CHALMERS

The effects of a Swedish investment support for photovoltaics on public buildings

An analysis of the dynamics of the innovation system

Master of Science Thesis

JOHANNA PORSÖ

Department of Energy and Environment
Division of Environmental Systems Analysis
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden, 2008

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Division of Environmental Systems Analysis
Department of Energy and Environment
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone + 46 (0)31-772 1000

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Abstract

The investment subsidy for PV (photovoltaics) installations on public buildings started in May 2005 and will end in December 2008. The aim of this thesis is to evaluate the impact of the investment subsidy on the dynamics of the PV innovation system. By identifying inducement and blocking mechanisms for further growth, the thesis also aims to give input to the discussion on how to continue supporting the PV innovation system.

A major observation made is that the Swedish innovation system for PV actually consists of three isolated subsystems: research and solar cell production, PV module manufacturing and PV system installation. It is shown that the two first mentioned subsystems are not affected by the investment subsidy and that their major driving force is the strong world market for solar cells and modules. The subsidy has, however, had a significant impact on the subsystem around the PV installations, as it has created a market space for PV installations. This has led to an increasing amount of firms working as PV consultants and PV system installers.

The subsidy has also led to an identification of a range of institutional problems affecting the subsystem around PV installations. These include the high costs of grid-connection, the Public Procurement Act, building permits and decisions made by the National Heritage Board concerning PV systems on churches.

Concerning a future policy to strengthen the innovation system for PV some issues are discussed in the thesis. Firstly, the entry of actors should be encouraged in order to develop the system. A future policy should aim to broaden the actor base and include actor groups which are not present in the innovation system today, e.g. the construction sector and the energy sector. This could be done by stimulating the development of a solar electricity market, including system buyers that do not have to comply with the Public Procurement Act in a future investment subsidy scheme, encouraging building integrated PV solutions and integrate knowledge about PV in educational programs related to the construction sector. Furthermore, a very important aim should be to make the policy long term in order to reduce the uncertainty for the involved actors.

Secondly, an important point is knowledge development and diffusion. In order for the knowledge acquired by the actors involved in PV installation to be utilized, repetition should be encouraged. Knowledge development is also connected to platforms where actors can meet. These platforms, e.g. seminars, make it possible for the actors to share knowledge and discuss problems.

Thirdly, the Government should aim at a policy with as high efficiency as possible, i.e. a policy that produces most in terms of value in relation to the resources spent. Values for the system buyer include the amount of electricity produced but also other diverse values like PR and goodwill. By choosing a support level that is low enough the system buyers will be forced to take such values into account, as the investment will not be economically profitable by only accounting for the electricity produced.

In the end, a subsidy can only be justified by the value it creates for society. The values gained are that knowledge and legitimacy are built up around a technology that could be of great importance for energy supply, the environment and industrial vitality in a not so distant future. The creation of a complete innovation system structure is of value, where all the relevant actor groups are represented. With the current subsidy the results have been mostly connected to the installations, but the aim should be to make a positive impact in the whole industry.

Finally, the thesis concludes that there are many issues to target simultaneously from different angles concerning the development of the PV innovation system. The investment subsidy is only one of them. There are additional actions that should be considered in parallel in order to drive the industrialization of PV in Sweden further. But a continued market support program is essential to keep the subsystem around the PV installations going. With some modifications a

broader range of actors can be stimulated to get involved increasing the breadth and pace of development.

Sammanfattning

I maj 2005 startade ett investeringsstöd för solcellsinstallationer på offentliga byggnader, vilket kommer att pågå till och med december 2008. Syftet med det här examensarbetet är att utvärdera effekterna av stödet på dynamiken hos innovationssystemet för solceller i Sverige. Drivkrafter och blockeringsmekanismer för en vidare utveckling av systemet kommer att identifieras med syftet att diskutera hur man fortsatt kan stödja innovationssystemet.

En viktig iakttagelse är att det svenska innovationssystemet för solceller består av tre isolerade delsystem: forskning och solcellsproduktion, produktion av solcellsmoduler och installation av solcellssystem. De två första delsystemen visar sig inte vara påverkade av investeringsstödet, då deras huvudsakliga drivkraft är den starka globala marknaden för solceller och moduler. Stödet har däremot haft effekt på delsystemet runt soclellsinstallationer, där en marknad har skapats. En följd av detta är en ökad mängd företag som arbetar med konsultverksamhet kopplat till solceller och systeminstallatörer.

Stödet har lett till identifiering av en rad olika institutionella hinder vilka påverkar delsystemet kring solcellsinstallationerna. Dessa hinder innefattar offentlig upphandling, höga kostnader för nätanslutning, bygglov och beslut tagna av Riksantikvarieämbetet angående solcellssystem på kyrkor.

Med avseende på val av framtida politiska styrmedel för att stärka innovationssystemet finns det ett antal punkter som bör tas hänsyn till. För det första, bör olika aktörers inträde i innovationssystemet uppmuntras. Ett framtida stöd bör syfta till att bredda aktörsbasen och inkludera aktörsgrupper som inte är närvarande i systemet idag, t.ex. aktörer inom byggsektorn och energisektorn. Möjliga insatser som kan göras är att skapa en marknad för solel, inkludera köpare av solcellssystem som inte behöver tillämpa lagen för offentlig upphandling, uppmuntra byggnadsintegrerade solceller och att inkludera mer kunskap om solceller i utbildningar med anknytning till byggsektorn. Dessutom är det viktigt att framtida stöd är långsiktiga, för att minska ovissheten för de inblandade aktörerna.

För det andra är kunskapsutveckling och kunskapsskridning en viktig aspekt. För att kunna använda kunskap som förvärvats av en aktör under en solcellsinstallation bör repetition uppmuntras. Kunskapsutveckling och kunskapsspridning är också kopplat till forum där aktörer kan mötas. Dessa forum, t.ex. seminarier, gör det möjligt för aktörer att dela med sig av sin kunskap och att diskutera problem, vilka har uppmärksammats som ett resultat av en ökad mängd solcellssystem.

För det tredje bör målet från statens sida vara att skapa ett stöd med så hög verkningsgrad som möjligt, d.v.s. att stödet leder till skapande av så mycket värde som möjligt i förhållande till de resurser som används. Värdet för en systemköpare inkluderar elen som produceras men även annat såsom PR och goodwill. Genom att välja en nivå på stödet som är låg nog tvingas systemköparna att reflektera över dessa värden, då de inte kan räkna hem investeringen genom att enbart ta hänsyn till den el som produceras.

Slutligen är det dock värdena för samhället i stort som måste kunna motivera existensen av ett stöd. Dessa värden består av kunskap och legitimitet som byggs upp kring teknologin, vilken skulle kunna vara viktig för energiförsörjningen, miljön och industrins livskaft i en inte så avlägsen framtid. Dessutom är skapandet av en struktur inom innovationssystemet, i vilken alla aktörsgrupper är representerade, av värde. Med det existerande stödet har dessa värden framförallt kopplats till själva solcellsinstallationerna, men målet bör vara att värden skapas för hela innovationssystemet.

Sammanfattningsvis vill det här examensarbetet visa på att det är många områden som bör ses över med avseende på att utveckla innovationssystemet för solceller i Sverige. Investeringsstödet är bara en del. Det finns ytterligare åtgärder som bör behandlas parallellt, men en fortsättning av investeringsstödet är nödvändigt för att delsystemet kring installation av solcellssystem ska överleva. Med lite modifikationer av dagens stöd, kan olika aktörer stimuleras att bege sig in i innovationssystemet vilket kan leda till att systemet breddas och att utvecklingstakten ökar.

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Glossary

BIPV	Building integrated PV
CIGS	Copper-indium-gallium-diselenide thin film solar cells
IEA	International Energy Agency
IEA PVPS	IEA Photovoltaics Systems Programme
PV	Photovoltaic, solar cell
PVT	Photovoltaic thermal
TIS	Technological innovation system

1 Introduction

The issue of climate change is continually gathering more and more global attention. Although the topic was once considered vague and controversial, today it is more or less agreed upon as a fact. As a result of the increased awareness of climate change, interest in renewable energy technologies, e.g. technologies that retrieve energy from solar radiation, has increased. As long as the sun shines it will provide the earth with energy. Solar thermal installations give us heat and solar cells, or photovoltaic (PV)[1] installations generate electricity. The latter will be the focus of this thesis.

The market for solar cells is growing rapidly, as demonstrated by the fact that the average annual growth in the world over the last ten years has been almost 40 percent (Malm, 2007). At the end of 2006, the cumulative installed power capacity had reached almost six GW within the IEA PVPS reporting countries.[2,3] However, this growth varies significantly between different countries and Germany and Japan alone accounted for 82 percent of the capacity installed during 2006 (PVPS, 2007).

In Sweden, the installed capacity of PV systems to date has been modest. IEA PVPS identifies four primary applications for solar cell power system: off-grid domestic, off-grid non-domestic, grid-connected distributed and grid-connected centralized. The majority of installed PV capacity in Sweden belongs to the first application, typically on private houses far from the electricity grid. However, it is grid-connected distributed PV installations that have been of the greatest recent interest, accounting for almost 84 percent of the cumulative installed capacity in the IEA PVPS reporting countries by the end of 2006. These kinds of applications have also been of increased interest in Sweden.

One significant barrier for the PV technology is that the electricity generated still is very expensive compared to electricity from other energy sources, when accounting for the cost of the installation. This fact makes the present market for PV strongly dependent on regulatory policies in order to make PV competitive.

Such policies can take various forms. The country which has been the most successful in encouraging PV installations, measured in terms of the capacity of PV installed, is Germany. Germany has implemented feed-in tariffs, meaning that, depending on the size and location of an installation, the producer is guaranteed a certain price for the electricity with a bonus if facade integrated (BMU, 2007).

In Sweden, an investment subsidy for PV on public buildings or buildings housing public activity was launched in May 2005. The cap for this subsidy scheme was initially set to 100 MSEK but was later increased to 150 MSEK. This subsidy for PV is part of a larger subsidy scheme supporting investments to make public buildings more energy efficient and for conversion to renewable energy sources. The investment subsidy supports 70 percent of the investment costs of a PV projects to a maximum of 5 MSEK per building (Riksdagen, 2007). The investment subsidy is planned to continue until the end of 2008, but the money is very likely to run out before that. At the end of 2007, 148 MSEK and 114 projects were approved (Boverket, 2008); thus the money is almost totally spent one year before the support program ends.

[1] Solar cells and photovoltaics (PV) are different names for the same thing. In this thesis PV will be used mostly when talking about the technology in general and solar cells when meaning the actual solar cell specifically, in contrast to PV modules which are assemblies of solar cells.

[2] This figure can be compared to the cumulative installed capacity of hydropower in Sweden in 2006, which was ca 16 GW (Nordel, 2007).

[3] IEA Photovoltaics Systems Programme (IEA PVPS) is a collaborative R&D agreement within the International Energy Agency (IEA). Long-term participating countries are Australia, Austria, Canada, Denmark, France, Germany, Israel, Italy, Japan, Korea, Mexico, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, the United States. Recently Malaysia and Turkey joined (PVPS, 2007).

1.1 Purpose

The investment subsidy will soon end and a decision must be made on how to continue. To this end, the existing scheme needs to be evaluated, in order to determine what was good about it, and also to learn from any mistakes. The purpose of this thesis is to analyze the impacts that the investment subsidy has had on the Swedish PV industry. The PV industry is defined here to include all the actors in the value chain: from solar cell producers to electricity consumers. Additionally, this thesis will identify challenges that need to be addressed and discuss possible actions in order to strengthen the PV industry.

1.2 Research questions

The purpose is broken down into sub-parts in the form of three research questions, in order to make it more manageable and give the thesis a logical structure. One way to approach the issue is through innovation theory, but the questions will first be formulated using everyday language:

1. What does the Swedish PV industry look like with respect to its actors and how has it changed over time since the start of the investment support?
2. What effects has the investment support had on the PV industry in Sweden, in relation to other determinants?
3. What hinders and drives the industrialization of PV in Sweden, and how can policy strengthen the industry?

In order to re-formulate the question with the help of innovation theory, some terms need to be explained. The object studied is the system, defined as the PV industry in Sweden. The time frame starts right before the investment subsidy was introduced and terminates at the end of the year 2007. The technology in question, as mentioned above, is PV. Blocking mechanisms are those that hinder the industrialization and inducement mechanisms are those driving it. With these terms in mind, the questions are re-formulated as the following:

1. What is the dynamics of the technological innovation system (TIS) for PV, in respect to the systems' different elements?
2. What are the effects of the investment subsidy on the dynamics of the innovation system, in relation to other determinants?
3. What blocking and inducement mechanisms can be targeted by policy in order to strengthen the innovation system, and what are the connected policy challenges?

The first question is the basis for the last two, and to answer all of the questions, an analytical framework will be used. The framework is described in section 2.1.

1.3 Structure of the thesis

Previously, an introduction to the thesis has been given and three research questions have been put forward. In order for the reader to attain an understanding of the analytical framework, the framework is described in section 2, which also describes the methodology used, i.e. how information was collected and synthesized. Thereafter, the framework is applied; presenting the Swedish PV innovation system on a structural and a functional level. Section 3 deals with the structure and gives an overview of the actors in the system. An analysis of the functional level is found in section 4, where inducement and blocking mechanisms are identified. The corresponding policy challenges are discussed in section 4.8. Finally, the conclusions are given in section 5, accompanied by suggestions on how the policy challenges can be targeted by policy.

2 Analytical framework and method

In this section, the analytical framework applied in this thesis is described. Thereafter, the method used is presented, i.e. a presentation on how information was collected and analyzed.

2.1 Description the analytical framework

In order to analyze the PV industry in Sweden and the impacts of the investment subsidy, an analytical framework is used to structure the analysis of the system in such a way that important aspects are covered. The framework is heavily based on Bergek et al. (2007; 2008) and adapted to this study.

The framework is built up as two levels: using a structural level and a functional level to describe the technological innovation system (TIS), which in our case is the Swedish innovation system for PV. The first level describes the components, i.e. the different actors, networks and institutions involved, while the latter stresses what is actually achieved in the innovation system.

In the framework applied, seven functions are used, and each of them will be briefly described.

2.1.1 Structural level

To start the analysis and to establish a solid footing, the different components', actors, networks and institutions, which constitute the structural level, are identified. Of special interest are the dynamics or the change over time, i.e. the entry or exit of actors into the innovation system, creation of networks and institutional alignment. Each of the components is briefly explained below.

Different kinds of actors are found along the value chain. In our case, dealing with the TIS for PV, this includes solar cell production and production of raw material, PV module manufacturing, PV consultants and installers and the customers buying the PV system, and the electricity consumers. Other actors involved are universities, media, authorities, energy companies, and grid owners. The dynamics are shown by the entry or exit and the size of actors.

Networks are the connections between the different actors and network formation can take place as the TIS develops. The networks can be of various nature, and one example is the interaction and learning taking place between buyers and suppliers. Another kind is a learning network, a network where knowledge and experience are shared and developed. There are also political networks; where actors form a coalition to influence decision makers, for example. These networks can be technology specific, where it is advocated for a specific technology, e.g. PV, or more general, e.g. about climate change.

The last structural components are institutions; for example, rules and regulations set by the state. They also include established practices set in the minds of people and actors, such as culture. When a new technology starts developing, the institutions are in general not adapted to it. "Institutions are very important not only for the specific path a technology takes but also for the growth of firms" (Johnson and Jacobsson, 2001, p. 5). A basic idea is that when different TISs compete, they are not only competing for market share but also for the adaptation of institutions to their advantage. Institutional alignment can take place as the TIS develops and institutional hindrances are identified.

2.1.2 Functional level

After identifying the components of the system and their dynamics, the TIS should also be analyzed on a functional level. The structural level by itself does not provide the whole picture of what functioning good or bad within the TIS. To analyze the functional level seven functions are used, each of them forming part of a process to deliver something of importance to the system. The functions are analyzed one at a time, looking at how well they perform.

i. Knowledge development and diffusion

This function illustrates to what extent the knowledge related to solar cells has been developed within the system. Knowledge can be developed within the system, i.e. learning, or it can be diffused or brought to the system from the outside, i.e. systems in other countries or other technical systems.

The knowledge can be developed at different levels. Firms develop knowledge as they get more experience and need to solve new problems. It can be developed in contact with other firms, when cooperating and exchanging knowledge. A major place for knowledge development is at universities and other research facilities, which may have resources that a single firm does not possess.

Diffusion of knowledge can occur from the universities to firms or vice versa, between firms, within a specific actor or line of business, and to society, where the general knowledge base is increased.

ii. Influence on the direction of search and the identification of opportunities

In order for actors to enter the TIS for PV, they must identify some kind of opportunity. This step can be influenced by the expectations on the future for PV in Sweden and in the world, by the fact that the market has been increasing in another country or an articulated demand. The perception of what an opportunity is can differ, as the same information can be perceived in different ways by different people in different situations.

Influence on direction of search and the identification of opportunities are also of importance within the TIS, as there may be different technologies competing and different markets to target. Regulations and policy, i.e. institutions, to which the TIS have to adapt, influence the direction of search.

iii. Entrepreneurial experimentation and management of risk and uncertainty

The evolution of a technical innovation system is characterized by uncertainty. There is uncertainty regarding which technology will be the "winning" one, what markets will be formed and what applications will be successful. This uncertainty is handled by society through entrepreneurial experimentation. It can be seen as learning by trial and error from a societal perspective, somewhat in a manner closely connected to knowledge development, although in this case, it is more of an applied nature.

For the firm experimenting, the risk is high as there are uncertainties about the technology and about the economic aspects. Governments can reduce risk through different policy measures, since, without experimenting, the innovation system may not develop very far.

iv. Market formation

In order for an innovation system for solar cells to develop, a market has to be formed. When a TIS starts to emerge, a market may not exist. There is little or no demand, as what is offered is often still under development and does not really provide a better alternative than what already exists. Technical developments that result in improved performance and a decrease in price following increased production, have not taken place.

A new TIS needs a market that grows. The first market emerging is often called a nursing market or a formative market. This stage can be manifested in the form of a niche market or a market protected through policy. In such a market, there will emerge a learning space where entrepreneurial experimentation can take place. Gradually the market will develop, uncertainty will decrease and the production has the opportunity to become more efficient.

v. Resource mobilization

Resources take on more than one form, as there are both financial resources and human resources. Financial resources are needed for research and for investments to take place, and while they are quite well defined, i.e. money, human resources, which covers the laborers and their knowledge and experience, are, in some cases, more tacit. Both the factual amount of people and the accumulated knowledge and experience that each of them possess is of importance. Significant actors that provide the system with human resources are universities. It is however not enough to only provide human resources, the system also has to have the ability to seize it. Otherwise the risk is that the system will lose the resources to other systems, or that fewer will enter these kinds of educational programs as they will not necessarily lead to any work opportunities.

There can also be human resources feeding the system that were not intended for that specific system from the beginning. Indeed, the system might even not have existed when the effort was made.

vi. Legitimation

This function points at a technology acquiring social acceptance. It includes people advocating for the technology, slowly convincing others. Legitimacy could also be achieved by the existence of policies targeting the technology, as that in itself shows sign of legitimacy. It can be interpreted that the government believes in it. Positive attention in media can increase legitimacy in general. Legitimacy can also be increased indirectly, for example, as the climate debate gets more attention.

vii. Development of positive externalities

The development of positive externalities is closely related to the other functions. One example is that increased legitimacy is not only useful to the one "producing" it, as also others can make use of it. As an example, when legitimacy has been acquired for a specific project, less lobbying will likely need to be done for a similar project.

As a market grows, there are more actors to share commonalities such as knowledge and labor. Shared labor increases the knowledge development and diffusion as people will bring knowledge with them when they change firms. There are also more actors to share the burden of influencing policy makers and working to make standards.

A larger market also gives firms the opportunity to specialize, which is related to knowledge development.

2.1.3 Identifying blocking and inducing mechanisms

Having structured the characteristics of the PV innovation system with the help of the functions described above, these will be used to derive the blocking mechanisms and the inducing mechanisms respectively. This derivation will be done for each function by establishing what is hindering and inducing the function.

Having identified the blocking and inducing mechanisms and estimated their importance, they will form the basis for a discussion about what to target with policy and how.

2.2 Collection and use of data

This thesis is a continuation of the work presented in the paper "Dynamics of the Swedish PV Innovation System – the Impact of a Recent Market Formation Programme" by Palmblad et al. (2006) and is mainly based on empirical data collected through interviews with different actors within the PV innovation system.

Altogether 29 interviews were performed during this thesis work, of which 14 were face to face. Furthermore, several short phone calls were made and informal face to face conversations were held. Palmblad made 51 interviews during the period from August 2005 to March 2006 (used in Palmblad et al., 2006). A portion of those interviewees were contacted for interviews during this thesis work. In total, 80 transcribed interviews were used in the completion of this thesis. Table 1 provides an overview of the interviews and to which actor group the persons interviewed belong.

	Linus Palmblad		Johanna Porsö	
Actor group	**Face to face interviews**	**Telephone interviews**	**Face to face interviews**	**Telephone interviews**
Solar cell producer			1	
Module manufacturer	1	3		1
PV system entrepreneur	4	1	3	6
PV consultant	1	1		
Application specialist	3	1		
Utility	2			
Buyer[4]	6	1	7	2
Architect	2	2		1
Electric consultant	1	1		
Electrician		2		1
Housing company	2	1		
Construction company	1	1		
Governmental agency	2	1	1	
Politician	1	2		
Academic organization	2	1	1	4
Research spin-off	1	1		
Industry organization		2	1	
Component manufacturer	1			

Table 1. An overview of the interviews upon which this thesis is based. The table is taken from Palmblad et al. (2006) and modified to include the interviews done by the author.

The interview questions were derived from the analytical framework used in this thesis, which was explained in the previous section. How the questions were used during the interviews varied depending on the specific situation. In some cases the interviewee was very talkative and the questions were mostly used as a check list, to make sure that all points were covered. In situations where the person was less talkative or did not consider him or herself sufficiently knowledgeable about the topic, the questions were relied upon to a larger extent.

As previously mentioned, the interviews were held either over the telephone or face to face and transcribed as soon as possible afterwards. The face to face interviews were generally longer than those over the telephone, and so more questions could be covered, but the length depended significantly upon how much the person being interviewed had to say about the various topics. Thus, the interview length varied from 45 minutes up to two hours.

The interviews conducted over the telephone ranged from several short questions to 30 minute conversations. Fewer questions were covered in comparison with the face to face interviews. In general the four or five questions with the highest relevance were used.

Due to the size of the system, the number of people involved, and the time frame of the thesis, all existing actors could not be interviewed, and thus only a portion of the actors were picked. In order to make the amount of traveling reasonable, the face to face interviews were conducted in Malmö, Lund, Stockholm and Göteborg. The names of the relevant people to talk to were collected gradually during the thesis work, from the interviews and media. The aim was to cover all of the different kinds of actors within the system.

[4] The following system buyers were interviewed by the author: Akademiska Hus Syd, Eksta Bostäder in Kungsbacka, Malmö Stadsfastigheter (the City of Malmö), SISAB (Skolfastigheter i Stockholm AB), Globe Arenas (Hovet, Stockholm), the Sport Administration (Idrottsförvaltningen) in Stockholm, the Church in Malmö and Ekologicentrum (Chalmersfastigheter).

Other sources of information were written ones, mostly found on the Internet, published by e.g. the Swedish Energy Agency or Elforsk.[5] Data from Boverket[6] (2007) about the projects was also used to identify projects and to establish relevant project details, i.e. information about characteristics of the installations and the amount of retrieved support per installation.

From the information retrieved through the interviews and the other information sources, an understanding about what was driving and hindering the different actors' behaviors was formed. This understanding made it possible to trace inducement and blocking mechanisms.

3 The structure of the PV innovation system

This section aims to give an overview and understanding of the actors, networks and institutions that exist within the TIS. The dynamics of the TIS will be analyzed on a structural level, with the intent of partially answering the first and second research questions. The functional dimension will be treated in Section 4.

3.1 Actors

As a first step, the actors populating the innovation system are presented and are sorted into different actor groups. Two actors, Midsummer, (a solar cell producer,) and the City of Malmö are attributed special attention in form of text boxes giving additional information. Networks and institutions are also presented.

3.1.1 Solar cells, PV modules and Balance of System components manufacturers

To date, there has been no solar cell production in Sweden, although several Swedish universities are researching into different types of solar cells. The most well known example is the Ångström Solar Center at Uppsala University, which performs research on CIGS thin film solar cells[7], and in 2003, a spin-off company, *Solibro AB*, was founded by four of the researchers from there (Stolt, 2006). In November 2006, Solibro entered a joint venture with the German firm Q-cells, forming Solibro GmbH of which Solibro AB owns 32.5 percent. Solibro AB in Uppsala will function as a manufacturing development centre. Solibro GmbH will start its production of CIGS in Thalheim, Germany (Q-Cells, 2006).

Midsummer AB is a company that was founded in 2004 and is located outside Stockholm, in Järfälla. They are planning a production of CIGS starting at the beginning of 2008, using a production technology different from Solibro. More information about Midsummer is found in Box 1.

Sweden presently has five firms producing PV modules, all of whom use silicon solar cells. In the south of Sweden, Swedish-owned *PV Enterprise* is located in Blekinge. PV Enterprise has most of its production there, but also has a smaller production facility in Poland. 95 percent of their production is sold to customers outside of Sweden, mainly in Germany. PV Enterprise has managed to get capital through a new issue of shares both in 2006 and 2007. The last one guaranteeing 50 MSEK in long term financing (PV Enterprise, 2006; 2007).

Further north, *Scanmodule* is located in Glava, Värmland, and is a part of the Norwegian company REC. Scanmodule has the largest PV production in Sweden. REC has its own silicon and cell production, securing Scanmodule's access to solar cells. Scanmodule is expanding rapidly and plans to have a capacity of 150 MW by spring 2008 (Schultz, 2007b).

Finally there are three firms in the north of Sweden. *n67 Solar* is located in Porjus, not far from Gällivare. n67 Solar started PV module production in 2006 and is currently doubling its capacity from 10 MW to 20MW. The company belongs to a Danish consortium. 100 percent of the

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[5] Elforsk's overall aim to coordinate the energy industry's joint research and development in Sweden (Elforsk, 2007).
[6] The National Board of Housing, Building and Planning
[7] CIGS (copper-indium-gallium-diselenide) thin film solar cells has the potential to become cheaper than the commonly used crystalline silicon solar cells, but has today a lower efficiency (IEA PVPS, 2008a).

production from n67 Solar is sold outside of Sweden, with the majority of the production going to Italy. There are no customers in Sweden making large enough orders, as the company sells their modules by the truck load (Rödder, 2007).

Midsummer AB

Midsummer is a company that has lately gotten increased attention in media coverage. It was founded in 2004, but the company purposely avoided attracting too much attention as they were wary of competitors in Asia copying their idea. Midsummer's goal is to produce CIGS and to start a demonstration line in 2008.

The idea behind Midsummer's process is to use sputtering, a technology used to make CDs and DVDs, instead of evaporating, used by e.g. Solibro. This knowledge was brought to the firms by the co-founder, Sven Lindström. He has been the CEO of a subsidiary company to M2, which manufactures manufacturing systems and equipment for CD and DVD, in California. When making CIGS, the major cost is the process, so by using sputtering, the cost of production can be decreased. The company is aiming to make smaller and faster production lines instead of one large one. Midsummer's business model is to make solar cells and to sell them to module manufacturers, i.e. only engaging in business-to-business interaction.

When Midsummer started out, they had a hard time attaining financial resources. The company managed to get money from Vinnova and the EU by becoming the coordinator in an EU project. The funding from the EU made it possible for them to acquire risk capital. In September 2007, Midsummer had taken in risk capital twice through new issuing of shares and the founders and employees owned 70 percent of the firm. The company is getting approximately one telephone call a week from venture capitalists, willing to invest.

Midsummer has expressed that they are having no real problems getting hold of the right personnel. They are paying good salaries and have managed to recruit employees from other firms. With regards to available labor with semiconductor expertise, there are pools of competent labor available on the market, in part because Ericsson has shut down their semiconductor division, which was situated in the same area, Järfälla, Stockholm, as Midsummer. Midsummer is also working in collaboration with Professor Eva Olsson at Chalmers University of Technology who has one researcher working full time with research related to Midsummer.

Within the company, they see Midsummer as being independent from the Swedish market. It is producing for the world market and does not see PV installations as being very suitable in Sweden. Midsummer is in contact with a company in Asia which will make the first test modules.

In November 2007, Midsummer was awarded with the "Rookie of the year award", for being the cleantech firm in Sweden with the most international potential. The award was given during the Kista Cleantech Venture Day.

Box 1 Midsummer AB (sources: Jaremalm and Lindström, 2007; STING, 2007)

The last two PV module manufacturers are found in Gällivare, *Gällivare PV* (GPV), owned by the German Solar World (Schultz, 2007a), and *Artic Solar*, owned partly by Naps System OY and partly by the German Alfasolar (Johansson, 2006). GPV was founded in 1991, at a time when the mining industry had made major layoffs, and Artic Solar was founded as a result of SolarWorld acquiring 100 percent of the GPV's shares. Previously, GPV has made modules mainly for Alfasolar and Naps. Artic Solar was founded with the help of former employees from GPV (Wille, 2007), and in Photon Magazine, an image of friendly co-operation between the firms is presented. The two firms help each other whenever there is a lack of material or personnel (Wille, 2007).

The Japanese solar cell producer, *Sharp*, also has a presence in Sweden, and include PV modules among their products in the Nordic countries since 2005. The decision to include PV modules in their assortment was based on the developments concerning PV in Europe and the investment support in Sweden (Granell, 2005). Sharp is active within the SolEl program (see 3.1.9).

Arontis Solar Concentrator AB is a research spin-off, although it has not been involved in projects within the investment program to date. The company started out as a non-profit research project and makes solar concentrating PVT (photovoltaic thermal) systems, which produce both electricity and hot water. Arontis Solar Concentrator AB was founded by Joakim Byström three years ago, and is based in Härnösand, cooperating with the University in Borlänge (Högskolan Dalarna), Chalmers University of Technology, the Royal Institute of Technology and Lund University. Arontis does not consider the Swedish market to be of great importance in terms of volume, but the market does play an important role in that it is the base for demonstration projects (Byström, 2006; Arontis AB, 2007).

The parts of the PV system, excluding the PV modules, are called the balance of system, or the BOS, components. Components included in this categorization are inverters, which transform direct current (DC) to alternating current (AC), cables, the mounting structure and possible storage devices, e.g. batteries (U.S Department of Energy, 2006). There is currently no Swedish manufacturer of inverters. The most well known possible company that could start production would be *ABB*. Cables, switches and such are mainly conventional products. (Statens Energimyndighet, 2007).

3.1.2 Consultants

In this thesis, consultants are defined as working with pre-studies, supporting the creation of tender invitations, and providing general project management and inspection. System installers are not included under this heading but are provided their own section below.

Energibanken was started in 1997 and is a PV consultancy firm (Hedström, 2005), and was the only firm of its kind before the investment support. The company has been involved in a large part of the projects that have taken place within the support (Andersson, 2007b). It carries out pre-studies and acts as support during installations, tender invitations and inspections of installed systems (Energibanken i Jättendal AB, 2007).

Since the investment subsidy started, more firms have seen an opportunity and have entered the TIS. One example is *ÅF*, who have to date helped prepare tender invitations and performed inspections, but are more recently also starting to do pre-studies (Juslin, 2007). ÅF has gotten involved in the SolEl program, offering a lecture series for architect students about PV in buildings (Dahlberg and Martinsson, 2007). Delegates from ÅF, together with Energibanken were present at the SolEl seminar in November 2007. Other consultancy firms include *Ramböll* and *WSP*. The latter has been involved in installations at ten schools in Älvsjö, at the culture centre (Kulturhuset) and at the city theatre (Stadsteatern), all in Stockholm. In Malmö, the firms *Reijlers* and *Grontmij* have been involved in projects. In the beginning of the investment subsidy the system installer *Switchpower* also performed some pre-studies (see 3.1.3).

To sum up, one can identify an increasing number of actors within this group.[8] Before the investment subsidy, there was only one actor within the group, and the system installers sometimes had to step in and support the consultants.[9] Today, a number of firms can take on tasks such as pre-studies, project management and inspection.

3.1.3 System installers (Turn key entrepreneurs)

A turn key entrepreneur or a system installer is a firm that designs the PV system and delivers it in a state that is ready to be used. These firms are directly affected by the investment subsidy as it is targeting PV system installations. In most cases, the firms involve sub-contractors for electrical work and for mounting. This section will briefly describe the system installers within the Swedish PV innovation system. An overview of their collaboration with supplier and sub-contractors will be given later on when describing networks within the innovation system.

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[8] The actors presented are firms, which have been run across during the work for this thesis. As only a part of the supported PV installations have been looked at, the existence of more involved consultancy firm is acknowledged.

[9] Switchpower did pre-studies especially in the beginning of the scheme (Machirant, 2007). NAPS has assisted one pre-study, for Medichus in Göteborg (Selhagen, 2007). Both Switchpower and NAPS state that they regularly get phone calls which questions about installations.

Before the support scheme, there was only one major actor, NAPS Systems (NAPS) (Selhagen, 2005). By spring 2006, Palmblad et al. (2006) had identified four additional actors: Switchpower, Exoheat, Celltech and Flex Fasader. By fall 2007, Celltech has decided to pull out and Glacell, Fasadautomatik, Solkraft Östergötland and Söderbergs Yttertak have entered the system. An overview of the actors and the change over time can be found in Table 2.

2004	March 2006	Nov 2007
NAPS	NAPS	NAPS
	Switchpower	Switchpower
	Exoheat	Exoheat
	Flex Fasader	Flex Fasader
	Celltech	Glacell
		Söderbergs Yttertak
		Solkraft Östergötland
		Fasadautomatik
∑1 firms	∑ 5 firms	∑ 8 firms

Table 2. The table shows the system installers within the Swedish system with the competence and aim to perform PV installations at different points of time.

Amongst the system installers, *NAPS* has been in the business the longest and has its main office in Finland. The company delivers PV systems to summer houses and boats to private customers, but also participates in larger installations both in Sweden and abroad. Up until November 2005, NAPS had performed 80-85 percent of the grid-connected PV installations in Sweden (Selhagen, 2005) and, before the investment support started, they did not have any competition from within Sweden, only from foreign firms (Selhagen, 2007). 2007 has been a busy year for NAPS, with Selhagen (2007) estimating that 70 percent of their business involves projects funded by the investment subsidy. By October 2007, they had performed eleven projects that have occurred within the scheme.

Switchpower, founded in fall 2004 with an office in central Stockholm, claims in September 2007 to have 40 percent of the market related to the subsidy (Machirant, 2007). According to Machirant (2007), the co-founder of Switchpower, they initially had to make really low bids in order to get their first projects as they could not compete with other companies such as NAPS because of their relatively low experience. Switchpower also performs pre-studies for PV installations.

Switchpower has begun to broaden its horizon and is looking into other markets, working in a project with a solar tracker in Dubai and also looking into the Greek market as Greece is on the brink of adopting the same kind of policy concerning PV as Germany (Machirant, 2007).

ExoHeat has completed around ten different PV projects that have been supported by the subsidy. The company was founded in fall 2004 and has been working with both solar heating systems and PV. In September 2007, Exoheat split into two parts, with one part of the original company keeping the name ExoHeat and staying in Båstad, from where the company originates. The second part, Glacell, is working out of Ängelholm. Glacell will concentrate on PV installations, glass integrated PVs and arena seats (Lundgren, 2007). The split has resulted in yet another actor on the market.

Celltech is a firm specializing in batteries and chargers, and consider their business as closely related to PV. When the investment subsidy started they decided to participate (Sandell, 2006), but after making several unsuccessful tenders, Celltech decided to exit the market in the first part of 2007. One of the problems, according to Sandell (2007), is that the tender invitations in many cases demanded that the entrepreneur presents three reference projects. This tender requirement posed a significantly challenge for new actors. Additionally, it is acknowledged that the most important reason contributing to Celltech's market exit was that the bids from the competitors were far too low, and with a profit margin of less than ten percent, Celltech decided that it was not reasonable to continue.

Flex Fasader delivers glass and aluminum facades, and cooperates with the German firm *Schüco*, who offers facade and energy solutions with building integrated PV (BIPV). The company works in close coordination with Schüco via Schüco's office in Stockholm, and has to date completed one PV installation on a school in Hallsberg. They had tendered for another project where it was later decided to not include PV. Flex Fasader have the competence required to install PV but is not actively looking for PV projects, although it might come in question if they do pursue such projects in the future (Karlsson, 2007).

A new actor that has entered the innovation system since the inventory performed by Palmblad et al. (2006) in spring 2006 is *Fasadautomatik*. Tengberg (2007) states that the company entered the market because of the investment subsidy and have so far unsuccessfully tendered for ten projects. To date, the company has not been cost competitive in their quotes and in some cases, has forgotten to include documents that were part of the tender process e.g. for reference projects. The company is working in coordination with the Danish part of Schüco, and because Fasadautomatik have completed no projects of their own, they use Schüco's references.

Another new actor is *Söderbergs Yttertak*, which is *Alwitra's* representative in Sweden. German company Alwitra specialises in roofs and offers a building integrated PV system (Alwitra, 2007), an example of which was used by Söderbergs Yttertak's PV installation on Hovet (Globe Arenas) in Stockholm. Hovet is Söderbergs Yttertak's only project so far (Söderbergs Yttertak, 2007).

Solkraft Östergötland was founded two years ago and work with PV and solar thermal installations, the latter being their main business. To date, the company has performed pre-studies for PV systems and their largest PV system installation was 1.3 kW. They have been tendering for larger projects and will hopefully start working on one in January 2008 (Pettersson, 2007).

In addition to the Swedish actors, the Danish firm *Gaia Solar* has also entered the Swedish market. They have completed nine projects in Sweden as a sub-contractor to Switchpower (Aarø, 2007).

In summary, before the support, there was only one actor within this line of business, NAPS, and the support has made it possible for more actors to enter. In December 2007, eight actors can be identified, of which four: Exoheat, Switchpower, NAPS and Gaia Solar, have collected a considerable amount of reference projects. There are actors that have tried to enter but did not succeed and actors that have entered the system by tendering on projects but still have not gotten any contracts.

3.1.4 Architects and construction companies

In many cases, architects are involved making the design of the system. *White arkitekter* has worked with PV since 2000, and a key person at White is Marja Lundgren who has written a book about BIPV, "Aktiv solenergi i hus och stadsbyggnad"[10], financed by Elforsk and has attended PV seminars (Lundgren, 2005; Elforsk AB, 2007). White is active within the SolEl program and has arranged trips to Copenhagen to look at solar cell installations. These trips have been popular and, in 2007, had 72 participants (Barosen and Gran, 2007).

[10] Freely translated to English: "Active solar energy in archetecture and urban/city planning"

Since the start of the investment support, many different architect firms have been involved in different projects, although there are no signs of firms being involved in more than one project. According to Edén (2007), a professor at the research group Built Environment and Sustainable Development at Chalmers University of Technology, there are not presently any firms that actively work to include PV in their work, not even White.

There are not many construction companies involved with PV, as many of the companies see the proposition as expensive and do not see the point, and furthermore, the investment subsidy does not target new buildings (Palmblad, 2007). The most involved construction company is *NCC* (Palmblad, 2007), a construction and property development company. NCC has been involved in making PV installations in Hammarby Sjöstad.[11] The view seems to be that the construction companies build exactly what the buyers ask for.[12] NCC has been involved in the SolEl program and taken part in developing the Internet tool Solcell.nu which is supposed to help and spread knowledge to different actors involved in PV installations (Elforsk AB, 2007).

Ekosol, founded in 2005, is a small actor in the construction sector. They do not build houses themselves, but cooperate with a construction company, Eksjöhus. The business idea is to put PV systems on detached houses in combination with a heat pump. The systems are owned by the house owner, with Ekosol then renting the PV system from the house owner and the electricity is fed into the grid. The bank, Swedbank (former Föreningssparbanken), has agreed to give a discount on the interest corresponding to the interest for the PV system (Ekosol AB, 2007). In Table 3, which aims to give an overview of the actors, Ekosol is found under "Applications specialists".

3.1.5 System buyers

The investment subsidy directly targets the system buyers and grid-connected PV installations in Sweden built outside of the investment subsidy are negligible. At the end of 2007, Boverket[13] had granted 114 project applications corresponding to almost 148 MSEK of the total 150 MSEK. The system buyers receiving the investment subsidy are (as the support demands) mostly public organizations. Typical buildings are school and university buildings, buildings owned by the Church, buildings for health care and museums. A few private buildings have also received support, as they have a public activity, e.g. a kindergarten and a tennis court.

A major system buyer is the City of Malmö through Malmö Stadsfastigheter. More information about Malmö is found in Box 2.

The City of Stockholm has also completed several installations, although they have been taking place in different administrations. After making several calls to relevant people within the City of Stockholm[14], no one with an overview was found. The projects are handled without any noticeable coordination.

Unlike other districts, the City of Stockholm provided a counter investment subsidy covering the remaining 30 percent of the investment costs, resulting in practically no costs for the buyer. After the election in 2006, the power shifted in Stockholm and this subsidy was removed, though projects already granted the financing still had the right to it.

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[11] JM was also involved in Hammarby Sjöstad (Engström, 2005).

[12] Gränne at NCC (Elforsk AB, 2007) says that NCC builds what is demanded and that they want to be able to offer PV solutions if it is asked for. Engström (2005) states that the constructions firms responsibility regarding PV is to carry out the buyers wishes.

[13] The National Board of Housing, Building and Planning

[14] The following people within for the City of Stockholm were talked to over the telephone in October 2007: Sandra Rödin, Carina Tensmyr Hildinger (project manager Miljömiljarden), Torbjörn Johansson (head of staff), Ulf Adaktusson (sport administration, formerly working with Miljömiljarden), Viviann Gunnarsson (former Environment City Commissioner), Jan Hyllengren (at secretariat for Miljömiljarden), Elvy Löfvenberg (Environment Co-ordinator, Sport Administration)

Solar City Malmö

Skåne is a "hot spot" with regards to PV installations. Up until the end of 2007, the installations in Skåne made up for 19 percent of the total funded projects and 31 percent of the granted funds (Boverket, 2008).

Many of the installations in Skåne are found in Malmö. A major actor is Malmö Stadsfastigheter within the City of Malmö, whose main task is to manage real estate e.g. schools, elderly care, culture and administration (Malmö Stad, 2008). In October 2007, they had six projects, of which five were completed and in operation. These projects are funded with almost 18 MSEK by the investment subsidy (Boverket, 2007). They also have plans for a seventh installation, including a solar tracker which orients the PV panel towards the sun.

At first, the focus was mostly on energy savings but as the City of Malmö discovered other values connected to the installations, the focus shifted towards making Malmö a center of excellence for solar energy and using their dominance to create publicity, marketing Malmö as a city of renewal. In order to spread the knowledge about solar energy technologies, the City of Malmö has initiated the foundation of a non-profit organization, Solar City Malmö, whose aim is to start and expand the solar energy business in Malmö. According to the project leader this requires that the actors are educated (Norlund, 2007). One person has been hired to work for the organization and is building up a web site. Even before the founding of Solar City Malmö, the project leader had been contacted by other organizations interested in having a PV installation. Another sign of the spreading interest is that the project leader has been contacted by schools within the City asking if there is a possibility to get PV on their roofs (Norlund, 2007).

The Church in Malmö has also established four PV installations independently from the City of Malmö. Unlike the City, the Church has no major plans for actively promoting the installations, and according to Andersson (2007a), that would be the task of a PR department, which the Church does not have. One of the ideas which came up when they decided to make the installations was that the installations themselves are visible, especially two where the solar cells are used as sun shields, placed above the windows. Andersson explains further that the Church does a lot of different energy efficiency measures but that they normally do not make efforts to expose that to the public. If people start asking questions about the solar cells this gives them the opportunity to talk about these things as well.

Box 2 Solar City Malmö

3.1.6 Energy companies, grid owners and electricity-consumers

In the end, PV systems are producing electricity which has to be consumed. If the PV system produces more electricity than the building consumes, the remainder has to be fed into the grid, although this is currently not the case for most PV systems in Sweden. This section handles the actors directly connected to the electricity produced, i.e. energy companies, grid owners and electricity-consumers.

Firstly, it can be observed that the larger energy companies in Sweden, i.e. *Vattenfall*, *E.ON* and *Fortum* are not directly showing active interest in solar electricity.[15] Despite this, Vattenfall and E.ON are both, through Elforsk, financing the SolEl program. Machirant (2007) states that Vattenfall has not shown any interest and that they are not very friendly towards distributed power sources, which PV systems on buildings is an example of. Smaller energy companies show a slight interest, with one example being *Falkenberg Energi*, a smaller energy company which only sells electricity from renewable energy sources. They are, according to Melin (2007), interested in the opportunity to sell solar electricity. They have also agreed to buy solar electricity from Ekosol (see 3.1.4).

In 2007, a report about the competitiveness of grid-connected solar electricity in Sweden was published.[16] It was financed by Elforsk, which is partly owned by Svensk Energi and consists of, among others, the larger energy companies and concluded that solar electricity is not a

[15] By reading in their homepages (www.eon.se, www.vattenfall.se, www.fortum.se), no information about involvement is found; with the exception of Sydkraft (now E.ON) that made a demonstration PV system in Malmö in 2000 (E.ON, 2000).

[16] Original titel in Swedish: Konkurrenskraft för nätansluten solel i Sverige (Carlstedt et al., 2006)

competitive alternative for the energy companies in Sweden. The report assumes that no price differentiation is made, where customers chose to pay a higher price for solar electricity.

The electricity-consumers can be seen at the end of the value chain. At this point electricity-consumers in Sweden cannot buy solar electricity, although there are some smaller firms that have shown interest in providing this product. It should be pointed out that there exists an interest from private consumers and signs that some are willing to pay extra in order to buy solar electricity. A survey done by the magazine "Vi i Villa" shows that 29 percent of the house owners answering the survey said that they would be willing to pay 2 SEK/kWh or more for 100 kWh/year if the money went to support the development of solar energy. On another question, 18 percent answered that they would invest in a PV system if they had 100 000 SEK to invest in their house choosing from a given number of alternative investments.[17]

The involvement of the grid-owners implies taking fees from the system owners if electricity is fed into the grid. The fee is supposed to cover the costs of metering. This point is further handled in section 3.3.

Switchpower, one of the PV system installers, has involved itself with this actor group. It has started buying electricity from Charlottendals Gård (a PV installation supported by the subsidy), paying them two SEK/kWh and see a future for a solar electricity market (Hagerrot, 2007; Machirant, 2007).

Another firm trying out its own niche is *Egen El*. Through Egen El, private consumers can buy or rent a PV system or a wind turbine. The company is applying net metering, meaning that the electricity produced by the system is subtracted from the electricity bought. They are offering to help their costumers with arguments in communication with their grid owners. According to Egen El both E.ON and Fortum has responded positively (Egen El, 2008).

Similar ideas are shared by *Ownpower* who aim to give people and firms an opportunity by sharing in local renewable energy plants, including PV systems. The concept is tried out in Gotland (Ownpower, 2008).

3.1.7 Industry Associations

There are two industry associations in Sweden which are directly connected to PV. The first one is Solar Energy Association of Sweden (Svenska solenergiföreningen, SEAS) representing both solar thermal and solar cells (SEAS, 2008). There was the perception that PV was partly neglected in favor of solar thermal. Therefore, in 2005, the Scandinavian Photovoltaics Industry Association (SPIA) was founded. The following Swedish actors are members according to the home page of the SPIA (2007) on November 19th: Celltech (decided to leave the SPIA in 2007), GPV, NAPS, Sharp, Energibanken, Solibro and Switchpower. Other members are Gaia Solar, Dansk SolEnergi, Schüco (all with contact information in Denmark).

Machirant, co-founder of Switchpower, is the SPIA's contact person. Due to lack of time and resources not as much work as wished for has been done and there are discussions about the possibility to merge with the SEAS in the future (Machirant, 2007; Palmblad, 2007). There are concerns about the objectivity of the SPIA. There are a limited amount of projects that the system installers have to fight for. As Switchpower, the most active member, has its own business, it can be hard to fully separate the interest of the firm and of the SPIA (Sandell, 2007; Selhagen, 2007). So far there has been some meetings taking place and they aim to have a dialog

[17] Vi i Villa's "Villapanelen" consists of 23 000 house owners from all around Sweden. 11 575 house owners answered on this specific survey. All together there were three questions related to solar electricity. The other alternatives if investing 100 000 SEK on your house were: renovate bathroom (24 %), renovate kitchen (23 %), lay out a new garden (9 %), renovate living room (4 %), renovate bedroom (2 %), do not know/no answer (20 %). The last question asked how much people were willing to pay if they were offered to buy 100 kWh solar electricity per year. The alternatives were: 400 SEK/year (4 %), 300 SEK/year (4 %), 200 SEK/year (21 %), normal electricity price (51 %), do not know/no answer (20 %) (Vi i Villa, 2007).

with the Ministry of Enterprise, Energy and Communications in order to make proposals about long term policies (Machirant, 2007).

There are also other initiatives which aim at supporting the use of solar energy. Soluppgång i Väst is a project initiated by Västra Götalandsregionen (the County Administrative Board of Västra Götaland) SEAS, Regional Energy Agency of West Sweden (Energiråd Väst) and nine municipalities in the west of Sweden. It aims to make it easier for people, firms and municipalities to invest and install solar energy solutions (Soluppgång i Väst, 2008).

3.1.8 Educational sector

One direct way of providing the TIS with human resources is through education. The following section will describe the situation in Sweden concerning educations relevant for the PV innovation system. They range from skills of a more practical nature, e.g. PV installation skills, to more knowledge about solar cells among e.g. architects and civil engineers. Education connected to PV within the disciplines of physics, chemistry and electro technology is excluded.

Heta Utbildningar in Härnösand belongs to the first mentioned kind and their Solar energy technician[18] program was started in 2006, with their program being a two year vocational education. There are 30 places and the first students will graduate in the end of spring 2008. The initiator to the program is Joakim Byström at Arontis (see section 3.1.1).

The main focus of the program is on solar energy but also includes bio energy. The program contains a three credit[19] course about solar cells taught by Mats Andersson at Energibanken. Courses related to thermal solar energy and heating, ventilation and sanitation knowledge[20] are allocated more space in the program (Birgersson, 2007; Öberg, 2008).

According to Ögren (2008) the students thought that the course in solar cells was too easy, and that there was not enough content for three credits. The course presents PV technologies and gives knowledge about selection of place for installation, dimensioning, direct current, inverters and cost calculation.

Birgersson (2007) at Heta Utbildningar points out that one problem is the lack of apprentice placements within the solar cell business. A course in solar cells is supposed to be more than an orientation course but the subject is such that the students need to get vocational experience. The problem is, according to Birgersson (2007), that the education is early in comparison with the market's development. The firms (the system installers) are small and their workload is not continuous.

Uppsala University offers a five-year *Master of Science in Energy Systems Engineering*, which was started in 2000 and had its first graduates in 2005. The university has increased the number of accepted students and presently offers 60 places each year. Concerning solar cells, they have a course in renewable energy where solar cells among others are covered. The aim of this course is to provide a general overview. For the fourth year students, they offer a selective course in solar energy.[21] A few graduated students have started working with solar cells, but since there are not so many firms, most of these students have joined research groups (Tengblad, 2007). A few have joined the spin-off firm Solibro. Tengblad has not experienced any articulated demand from the market concerning desired competences in the solar cell field.

In Borlänge at the Högskolan Dalarna, *the European Solar Engineering School* (ESES) is offering a master program in solar energy. By November 2007, the total number of graduated students had arrived at 85. Most of the students are from outside Sweden and even if some of them want to

[18] In Swedish: Solenergitekniker

[19] One credit (KY-credit) corresponds to one week of studying. One year of full-time studies corresponds to 40 credits.

[20] In Swedish: VVS

[21] Solar Energy – Technology and Systems, 7.5 ECTS. The course covers solar cells, solar thermal and utilization of direct solar heat in buildings (Uppsala Universitet, 2008).

find work in Sweden afterwards, the opportunities are not very many. The program started by focusing on solar thermal but has expanded towards solar cells and contains now two courses about solar cells. ESES do not perform research, they are concentrating on education. They have plans to look into system development (Lindberg, 2007).

In order to integrate PV in buildings and make it a standard building element, there has to be increased knowledge among architects. One place where that can be created is within the architect education curriculum. According to Edén (2007), a professor at the research group Built Environment and Sustainable Development at Chalmers University of Technology, this education is lacking. At Chalmers University of Technology, there is only one course in one of the master programs that contains a part about PV. Edén also states that there is a lack of knowledge and a lack of cooperation between the different disciplines involved, i.e. civil engineering, electrical engineering, technical design and architecture. At the Lund University, the situation seems to be similar (Nilsson, 2007a).

There has been a project within SolEl program (as mentioned in section 3.1.2), where two consultants from ÅF visited Chalmers, Lund University and the Royal Institute of Technology (KTH) and gave lectures about PV and, in connection, took the students on a field trip looking at PV installations (Dahlberg and Martinsson, 2007).

To sum up, the Swedish system provides education concerning system installations but there are barely any apprenticeships or permanent jobs offered afterwards. There also exist engineering programs where the students can take courses in solar energy, although few of the students find jobs in Sweden outside the university world. Knowledge on how to integrate PV in buildings is spread modestly in educations in architecture and civil engineering.

3.1.9 Research

There is research connected to PV performed at several universities and other organizations in Sweden. More detailed information about the status from year 2000 until 2005 is found in Statens Energimyndighet (2007), where the Swedish research environments are described, key researchers, research areas and courses offered are summarized. This section refers to that report where nothing else is stated.

At Uppsala University, research is mainly done on thin film solar cells, CIGS, and they have connections to Solibro, which hived off from the research group. At the Royal Institute of Technology in Stockholm, the research is directed towards dye-sensitized solar cells. At Linköping University, the focus is on organic semiconducting materials. Research is also performed at Chalmers University of Technology closely related to the CIGS producing firm Midsummer. Chalmers University of Technology also has research more directed towards policy issues.

At Lund University, the research is focused on building integration of PV and on PV concentrators.[22] Some of the research is financed by Vattenfall. Vattenfall Research and Development AB has a history of solar cell research and technology monitoring, but this is being wounded up.

ABB has been working with the issue of grid-connecting PV systems, and in 2005, they constructed a small PV system for evaluation purposes.

Research efforts have also been financed through the *SolEl 03-07 program*, which has supported applied PV projects. The starting point for the program was that the Swedish market for PV will develop from niche markets to grid-connected production, in a long term perspective and under commercial conditions. Further, the goals of the program were to increase the competencies within the industry and universities as related to PV systems, as an energy source and a building

[22] The basic idea with PV concentrators is the use of cheaper reflector surfaces to reflect the solar radiation towards the more expensive PV surface. In this way the solar radiation get a higher concentration which generates more electricity (Nilsson, 2007b).

component. It also aimed to demonstrate applications with focus on costs and usefulness and to provide knowledge about system related issues. The budget of SolEl was approximately 3,5 MSEK per year and was financed partly by the Swedish Energy Agency and by a number of companies[23] (SolEl 03-07, 2008b). The current version of the program ended in December 2007 and by November 2007 the financing of a continuation was not yet resolved (Adsten, 2007).

Sweden is also involved in the IEA Photovoltaic Power Systems Programme (PVPS) and has people involved in approximately half of the task groups.[24] PVPS is a R&D agreement within the International Energy Agency (IEA), whose aim is to conduct projects on the application of PV.

3.2 Networks

Having identified a range of actors and sorted them into groups, this section will describe the networks between the different actors. As described in the analytical framework, there are different kinds of networks that can be formed.

The first group of networks to be described are *supplier-buyer networks*. Switchpower is involved in supplier-buyer networks with GPV, from where they buy their modules and with Fronius, who produce inverters. Machirant at Switchpower already had contact with GPV when Switchpower was founded ensuring that they get a supply of modules at a fair price. Switchpower has, according to Machirant (2007), built up a good relationship with Fronius and some sort of "preferred delivery status" within Sweden. A relationship is also built up with German SolarWorld in order to have strong enough support when going international.

NAPS has also established supplier-buyer networks, buying inverters from SMA as they have done for the last ten years. NAPS is happy with SMA and is able make larger orders. When NAPS need specially made modules, they are able to attain them from their own production, Artic Solar in Gällivare. The production by Artic Solar is not large enough to cover NAPS' need for modules and, thus, they buy modules from the Japanease company Kyocera. To have a steady contact makes it easier to get hold of modules (Selhagen, 2007).

Continuous networks of buyer-supplier character involving the system buyers can not be identified, since the Public Procurement Act is applied by most of the system buyers. Although Exoheat has been contracted by the City of Malmö for many of their projects, it seems like Exoheat has acquired the project at the tennis court in Båstad due to personal networks (Tebäck, 2007).

Another kind of network, closely connected with the previous, is cooperation between firms, and in this thesis, the topic is handled separately and is called *partner networks*, in order to point out that these networks imply more direct contact between the firms.

One example is Switchpower's cooperation with Gaia Solar or NAPS, whom have started to cooperate with the electrical installation firm YIT, which also makes the mounting. The cooperative venture has completed three projects together so far and is planning more (Selhagen, 2007). YIT has approximately 140 offices in Sweden (YIT, 2008) and by using them, NAPS gets local project management. In this way, YIT learns about the technology and they can offer a fixed price for the electrical installations. The mounting is still paid for by the hour, but the goal is to get a fixed price for that as well (Selhagen, 2007).

ExoHeat has cooperation with the electrical installation firm Lambertsson, a subsidiary company to Peab. They cooperate already when tendering for a project. Ola Angel, who is responsible for the electricity division within Lambertsson knows Pontus Lundgren, the CEO of ExoHeat (as

[23] Financiers of SolEl 03-07 stage two: ARQ stiftelsen arkitekturforskning, EkoSol AB, Energiföretag via Elforsk (Vattenfall, E.ON, Göteborg Energi, Mälarenergi, Jämtkraft, Borlänge Energi, Falkenberg Energi), Energimyndigheten (Swedish Energy Agency), Fastighets AB Brostaden, Malmö stad Stadsfastigheter, Sharp, Statens Fastighetsverk, Svenska Byggbranschens Utvecklingsfond (SBUF) via NCC Construction Sverige AB (SolEl 03-07, 2008a)

[24] E.g. Mats Andersson (Energibanken), Peter Krohn (Vattenfall Utveckling AB), Carina Martinsson (ÅF), Lars Stolt and Ulf Malm (Uppsala University) (IEA PVPS, 2008b)

from September 2007 CEO of Glacell) since earlier (Angel, 2007). Angel (2007) points out that the cooperation is based on the fact that they know and trust each other. Lambertsson is found in different places in Sweden. If one local section of Lambertsson is about to make their first PV installation they send someone experienced there to show them how it is done (Angel, 2007).

Something in between supplier-buyer networks and partner networks are the networks that Alwitra and Schüco have developed, connecting the Swedish and the German system. They are using Swedish retailers to make their products reach the Swedish market.

Learning networks can be identified to some extent in the networks describe above. Further, many of them are connected to the universities. Midsummer AB is cooperating with Professor Eva Olsson at Chalmers University of Technology (see Box 1). Exoheat has contact with Björn Karlsson at Lund University and Jan-Olof Dalenbäck at Chalmers University of Technology (Demeter and Lundgren, 2007). Both Karlsson and Dalenbäck have also been in contact with system installers.[25] There are also learning networks between system installers themselves, sharing knowledge about e.g. tender invitations and giving advice.[26] Other networks are between the universities and system buyers which are connected to general knowledge about PV and to its applications.[27] Typically, a project leader is in contact with a university looking for support and ideas on how to implement PV.

An *internal network* is here defined as a network within an organization, with one example being the City of Malmö, the only organization that has had more than one project taking place at different points in time in one geographical area. This idea means that the same people in the organization have had to make a decision about PV installations more than one time. After several projects, the network of involved parties in the organization is suggested to have grown stronger. Further networks have the opportunity to be created with the formation of Solar City Malmö.

This network strengthening in Malmö can be directly contrasted to the City of Stockholm, where weaker networks can be spotted. The City of Stockholm has had several projects but they have been taken care of by different administrations and in the case where there has been more than one project, they have been executed at the same time and have been treated as one larger project. The only noted linkage between the projects is the pre-study about potential locations for PV systems done by Energibanken. which was order from the City of Stockholm (Andersson, 2007b).

Akademiska Hus is another organization that has had more than one project at different stages. The difference compared to the City of Malmö is that, to date, none of the regional administrations have completed more than one.

Other organizations contributing to forming networks of a more political kind are the industry associations SEAS and SPIA, which provides a platform for actors to meet.

Platforms for the creation of different kinds of networks include the different seminars that have taken place within e.g. the SolEl program and the Solar City Malmö. These platforms function as meeting points where people get inspired and get in contact with others. This idea will be further discussed in section 4.1. The SolEl program has also gotten different actors to come together and

[25] Karlsson has also been in contact with Malmö Stad and Akademiska Hus Syd, and Dalenbäck with Eksta Bostäder in Kungsbacka (Norlund, 2007; Tirén, 2007; Åström, 2007).

[26] Akademiska Hus Syd, responsible for the installation at Ekologihuset in Lund, is one example, contacting Martin Norlund at Malmö Stadsfastigheter to get advice (Åström, 2007). SISAB has gotten parts of their tender invitation from another project and they passed it later on the sports administration in Stockholm. A project in Västerås has also contacted SISAB (Bäcklin and Öberg, 2007).

[27] Eksta Bostäder has been in contact with Jan-Olof Dalenbäck at Chalmers (Tirén, 2007). Åström at Akademiska Hus is in contact with Björn Karlsson at LTH concerning the solar cell installation at Ekologihuset, in the campus of Lund University, and regarding plans of a hybrid installation at Biologihuset, the building next to Ekologihuset (Åström, 2007). Martin Norlund at Malmö Stadsfastigheter has also been in contact with Björn Karlsson (Norlund, 2007).

work with tasks within the support and in this way encouraged the creation of networks (see section 3.1.9).

3.3 Institutions

A range of different laws, regulations and customs affect the PV innovation system. This section is not an attempt to cover them all, but to point out important ones.

One institution that frequently occurs is the discussion about the grid-connection, related to the regulation of the *infeed* of electricity into the grid. This is a topic which has not been significantly explored previously as grid-connected PV installations were rare. With an increasing amount of PV installations, the issue has gained more and more importance. The problem is that in order to feed electricity into the grid, metering by the hour needs to be made. This requirement results in high costs which has hindered installations of this kind, or at least led to adjustments concerning size to avoid net electricity surplus (Norlund, 2007; Söder, 2007).[28] The issue has lead to an official report by Lennart Söder at the Royal Institute of Technology which was handed in to the government in January 2008. The report deals with the grid-connection of power stations producing renewable electricity. If the proposal in the report, which involves removing the demand for hourly metering, is received positively, it can be adopted at the earliest by the beginning of 2009 (Söder, 2007).

The Public Procurement Act affects the decision as to which system installer is hired. Because of the tendering process, the system installer cannot be involved from the start, as the tender invitation should be impartial. Tendering results in significant administrative work which is not always considered to be necessary[29] and the details and demands in the tender invitation can differ. One condition that has occurred in numerous invitations is that the system installer must present three reference projects, which can be hard for a newly established firm.[30] On the other hand, tendering is applied for a valid reason. It opens up the market for fair competition which also can be considered as something positive.

Another institution is the existence of *building permits* and what influences if an installation gets one or not.[31] This institution is linked to the perception of what is aesthetically desired. Even if a project is approved, the process normally implies a time delay.

Additionally, *the National Heritage Board*[32], which is the authority responsible for issues concerning cultural environment and cultural heritage, has rejected proposals of PV installations on the roofs of churches. One case, the church in Fläckebo, got significant media and public attention. The

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[28] Söder (2007) mentions a estimated annual cost of 4900 SEK for hourly measuring for low voltage. Fortum charges Eksta Bostäder more than 4000 SEK per year as they need to feed electricity into the grid (Tirén, 2007).

[29] Machirant (2007), Switchpower, sees the Public Procurement Act as a blocking mechanism, which involves a lot of administrative work, a lot of which is unnecessary. Tenggren (2007), Fasadautomatik, states that the one making the tender invitation not always knows much about technology. When tendering the invitation have to be followed to the point. There is no room for discussion about alternative solutions. This takes a lot of energy and work (Tenggren, 2007).

[30] Globe Arenas (Hovet) demanded the system installers to present three reference projects (2007). Sandell (2007) states that they have come across this demand several times and that is seem like organizations are copying parts of the tender invitation. This theory is supported by SISAB (Bäcklin and Öberg, 2007) who states that they have copied parts of the tender invitation from another organization and that they have shared their invitation with the sport administration in Stockholm.

[31] The Church in Malmö encountered problems when putting up sunshades at one of their parish houses. They did not know that they needed to apply for building permit (Andersson, 2007). Apparently the parish house was designed by a famous architect. The local building committee found out about it after the sunshades were installed and demanded the Church to remove them. When Eksta Bostäder put up PV on the roof of Fjärås health center outside Kungsbacka they did not bother to apply for a building permit at all, thus avoiding the bureaucracy, even though they needed one (Tirén, 2007).

[32] In Swedish: Riksantikvarieämbetet

latest development is a rejection on the appeal to the Swedish Supreme Administrative Court and a motion to the Swedish Parliament on the theme has been written.[33]

The view on PV in the society in Sweden is positive, as there is a general underlying belief that PV is a future technology. This belief is shown by the result of an annual poll done by SOM-insitutet. In their report "Energiopinionen" (Holmberg, 2006) it is shown that, during the last six years, approximately 90 percent of the people taking part in the poll thought that Sweden should invest the same amount or more as is presently occurring on PV technology. This figure is slightly higher than for hydro power and wind power (Holmberg, 2006). This observation is supported by the result of the survey done by Vi i Villa presented in section 3.1.6.

3.4 Summary – structural level

The following section will aim at answering the first and second research questions on a structural level.

1. What is the dynamics of the technological innovation system (TIS) for PV, in respect to the systems' different elements?
2. What are the effects of the investment subsidy on the dynamics of the innovation system, in relation to other determinants?

Two main messages will be presented. The first one is treating the change in the number of actors. The actor groups can be separated into those which have grown and those where no change has been identified. The second message is that the system seems to consist of three isolated subsystem, of which the effects will be discussed.

Firstly, since the investment subsidy started, the Swedish PV innovation system has grown in terms of number of firms, which is shown in Table 3. Noticeable is the entry of Midsummer, producing CIGS solar cells. Moreover, the PV module manufacturers have increased both in number and, above all, in their total production capacity. Since the investment subsidy started in May 2005, the actor groups directly connected to the PV system installations have also grown significantly. Among the PV system installers this is clearly shown. Before the investment subsidy, only one such firm existed. Today eight different firms can be identified. Through the positioning of several PV system installers there is the involvement of two electrical firms. There are also more consultants able to work with PV installations today compared to before the investment subsidy existed.

Some actor groups have however not experienced any significant growth. There is still no actor producing BOS components and there is no notable change within the construction sector, i.e. among the construction companies and the architects. The latter is a sector, within the system, which can be considered very weak. The lack of education connected to this sector is also a weakness. The change among the energy companies is not very large either. The larger companies still do not show much interest. The willingness to work with solar electricity is expressed by smaller companies.

[33] There proposal about the PV installation on Fläckebo church first got refused by the National Heritage Board and the county administrative board of Västmanland. The church in Fläckebo did not give up and appealed to the Swedish Supreme Administrative Court, which later decided to be on the National Heritage Boards side, stating that the installation would distort the cultural historical value and disturb the public (Lundberg, 2007; Ramqvist, 2007). There has also been a motion (Motion 2007/08:Kr220) written about this and handed in to the Swedish Parliament in October 2007. The aim is to adjust the rules and regulation to present time.

<table>
<tr><th></th><th>2004</th><th>March 2006</th><th>Nov 2007</th></tr>
<tr><td>Cell manufacturers</td><td></td><td></td><td>Midsummer</td></tr>
<tr><td>Module Manufacturers</td><td colspan="3">Gällivare Photovoltaic</td></tr>
<tr><td></td><td colspan="3">Arctic Solar</td></tr>
<tr><td></td><td colspan="3">Scanmodule</td></tr>
<tr><td></td><td colspan="3">PV Enterprise</td></tr>
<tr><td></td><td></td><td colspan="2">Sharp</td></tr>
<tr><td></td><td></td><td></td><td>n67 Solar</td></tr>
<tr><td>PV system entrepreneurs</td><td colspan="3">NAPS</td></tr>
<tr><td></td><td></td><td colspan="2">Switchpower</td></tr>
<tr><td></td><td></td><td colspan="2">Exoheat</td></tr>
<tr><td></td><td></td><td colspan="2">Flex fasader</td></tr>
<tr><td></td><td></td><td>Celltech</td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Gaia Solar</td></tr>
<tr><td></td><td></td><td></td><td>Söderbergs Yttertak</td></tr>
<tr><td></td><td></td><td></td><td>Glascell</td></tr>
<tr><td></td><td></td><td></td><td>Fasadautomatik</td></tr>
<tr><td></td><td></td><td></td><td>Solkraft Östergötland</td></tr>
<tr><td>Consultants (pre-studies, inspectation, project management)</td><td colspan="3">Energibanken</td></tr>
<tr><td></td><td></td><td colspan="2">Rejlers Ingenjör AB</td></tr>
<tr><td></td><td></td><td colspan="2">WSP</td></tr>
<tr><td></td><td></td><td></td><td>Ramböll</td></tr>
<tr><td></td><td></td><td></td><td>ÅF</td></tr>
<tr><td></td><td></td><td></td><td>Grontmij</td></tr>
<tr><td>Electricians (excl local one-time installers)</td><td></td><td></td><td>Lambertsson</td></tr>
<tr><td></td><td></td><td></td><td>YIT</td></tr>
<tr><td>Building companies</td><td colspan="3">NCC</td></tr>
<tr><td>Architects (more than one project)</td><td colspan="3">White</td></tr>
<tr><td>Applications specialists</td><td></td><td colspan="2">Ekosol</td></tr>
<tr><td></td><td></td><td colspan="2">Schüco</td></tr>
<tr><td></td><td></td><td></td><td>Alwitra</td></tr>
<tr><td>Research Spin-offs</td><td colspan="3">Solibro</td></tr>
<tr><td></td><td></td><td colspan="2">Arontis</td></tr>
<tr><td>National R&D programmes</td><td colspan="3">Elforsk</td></tr>
<tr><td></td><td colspan="3">SolEl 03-07</td></tr>
</table>

Table 3. An overview of the actors within the Swedish PV innovation system and their approximate entrance (excluding peripheral actor groups, e.g. energy companies)

The second main message relates to the overall structure of the Swedish TIS for PV. The Swedish system seems to fall apart into three subsystems, which are more or less isolated from each other. Figure 1 illustrates the different parts of the system. The solar cell manufacturing has its own subsystem (1). Midsummer aims to sell to the global market. The research taking place about solar cells is in a few cases connected to production; both Midsummer and Solibro are each supported by research from the universities. Solibro is based on research performed at Uppsala University and is connected to the German system and module manufacturing there. Midsummer is supported by research taking place at Chalmers University of Technology.

The PV module manufacturers make up another subsystem (2). They are not selling much to Swedish installers, but are aiming at the global market. The change which has occurred in these two subsystems, i.e. the subsystem around solar cell respectively PV module manufacturing, is mainly driven by research and the global demand and expectations of future potential for solar cells and PV modules. The current investment subsidy does not seem to have any impact on these two subsystems.

The third subsystem contains the PV system installers and the PV system buyers (3). The PV system installers (on behalf of the system buyers) turn to the global market in order to get PV modules, even if some are bought from Swedish manufacturers. Further, there is some connection between the system buyers and the universities concerning knowledge about applications. This is the subsystem which is targeted by the investment subsidy. The subsidy has a significant effect on the PV system installers, consultants and system buyers. The networks created among the actors in this subsystem can, therefore, also be seen as a direct effect of the investment subsidy.

Besides the two main messages above yet another point can be mentioned. Even though the number of actors in connection with the installations has increased, the system is still relying on a limited group of motivated people. These people are especially those which engage in activities outside their firm or in other organization, which have a drive believing in PV or where their firm is strongly depending on a subsidy. This makes the system vulnerable, as if these people decide to leave the innovation system a lot of the gained experience is lost.

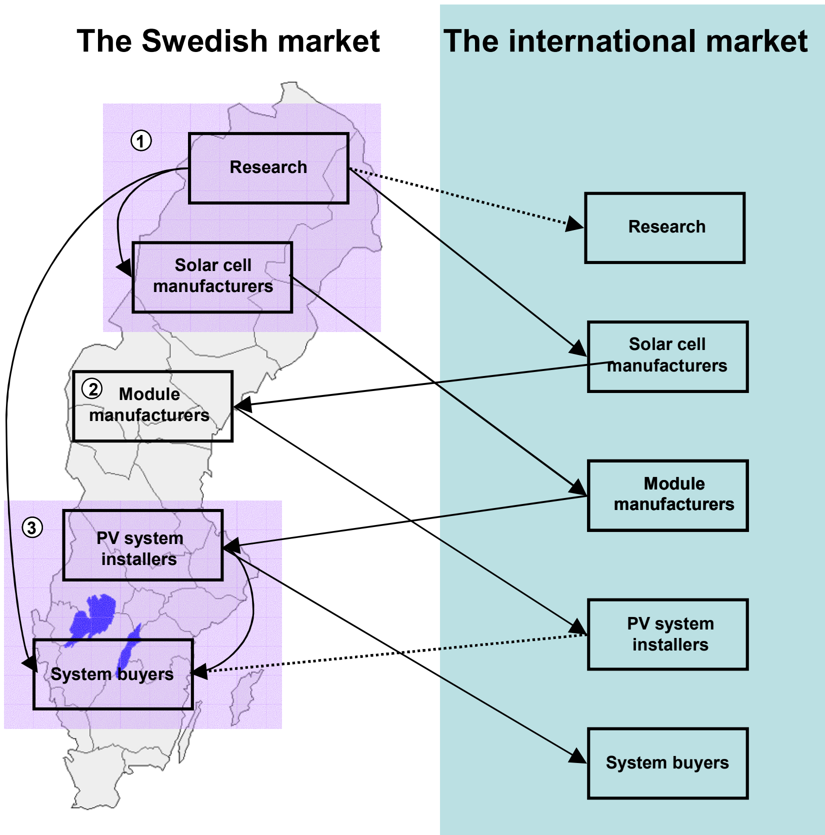

Figure 1. The Swedish system and its connections to the global market. (The map of Sweden is downloaded from the website of Marianne Wartoft AB www.wartoft.nu/images/seterra/sverige.gif, 2007-12-01)

4 The functions of the PV innovation system

The purpose of this thesis is to analyze the impacts that the investment subsidy has had on the Swedish PV industry and to identify challenges that need to be addressed. The previous section has given an understanding of the structure of the PV innovation system. This section aims to bring about a second dimension, when answering the first and second research questions:

1. What is the dynamics of the technological innovation system (TIS) for PV, in respect to the systems' different elements?
2. What are the effects of the investment subsidy on the dynamics of the innovation system, in relation to other determinants?

This will be done by applying a functional level to the analysis. The seven functions used are described one at a time in their own sections. Further, inducement and blocking mechanisms connected to the functions are presented. In the end of each section, dealing with a specific function, a table summarizing its key features, inducement and blocking mechanisms is found (Table 4 – 10). In section 4.8, the mechanisms are used to identifying policy challenges which aims to answer the third research question:

3. What blocking and inducement mechanisms can be targeted by policy in order to strengthen the innovation system, and what are the connected policy challenges?

4.1 Knowledge development and diffusion

A great deal of knowledge development takes place at the universities. This knowledge diffuses into society in different ways. One kind of diffusion is through commercialization, e.g. through Solibro. Concerning Solibro, knowledge has spread to the German system through the joint venture with Q-Cells (see section 3.1.1). Another kind of knowledge diffusion is the one from the universities to the system buyers, which is more connected to general knowledge about PV and to its applications and can be identified in several cases.

Research can also take place within firms and knowledge can be diffused from other TIS. Midsummer (see Box 1) is not the result of commercialization of university research. The knowledge about the technology is diffused from the DVD and CD industry and they are performing their own R&D, even though they are cooperating with Chalmers University of Technology.

The system installers and consultants have also learned more through the increasing amount of projects and diffusion within the actors can be seen.[34] The system installers can be divided into two groups. The ones that have done one project, and thus learned the basics and the firms that have done more, i.e. Exoheat, NAPS and Switchpower, which have gotten the opportunity to develop their knowledge even more. The above mentioned firms have also started steady co-operation with sub-contractors, thus increasing the sub-contractors specialized knowledge through acquired experience. These co-operations are treated in section 3.2, as buyer-supplier and partner networks.

PV seminars are driving the knowledge development. They are an important place where the actors can meet and share knowledge, i.e. knowledge is diffused (Nilsson, 2005; Andersson, 2007a; Norlund, 2007; Åström, 2007). There are PV seminars connected to the SolEl program

[34] Andersson (2007) at WSP states that he has learned more about the installation of PV system. During his second project he paid more attention to how the mounting and the wiring were done. A start at knowledge diffusion can be seen in WSP, where Andersson (2007) says that he has been contacted from the offices in Göteborg and Malmö concerning PV systems.

and seminars within BeBo[35], where the Swedish Energy Agency has been informing about the subsidy (Tirén, 2007). The SolEl program also partly finances a newsletter, PVTnytt which aims to spread knowledge about PV and solar thermal.[36] Solar City Malmö, which is under development and can be seen as an indirect result of the investment support, also has the potential to contribute. The City of Malmö has already held a seminar together with Skane Energy Agency (Energikontoret Skåne) and they have plans to have more.[37]

A direct outcome of the investment support is several PV projects. It is a fact that a significant number of high profile buildings have PV installations as a result of the support, e.g. Hovet next to Globen in Stockholm and Ullevi in Göteborg. In many cases information boards next to the installation show the production of electricity.[38] Visible installations can be assumed to make the society more aware of the PV technology.

An increasing amount of projects has increased the knowledge about PV projects both in general and within the actors connected to them. Further, there are signs of knowledge diffusion within actors. Concerning the buyers, they have acquired enough knowledge to be able to make the investment take place. A condition for this is that knowledge is diffused through the organization. Löfvenberg (2007) at the Sport Administration in Stockholm says that she had been lobbying for PV in the organization in order be able to get a PV system when the subsidy gave the opportunity. Other examples of where knowledge diffusion has been taking place within the organization are Akademiska Hus and the City of Malmö.[39]

By repetition, i.e. a second PV installation, the buyer has to opportunity to go further. In Malmö, where several projects have been launched, the knowledge has had the opportunity to develop even more, as they can use the knowledge acquired in earlier project in later ones. Norlund (2007), at Malmö Stadsfastigheter, states that he has indeed learned more, especially about the administration, and that the experiences have been used in projects later on (see Box 2). At this point in time, there are few cases where the same organization has made more than one project. This can be considered a blocking mechanism, blocking the utilization of the created knowledge.

An actor group which does not show any signs of developing knowledge within the area is the construction sector. In order to get more building integrated PV (BIPV) solutions they are an important group as they are involved in the planning and construction of new buildings. If a PV installation is considered already at the planning stage of a building, better solutions are expected. The sector's lack of involvement or more importantly the reason for it can therefore be considered a blocking mechanism for knowledge development within the area.

Even though this thesis is focusing on the Swedish system one can not see it as isolated, but one affected by its surroundings. A direct example of this is the diffusion of knowledge that one can expect from foreign firms entering the Swedish market. There are two German facade and roof firms present in the Swedish system: Alwitra and Schüco. They are providing building integrated solutions and are bringing knowledge about these kinds of applications into the system.

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[35] BeBo stands for Beställargruppen för bostäder (Freely translated into English: The Ordering Group for Housing), a network formed by the Swedish Energy Agency consisting of representatives from several real estate firms in Sweden. The goal is to make sure that energy efficient systems and products reach the market faster.

[36] PVTnytt can be found at www.pvtnytt.se and is published by Joakim Byström at Arontis.

[37] The seminar was named Solceller i Bebyggelse – Ett seminarium om praktisk användning av solceller (Freely translated into English: Solar cells in built environment – A seminar about practical use of solar cells). In connection to the seminar there was an exhibition with Skane Energy Agency, Energibanken, NAPS Sweden AB, Switchpower, Gaia Solar, GPV, Exoheat, Sharp, Celltech and Ekosol System AB. Skane Energy Agency have also had a seminar about the investment subsidy (Energikontoret i Skåne, 2008).

[38] E.g. the tennis court in Båstad; Health Center in Fjärås (Eksta Bostäder); schools in Älvsjö, Stockholm (SISAB); Ekologihuset in Lund (Akademiska Hus Syd)

[39] Henrik Åström (2007) at Akademiska Hus Syd and project leader for the installation at Ekologihuset at the campus of Lund University states that he had to convince the managers in order to get the PV system and that the first reaction was that he should forget about it. As for the City of Malmö several decisions concerning PV systems have been made, implying that knowledge about PV has diffused through the organization. The diffusion also shows from the request from parts of the organization to get PV systems (see Box 2).

Key features	Inducement mechanisms	Blocking mechanisms
• R&D taking place at the universities. • Fairly good in the whole system with the exception of the building sector (architects and building companies). • Three system installers who have done several projects. • Seminars and meeting points is an important platform for spreading knowledge. • Effect of the subsidy: – A large amount of visible installations and the attention around them spread knowledge to the society in general. – The subsidy has resulted in a significant amount of PV installations. Actors have gotten experience by working with these. – Specialization of firms connected to system installation.	• Seminars • The investment subsidy (applications, opportunity for repetition • R&D support	• No incentive for involvement of the construction sector • Unutilized knowledge within system buyers if they only make one installation

Table 4. The table provides an overview of the function knowledge development and diffusion by presenting its key features and inducement respectively blocking mechanisms.

4.2 Influence on direction of search and identification of opportunities

Solar energy is defined as a clean technology, cleantech, which lately has received increased attention in media and has attracted more investors (see section 4.5). This is connected to the debate about climate change giving this kind of industry more legitimacy (see section 4.6) and can be expected to influence the development the PV industry all over the world, including Sweden.

From Sweden, we can observe many other countries and see a strong growth within the PV industry. Germany is leading, but many other countries are following their example, showing faith in the future of PV. This fact has influenced the Swedish system, especially the solar cell and PV module manufacturers, as they are acting on the global market.

The investment subsidy has had an impact on the amount of PV system installations taking place within the Swedish system. There would be very few projects if the investment subsidy did not exist. Without the subsidy, organizations would most probably spend their money on other activities.

There are different aspects affecting which organizations that decide to invest in PV systems. Since the subsidy targets public buildings, the system buyers are public or are housing a public activity. The investment also attracts organizations which value the PR and goodwill that is connected to a PV installation.[40] The system buyers have in many cases a key person interested in PV which have come in contact with PV and other buyers at a seminar, for example.[41] There are also some cases where the environmental goals for the organization are considered to go hand in hand with a PV installation.[42]

The characteristics of the installations themselves are partly dependant on the design of the support, which results in installations on public building which in many cases are quite high profile. Further, it targets already existing buildings resulting in a majority of the PV systems installed outside the building envelope, i.e. not integrated in the facade or the roofing.[43] These

[40] Malmö Solar City Malmö use the PV installations in PR purposes in order to profile the City (Norlund, 2007). Båstadtennis & Hotell is also using the installations in PR purposes (Henningsson, 2007).

[41] Machirant (2007) at Switchpower says that there is a driven person behind every project who has communication and political skills, in order to get acceptance for the project within the organization. Examples of such people, come across in this study, are Henrik Åström at Akademiska Hus Syd, Martin Norlund at Malmö Stadsfastigheter (the City of Malmö) and Elsy Löfvengren at the Sport Administration in Stockholm.

[42] Examples of system buyers where the PV project is stated to be in line with the environmental values or responsibilites of the organization: Akademiska Hus Syd (Åström, 2007), Globe Arenas (Grönlund, 2007), the City of Malmö (Lindhqvist, 2007).

[43] In the project information provided by Boverket in August 2007, 68 percent of the granted projects belonged to the category "PV systems integrated outside the insulation". The other categories are: integrated in the roof (19 %), integrated in the facade (19 %) and other (6 %) (Boverket, 2007) .

limitations can be interpreted as blocking mechanisms, blocking the development of BIPV solutions and the possibility for non-public buildings to invest in PV systems.

Another characteristic of the PV systems supported is the maximum level of support per building (5 MSEK), which has the possibility to affect the size of the installations. By August 2007, approximately six percent of the granted projects were supported by 4,5 MSEK or more, which suggests that the maximum limit has not been a critical constraint (Boverket, 2007). More important considering the size of the installation is the blocking mechanism consisting of the high costs for feeding in electricity into the grid. This has resulted in many installations being dimensioned not to produce more than the minimum consumption of the building, in order to avoid a net electricity surplus.

The design of the support also influences the system installers directly connected to it. Since the support targets public buildings the Public Procurement Act has to be applied in most cases. This hinders new potential system installers to enter the system. Further, the short time span and uncertainty about future support for PV installations makes the system installers, relying on the Swedish market, look at markets abroad or at niche markets.[44]

Key features	Inducement mechanisms	Blocking mechanisms
• The PV industry is growing in other countries and this is influencing the solar cell and PV module manufacturers in Sweden. • The sizes of the systems are partly affected by the issue of grid-connection. • Effect of the subsidy: – The subsidy is of importance, although it is short term. There are consultants and system installers identifying this as an opportunity. – The subsidy has lead to a significant amount of PV projects. – The design of the subsidy is affecting the outcome of the PV systems (kind of building, size, choice of entrepreneur, organization).	• The design of the subsidy: public, high profile buildings; the level of support (70 %) • Strong growing global market for solar cells and PV modules • Word of mouth (at seminars)	• Tendering (the Public Procurement Act) • No subsidy targeting new buildings • Uncertainty about future policy • No long term vision of the subsidy • Grid-connection (costly)

Table 5. The table provides an overview of the function influence on direction of search by presenting its key features and inducement respectively blocking mechanisms.

4.3 Entrepreneurial experimentation

Entrepreneurial experimentation can be identified in different places in the value chain by the entrance of new firms and what kind of activity the firms perform.

In the top of the value chain, a solar cell manufacturing firm, Midsummer, has entered (see Box 1), trying out a new way of producing CIGS. Also Solibro, starting its production of CIGS in Germany, and Arontis, making PVT systems, are examples of entrepreneurial experimentation within this actor group (see section 3.1.1). The PV module manufacturers have increased their total production capacity.

Among the groups directly connected to the subsidy some experimentation can be seen, although the experimentation is not very differentiated, i.e. the services offered do not differ very much. The group earlier defined as consultants have had new firms entering, but still only one firm, Energibanken, is specializing on PV systems. For the other firms the PV projects stand for a very small part of their business. The major entrance of firms has taken place within in the group of system installers. Before the investment subsidy there was one firm, NAPS. In December 2007, they were eight (see section 3.1.3). Although many new firms, they are all basically offering the same kind of services, which is closely related to the investment support. Noticeable is that the firms most dependant on the support has started experimenting within other areas (see section 4.2), as a result of the uncertainty about a continuation of the subsidy.

[44] Switchpower is entering the Greece market and Dubai (see 3.1.3). Glacell aims at glass integrated solutions (Lundgren, 2007).

In a few actor groups very little entrepreneurial experimentation can be identified. As mentioned earlier there is a lack of BOS component manufacturers in Sweden and there are no sign of potential firms willing to enter the system. The construction sector is not showing any interest, except from Ekosol (see section 3.1.4), and only little entrepreneurial experimentation is taking place within the area of marketing and selling electricity generated from solar cells to consumers. The smaller energy companies have a friendlier attitude and show more interest than the larger ones. There are a few firms aiming at providing solutions in order to produce and buy solar electricity (see section 3.1.6) but so far the progress is limited. A reason for this, blocking the experimentation in these sectors might be that there is no support targeting these groups. The current investment subsidy targets mainly already existing buildings and there is no market where solar electricity can be sold and bought.

Experimentation has also taken place considering applications. Examples from the buyers perspective are the plans for a solar tracker in Malmö (Lindhqvist, 2007; Norlund, 2007) and a hybrid (PV and solar thermal) in Lund by Akademiska Hus Syd (Åström, 2007). Both were planned to be supported by the investment subsidy. Similar application experimentation is also performed by Arontis, but in this case from a producer's perspective.

Key features	Inducement mechanisms	Blocking mechanisms
• There is entrepreneurial experimentation taking place in most part of the value chain. More or less missing in Sweden is BOS-component manufacturers and the building sector. • Little experimentation, but some, providing the end-consumer with solar electricity. • Effects of the subsidy: – The experimentation of firms in the actor groups closely connected to the PV installations can be interpreted as a result of the program as the risk has been reduced. – There is some experimentation with new applications within the investment subsidy.	• Strong growing global market for solar cells and PV modules • The investment subsidy	• No subsidy targeting BIPV solutions • No functioning market for solar electricity in Sweden • Uncertainty about future policy • Limited group of system buyers targeted by the support.

Table 6. The table provides an overview of the function entrepreneurial experimentation by presenting its key features and inducement respectively blocking mechanisms.

4.4 Market formation

The Swedish PV innovation system consists of several markets, markets for solar cells, PV modules, PV systems, BOS components, solar electricity etc. The focus of this thesis is the market for PV installations as that is the primary target of the support, but the other ones are, of course, also of importance.

Concerning PV systems, the subsidy has created a market space, as a demand has been created. It has made it possible for additional firms to enter. The subsidy has been the driving force for this market creation, which is clearly shown by the fact that there existed very few grid-connected PV installations before the subsidy. Further, a general statement is that the supported projects would not have taken place without the subsidy (Andersson, 2007a; Grönlund, 2007; Åström, 2007). The impact is also shown by the effect the short time span of the support has. As the subsidy is ending and as there is no decision on a continuation, potential buyers have a hard time making plans, putting projects on hold, waiting for a decision about a possible future policy.[45]

An ability to recognize additional values can be identified among some of the buyers (Andersson, 2007a; Norlund, 2007; Åström, 2007), though it does not seem to be existing everywhere. It is connected to the market formation as it can be seen as an extra asset or as a parallel market, increasing the willingness to pay. This point is closely related to legitimation in section 4.6.

[45] Akademiska Hus Syd wants to make one more installation but it is dependant on future support according to Åström (2007) at Ekologihuset. Norlund (2007) at Malmö Stadsfastigheter says that there will be no installations without the support. They will wait and see what happens.

Several factors are blocking market formation. The uncertainty about maintenance is one.[46] This is addressed briefly by the publishing of a handbook for installations of grid connected solar cells which is financed by the SolEl program. Another blocking mechanism, on its way to be solved, is the high cost of feeding in electricity into the grid, about which an official report is written.

Yet another blocking mechanism is that a building permit is needed for many installations. This has in some cases lead to disagreements and delays.[47] A special case connected to this is PV installations on roofs of churches, which is handled in section 3.3.

Finally, the market for solar electricity should also be mentioned. As for now there is no possibility for the private consumers to buy solar electricity. The survey by Vi i Villa (2007) mentioned in section 3.1.6 shows that there is a potential market though.

Key features	Inducement mechanisms	Blocking mechanisms
• The markets for solar cells and modules are global and growing. • There is no market for solar electricity in Sweden. • Effects of the subsidy: – The subsidy has created a market space for PV system installations but has not affected the market for solar cells or modules. – The PV installations supported by the subsidy has shred light upon issues like: the uncertainties about maintenance, the problem with building permits, especially for churches and the high costs of grid-connection.	• The investment subsidy • Increased knowledge about maintenance	• Grid-connection (costly) • No functioning market for solar electricity in Sweden • Building permits

Table 7. The table provides an overview of the function market formation by presenting its key features and inducement respectively blocking mechanisms.

4.5 Resource mobilization

The investments subsidy is contributing with 150 MSEK for PV system installations. This support is targeting the system buyers and is the major source of financing of the projects. Together with the 30 percent that the buyers have to finance themselves, a total of 214 MSEK will be spent on PV projects over approximately three and a half year. The significance of this number can be discussed. In order to comprehend its size, it can be put into relation with the total cost of the green certificates for the electricity consumers in 2006 which was 3298 MSEK, i.e. the cost for only one year (Energimyndigheten, 2007).

Financial resources in the form of investments are necessary for firms in order to grow, especially in the beginning. There seems to have been a change taking place the last year in this area. Solibro has earlier had problems finding Swedish investors (Bengtsson, 2007). This can be compared to firms like Midsummer and PV Enterprise, which more recently have been able to attract investors. The interest in cleantech industries has increased.[48] In the US, 2007 was a record year for cleantech investments and the area where most money was invested is solar energy (Alpman, 2007).

The system is currently provided with human resources through education, with the exception of the construction sector. There is no sign of interest from this sector to involve itself with PV and

[46] Maintenance was expressed as an issue discussed in connection to the project at Åkeshovshallen. The project will serve as a demonstration project and will be evaluated in one or two years time (Löfvenberg, 2007). Maintenance is an issue at Hovet, where they have to handle snow on the roof, which they might have to shovel away as it can make the roof too heavy (Grönlund, 2007). The issue was also addressed concerning the projects in Älvsjö (SISAB) (Bäcklin, 2007)

[47] SISAB had to choose another, more expensive color on the PV modules (Bäcklin and Öberg, 2007). Another example is the case with the church in Malmö (see section 3.3)

[48] When Solibro was looking for investors in 2006, they did not have any success getting Swedish ones. It ended up with the German firm Q-cells investing in Solibro in December 2006, resulting in a production site in Germany (Bengtsson, 2007). Midsummer (see Box 1) is approached approximately once a week by cleantech investors. PV Enterprise managed two new emissions (see section 3.1.1). The attention paid to cleantech has increased generally in Sweden, which can be illustrated by a number of articles in newspapers.

PV is not integrated into relevant educations, i.e. architecture and civil engineering. However, concerning the educations that exist, the capacity of the system to make use of the human resources is also of importance. This can be illustrated by the fact that the master program in Borlänge has very few Swedish students and few stay in Sweden after the education. Another example is that Heta Utbildningar in Härnösand has difficulties finding enough vocational training positions, at the same time as the system installers express a lack of experienced labor (Selhagen, 2007; Machirant, 2007). This can be explained by the uncertainty about future support. There is no possibility to invest in new employees, according to Selhagen (2007) at NAPS, with this large uncertainty.

At Midsummer, the solar cell producer, there has been no problem getting hold of competent employees. Due to the abundance of people available in the area where they are situated, formerly working with semi conductors at Ericsson (see Box 1 about Midsummer).

Key features	Inducement mechanisms	Blocking mechanisms
• Increased interest for cleantech, has resulted in investors willing to invest in the PV industry. • Education concerning more practical PV installation tasks and solar energy are existing but the system has a hard time absorbing it. • There is a lack in the education for architects and civil engineers concerning PV. • Effects of the subsidy: – The subsidy contributes with 150 MSEK. In total 214 MSEK is spent on PV systems within the frames of the subsidy.	• Education exists • Strong global market for solar cells and modules • High interest in cleantech firms	• Uncertainty about future policy • System not able to absorb human resources • Little knowledge about PV among the construction sector • No integration of PV in educations for architects and civil engineers.

Table 8. The table provides an overview of the function resource mobilization by presenting its key features and inducement respectively blocking mechanisms.

4.6 Legitimation

The legitimation is influence by what is both inside and outside the system. Factors affecting the system from the outside can be seen as exogenous and examples are the increasing intensity in the debate about climate change and the growth of the solar cell industry in other countries like Germany.

Legitimation can also be look at on an organizational level. In order for a project to get launched it has to be a decision made by the decision makers in the organization. It can be expected that a decision not only based on economics purely related to the electricity production gives the installation more legitimacy. Examples of where additional value has been taken into account are in the City of Malmö, at Ekologihuset in Lund by Akademiska Hus Syd and at Hovet in Stockholm.[49]

An interesting comparison can be made between the City of Stockholm and the City of Malmö considering legitimation. Even though it is stated that additional values, which could lead to increased legitimation, are taken into account at Hovet in Stockholm the overall legitimation seem to be much higher in Malmö. This might be partly a result of that the administrations in Stockholm have received the remaining 30 percent of the investment costs covered by the City. If an organization does not have to pay anything itself it is probable that less discussions about the investment is taking place. The lack of discussion held to present the motives for the PV

[49] In the case of the City of Malmö the added value has been to use the PV installations when profiling the city (Norlund, 2007), see Box 2. Åström (2007) states that the installation at Ekologihuset was partly motivated by the PR that it would give Akademiska Hus. Working with renewable energy sources fits well to the profile that Akademiska Hus has. Grönlund (2007), real estate manager and responsible for the PV installation at Globe Arenas, explains that they have an environmental responsibility and with 100 percent coverage of the investment cost "you have to do it". He also sees it as a way to gain goodwill and market. They have had media and politicians there. The installation can not be seen from the ground and at the time of the interview they had not yet put up any information signs about the installations. When asked about this it seemed like Grönlund had forgotten about it.

system hinders the discovery of additional values and the spreading of knowledge within the organization to take place.[50]

Positive experience connected to the actual PV systems installed has also had a positive influence on the legitimitation, both for PV in general but also for the system installers and the products (solar cells and BOS components). Throughout the interviews the system buyers have stated no problems with the running installations (Bäcklin and Öberg, 2007; Grönlund, 2007; Norlund, 2007; Tirén, 2007). The system installers are also seen as very competent by the same system buyer. Juslin (2007) at ÅF says that it really has been a pleasure working with them (aiming at Exoheat and Switchpower) as they are very competent in comparison with electricians in general and that everything has gone smoothly. Finally, media has also pictured the installations in a positive way.

The above mentioned points, i.e. successful projects and positive experiences from the installers and the products feed the Swedish system with legitimacy together with the efforts done by lobbying organizations like SPIA. Yet another point is the investment subsidy itself. The existence of the subsidy shows belief from the politicians, even though the short time span can be interpreted as ambiguity. An increased legitimation among the politicians also shown by a motion on the subject was handed in to the Parliament in fall 2007. The motion says that Sweden should support the economic conditions for research, production and storage of solar energy[51]. On the other hand, the lack of involvement from the large energy companies has a negative impact on the legitimation.

There is a general belief that PV is something that will grow in the future, at the same time the belief is that the technology still have to develop a lot in order become less costly (Bäcklin and Öberg, 2007; Grönlund, 2007). The society in Sweden is also positive to PV as stated in section 3.3.

Key features	Inducement mechanisms	Blocking mechanisms
• Positive experiences by the organizations concerning the PV installations. • Negative signals are sent from the large power companies. • There is no long term vision from the politicians. • The ability to account for additional values of a PV installation varies. • Effects of the subsidy: – Legitimacy has been created by the installations getting positive attention in the media and functioning very well. – The short term duration of the subsidy has a negative impact	• Climate change debate • The existence of the subsidy • Positive experiences from the PV installations • Increased legitimation internationally	• Uncertainty about future policy • Signals from larger power companies • Too much support (in the case of Stockholm) • No long term vision

Table 9. The table provides an overview of the function legitimation by presenting its key features and inducement respectively blocking mechanisms.

4.7 Development of positive externalities

There are some developments of positive externalities taking place within the system. One is the legitimacy which is created. Most noticeable is the City of Malmö which is working actively to increase legitimacy. They have not only increased the legitimacy internally but also on a national level, which benefits the whole system.

Another example is the central role of Switchpower and Energibanken, which by their advocating activities feed the system with legitimacy. Both these firms are members of SPIA. The effort by

[50] Löfvenberg (2007) at the Sport Administration says that the only questions have been about the maintenance. Grönlund (2007) at Globe Arenas, states that no one in the organization really cares about the installations except from the people in the real estate division. At SISAB, Bäcklin questions if information about the solar cells actually has spread through the organization. Öberg says that the schools have had no real questions, but that the question about money has been a bit sensitive. He did not know that the costs were fully covered. (Bäcklin and Öberg, 2007)

[51] "[…]Sverige bör främja de näringspolitiska förutsättningarna för forskning, produktion och lagring av solenergi som ett led i kampen mot klimatförändringarna och miljöförstöringen." (*Motion 2007/08:N214*)

the organization affects not only the members but all the actors in the system. Unfortunately is seems like SPIA has not reached its full potential. SEAS is more active but is at the moment not fully taking the interest of PV into account.

The investigation about the costs of grid-connection is valid for renewable electricity producers in general (see section 3.3). Hence, this is also a case of positive externalities. In this case it involves other innovation systems, as the issue concerns also other kinds of renewable energy sources.

Concerning the PV module manufactures, a cluster formation can be identified in Gällivare. Artic Solar was founded with help from experienced former employees of GPV. The firms are today, to a certain point, co-operating, by using the same labor pool and also by sometimes sharing their employees as well as material.

Further, a development connected to the development of knowledge and a result of the increasing amount of installations is the division of labor and fixed cooperation that has occurred between system installers and sub-contractors concerning electrical installation and mounting (Selhagen, 2007; Demeter and Lundgren, 2007). In this way the sub-contractors get the chance to develop their knowledge within the area as they are involved in more than one project.[52]

The positive externalities identified so far are limited. The investment subsidy has created some but considering its small scale in financial terms and its short time perspective, it is hard to say what is possible. A larger and broader investment subsidy might increase these positive externalities, by drawing more attention to institutional obstacles, inducing knowledge development and legitimation. Thus, the small scale of the investment subsidy can be considered a blocking mechanism.

Another question is what effect the three subsystems have on this function. The existence of positive externalities implies that there is no "perfect market" where everything has to be paid for in relation to its value. Positive externalities have been identified within the subsystems both around PV module manufacturing and PV installations, through network formation and personal contacts, which counteract the "perfect market". The question is why this should not be valid also for an integrated system, with a greater extent of networks. If following this line of reasoning, the fact that the system is divided into three isolated subsystems is a blocking mechanism as it prevents the system from developing these features which leads to positive externalities.

Key features	Inducement mechanisms	Blocking mechanisms
• Positive experiences by the organizations concerning the PV installations. • Negative signals are sent from the large power companies. • There is no long term vision from the politicians. • The ability to account for additional values of a PV installation varies. • Effects of the subsidy: – Legitimacy has been created by the installations getting positive attention in the media and functioning very well. – The short term duration of the subsidy has a negative impact	• Climate change debate • The existence of the subsidy • Positive experiences from the PV installations • Increased legitimation internationally	• Uncertainty about future policy • Signals from larger power companies • Too much support (in the case of Stockholm) • No long term vision

Table 10. The table provides an overview of the function development of positive externalities by presenting its key features and inducement respectively blocking mechanisms.

4.8 Policy challenges

In section 4.1 – 4.7, the key features of the TIS for PV where identified and sorted by function. Further, inducement and blocking mechanisms were derived for each function. This section will aim to identify and discuss the policy challenges in connection with those mechanisms, taking

[52] Selhagen (2007) states that YIT in Malmö has learned to install solar cell systems.

into account what the effects of the current investment subsidy are. Together with the stated inducement and blocking mechanisms this aims to answer the third research question: What blocking and inducement mechanisms can be targeted by policy in order to strengthen the innovation system, and what are the connected policy challenges? An overview of the key features, inducement and blocking mechanisms together with the corresponding policy challenges are found in Table 11.

What is considered a policy challenge is naturally depending on what is considered desirable. The focus of this thesis is the investment subsidy. As concluded earlier the Swedish PV innovation system consist of isolated subsystems. The question is an integrated system should be wished for is left unanswered by this thesis. Instead, the system is looked upon, taking into account the different parts' isolation.

Below, each policy challenge is described in connection with the corresponding blocking mechanisms. A discussion about their interconnection and how to target them is given for each identified challenge.

Long term policies

The lack of a long term perspective of the current support is a blocking mechanism connected to several functions; influence on direction of search, entrepreneurial experimentation, resource mobilization and legitimation. Many of the other policy challenges, described below, are depending on a long term perspective. It is important for especially small and specialized firms to be able to somewhat foresee the future, as their risks are not very spread. This can not be expected to be done totally by policies but at least long term policies dramatically reduce uncertainty, in particular when the market is heavily dependant on the particular policy, like in the case with the investment subsidy for PV.

With a long term perspective firms might also dare to invest in employees, by providing apprentice places or train new employees. In this way they have the ability to make use of the human resources that the system already today provides.

Finally, adapting a long term policy can be interpreted as a statement by the government, showing faith in the technology and leading to increased legitimacy.

Involvement of the building sector

The lack of interest from the building sector to enter the system is identified as a blocking mechanism. This lack of involvement blocks the development of knowledge concerning new applications and BIPV solutions. It is reasonable to argue that PV installations which are planned from the start when designing buildings have the chance to become more efficient than the ones put on existing buildings. BIPV solutions planned from the start can, for example, be sun shades, which decrease the need for cooling (there are some examples of this within the program), and PV integrated in the roofing. The latter can save other building materials as it can substitute the normal roofing. A well thought through installation might also be more aesthetically appealing. In order to include PV already in the planning stage, architects and construction companies have to enter the system. This could be induced by a policy that targets BIPV solutions, encouraging entrepreneurial experimentation. A subsidy could be differentiated, giving more support to BIPV solutions.

It also implies that PV is integrated in the corresponding educations, e.g. architecture and civil engineering, as knowledge about PV is needed within the building sector. In order to get a sustainable solution providing the building sector with people able and willing to work with PV, it makes sense to start at the bottom, among the students. It is important to spread knowledge about PV already from the beginning. Not including PV in the educations but at the same time aim at getting more BIPV solutions can be compared to artificial respiration. Further, this is something that probably takes some time to implement, as it has to be decided on by the universities and teachers themselves have to become knowledgeable within the topic. Therefore a proactive approach is preferable.

A long term perspective, treated above, is of great importance here, to make sure that there is enough time for the decision and planning process and the actual construction of the building. To further make it easier and less costly standardized BIPV solutions, which can be produced in high quantity, are wished for. The entrance of the building sector might be the first step and hopefully these solutions would come as a natural result.

Support to private and commercial buildings

The current subsidy has targeted public buildings and therefore, to the larger part, the public sector. This is connected to a certain kind of administration and a certain structure of the organizations buying the systems. Private companies might value a PV installation in a different way, with the purpose of increasing their goodwill and PR. They could therefore be an interesting group to target as they might see larger values. Private house owners might experience yet other values. The fact that these groups are not bound to the Public Procurement Act might also open up for new solutions as cooperation with system installers could be formed in another way. The Public Procurement Act can be seen as hindering buyers and system installers to continue working together automatically on a possible new project, which could hinder the development of positive externalities, and also, depending on the demands in the tender invitations, hinder the entry of new firms. This could result in blocking of network formation and network development between the system installer and the buyer. To sum up, a result of including commercial and public building can be projects taking place without applying the Public Procurement Act which hopefully lead to developed cooperation and less administration, as well as the possibility for increased entrepreneurial experimentation.

Solar electricity market

The lack of opportunity for the end-consumers to buy solar electricity is a blocking mechanism. A policy challenge here is to design a system where solar electricity can be sold and bought. By doing this price differentiation can be applied and solar electricity has the opportunity to be profitable. As mentioned in section 3.1.6, there exists an interest from the consumers. A system like this would reduce the need for investment support as solar electricity can be sold to a higher price than the spot price. Hopefully this would be considered as an opportunity resulting in more firms entering the system selling solar electricity.

Reduce dependency on large power companies

The signals from the larger power companies are hindering the legitimation process. One solution would be if their attitude could be changed. As this solution might be unrealistic in the near future another option is to become independent of them. The question is how this can be done. A solar electricity market, as mentioned above, could be one part of the solution. This would give small actors the opportunity to sell solar electricity. A reduction of the high costs for grid-connection is also welcomed, as this opens up for more actors to feed in solar electricity into the grid. The dependency is also reduced by finding alternative funding possibilities for activities like the SolEl program, which today to a large part is financed by Svensk Energi where the larger power companies are important interested parties.

Lower costs for grid-connection

The cost connected to feeding electricity into the grid is relevant for two functions; influence on direction of search and market formation. As mentioned above there has been an investigation done and there is the possibility that there will be changes in the law which would be beneficial for small distributed grid-connected PV systems. The challenge is to remove the hindrance of the high costs connected with the grid-connection. The existing investigation recommends that this should be done by changing the requirements for the metering.

Platform for meetings and organization

A role which has been played by the SolEl 03-07 program has been identified as an inducement mechanism. Unlike the other points in this section, targeting blocking mechanism, this one aim to put focus on an inducement mechanism, which exists. The PV installations are making us aware of issues that have to be taken care of (e.g. the grid-connection issues). As important as the identification of these issues is a forum where they can be communicated and discussed and a place where counter actions can be planned and from which they can be financed. A program like SolEl plays an important role as a complement to the investment subsidy.

SPIA has also the potential to contribute, even if it not very much has happened yet. A number of firms are members. There are more firms which could join. The financing is an important issue as well as the time that the members have on their hands to spend on the organization. It can only be expected go so far depending on solely the motivation of a few people.

The policy challenge in this case implies to acknowledge the importance platforms like SolEl, SPIA and also Solar City Malmö, and to encourage a continued support of them. These are necessary platforms in order to discuss problematic issues and form networks. They are of significance showing demonstration project and working to reduce institutional obstacles observed. They are contributing to positive externalities, i.e. efforts that the whole system gains on.

"Practice makes perfect" – encourage repetition

Within the system today there are several actors which have started to acquire experience by doing several installations. This is particularly true for some of the system installers. By learning from previous projects knowledge is developed. With an increasing amount of projects all the actor groups directly connected to the installations have the opportunity to practice and use their build up knowledge. This can also be expected to apply to the system buyers. Here the question is not as much about the technical part as about the administration. It is both about developing knowledge about how to execute the project and about increasing the legitimacy for PV within the organization. To encourage an organization to do several projects installing PV, the system would make use of the efforts made connected to the first installation. This could possibly be solved by simply encouraging more PV installation in general.

Maintenance

As PV installation has not been very common in Sweden there has been questions about how the maintenance is handle and how much work it includes. This blocking mechanism can be expected to be solved with time as more experience is gained form the existing and future installations. The issue has been acknowledged and a handbook about maintenance has been written, work which was financed by the SolEl program.

Building permits and society's perception of PV installations

To get a building permit for a PV installation is not always easy. This not solely a policy challenge but also a question of values. It might not be a major issue today but there are cases where special attention has been paid, e.g. the church in Fläckebo and the installations of PV system on buildings with a cultural heritage or of architectural value.

Chose the right level of support

By identifying values, other than electricity, the investment becomes more attractive. Organizations buying PV systems should be encouraged to reflect upon this. By doing this part of the cost for the PV installation can be allocated to for example PR. It is not obvious that the process of identifying this added value takes place. One possibility is to make sure that the investment subsidy is just low enough to not make the investment profitable purely in economical terms. This would hopefully lead to internal discussions about the installation, where these values would be identified.

Function	Key features	Inducement mechanisms	Blocking mechanisms	Policy challange

Knowledge development and diffusion	• R&D taking place at the universities.
	• Fairly good in the whole system with the exception of the building sector (architects and building companies).
	• Three system installers who have done several projects.
	• Seminars and meeting points is an important platform for spreading knowledge.
	• Effect of the subsidy:
	  • A large amount of visible installations and the attention around them spread knowledge to the society in general.
	  • The subsidy has resulted in a significant amount of PV installations. Actors have gotten experience by working with these.
	  • Specialization of firms connected to system installation.
		• Seminars
		• The investment subsidy (applications, opportunity for repetition)
		• R&D support
			• No incentive for involvement of the construction sector
			• Unutilized knowledge within system buyers if they only make one installation
				• Involve the construction sector.
				• Encourage organizations to do more than one project.

Influence on direction of search	• The PV industry is growing in other countries and this is influencing the solar cell and PV module manufacturers in Sweden.
	• The sizes of the systems are partly affected by the issue of grid-connection.
	• Effect of the subsidy:
	  • The subsidy is of importance, although it is short term. There are consultants and system installers identifying this as an opportunity.
	  • The subsidy has lead to a significant amount of PV projects.
	  • The design of the subsidy is affecting the outcome of the PV systems (kind of building, size, choice of entrepreneur, organization).
		• The design of the subsidy: public, high profile buildings; the level of support (70 %)
		• Strong growing global market for solar cells and PV modules
		• Word of mouth (at seminars)
			• Tendering (the Public Procurement Act)
			• No subsidy targeting new buildings
			• Uncertainty about future policy
			• No long term vision of the subsidy
			• Grid-connection (costly)
				• Let project outside the frame of the current subsidy take place, i.e. not only target public already existing buildings.
				• Reduce costs for feeding in to the grid (Hopefully being solved by investigation)
				• Long term policy

Entrepreneurial experimentation	• There is entrepreneurial experimentation taking place in most part of the value chain. More or less missing in Sweden is BOS-component manufacturers and the building sector.
	• Little experimentation, but some, providing the end-consumer with solar electricity.
	• Effects of the subsidy:
	  • The experimentation of firms in the actor groups closely connected to the PV installations can be interpreted as a result of the program as the risk has been reduced.
	  • There is some experimentation with new applications within the investment subsidy.
		• Strong growing global market for solar cells and PV modules
		• The investment subsidy
			• No subsidy targeting BIPV solutions
			• No functioning market for solar electricity in Sweden
			• Uncertainty about future policy
			• Limited group of system buyers targeted by the support.
				• Involve the construction sector.
				• Make it profitable to sell solar electricity.
				• Long term policy

Market formation	• The markets for solar cells and modules are global and growing.
	• There is no market for solar electricity in Sweden.
	• Effects of the subsidy:
	  • The subsidy has created a market space for PV system installations but has not affected the market for solar cells or modules.
	  • The PV installations supported by the subsidy has shred light upon issues like: the uncertainties about maintenance, the problem with building permits, especially for churches and the high costs of grid-connection.
		• The investment subsidy
		• Increased knowledge about maintenance
			• Grid-connection (costly)
			• No functioning market for solar electricity in Sweden
			• Building permits
				• Create the opportunity for the electricity-consumers to buy solar electricity.
				• Make it profitable to sell solar electricity.
				• Increase acceptance for PV installations and encourage aesthetic solutions

Resource mobilization	• Increased interest for cleantech, has resulted in investors willing to invest in the PV industry. • Education concerning more practical PV installation tasks and solar energy are existing but the system has a hard time absorbing it. • There is a lack in the education for architects and civil engineers concerning PV. • Effects of the subsidy: • The subsidy contributes with 150 MSEK. In total 214 MSEK is spent on PV systems within the frames of the subsidy.	• Education exists • Strong global market for solar cells and modules • High interest in cleantech firms	• Uncertainty about future policy • System not able to absorb human resources • Little knowledge about PV among the construction sector • No integration of PV in educations for architects and civil engineers.	• Long term policy • Integrate PV into the architect and civil engineering education (as part of involving the construction sector)

Legitimation	• Positive experiences by the organizations concerning the PV installations.
	• Negative signals are sent from the large power companies.
	• There is no long term vision from the politicians.
	• The ability to account for additional values of a PV installation varies.
	• Effects of the subsidy:
	  • Legitimacy has been created by the installations getting positive attention in the media and functioning very well.
	  • The short term duration of the subsidy has a negative impact
		• Climate change debate
		• The existence of the subsidy
		• Positive experiences from the PV installations
		• Increased legitimation internationally
			• Uncertainty about future policy
			• Signals from larger power companies
			• Too much support (in the case of Stockholm)
			• No long term vision
				• Long term policy
				• Become independent of the large power companies
				• Find the right level of the subsidy

Positive externalities	• Existence of industry associations (SPIA, SEAS).
	• Lobbying and work for legitimation done by the City of Malmö and the industry association SPIA.
	• Specialization connected to PV system installations.
	• Cluster formation in Gällivare
	• Effects of the subsidy:
	  • The increasing amount of projects following the investment subsidy has led to firms specializing
	  • SPIA and the Solar City Malmö
		• Firms dependent on PV advocating
		• Increasing amount of project (due to investment subsidy)
		• Lobby organizations, platforms
			• The small scale of the subsidy
			• No connection between the subsystems	

Table 11. An overview of the key features, inducement and blocking mechanisms, and policy challenges sorted by function.

5 Conclusions

The investment subsidy for PV installations on public buildings will end in December 2008. The aim of this thesis is to evaluate the impact of the investment subsidy on the dynamics of the PV innovation system. By identifying inducement and blocking mechanisms for further growth, the thesis also aims to give input to the discussion on how to continue supporting the PV innovation system.

In the introduction, three research questions were formulated:

1. What is the dynamics of the technological innovation system (TIS) for PV, in respect to the systems' different elements?
2. What are the effects of the investment subsidy on the dynamics of the innovation system, in relation to other determinants?
3. What blocking and inducement mechanisms can be targeted by policy in order to strengthen the innovation system, and what are the connected policy challenges?

The questions were used to structure the analysis. The outcome of the analysis is used in this conclusion which is addressing the aim of the thesis. The purpose of this conclusion is to discuss the desired properties of a future policy, referring to the identified weaknesses in the system and the impacts of the current investment subsidy.

The conclusion is made out of four major themes: impact of the investment subsidy, entry of actors into the TIS, knowledge development and stimulating discovery of multiple values. The first theme is connected to the first two research questions, whereas the last three targets the third question.

Impact of the investment subsidy

A major observation made is that the defined innovation system actually consists of three isolated subsystems: research and solar cell production, PV module manufacturing and PV system installation. Since the start of the investment subsidy there has been several firms entering the system. Most entries have occurred in the subsystem around the PV system installations and are a result of the increasing amount of projects brought forward by the investment subsidy. Network formation can also be observed within the subsystem between system installers and their suppliers and sub-contractors and can be considered an indirect effect of the subsidy.

The subsidy has also lead to an identification of a range of institutional problems affecting the subsystem around PV installations. These include the high costs of grid-connection, the Public Procurement Act, building permits and decisions made by the National Heritage Board. The subsidy has meant increasing attention to the issue of grid-connection, which hopefully will solve the problem. Attention to the possibility for churches to get PV installations has lead to a motion submitted to the Parliament.

Another interesting change in the structure since the subsidy started is the entry of Midsummer, making CIGS thin film solar cells. The Swedish research spin off firm Solibro has also taken steps towards mass manufacturing of CIGS, but in its case in Germany. There has also been one entry of a PV module manufacturer, making them five in total. More interesting in the latter group is the large capacity increase which has occurred lately. These developments can not be seen as a result of the investment subsidy but as a result of the growth in the PV industry world wide.

Since the subsidy started there is no significant change within the construction sector. Their lack of involvement can partly be explained by the design of the subsidy, which primarily targets already existing buildings. The involvement of energy companies and electricity consumers is also lacking.

The overall conclusion concerning the investment subsidy is that it has made a difference, although mostly noticeable in the subsystem around the installations. The subsidy has created a market space for PV installations. The investment subsidy has led to knowledge development concerning the installation and maintenance of PV systems. The installations have given attention to some institutional hinders and efforts to solve some of these can be identified. An increase in legitimacy can also be seen, for example through two motions to the Parliament connected to PV.

Entry of actors into the TIS

As mentioned above there are some actor groups missing in the TIS. The lack of some of these actor groups blocks the development of the TIS. Suggestions on how to handle this are presented below.

By implementing a policy with a long term perspective uncertainty would be reduced. Such a perspective would enable firms to plan for the future, especially when their whole business is depending on the specific policy. The situation like the one today, where the funding has run out one year before the subsidy ends, should be avoided. The results of this can be devastating for the firms which rely on PV installations. Further, a long term perspective is a sign of belief in the technology from the Government.

The current policy is an example of a policy which has made actors enter the subsystem around PV installations, i.e. system buyers, system installers and their sub-contractors and consultants. To further lower the barriers to entry, PV installations could also be supported in cases where the Public Procurement Act does not have to be applied. This could be done by opening up future subsidies to also include private and commercial buildings. This could also increase network formation between system buyers and installers as the tendering process can be more informal.

Measures should also aim to broaden the actor base by including actor groups that are missing today, e.g. the construction sector. This could be done by encouraging PV systems to be considered already at the design stage of a building and by encouraging BIPV solutions, by e.g. a differentiated support. To involve the construction sector, efforts have to be made concerning the education for architects and civil engineers. At this point there is very little knowledge about PV included in these educational programs.

An actor group which is currently shut out of the TIS is the electricity-consumer (excluding the PV system owners). At the moment there is no possibility to sell or buy solar electricity. A possible solution would be to create a solar electricity market where such trade can take place. If this possibility becomes reality the producers will get the opportunity to sell the solar electricity to a higher price than the spot market price for electricity.

Today, the larger energy companies are not showing any interest in solar electricity, though they are partly involved by financing Elforsk and thereby the SolEl program. By being involved but not interested is by itself a statement, which can hurt the legitimation. Smaller energy companies, e.g. Falkenberg Energi, are friendlier and want to sell solar electricity if they had the opportunity to buy it. The creation of a solar electricity market as mentioned above could also solve this problem.

The current investment subsidy has not affected the solar cell and PV module manufacturers. Right now their driving force is the strong world market for solar cells and modules. Although in the long run the increased legitimacy for PV caused by more PV installations is likely to affect also them. As the size of the total subsidy is limited, no conclusion can be made about the possible impacts of a larger one. Concerning the financial resources of these firms, there is signs of improvement connected to the increased interest in cleantech. One point that could be directly targeted by a future policy is the connection between university research and industry, e.g. commercialization of research and the entry of university spin-offs.

Knowledge development

Building up knowledge and spreading it is also one point which has received attention in the thesis. A direct result of the investment subsidy has been several PV installations, which by their visibility spread knowledge to the society. Carrying out the installations has also resulted in knowledge development. This knowledge development has been both technical and administrative. There are especially a few system installers and their sub-contractors that have managed to acquire experience through a number of projects. Besides experience some sub-contractors have gotten the possibility to specialize. Concerning the system buyers only one case is observed, the City of Malmö, where they have actually made use of knowledge acquired during earlier projects. If there is a continuation of the subsidy, the number of installations will continue to increase. More projects give the actors involved the opportunity for repetition, which will hopefully lead to building up more knowledge. Though, it can be questioned what is the most desired, either a TIS with as many unique system buyers as possible or a TIS with fewer system buyers but with the opportunity to develop their knowledge further. Many different system buyers might be wished for considering spreading legitimacy, but there is also the risk that a single project might get "lost" in the organization of the system buyer. It is also relevant to ask what the value of the knowledge concerning the execution of the project is worth if they do not get the opportunity to make use of it by carrying out a second project. Considering this and the focus that the City of Malmö has gotten as a result of the many PV installations that they have done, the conclusion is that system buyers should be encouraged to make more than a one single project.

The importance of platforms where the actor can meet is identified in this thesis. These platforms, e.g. seminars, make it possible for the actors to share knowledge and discuss problems, which have gotten attention as a result of the supported PV systems. They create places for network formation, for discussions about problems and make it possible to join forces and take action. This work has shown itself to be important when attempting to change institutions. The SolEl program has proved to be a useful platform, providing meeting points and as well as minor investigations. Solar City Malmö, which can be seen as an indirect result of the investment subsidy, also has the potential to contribute as a place for actors to meet.

Stimulating discovery of multiple values

The aim from the Government when applying a policy should be to create a policy with as high efficiency as possible, i.e. a policy that produces the most in terms of value in relation to the resources spent. In this case, the efficiency should not be measured in kWh per SEK. The efficiency defined here should be the total amount of value per SEK. Value for the system buyer includes the amount of electricity produced but also other values like PR and goodwill. The trick is to make sure that all of these values are taken into account. If this was done for every project it can be assumed that the support level could be lower than it would be if only economical terms were considered. It might also work the other way around, that by choosing a support level low enough the system buyers will be forced to take values such as PR and goodwill, into account. Opening up a future subsidy to private and commercial interests, as mentioned previously, could be beneficial. By including firms from outside the public sector other values might be taken into account.

In the end the values for the society have to be what justifies the subsidy. The values gained are that knowledge and legitimacy are built up around a possible future technology and that the system acquires a structure, in form of a system where all relevant actor groups are represented. So far, the TIS has not a fully populated value chain, as there are some actor groups missing. With a complete structure in place, where all different actor groups are present, the system will have a better chance at developing. The existence of a complete structure can be expected to lower the threshold for new firms entering. Further, more complete solutions might be a result, when the whole value chain is linked together. With the current subsidy the results have been mostly related to the installations, but the aim should be to create a positive impact for the whole TIS.

Finally, the conclusion is that there are many issues to target from different angles concerning the development of the PV innovation system. The investment subsidy is only one of them. There are additional actions that should be considered in parallel to develop the system further, e.g. to continue providing platforms for meetings. But a continued market support program is essential to keep the system going. With some modifications a broader range of actors can be stimulated to get involved increasing the breadth and pace of development.

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