climate/energy concern. The cost barrier is still an important issue, but also softer aspects such as the knowledge and attitude towards PVPS' should be taken into account when discussing the diffusion possibilities for PVPS' in Denmark

Lack of knowledge about the properties and functionality of PVPS' within the public and thus the potential end-users is another characteristic found in the innovation system. This is an issue of importance because the end-users are outside the traditional energy sector, who have limited interest for the technology from a production point of view, as concluded in chapter 4.

It's difficult to give a complete explanation for this, as there actually are several grassroots and NGO's touching upon the issue. There is on the other hand no coordinated communication effort and the technology is not that visible in the media. The same is the case for the political debate, where little attention has been paid to the technology since the change in government in 2001, where cost competitiveness became the main criteria for the priorities within renewable energy. An interesting point in this respect is that the political acknowledgement was perceived to be one of the most important non-policy drivers for wider diffusion by several actors from the innovation system.

It is, in other words, important that the government communicates that PVPS' are a viable and maturing technology, understood in the sense that the crystalline based systems are functioning, predictable and usable already in today's energy system and thus has other potentials than powering off-grid summer houses and small electrical appliances. Such an acknowledgement would naturally not have any effect on the high cost or the problems related to the complex implementation process, but on the other hand it would support the already existing Danish goodwill towards solar energy and increase the legitimacy of the technology.

A political trend across all parties in the parliament, which on the other hand have benefited from the diffusion of PVPS' in Denmark, is the increased focus on climate and energy issues in general and in relation to the 15^{th} IPCC conference specifically. In that context PVPS' is a manageable and very visible way for businesses in the commercial sector and institutions to symbolize climate concern, which according to one of the major projectors have caused a boost in the market lately. These showcases are interesting because the electricity production consequently becomes secondary to the symbolic value. This concept would naturally be more widespread if the cost of the system decreased, as in general, the longer their estimated payback time the less aware the commercial sector is of these opportunities,

The rise of climate and energy on the public agenda is possibly also the reason behind the indications of a somewhat increased political attention with the prioritization of the 25 million demonstration pool targeting PVPS among other small scale renewable energy technologies, mentioned in the previous chapter. Solar City Copenhagen is under the impression that the changes in the public agenda also are increasing the media's attention towards the technology.

7.2 Cost distribution and sources of cost and DK reduction possibilities

The major findings for the second set of research questions "How are the estimated costs distributed along the value chain of a PV's system?" and "Where are the sources of cost and the Danish cost reduction potentials?" are presented below:

- The cost distribution between the technology and the implementation varies considerably for PVPS'. Cost reductions related to implementation of the PV modules are therefore important for a total cost reduction: Moreover, cost reductions related to implementation are related to national learning and can be supported by national policies.

- Add-on standard systems are perceived to have the lowest cost for retrofit projects; whereas building integrated PVPS' can result in equal or lower costs, when it comes to renovation or new build projects. This is primary due to substitution of alternative roof and facade materials, but also due to the perception of double functions of the PVPS' as for example sun-screens and as holding communicational value. Special designs and architectural demands drive up the cost, but these should be weighed against the additional values of such systems.

- Factors causing increased costs in relation to implementation are: the number of actors involved the experience of the involved actors and communication and coordination process among them. This is particularly the case for building integrated PVPS projects where the contractors generally have less experience and where there is more design and architecture involved.

- Learning from experience among the actors and simplification and coordination of the projects and processes are target areas for policy intervention in relation to cost reduction.

7.2.1 Cost reductions and the impact of the projecting link

A starting point for this discussion would be to acknowledge that even though the cost reduction potential related to the modules is perceived to be great, and even though the data from this thesis shows that the modules contribute to a considerable share of the final system cost, there are for PVPS' a lot of other elements determining the final system price. Because these issues are related to the implementation of the technology and not the technology itself, it is not a valid solution for Danish Policy makers to wait with learning and experience gathering of PVPS' until the international cost decrease on the modules occur as predicted by learning curves for example (as shortly described in chapter 3). This is because of the connection between the cost reduction potentials and the geographical orientation of the two different types of learning, where the primary arena for the implementation part of the value chain is national.

When analyzing this in the context of the findings from chapter 4 and 5 it appears that the possibilities for cost reduction in Denmark should be found primarily within the implementation area. This is because the amount and magnitude of actors contributing to the international learning connected to the production of the PV technology for the international market is minor, but also because a large, although varying, share of the final price is related to the implementation of PVPS', and the majority of this is happening in a national context. This consequently means that it not will be possible to transfer all needed experience in this area from other countries, because much of this is directly related to a national context, like building tradition, regulation, administration, attitude and culture – all of which are issues where lack of experience increase the costs.

Another related perspective is that if the Danish policy makers wish to fully benefit from the future cost reduction related to the technology itself, learning within the national implementation area is required to discover and manage barriers and costs related to national conditions and policies. Otherwise, these will still constrain the diffusion in the future. Besides that, the whole industry development perspective should be emphasized, because it holds indications of several Danish business opportunities. This is discussed further in the next section.

It should be considered positively when a finding from chapter 4 indicates that the attitude towards PVPS' within this group is changing. Still it is interesting and important to reflect over how this change could affect the cost issue and thus implementation. Naturally an increased interest from the projecting actors must be considered as an important driver. On the other hand, the market is still small and the actual number of projects available in Denmark limits the possible experience of the increasing number of actors willing to carry out PVPS' projects. This means that the coordination and communication problems probably won't decrease in the short run. On the other hand the positive attitude from this group of actors could help to prioritize and pay attention to possible demands for the system earlier in the implementation process, and thus avoid some of the costs related to failures and uncoordinated processes.

The increasing number of agents in this category could also have a different impact on the cost issues. From a pure market perspective one would assume that an increasing number of actors on the market also would increase the competition and therefore decrease the prices for the end-users. On the other hand it would be naive to think the sudden change in interest from these actors is emerging by pure coincidence. As identified in the previous chapters this interest has grown in parallel with the rising climate and energy concern in society in general. In this context the PVPS' are to an increasing degree implemented for image reasons by new end-user segments such as the commercial sector. The point therefore, is that these projects are carried out where the high tech image and climate symbolism is one of the main concerns and where the projecting actors consequently are able to market PVPS' as unique climate projects, which require extensive time use. By framing PVPS' as special technical features instead of just an alternative building element, these actors could be able to make a considerable profit from the projects. This limits the actual cost reduction for the end-users and the attained learning would not necessarily contribute to a breakdown of the cost barrier as much as actually possible. The difference between the cost and price is a general problem within the field of PVPS' especially on the international market where the market price has been affected by a shortage of silicon the last years and a massive demand for PV modules from countries with strong supporting schemes such as Germany, according to the interviewees, has contributed to a pricing disconnected from the actual cost of the technology. It's naturally outside the scope of this thesis to go into the dynamics of the international market, but the idea is to underline the importance of the actor and market dynamics and that the new climate framing of PVPS' could have contradicting effects in the national context. Obviously it should be considered as an important driver for implementation and thus learning, but also it has somewhat moved the perception of PVPS' from being a renewable electricity production technology with various technical and environmental advantages, towards being a symbol of climate concern used as displays of dedication. This change might consequently contribute to an increased gap between the cost of the PVPS and the price the end-users must pay when they are willing to pay for the symbolism of the PVPS'. If that's the case it might take a while before a cost shakedown will occur, and the increased learning connected to implementation will affect the end-user price as much as the cost of the PVPS.

7.2.2 Potentials for industrial development

In chapter 5, a number of factors complicating the implementation process and determining the cost was identified. Based on the findings it is relevant to discuss where the Danish potentials for strengthening the diffusion of PVPS shall be found – in other words: Which potentials can be used to enhance the existing innovation system and deal with the identified barriers.

The interviews leave the notion that there seems to be two general opportunities for development in the Danish system, both of which have simplification as the key issue, and where efforts are presently in the research state. An important factor is, as already touched upon, which types of PVPS should constitute the future of the Danish implementation. An important characteristic is that the Danes have higher aesthetic demands for the PVPS' than the end-users in neighboring countries such as Germany and Sweden (Nielsen, 2008)(Aarø, 2008a). Whether this is specifically for PVPS', due to the negative image of the thermal solar systems, or whether it is a general attention towards these issues in the building culture cannot be determined. Building integration and thus, industrial development in this field is perceived to be essential for a wider diffusion of PVPS' in Denmark. In the same way industrial development sets the difference in building traditions limits to how much can be directly transferred from other countries, both when it comes to knowledge and when it comes to actual artifacts, such as mounting systems. This result in a situation equal to the case for efficient windows, where more efficient products are available in Germany and Austria, but where the lack of adjustment to Danish design and standards make building contractors choose Danish products of lower quality (Poulsen, 2008). A business opportunity is therefore available for developing industrial design within a tradition that is more focused on the visual impression and Danish building characteristics. Suggestions to this have been to integrate PVPS' into existing and well known building materials such as tiles, windows or full surface elements. This is, as mentioned, the case for some of the R&D projects currently going on, but a couple of these combined products are already produced by Danish actors. Examples of this is Danfoss, who produces PV driven water pumps, and the window manufacturer Velux, who already has thermal solar solutions, but who now promotes a PV window on the southern European markets (Energistyrelsen et al., 2003, p. 7,15).

This kind of development would not only be important to the wider diffusion of PVPS in Denmark, but would also be able to contribute to the Danish economy. The contribution could be in terms of job creation and be to provide a niche for export in the international market. This is contrary to the current situation, where the amount of jobs in the sector is relatively low due to the large import of standard module systems. It therefore seems obvious to draw on Denmark's current international position in energy technology, system development and industrial design (Energistyrelsen et al., 2003, p. 7). In 2005 Denmark had a 39 billion DKK export and the annual growth in the sector was far beyond the general growth in export between 1996 and 2005 (Ahm et al., 2006, p. 27). The combination of existing quality products and PV technology might therefore be the Danish possibility to enter the international PVPS market, which otherwise as described, is dominated by large and consolidated industries.

An alternative to this niche would be to continue the import of modules, but focus on a wider standardization of the mounting systems related to integrated systems – an issue which has already been touched upon in the "Rationel Montage" research project (Esbsen Rådgivende Ingeniører, 2006). As identified in chapter 5 the BIPV projects usually have a higher share of cost related to installation and projecting, because these projects are customized, as standardized systems for BIPVPS' adapted to the Danish market are not available. The BIPV systems seem to have a reduction potential in simplification and standardization of the processes. For this sort of system the potential would primarily be within the design and craftsmanship related to installation, and important factors are still experience and the learning processes in relation to the involved actors

For integrated standard solutions, the potential of the pre-fab housing sector should be emphasized, because such development could decrease a large share of the cost related to the lengthy building chain and the complex interaction among actors. There are several projects going on already, and a new example of this is the roof solution company Komproment Aps, which in September 2008 via the home improvement retail store STARK, marketed their concept roofs in an "energy" version, which can include solar thermal or PV modules. The customers are however recommended to choose the thermal solar solution, as it has better economy for the time being (STARK, 2008).

In the same way will it be interesting to see whether PVPS could be a part of a future ESCO concept for the utility companies. As mentioned in chapter 4, such a concept could reduce some of the barriers, especially to the public sector. On the other hand, the long pay back time of PVPS should be kept in mind. This means that it would require some long-term contracts for the ESCO companies to invest in the PVPS, and it is likely that the technology therefore wouldn't be the first choice for investment in energy saving solutions.

7.3 Current policies for support and diffusion

This section focuses on the issues relating to the third research question of "how do different current policy instruments support the diffusion of PVPS' in Denmark?" The major findings are:

- The primary direct policy driver today is the net-meter scheme, which is eligible for private end-users and institutions. This is considered to be of great importance. The direct policy driver for the commercial sector is a feed-in tariff, but it's too low to constitute a primary incentive for implementation, due to the advantageous electricity prices for this sector.

- The building codes constitute a strong, although indirect, policy driver for PVPS', and the effect is expected to increase, as the code gets tightened in the near future. At the moment it is primarily luxury building projects such as hotels or offices with large window areas that are driven by the codes. Since the municipalities were allowed to include energy consumption demands in their spatial planning and as some demand the energy saving standards in their internal guidelines, the drive through the building codes is increasing. It is however important to notice, that the building codes only apply to new builds and renovations covering more than 25% of the envelope (single family houses are included in by this rule only in case of total renovations)

- None of the policy instruments are specifically targeting BIPVPS', which has a large share of cost connected to implementation and where the national reduction possibilities therefore are higher, but also where the additional value of the PVPS is greater.

- The research on PVPS is targeting both the technology itself and the implementation of it, but there appears to be a lack of cooperation between the actors in the research institutions and the research carried out in the PVPS business.

- The new ForskVE program will increase the possibility of projects related to diffusion, building integration and projects for the commercial sector and also aim to encourage actor cooperation. It's not to say whether the granted funding is sufficient as it is an undifferentiated part of a bigger pool for small RES-E technologies, and the program is currently limited to a four year period.

- The public sector should be considered in case of increased policy support for end-users, due to their administrative barriers, forthcoming renovation process and values related to education and information.

7.3.1 Direction of current policies

A very basic finding from chapter 5 of this thesis was that the total cost as well as the cost distribution for a PVPS varies a lot depending on a number of factors, where the question is whether the system should be add-on or integrated, retro-fit or applied on new build. These questions are also of high importance when it comes to discussion of the Danish potential and how they are supported by the current policies. When we design policies we therefore need to decide what kind of PVPS' to push for Denmark and on which types of buildings we want PVPS to be installed. None of the direct policies (e.g., the net meter scheme and the alternative feed-in tariff differentiates between the system types (The only rule is that it should be below 6kWp) or the state of the building. Such differentiation is seen in for example Germany, in Italy and in Switzerland, where the feed-in tariff is differentiated depending on the size and type of system, with the highest tariff for the BIPVs and the lowest for the large ground mounted free field systems(PV Policy Group et al., 2006). This differentiation the supporting policies consequently take into account the difference in system costs.

When making a pure economic calculation, the Danish policies foremost push for implementation of standard add-on and retrofit PVPS', which makes the standard add-on systems the cheapest per Wp. The incentive distribution of integrated versus ad-on systems is too a large degree the same when it comes to the major indirect policy drivers - the building codes and the municipal spatial planning. The somewhat different result of the two policies is however, that the building codes only affect new build and extensive renovation, and this means that the building integrated systems can turn out as an equally cost intensive solution, due to the finding of chapter 5, that BIPVPS' can be equally cheap to use in new build if substitution of material, double functions and preparations in the building is managed properly.

The fact that the building codes constitute a large driver for the implementation at the moment can have both pros and cons for the diffusion and direction of PVPS'. It's found that for the time being, it is primary the hotels and private and commercial luxury buildings where PVPS' come in handy when struggling to comply with the standards. These projects normally have larger budgets, which could give room for interesting architectural solutions and utilization of substitution, double functions and communicative effects. On the other hand it was the impression of several interviewees that the PVPS' in many of these projects are nothing more than an extra appendix to the project, which is not included in the project before it is realized that the building will have problems complying with the standard. In the end of such processes a standard add-on system could provide an easier solution.

Another aspect of the discussion is naturally in what context we would like the technology to diffuse. The drive from the building codes results currently in a development, where PVPS' are helping the new buildings with the highest energy consumption to comply with standards, instead of the encouraging the technology to be used in a general context towards more energy efficient buildings. On the other hand this should obviously be seen in the light of a future tightening of the codes, which will increase the general energy efficiency demands further, and promote growth in municipal initiatives which utilize the new opportunities in planning policies.

8 Recommendations and sum up

It's generally acknowledged that policy support can help to support the diffusion of renewable energy technologies that are not yet competitive on the market. In line with this, this thesis has pointed to the high cost, as well as the complex innovation system to be the major barriers to diffusion of PVPS, both in general and in the specific case of Denmark.

This thesis draws attention to the importance of understanding the subsequent characteristics, drivers and barriers in the innovation system where the policies should be used, as well as to how the general climate concern and the existing policies impact the diffusion. Still, when high cost is determined to be the major barrier for diffusion it is, as underlined in this research, important to consider the scope of the cost and the learning required for cost reduction (e.g., to increase the level of detail and consider what the origin of the costs is, and how this should be taken into account when constructing policies to support PVPS'). A high share of the cost is connected to the technology itself, but a considerable although differentiating share of the cost is connected to implementation. Therefore a cost reduction for that share will only be possible with learning and experience by actual deployment of the technology, and that is where the national policies have the possibility to support the development.

The largest national cost reduction potential is found within the BIPV systems, because they often have a higher share of their cost connected to the implementation, but also because these projects suffers the most from the lack of experience and a lengthy and complex building chain. Still none of the current policy instruments are encouraging the use of these systems specifically. At the same time also the primary commercial development potential for the current Danish PV business is assumed to be within the building integrated systems. This is where it would be possible to utilize Danish competences within industrial design and product integration to simplify and standardize building integrated systems, but even with such new PV building element solutions practical experience in a home market will be needed. A more focused policy support on BIPVs could also emphasize and communicate the opportunities of substitution, double functions, and architectural opportunities, which are the other advantages with this type of system. Some support might come with the ForskVE program, but as many uncertainties are still present with regard to available amount and granting priorities, it's recommended to do a follow up these issues.

8.1 Further research

The research on cost reductions for PVPS' is, as mentioned, primarily focused on the technology specifically and not on the cost reduction potentials related to the implementation part. Further research is needed in this area to get a more in-depth understanding of the dynamics of cost reduction related to implementation and how this can be supported by national policies. While this thesis is limited to the existing Danish policies another interesting issue for further research would be to investigate how international experience with different models of policy intervention affect the path of development for implementation in different national PV innovation systems. Also a more cross technological study would be interesting in order to compare how the innovation system characteristics, distribution of cost and national learning potential differentiates for different renewable energy technologies and thus how policy instruments could be designed based on that knowledge.

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Other

Solar city Malmö seminar (2008, May 25) Solceller i stor och liten skala

Appendix 1; Basic structure of interviews

The basic interview questions were used as the general framework to guide and structure all conducted interviews. The interviews was, however, of semi-structured character, which means that a number of general discussions, points and follow up questions was included as well. In the same way were not all themes equally relevant for all interviewees, and the questions were naturally also adjusted along the process. The interviews were conducted in Danish and the questions presented below are thus translated.

Intro-question

Can you shortly explain position and purpose of your organization; it's relation to the DK PV innovation system and your position within it?

Actors of the PV innovation system

Which actors are, in your opinion, the most important for the Danish PV system? Why?

Are there any networks formal/informal which you consider to be of importance for the PV system? Why?(DK and international) Are they influential? → Where and how?

Are there any actors, networks or institutions you feel is missing in the Danish innovation system??

Cost distribution & sources of costs

What do you consider to be the different sources of cost related to implementation?

Are any of these specific to DK?

Where in the value chain of the PVPS, do you see the biggest sources of cost?

Where in the value chain do you see the biggest potential of cost reduction?

Can you give an estimation of how the costs are distributed across the value chain of a PVPS? (Firm specific) Concerning the operations you carry out, can you give suggestions of what makes the costs? (Economically and in time consumption)

(The difference between the different generation of PV's –what's used and available??, how will it make a difference to the distribution costs?)

Policies

Which policies (info, subsidies etc) are, in your opinion, most influential on the current PV system? Why? (Promoting and discouraging? Direct/ indirect)

What is the R&D funding / Grants of special influence?

Public attitude

How much is PVs/PVP'S a part of the public agenda/ debate and are there any main issues/ framings that are continuous?

Do you have an impression of the general public's attitude (norms/beliefs) towards PV's (how's the attitude towards PVs/PVPS'

Has it changed/ is it changing?

Political attitude

How much is PVs/ PVPS' a part of the political agenda/ debate and are there any main issues/ framings that are continuous?

Do you have an impression of the attitude (norms/beliefs) towards PVs/PVPS'?

(Are some RES-E technologies found more accepted than others?)

Has it changed/ is it changing?

Outro-questions

Going back to our previous discussion on the current PV system, what do you think will be the determinate drivers/ barriers to further positive development/success?

With perspective to the rest of the Nordic countries, do you have knowledge on whether their PV innovation systems are different in any significant ways? How?