Dynamics of the Swedish PV Innovation System

– the impact of a recent market formation programme

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DYNAMICS OF THE SWEDISH PV INNOVATION SYSTEM – THE IMPACT OF A RECENT MARKET FORMATION PROGRAMME [a)]

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ABSTRACT: Support from the Swedish government to the PV sector has so far focused on research, development and demonstration. In May 2005, however, the government introduced a market deployment initiative directed at PV systems on public buildings. Although the subsidy scheme is relatively small, it is expected to lead to a significant relative increase in installed PV capacity. The aim of this study is to make an early evaluation of the market deployment initiative by analysing its effects on the dynamics of the Swedish PV innovation system. Preliminary results suggest that the market support has had several positive effects. It has led to the start of a number of new PV projects and influenced the dynamics of the Swedish PV innovation system in terms of both building the structural components and strengthening the functions of the system. The paper also describes the most notable blocking mechanisms that threaten to obstruct further development of the innovation system and which, therefore, need to be dealt with by policy measures.
Keywords: Funding and Incentives, National Programme, PV Market

1 INTRODUCTION

Until 15 May 2005, support from the Swedish government to the PV sector was largely limited to research and development. From this date, however, a market deployment programme directed at PV systems on public buildings is running. The size of the subsidy scheme is SEK 150 million (approx. EUR 16 million) and the stop date is 31 December 2008. The subsidy is 70 per cent of the cost of the PV installation. The maximum support per building is SEK 5 million.

The PV subsidy is part of a broader subsidy scheme, which aims to contribute to reaching the Swedish energy and climate goals by increasing the share of renewable energy as well as to contribute to the generation of employment opportunities. Specific goals of the PV market support are to (1) increase the installed PV capacity from about 3.6 MWp to about 7.6 MWp; (2) create prerequisites for further diffusion of PV systems and (3) enable the development of a competent PV industry (along the whole value chain) with a future export potential [1, 2].

The purpose of this study is to make an early evaluation of the market support. This goes much beyond just looking at the added PV capacity, i.e. goal number 1. In order to assess the impact of the support on goals 2 and 3, we trace the effects on the formation of a Swedish innovation system centred on solar cells. Hence, we analyse not only how markets emerge but also the extent to which new actors enter into the system, how new networks are formed and if institutions are aligned to the new technology. That is, we assess the impact of the market deployment scheme on the formation of the structural elements of an innovation system.

In addition, we undertake a preliminary analysis of what is being achieved in that system in terms of seven key sub-processes (*functions*), in industrial development e.g. resource mobilization and entrepreneurial experimentation, as well as the extent to which these are linked in a self-reinforcing process. The functional pattern (i.e. the extent to which these functions are present) is described and evaluated. The existence of strong and weak functions can be explained by inducement and blocking mechanisms. Applying this approach has, therefore, the added advantage that it allows us to identify the key policy issues (i.e. removing, reducing or counteracting blocking mechanisms) that need to be handled if the system is to be further developed.

The paper is structured as follows. Section 2 describes key features of the Swedish innovation system for PV prior to the market deployment scheme. Section 3 outlines our analytical framework. Section 4 analyses the structure and functions of the emerging system. Central inducement and blocking mechanisms are identified in section 5 together with a tentative specification of key policy challenges for a further development of the innovation system. Some concluding remarks are given in section 6.

2 THE SWEDISH PV INNOVATION SYSTEM PRIOR TO THE SUBSIDY SCHEME

Before May 2005, there were no subsidies aimed directly at promoting PV. The Swedish policies, which could indirectly promote the use of PV power systems, were taxes related to conventional electricity production and a tradable green certificate scheme, which was launched in May 2003. The certificate scheme promotes electricity generated from renewable energy sources, without any further distinction between technologies. For every MWh of renewable electricity that an electricity company produces it receives one certificate, the price of which has been in the order of SEK 200 (about EUR 22)[1]. The current level of energy taxes and the value of the renewable energy certificates are, however, too low to have any impact on the PV market at today's PV cost level.

The attitude towards renewable energy is though, on the whole, positive among the public and there seems to be a general belief in Sweden that PV is a desirable sustainable technology for the future. There is, however, an ignorance of PV among the general public and several actor groups. Furthermore, there is a very strong emphasis on the value of low electricity prices by industry (in particular the paper and pulp industry) which may have led to a sceptical attitude towards PV in the larger utilities and to little interest in PV among private investors. Lately, the strong international progress in the field, not least in terms of rapidly growing industries and employment opportunities, has meant that the opportunities connected to PV are slowly becoming more recognised in Sweden.

This section describes the Swedish innovation system centred on PV prior to the subsidy scheme, i.e. a system that was small and fragmented. We outline the contours of it in terms of research, markets and actors.

2.1 Swedish PV research

PV is a part of the national long-term energy research programme. The overall aim of the programme is to establish an ecologically and economically sustainable energy system and to secure the energy supply. The main emphasis is on energy-efficiency and renewable energy, such as biomass, hydropower, wind power and PV. The Swedish Energy Agency provides funding for research, cost-shared technological development and, in some cases, demonstration projects as well as for the commercialisation of the results of energy-related R&D.

PV research has not been focussed on silicon technologies, but on CIGS, dye-sensitised and polymer cells. There is also research on low-concentrating PV systems and PV-thermal systems as well as on building integration. There is no Swedish research on PV specific BOS components.

The Ångström Solar Center programme, which started in 1996, is considered the flagship of solar energy research in Sweden. The approach was to depart from leading scientific platforms and evolve progressively, via scale-up and prototype manufacturing, towards commercialisation in three project areas: CIGS thin film solar cells, dye sensitized solar cells and electrochromic windows.

The thin film CIGS solar cell technology is the project area which is closest to industrial realisation and a spin-off company, Solibro AB, has been started (see Box 1 below). The research on dye sensitized cells aims at developing cells which can be manufactured at very low cost using a continuous process. Efficiencies are still low compared with cells of conventional crystalline silicon or CIGS and the competitiveness for this technology is currently in the area of niche products. Basic research is aimed at finding new combinations of dyes and electrolytes which can increase the cell efficiency. The Ångström Solar Center, which received a total funding of about EUR 16 million, ended as a joint programme in March 2005. However, the research on CIGS and dye sensitized cells receives continued funding from the Swedish Energy Agency.

The SolEl programme is a national R&D programme with focus on PV systems and their applications. The programme is financed by the Swedish Energy Agency, utilities, manufacturing companies (PV and other), construction companies and property managers. The main objectives of the SolEl programme are technical development, information dissemination and analysis (both technical and non-technical) of applications and costs of PV systems. The programme closely follows the rapid international development for PV in general and grid-connected BIPV in particular. It also provides a basis for international exchange, such as Sweden's participation in International Energy Agency's implementing agreement on Photovoltaic Power Systems. In addition, the SolEl programme performs studies of the feasibility, procurement, installation and operation of Swedish PV installations and it has implemented a web based monitoring system for grid-connected PV installations in Sweden. Development of concentrating PV systems and PV-thermal concepts are also included the programme.

The interest from the Swedish construction industry in the SolEl-programme has increased due to the strong international development in the field of BIPV. The more recent involvement of the building industry and property managers in the programme has shifted its focus somewhat, from stand-alone systems towards PV in buildings. Recent programme activities include the development of a tool for carrying out PV projects in the built environment in the form of a web based information platform for architects, constructors and other actors. Thus, by interacting with many different actors, the SolEl-programme is a key node in an emerging Swedish network connected to solar cells.

2.2 The Swedish PV market

The Swedish electricity supply system is largely based on nuclear power (about 45 per cent of the electricity supply) and hydropower (about 45 per cent). Although growing rapidly, mainly due to the introduction of the tradable green certificate system in 2003, biomass-fuelled CHP and wind power still gives a relatively small contribution to the national electricity supply. With an installed capacity of about 3-4 MWp, a negligible fraction of the electricity supply comes from PV and the market growth was fairly slow (6–7 per cent p.a.) prior to the subsidy scheme. The market for PV is dominated by

[1] The electricity consumers are required to buy certificates in proportion to the amount of electricity they consume. During 2006, the consumers are required to buy certificates corresponding to 12.6 % of their consumption. This figure is raised each year, and will be 16.9 % in 2010.

domestic stand-alone PV systems. The majority of these systems are small and used to supply electricity off-grid to recreational homes. Apart from this market, there are some off-grid non-domestic systems, supplying electricity for telecommunication systems, lighthouses, etc., as well as a few grid-connected systems.

The grid-connected systems are so far mostly projects intended to demonstrate the PV technology or to conduct research. Some installations have also been made in high profile residential, office and public buildings, with the primary objective to show environmental concern or increase the awareness of renewable energy solutions. Examples of such installations can be found in the new residential area Hammarby Sjöstad in Stockholm (first true BIPV projects with about 50 kWp in total), which has a strong environmental profile and in which several construction companies have chosen to demonstrate PV as a means to fulfil ambitious goals for reduced environmental impact.

2.3 Swedish PV actors

Table I provides a list of the main actors in the Swedish PV innovation system in about 2004. Some of these are stable members of the system (e.g. module manufacturers) whereas others are more on the fringe of it, e.g. a temporary activity in connection with a demonstration project. There is large capacity among the four module manufacturers, at least set in relation to the domestic market, and this industry has grown significantly during the last couple of years. The firms buy silicon cells from abroad and assemble modules, which are to a large extent (approximately 95 per cent) exported[2].

Table I: Main actors in the Swedish innovation system for PV about 2004

Actor groups	**Companies**
Module manufacturers	Gällivare Photovoltaic, PV Enterprise, Scanmodule, Arctic Solar
PV system entrepreneurs	NAPS
PV consultants	Energibanken
Building sector	NCC, White
Utilities	Vattenfall, Göteborg Energy
Complementary product manufacturers	ABB
Application specialists	–
Research spin-off companies	Solibro, Arontis
Academic organisations*	Ångström Solar Center at Uppsala Univ., SERC at Dalarna Univ. College
Governmental agencies	Swedish Energy Agency, Formas***
National R&D programme	Elforsk, SolEl
Buyers**	Malmö Stadsfastigheter, JM, IKEA
Industry associations	SEAS

* Research is also conducted at other universities, e.g. LiTH, Chalmers, KTH and LTH

** There are several other actors that also have invested in PV systems, these are just some examples

*** The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning

The already mentioned spin-off company Solibro AB in Uppsala was founded in 2003 and is currently scaling up the processes for making thin film CIGS. The aim is to install a complete line for fabrication of modules and to have modules on the market in 2008. Another notable spin-off is Arontis (see Box 1).

Prior to the subsidy scheme there were only a few small consultancy firms that designed, marketed and installed PV products and systems. There were no feed-stock or cell manufacturers in Sweden or any manufacturers that produced PV specific balance of systems components, such as inverters, storage batteries, supporting structures or DC switch-gear. Finally, the Swedish industry association for solar energy, SEAS, was mainly focused on thermal solar energy, which has been regarded as a problem by PV enthusiasts.

Box 1: Example A of a research spin-off: Solibro

The research on thin-film CIGS cells started already in the beginning of the 80's at the Royal Institute of Technology in Stockholm. In 1997, the research got a substantial upswing due to the start of Ångström Solar Center at Uppsala University and the research became more focused on industrialisation. Solibro AB was founded in 2003 by four researchers from Ångström Solar Center.

Solibro is funded by ABB, Vattenfall, Eon, Sjätte AP-fonden and Future Energy Invest. The Swedish Energy Agency funds specific technological development projects at Solibro. In the first phase, Solibro have to demonstrate that the production line can work as planned. The critical part is the CIGS deposition. In the beginning of 2006 Solibro stands before the initiation of the second phase, which is to build a complete production line for thin-film CIGS modules. The first commercial modules are planned to become available on the market in 2008. However, Solibro also plan to reach out with a number of test modules in 2006 or 2007. The current subsidy scheme offers a good opportunity to finance a larger demonstration system.

Solibro have recently introduced a more aggressive strategy in order to speed up the process. This is because the limited access to silicon feed stock has opened up a window of opportunity for alternative technologies to the dominating silicon based PV modules. A second reason is decisions by Solibro's competitors to start up production facilities.

Source: Stolt, 2006 [3]

Box 1: Example B of a research spin-off : Arontis

Arontis started as a non-profit research project. Subsequently, there were frequent co-operation with several universities, e.g. the university in Borlänge, Chalmers, the Royal Institute of Technology and Lund University. The govern-ment owned utility company Vattenfall has also been involved in the project. The resulting product is a concentrating combined PV/solar heating system. It is built on a one-axis tracker and concentrates the solar irradiation eights times on a PV cell that is cooled by water. The benefit of the co-generated heat is a drastically lower cost for PV electricity production, if the heat can be utilized or sold.

In 2005, Arontis started to work towards a commercialisation of the product. The plan is to build a series of Beta systems in the spring 2006 at different locations in Europe. If the tests fall out well they expect to initiate commercial production in the autumn 2006.

The technology is designed for larger systems, at least 200 m^2. Potential buyers are buildings that use hot water also in the summer, e.g. hotels, sports facilities and some industries. The Swedish market will be of little importance in terms of sales volumes, but as a platform for testing products it is of great importance for Arontis.

Source: Byström, 2006 [4]

In summary, prior to the market deployment programme, there was no complete innovation system in place. There were few and scattered industrial actors and the strength lay in module manufacturing. These firms were though connected mostly to the German and Norwegian innovation systems. Another source of strength lay in research (and in the learning networks

2 The oldest and largest module manufacturer is Gällivare PhotoVoltaic AB (GPV), which is a fully owned subsidiary of the German company SolarWorld AG. The manufacturer Scan Module is owned by the Norwegian company REC.

connected to two academic spin-offs) and in a small but active 'node' in the form of the SolEl programme that acted as a meeting place and information exchange. Markets were tiny, however, and the institutional framework did not support PV, more than in terms of science policy.

3 ANALYTICAL FRAMEWORK AND METHOD[3]

In order to be able to trace the impact of the subsidy scheme, we need to develop an understanding of the key processes in the evolution of a technological innovation system (TIS) that this programme may have an impact on. These can be defined at a structural and at a functional level.

3.1 The structural level

A technology-specific innovation system (TIS) may be defined as:

"…. network(s) of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse, and utilize technology." [7 (p.111)]

A TIS is, thus, made up of three elements: firms and other organisations, networks and institutions. The *firms* are found within the whole value chain. For instance, in the case of solar cells they include manufacturing of machinery to make thin film solar cells, machinery suppliers to wafer producers, cell and wafer producers, engineering firms designing and delivering whole systems, roof and façade manufacturers, electricians, architects etc. Other organisations include: universities and other parts of the educational subsystem, industry and other professional organizations, bridging organizations, other interest organizations, such as Greenpeace, and government bodies. In the course of the formation of the TIS, each new firm (and other organization) that enters the system brings knowledge, capital and other resources into the industry. New entrants experiment with new combinations, fill 'gaps' (e.g. become a specialist supplier) or meet novel demands (e.g. develop new applications). Similarly, other organisations enter into the system and enriches it, for instance in the form of universities providing specialised courses; bridging organisations that act as meeting places and interest organisations that promote the system in the public arena.

The *networks* can be of various types. A first set of networks is learning networks. These can be user-supplier networks, networks between related firms [8], networks between competitors (direct or via a joint labour market) or university-industry networks. These constitute important modes for the transfer of tacit and explicit knowledge. The network also influences the perception of what is possible and desirable, i.e. images or expectations of the future, which guides specific investment decisions [9].

A second type of network refers to those that have as objective to influence the political agenda. These are focussed on in the political science literature (see, e.g., [10, 11]), which argues that policy making takes place in a context where *advocacy coalitions*, made up of a range of actors sharing a set of beliefs, compete in influencing policy in line with those beliefs . For a new technology to gain ground, *technology specific coalitions* need to be formed and to engage themselves in wider political debate.

As firms and other organisations enter into the TIS, these two different types of networks have to be formed, enlarging the resource base of the individual firm (in terms of information, knowledge, technology etc.) and giving the collective a voice in the political arena.

The third element is institutions. These refer to legal and regulatory aspects as well as to norms and culture. In this, institutions regulate interactions between actors and define the value base of various segments in society (norms). Institutions also refer to beliefs (cognition) that influence firms' decision in the form of frames [9] that structure learning processes (problem agendas, guiding principles, ways to do business, etc). Central to the framework is, therefore, the evolution of the institutional playing field which is formed in a political process where various advocates, including firms, governments etc, of the new (and old) technologies participate [12]. Particularly important is the strategising by advocates of the new technologies that attempt to align institutions to the new technology.

The formation of a new TIS, thus, involves three structural processes; entry of firms and other organisations, formation of networks and institutional alignment. In order for the TIS to eventually have an impact of the energy sector, these three constitutive elements need to be put in place. For a TIS that is in a very early phase of development, *a first point of evaluation* is to assess the extent to which the market deployment programme enables these constitutive elements to be put in place. This evaluation consists of mapping the type and number of entrants into the whole value chain, the networks that these actors form and the nature of institutional change.

3.2 The functional level

We are not interested in the structure as such, but rather how the system's structure change and grow, in order to have an impact on the ultimate 'goal' of the system which was to generate and diffuse new technology [7]. Hence we need a second level of analysis with concepts for different kinds of structural change, or key processes in the innovation system. These processes are here labelled 'functions'[4]. In what follows, we will outline the content of seven functions.

(i) Knowledge development and diffusion

This is the function that is normally placed at the heart of a TIS in that it is concerned with how the TIS performs in terms of its knowledge base and, of course, its evolution. The function captures the breadth and depth of the knowledge base of the TIS and how that knowledge is diffused and combined in the system.

(ii) Influence on the direction of search

If a TIS is to develop, a whole range of firms and other organizations have to enter into it. These do not

[3] This analytical framework draws heavily on [5] and [6].

[4] See [13], [14] and [6].

only have to have the ability to identify new opportunities but there must also be sufficient incentives and/or pressures for them to undertake investments in the TIS. The second function is the combined strength of factors influencing the search and investment behaviour[5]. Examples of these are beliefs (expectations) in growth potentials [15], regulations, articulation of demand by leading customers, technical bottlenecks (e.g. [16])[6].

(iii) Entrepreneurial experimentation

A TIS will evolve only if there are entrepreneurs that conducts technical experiments, delving into uncertain applications and markets. Handling these uncertainties is a fundamental feature of technological and industrial development. From a social perspective, the way to do so is to ensure that many entrepreneurial experiments take place. These experiments imply a continuous probing into new technologies and applications, where many will fail but some may succeed. As emphasised in Strategic Niche Management (e.g. [15, 9]) a multi-dimensional social learning process will unfold through the course of these experiments. A TIS without a vibrant experimentation will stagnate and, indeed, without the initial experiments, it will not be formed. Of course, in this learning process, knowledge formation takes place, but of a more applied nature than that captured under the first functional heading. One particularly important form of learning is that related to institutional constraints to the growth of the system – constraints that are 'discovered' as and when entrepreneurial experimentation takes place.

(iv) Resource mobilization

As a TIS evolves, a range of different resources needs to be mobilized. These resources are of different types, technical, scientific, financial, etc. Hence, we need to understand the extent to which the TIS is able to mobilize human capital, financial capital and complementary assets.

(v) Market formation

For an emerging TIS, markets may not exist, or be greatly underdeveloped. Market places may be absent, potential customers may not have articulated their demand, or have the competence to do so, price/performance of the new technology may be poor, uncertainties may prevail in many dimensions. Institutional change, e.g. the formation of standards, is often a prerequisite for markets to evolve as are the availability of complementary products and services.

Market formation normally goes through three phases with quite distinct features. In the very early phase, 'nursing markets' need to evolve so that a 'learning space' is opened up [17, 18]), in which the TIS can find a place to be formed. The size of the market is often very limited. This nursing market may give way to 'bridging' markets which allow for volumes to increase and for an enlargement in the TIS in terms of number of actors [19]. Finally, in successful TIS, mass markets may evolve, often several decades after the formation of the first market.

(vi) Legitimation

Legitimacy is a matter of social acceptance and compliance with relevant institutions; the new technology and its proponents need to be considered appropriate and desirable by relevant actors in order for resources to be mobilized, for demand to form and for actors in the new TIS to acquire political strength. Legitimacy also influences expectations among managers and, by implication, their strategy (and, thus, the function 'influence on the direction of search'). As is widely acknowledged in organization theory, legitimacy is a prerequisite for the formation of new industries [11] and, we would add, new TIS. Legitimacy is not given, however, but is formed through conscious actions by various organisations and individuals in a process of legitimation, which eventually may help the new TIS to overcome its 'liability of newness' [20]. This process may take considerable time and is often complicated by competition from adversaries defending existing TISs and the institutional frameworks associated with them [21, 22]. As mentioned above, for a new technology to gain ground, a *TIS-specific advocacy coalition* need to be formed, gain influence over institutions and secure institutional alignment.

(vii) Development of positive externalities (free utilities)

As markets go beyond the first niches, there is an enlarged space in which the emerging system can evolve and the functions be strengthened. Structural change in the form of entry of firms is central to this process. First, new entrants may resolve at least some of the initial uncertainties with respect to technologies and markets [23], thereby strengthening the functions 'influence of the direction of search' and 'market formation'. Second, new entrants may, by their very entry, legitimate the new TIS [24]). New entrants may also strengthen the 'political' power of advocacy coalitions that, in turn, enhances the opportunities for a successful legitimation process.

By resolving uncertainties and improving legitimacy, new entrants may confer positive externalities on other firms, established as well as new entrants. Further externalities may arise due to the co-location of firms. Marshall [25] discussed economies that were external to firms but internal to a location. Developing his ideas, Audretsch; Feldman [26] and Krugman [27] outlined three sources of such economies[7]:

- Emergence of pooled labour markets, which strengthens the function 'knowledge development and diffusion' in that subsequent entrants can recruit staff from early entrants (and vice versa as times go by).
- Emergence of specialized intermediate goods and service providers; as a division of labour unfolds, costs are reduced and further 'knowledge develop-

[5] This function also covers the mechanisms influencing the direction of search within the TIS, in terms of different competing technologies, applications, markets, business models etc.

[6] Frequently, there is a need to coordinate investments between firms. For instance, a shift to fuel cell powered automobiles requires a simultaneous investment in development and production of fuel cells, fuel cell driven cars, production of energy carriers for fuels cells, 'petrol stations' for fuel cells, etc. Coordination then requires that a range of firms supplying complementary products/services are influenced in their respective search and investment processes.

[7] In addition to these, they also mention provision of non-tradable inputs specific to an industry.

ment and diffusion' is stimulated by specialization and accumulated experience.

- Information flows and knowledge 'spill-overs', contributing to the function 'knowledge development and diffusion'.

Hence, new entrants may contribute to a process whereby other functions are strengthened, benefiting other members of the TIS through the generation of positive externalities[8]. This function is therefore not independent, but rather one which indicates the dynamics of the system.

The *functional pattern*, i.e. *what is being achieved*, can be analysed empirically[9]. This means that the seven processes are mapped empirically. *The second point of evaluation* is to assess how the subsidy scheme has influenced the functional pattern of the emerging system. Additionally, policy makers can assess the strengths and weaknesses of each function. It follows that they can also formulate 'second round' policy problems in functional terms, i.e. 'what do we think should be happening that is not'. For instance, the number and range of entrepreneurial experiments may be judged to be inadequate.

The evolution of the TIS is in part a result of the internal dynamics of the TIS where each TIS has unique features in terms of the constellation of actors, character of networks and nature of institutions. In rapidly developing TIS, a chain reaction of positive feedback loops may materialise setting in motion a process of cumulative causation [30]. However, the internal dynamics is only part of the picture. There are factors influencing many TIS simultaneously, for instance institutional change in the form of tradable emission permits. These interact with internal processes and influence the evolution of a specific TIS.

To make a distinction between the endogenous and exogenous, [31] conceptualises the technology-specific elements as a 'niche' and refers to 'niche-internal' processes and to the more general elements as 'regimes' and 'landscapes'. The interplay between the 'niche' and the regime (roughly sector, e.g. the agricultural sector) is a central part of the evolutionary process. This distinction is useful and echoes the work of Myrdal p. 18 [30] who showed a keen understanding of the interplay between internal and external sources of dynamics and even suggested that "… the main scientific task is…to analyse the causal inter-relations within the system itself as it moves under the influence of outside pushes and pulls and the momentum of its own internal processes".

Endogenous driving forces may be demand from a leading-edge customer and an exogenous may be the climate debate and consequent problems for the dominant regime. From the perspective of an emerging TIS, it is particularly vital to identify blocking mechanisms, i.e. factors that provide obstacles to the development of powerful functions and, therefore tilt the selection environment in favour of incumbent technologies[10]. An endogenous blocking mechanism may, for instance, be poorly developed networks that limit knowledge diffusion and legitimation. An exogenous blocking mechanism may come in the form of highly organized incumbents that defend their markets and investments or in the form of institutions that are aligned to the dominant technologies.

A third point of evaluation is to assess the impact of the market deployment programme on the further endogenous dynamics of the system, how processes or functions influence each other and in particular if virtuous circles emerge through positive feed-back.

The fourth point of evaluation is to specify the most important 'blocking mechanisms' that limit the impact of the market deployment programme and which should be the focus of policy intervention in the next round of intervention.

3.3 Method

Interviews have been used as the main method. In order to create a holistic picture of the Swedish PV innovation system, the interviewees were chosen from the whole actor chain. Table II below reveals the number of interviews listed by actor group.

Table II: Interviews listed by actor group

Actor group	Face to face interviews	Telephone interviews
Module manufacturer	1	3
PV system entrepreneur	4	1
PV consultant	1	1
Application specialist	3	1
Utility	2	
Buyer	6	1
Architect	2	2
Electric consultant	1	1
Electrician		2
Housing company	2	1
Construction company	1	1
Governmental agency	2	1
Politician	1	2
Academic organisation	2	1
Research spin-off	1	1
Industry organisation		2
Component manufacturer	1	

All in all, 52 interviews were made (30 face to face and 21 via telephone)[11]. Actors involved in seven of the new projects were approached but interviews were also made with other central actors. Some additional actors that are on the fringe of the PV innovation system today, but that might play an important role in the future were also interviewed. A face to face interview lasted 1–2 hours but the telephone interviews were shorter, typically 15–30 minutes. Beside the interviews, we participated in two public seminars[12]. These were valuable for making

[8] To these, we may add that the greater the number and variety of actors in the system, the greater are the chances for new combinations to arise, often in a way which is unpredictable[28]. An enlargement of the actor base in the TIS therefore enhances both the opportunities for each participating firm within in the system to contribute to 'knowledge development and diffusion' and for the firms to participate in 'entrepreneurial experimentation'.

[9] This was first demonstrated in [13] and in [29], where analyses of functional patterns were used to understand the evolution of two TIS in the energy field (wind power and solar power).

[10] See [32]; [33]; [34].

[11] 16 of the face to face and 12 of the telephone interviews were made in connection with an earlier study [35].

[12] 'Solceller i Bebyggelse', Malmö 27/01/2006 and 'Solel, småhus och solelhandel', Uppsala 8/02/2006

new contacts, conducting informal interviews and to receive impressions from the activity in the PV innovation system.

4 CHANGES IN THE STRUCTURAL COMPONENTS, FUNCTIONAL PATTERN AND DYNAMICS OF THE TIS

The analytical framework described how the evolution of an innovation system can be analysed at two different levels. It also suggests how dynamics may be analysed in terms of positive feed-backs. In this section we will assess how the market formation programme has influenced a) structure, b) functional pattern and c) dynamics in terms of positive feed-back loops.

4.1 The first point of evaluation: the market formation programme's influence on the structure of the TIS

This section describes the first level of analysis, i.e. how the market formation programme has affected the structural components of the innovation system: entry of new actors, formation of networks and institutional alignment.

(i) Actors

The subsidy scheme is part of a larger support programme including eight different energy saving and conversion measures[13]. Statistics on the market formation programme[14] shows that slightly more than half of the initial 100 MSEK had been assigned already by the end of February 2006. This suggests that all the money may well be assigned before the programme terminates in 2008. Table III shows how the money had been distributed by the end of February 2006.

Table III: Distribution of applications and approved funds. Soruce: The Swedish National Board of Housing, Building and Planning, July 2006 [36]

County	Received applications	Approved applications	Approved amount [SEK]
Blekinge	3	1	586 250
Dalarnas län	1	1	2 961 000
Gävleborgs län	3	2	336 000
Hallands län	3	2	7 303 700
Jämtlands län	1	1	97 230
Kalmar län	1		
Norrbottens län	1		
Skåne län	15	12	26 891 600
Stockholms län	26	26	20 566 000
Uppsala län	1		
Värmlands län	1	1	875 000
Västmanlands län	2	1	1 537 200
Västra Götalands län	8	6	9 023 000
Örebro län	3	3	4 436 817
Östergötlands län	2	2	2 650 312
Total	**71**	**58**	**77 264 109**

The large number of new projects implies that many new actors come into contact with the PV technology in the role of buyers and enter the TIS. It is common that these are municipal companies, since the support programme is directed towards public buildings.

Before the market formation programme the only company in Sweden working with larger PV installations on buildings was *NAPS*. But the new projects have opened up a market space for new PV system entrepreneurs to enter. *Switchpower* realized the potential when the discussion about the programme started and have now established themselves as a turn-key system supplier [38]. *Exoheat* worked earlier with delivering solar heating systems. PV systems were included in their plan from the beginning but they did not intend to start with it until several years ahead. But the support programme offered them an opportunity to initiate their PV division [39]. *Celltech* is another of the new PV system suppliers. They originally came from the battery sector, but have also worked with professional stand-alone PV systems. With the support programme they have diversified to larger PV systems on buildings [40].[15]

But it is not only the PV system suppliers that see market opportunities. Two large multinational module retailers have established PV divisions in Sweden since the introduction of the market formation programme. One of these is *Sharp*, the world leading PV module producer [41]. The other is *Schüco*, a German company working with facade and roof solutions that have developed and integrated solar energy solutions into their facade and roof systems [42]. A Swedish facade company that works with Schüco´s products is *Flex fasader*. They have recently built their first PV system [43]. This means that five or six PV system deliverers may be able to make offers on the projects within the support programme, a distinct increase in the number of actors and competition compared to the situation prior to the programme.

A very important result of these new entrants is that they have recognized the need for a TIS specific industry association and together with some of the existing actors they recently formed the Scandinavian Photovoltaic Industry Association (SPIA).

In addition to these active entrants, there are new actors coming into contact with the PV technology in a more passive way. Many actors are involved simply because they are natural partners of the buyer. These are mainly actors from the building sector such as architects, electrical consultants and electricians. Although it might not have been an active choice to work with PV, they are nevertheless learning about the technology.

The market formation programme has also meant that the authorities responsible for information diffusion and approving the applications are forced to gain knowledge about the PV technology. The regional and local energy advisors through their central organization at the Swedish Energy Agency are responsible for the information diffusion and the county administrations are responsible for approving the applications. Finally, the majority of the new projects are grid-connected systems and this ensures that the grid owners become involved.

Many buyers just do one project, but a few have integrated PV in their strategy, such as Malmö Stadsfastigheter. They are part of the municipality in Malmö with the task to manage the public buildings in Malmö. They have ambitious plans for using solar energy and they had built a PV system already before the

[13] Details about the whole programme can be found in BFS 2005:6 [37]

[14] http://www.boverket.se/templates/Page.aspx?id=470

[15] The market formation programme also offers an opportunity for foreign companies to enter the Swedish market. However, documents for the public purchase process are often demanded in Swedish, which is a barrier for foreign companies.

support programme. But the programme gave them the opportunity to start new projects and they have a vision of Malmö as the Solar City of Sweden [44].

An effect of the support programme is that it increases the beliefs in a take-off for the Swedish PV market also for actors in the Swedish PV innovation system that are not directly involved or targeted by the market formation programme. Ekosol is an example of such a company. They have created a unique concept for overcoming the high cost barrier without subsidies and gained a lot of interest for future PV projects on detached houses [45], se Box 2. As also indicated in Box 2, the Ekosol concept has also led to the entry of a smaller utility, Falkenberg Energy, who will buy the electricity from Ekosol´s first systems [46].

Box 2: Ekosol

Ekosol is one of the newly established actors on the Swedish PV market. Kjell Bylund and Richard Nilsson founded the company in the beginning of 2005. They had plans to develop a way to put PV panels on detached houses and they received funds from the Swedish Energy Agency for their first project in Strängnäs.

The concept they have created is called *Ekosol Inside* and is built around a detached house with a 6 kW PV system on the roof. The size of the PV system is calculated to cover the annual electricity demand of a heat pump that controls the heating of the house. Ekosol rents the PV system from the house owner who gets a guaranteed income. All the electricity is then sold to a utility, Falkenberg Energy. On top of this, Ekosol have managed to make a deal with a bank who gives an ‘environmental discount’ on the interest on loans for the house that corresponds to the interest cost of the PV system. Additional partners in the concept are Sharp who delivers the PV modules, IVT who delivers the heat pump and Bravida who takes responsibility for installation and service of the PV systems.

The concept is based on different needs from different actors. Ekosol wants to protect the environment and at the same time develop a profitable business concept. The municipalities are interested in new environmental projects and therefore willing to put land area at disposal. The housing companies desire attractive housing lots for new houses. At the top of this demand chain is, of course, the customer that has a demand for a nice house in a good location with an economic and convenient energy system. The basic idea is that when the customers are looking for a house they first prioritise where they want to live and second what kind of house they want. Operation costs comes at third, fourth or fifth place. And for a house that costs between 3 and 4 MSEK the extra cost of the PV system “disappears”.

In their first project in Strängnäs, Ekosol is working with the housing company Eksjö Hus. Ekosol’s ambition is that 1000 houses will be equipped with their PV systems by 2010.

Source: Bylund, 2005; Nilsson, 2006

To conclude, a number of new actors have entered the TIS as a consequence of the subsidy scheme. The hitherto poorly populated system is now beginning to be filled with a whole range of organisations. The most notable change is that several new PV system suppliers have established themselves. Important is also the entry of two large international companies, Sharp and Schüco, as well as Ekosol’s special concept and Malmö Stadsfastigheter’s ambitious plans. Finally, a TIS specific industry association have been formed. A summarising table of the actor base in the Swedish PV sector as of March 2006 can be found in Appendix I.

(ii) Networks

Until recently, there was no effective advocacy coalition [47], but the formation of SPIA in 2005 is a milestone in forming one. SPIA has as goal to help accelerate market diffusion of PV systems in Scandinavia. The members in SPIA are mainly PV system suppliers, PV module retailers and manufacturers. SPIA will work as a platform for actors in the Scandinavian PV sector, developing the networks between module manufacturers and PV system suppliers. SPIA will also work with communication towards politicians and the general public. This means that SPIA will be a node in an emerging advocacy coalition that will argue for pro-PV policies and raise awareness and knowledge among the general public [48].

The user – supplier and supplier – supplier networks in an immature market like the Swedish one are normally poorly developed. The many new projects oblige new actors to get in contact and this will create/improve these networks, but existing networks can also be developed to incorporate PV technology, as in the case of Schuco and Flex fasader. The new firms that have established themselves on the Swedish market are, of course, also very important for the development of these networks. Ekosol is an exceptionally good example of this. Through their specific concept they have created a network with a range of different actors.

When a new programme that supports a rather unknown technology is introduced, it is necessary to start information campaigns to inform about the details of the programme and to raise knowledge of the technology. This has been done in a number of different ways. The Swedish Energy Agency has been responsible for providing information and they have used their network of energy advisors; information has also been sent to potential buyers and they have informed various task groups[16]. Additionally, a number of seminars have been arranged with the purpose of raising knowledge about PV systems in the built environment and to increase the awareness of the market formation programme. These seminars have also worked as a platform where experiences are exchanged and networks have been created or strengthened.

(iii) Institutions

The most obvious institutional change is the market formation programme itself; there is now an economic support to apply for. But the support programme has also had effects on the beliefs in and expectations of PV technology. The PV markets in other countries, in particular Germany and Japan, have had a rapid growth due to effective support programmes. The introduction of a support programme in Sweden has raised the expectation that Sweden will follow these countries and there is now a belief among several actors in the Swedish PV system that the Swedish PV market is ready for a take-off [41, 42].

For emerging technologies there are, of course, a number of institutional bottlenecks that obstruct the development. When the number of projects and entrepreneurial experimentations increase, these bottlenecks become apparent though. This has recently led to the articulation of necessary changes in the institutional framework, e.g. the regulatory framework regarding grid-connection of PV systems [46].

(iv) Summary of the effects on the structural components

The subsidy scheme has, so far, led to three

[16] E.g. BELOK, which is a cooperation between the Swedish Energy Agency and the largest public house owners focused on energy efficiency and environmental issues, and the corresponding task group for residential buildings, BEBO.

particularly important changes in the structure of the innovation system. First, the new actors that have been attracted by the support programme. New entrants are of course a requirement if the system should grow. Especially important are the new firms that have established themselves in the new market space created by the subsidy scheme, e.g. the PV system suppliers and PV module retailers. They have entered the market because they believe that it will grow and will, therefore, make a lot of effort to support this growth. A result of this is the creation of SPIA. The formation of this key 'node' in an emerging advocacy coalition is a second important change. It will improve the networks between the actors in the PV sector and facilitate for the communication process towards politicians and the general public. A third effect of the support programme is that it has raised the expectations and beliefs in a take-off for the Swedish PV market.

4.2 The second point of evaluation: the market formation programme's influence on the functional pattern

This section deals with the second level of analysis, i.e. how changes in the structural components, as well as in exogenous factors, affect each of the seven functions that capture what is going on in the TIS.

(i) Market formation

The Swedish PV market is in a very early phase. As stressed in the analytical framework it is necessary to open up a 'learning space' in which the TIS can develop. The market formation programme has certainly helped to begin creating such a space and especially for larger grid-connected systems on buildings. As mentioned in the Introduction, the installed capacity is expected to double. The increase is even larger when we consider that grid-connected systems had only about 200 kWp installed power before the programme [49].

If the application rate for the first nine months continues, all of the 150 MSEK will be approved by 2008. The positive consequence of funding running out well before the end of the scheme is that it shows that there is a large interest among investors. Some PV system entrepreneurs ([42], [48]) also report that potential investors that are not included in the support programme show interest in building PV systems[17]. The **assessment** is that the market formation programme is actually creating a market as intended, and there are signs indicating the emergence of additional markets.

(ii) Influence on direction of search

As discussed above, the market formation programme gives strong incentives for new actors to enter the TIS. Prior to the scheme, the market was dominated by off-grid applications but with the market formation programme; there is more focus on larger grid-connected systems on buildings. A wider range of firms are, therefore, now induced to enter the emerging TIS. The incentives consists of both the economic resources that the support programme brings and the increased expectations and beliefs that Sweden will follow the example from many other countries, in particular Germany, and develop policies for accelerating the market diffusion of PV systems.

One purpose with the market formation programme was to create prerequisites for a Swedish PV export industry [2]. Sweden has prominent research groups that have created industrial spin-offs that may, eventually, become larger firms. Solibro is one example and Arontis is another. But the support programme came a little too early for these companies since they have no commercial production planned until the programme ends. However, it gives them an extra driving force to speed up the process[18], and both Solibro and Arontis say they will try to receive money to build a demonstration system within the support programme. The **assessment** of the influence on direction of search is that the support programme gives strong incentives for new entrants.

(iii) Entrepreneurial experimentation

Entrepreneurial experimentation is driven by four factors. One is *governmental support for R&D* at the Universities with subsequent formation of firms. The subsidy scheme had no effects on the initiation of these experiments. However, both Solibro and Arontis underline the importance of a home market where they can demonstrate and test their products [3, 4]. This means that a support programme that creates this market space is crucial for their ability to develop as firms.

Another driver of entrepreneurial experimentation is the *climate change debate* and, a third, the *rapid growth of the PV market in nearby countries* such as Germany. Ekosol has been described earlier and they represent a very good example of how expectations of market potential for the PV technology may lead to experimentation with new business concepts.

The effect of the *market formation programme* on the entrepreneurial experimentation is that it has encouraged a number of new actors to experiment and enter the TIS. The new entrants are both new firms that experiment with establishing themselves as suppliers[19] and new buyers that experiment with investing in new PV systems. The **assessment** of the entrepreneurial experimentation is that there is a substantial activity and the market formation programme is important, while not being the only driving force.

(iv) Knowledge development and diffusion

Knowledge formation was earlier concentrated to R&D where Sweden has a prominent place with several high-class research institutes[20]. There is also a good knowledge base in PV module manufacturing. The first firm started in the early 90's and since then three other firms have entered the TIS. The number of grid-connected PV systems on buildings has, however, been few and one company has built the majority of them [50].

[17] This is because they have misunderstood the support programme and think they can receive money as well. However, it indicates that there is an interest among other actors in the society.

[18] Speed is essential for Solibro since there are several competitors worldwide who also have declared that they soon will have commercial production.

[19] When new actors with different backgrounds come in contact with PV it increases the chances of entrepreneurial experimentation. For instance, Celltech originally comes from the battery sector so for them it is natural to experimenting with new stand-alone products where PV cells can be used instead of batteries or grid-connection [40]. They are, for example, working with PV powered parking meters and bus stop signs.

[20] Mainly Ånström Solar Center in Uppsala, but there are several others as well.

This means that the knowledge of how to build these systems had only developed among very few actors and not been diffused in the building sector.

The subsidy scheme has led to changes in this function. More actors are learning to design and deliver a PV system. The increase in number of projects, and the associated information campaigns, inevitably leads to a diffusion of knowledge in the building sector, as well as among the public. The investors themselves add to this process since even with 70 per cent economic support, the buyers have to use other motives than the produced electricity to motivate the projects [51]. Marketing and educational purposes are examples of such motives and this will increase the knowledge development and diffusion.

The implementation of a large number of projects means that knowledge about blocking mechanisms is gained and institutional barriers become apparent. The issues connected to the grid-connection of PV systems are one clear example of this and it has also ensured that the grid owners become involved and have to gain knowledge about the PV technology. The state authorities that are connected to the market formation programme and electricity production are also forced to learn more about the PV technology[21] in order to be able to make correct decisions and to provide adequate information.

The **assessment** of the support programme's effect on the knowledge development and diffusion is that it has induced a shift in this function. The well-developed knowledge base in research and module manufacturing has now started to be supplemented with more applied and close to market knowledge development and diffusion.

(v) Legitimation

There are several factors that may have a positive effect on the process of legitimation of PV technology. There seems to be a general positive attitude and PV is recognised as an environmental friendly and sustainable future technology [52]. It also matches the political ambitions to transform the energy sector towards one with more renewable energy and with greater security of supply. The impressive growth of PV markets in other countries, most notably Germany, in response to subsidy schemes, has probably increased the general belief in the technology and acceptance for market intervention. A positive factor is also that many housing companies, and thereby potential buyers, are working with energy saving measures and they therefore become susceptible to these kinds of support programmes. The introduction of the support programme itself also gives legitimacy since it sends signals that it is a desired technology.

But there are also several factors that have a negative effect on the legitimation process. Even though the PV technology is seen as a future technology there is a great deal of scepticisms towards the role of PV power in Sweden. Sweden has good access to other renewable energy sources, i.e. hydropower, wind power and biomass, at a quite low cost. This creates a competitive situation with these technologies [53]. It is also a common cognitive framework, or belief that centralised energy production is seen as most efficient and there are clearly very influential actors that do not perceive the PV technology as a suitable technology for the Swedish energy system [2].

The **assessment** of the legitimation process for the PV technology is that it is still in a very early phase, but it has certainly started and the support programme has increased its momentum. The formation of the TIS specific industry association is a valuable change and this advocacy coalition will play a central role in the legitimation process.

(vi) Resource mobilisation

The market formation programme has involved a large increase in financial resource mobilisation for the TIS. Money comes from both the programme itself and from the newly established firms. The new actors also help bringing human capital to the TIS and they invest in educating more human capital. The building sector‘s demand for human capital with PV competence is, however, weak. But this is likely to change if the TIS continue to develop the building integrated systems application.

There is, with one or two exceptions, no organized integration of PVs in the architect and civil engineering education. However, there are elements included in courses, e.g. in the form of project work [54]. To make changes in the curriculum often takes a long time, but the academic world seems to be responsive when there is a demand articulated by the PV industry. One example is the special course for building integrated PV that was arranged by LTH [55]. Another example comes from Härnösand, where a vocational training for solar energy technicians has started [4]. The **assessment** of this function is that the support programme has brought economic resources, both in itself and also through investments from the new entrants. The educational resources are still in its infancy but the academic world seems to be responsive.

(vii) Development of positive externalities

The analytical framework points to new entrants as central for this function and a number of new entrants have recently entered the TIS. It is likely that these new entrants will strengthen the process of legitimation of PV technology. The formation of the PV sector specific advocacy coalition is a very important step in this process.

It is also likely that the newly established actors will have an effect on other actors that are interested in the PV market but are uncertain for various reasons. When these first movers show that it is possible and that initial problems can be solved it will lower the uncertainty and other actors might follow the first movers. Similar first mover effects can also inspire new buyers and thereby stimulate market formation. Potential buyers are often hesitant to experiment with new technologies; they often wait out the results of the first experiments. That is why pioneers with ambitious goals, such as Malmö Stadsfastigheter, can have a large effect by reducing the initial uncertainty and inspire other potential buyers[22].

[21] There is at least one case where the PV system will produce more electricity than is used internally in the building, which puts even more pressure on the grid-owners to come up with a standard procedure.

[22] One example of this that can have a significant effect on the Swedish PV market is if other cities decide to challenge Malmö Stadsfastigheter´s plans of making Malmö the 'Solar city' of

The new PV system entrepreneurs are specialised in providing intermediate goods and services. Specialisation and accumulated experience among these actors further increase knowledge development and diffusion. New actors will gain experience from their first projects which suggests that they may be able to provide even better services to the next customer[23].

There are many situations where knowledge is transferred for free and thereby become a positive externality. A very good example of where such knowledge spill-overs occur is at platforms where actors from the PV innovation system can share experiences and discuss problems, e.g. at seminars. These fora can, for example, be used to demonstrate successful projects in order to inspire, or to discuss certain problems in order to gain knowledge and achieve a focus on creating legitimacy for that certain issue. Additionally, it offers a perfect place to make contacts within the sector and to share experiences with other actors that have been or that are in the same position, e.g. carrying out a first PV project. A concluding **assessment** of this function is that there is clear evidence of the provision of positive externalities, both actual and potential.

(viii) Summary of effect on the functional pattern

The subsidy scheme has certainly had a positive effect on the functional pattern of the emerging TIS. All the 150 MSEK will probably be used and this *market formation* opens up small learning space for the emerging TIS. This has been enough *to influence the direction of search* for a number of actors. The new entrants and new projects constitute *entrepreneurial experiments*, but there are also several other experiments going on, and for different reasons. Government R&D programmes, progress in other countries and the climate change debate have increased expectations in PV power. New actors, more projects and more experimentation all lead to applied and close to market *knowledge development and diffusion* that supplements the hitherto focus on R&D and module manufacturing. Implementation of new projects has also generated knowledge about blocking mechanisms in the institutional framework, e.g. the regulatory framework for grid-connection.

A TIS specific advocacy coalition is beginning to form and the *legitimation* process has taken a large step forward. However, it is still in a very early phase and this is usually a long process. Regarding the *resource mobilisation*, the support programme has of course meant a large increase of economic resources for the Swedish PV sector. But the new companies that have entered as a result of that also bring various types of resources into the TIS. Finally, there are indications of *positive externalities* and it is likely that more will be seen as a result of the market formation programme.

4.3 The third point of evaluation: Dynamics and positive feedback mechanisms

The section will analyse the extent to which we may discern that the subsidy scheme has influenced the internal dynamics of the system and how self-reinforcing mechanisms may eventually arise and lead to the formation of positive feed-back loops.

The seven functions from the analytical framework are not independent of each other; they may be linked and one function may tie into and influence other functions. Through these linkages, it is possible that virtuous circles, involving positive feed-backs can materialise. Such positive feed-backs are central to the development of a TIS. The two figures below describe how positive feed-back loops *may* occur in the Swedish PV innovation system. Both figures start from the market formation function. At this time[24] it is not possible to distinguish any complete positive feed-back loops from the support programme's effects on market formation back to additional market formation. However, it is possible to observe some of the connections in these figures and it is likely that complete positive feed-back loops will emerge.

The first figure describes feed-back mechanisms in the market and supply chain. It is divided in one internal feed-back loop, where new actors use the increased availability of resources and knowledge to experiment and try to find new market opportunities, and one external feed-back loop that describes positive externalities between actors in the PV sector. An observable example of an internal process is Ekosol's concept. As regards the external feed-back loop, gained experience by new entrants, knowledge spillovers among actors, and reduced uncertainties are observable positive externalities. It is, however, still too early to be sure about the effects on market formation.

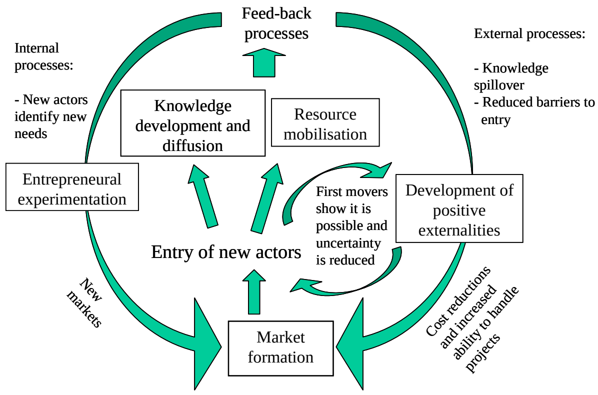

Figure 1: Positive feed-back loops in the market and supply chain

The second figure describes feed-back mechanisms connected to institutional change. It shows how knowledge about institutional barriers is gained through the new projects.

Sweden. A large increase of approved applications in Stockholm in the beginning of 2006 is a possible indication of that they want things to happen there as well.

[23] This knowledge development can also detect potentials for cost reduction. The increased amount of actors competing over the same projects is also a potential for cost reductions.

[24] 14 months after the introduction of the market formation programme

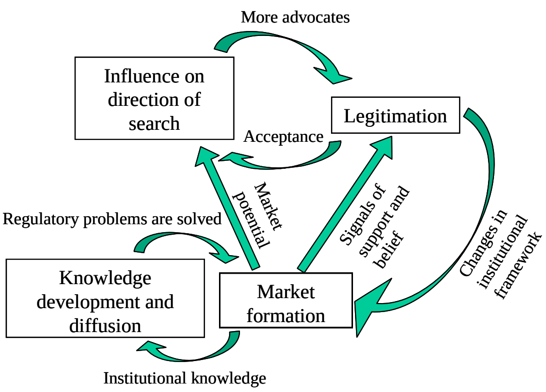

Figure 2: Positive feed-back loops connected to institutional changes.

The smaller circle indicates learning about 'simple' questions that can be solved easily. However, often institutional change requires a previous build up of legitimacy. Coming to the larger circle, the subsidy scheme strengthens both the 'influence on direction of search' and the 'process of legitimation'. These two functions are connected; more actors imply more 'advocates' that lead to an ability to attract new actors. Enough legitimacy may eventually be built up to change the institutional framework in a way that enables further market formation, e.g. a new support programme. The processes in this figure have just started and they are driven by both individual firms and by the PV specific advocacy coalition that is beginning to take form.

5 CENTRAL INDUCEMENT AND BLOCKING MECHANISMS – THE FOURTH POINT OF EVALUATION

While analysing the dynamics in the functional pattern it becomes apparent which mechanisms that are blocking the development and which that are inducing it. This section is a summary of the analysis with the purpose of creating an overview of the dynamics in the system. Identifying the inducement mechanisms is a way of evaluating the positive effects of the market formation programme and identifying the blocking mechanisms is of special importance since they point out crucial targets for the next round of policy interventions – the fourth point in the evaluation.

5.1 Inducement mechanisms

The subsidy scheme mobilised resources and opened up a market space, see Figure 3. This influenced the direction of search of both investors in PV systems and suppliers. Entry of firms into the TIS was, thus, stimulated and these had a positive impact on some functions. Among these, we find 'influence the direction search' of yet more entrants which suggests that we may be seeing the beginning of positive feed-backs. A positive "side-effect" of the support is the information campaigns that have positively influenced both knowledge diffusion, legitimation and positive externalities. There are, of course, also other sources than the support programme that have a positive impact on the functional pattern. Three of these are indicated by the dashed lines in the figure.

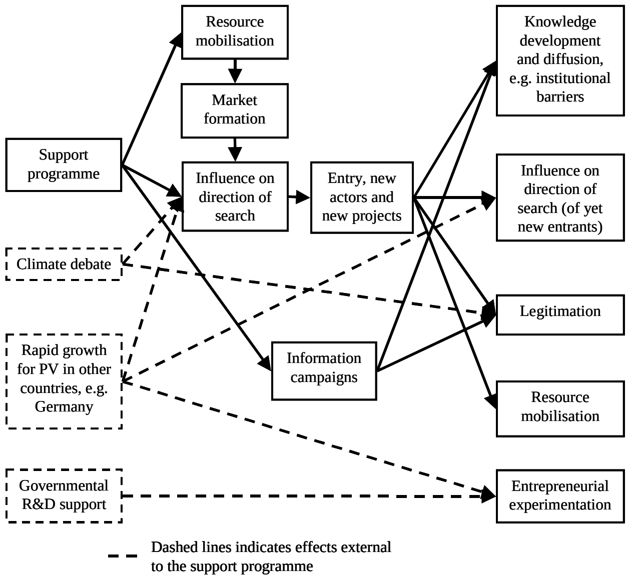

Figure 3: The effects of the inducement mechanisms on the functional pattern

5.2 Blocking mechanisms

This section lists the most prominent blocking mechanisms and describes their effects on the functional pattern, see Figure 4. Obviously, the main barrier to market formation is the high cost of PV systems [56]. This barrier is strengthened by difficulties to include other values than economic ones in pay-back calculations. Another barrier is the lack of adapted standards and regulations, e.g. the current rules for grid-connection of PV systems[25].

Many of the actors in the value chain have very little or no experience of PV technology. So, there is a lack of knowledge among actors in the value chain. Many of the actors that have some experience of PV are only occasionally involved in PV projects which mean that there are no incentives for a systematic knowledge build up [50]. For many companies, especially in the building sector, these incentives are further lowered by the fact that PV projects are an extremely small niche of their regular business [58]. In terms of structural components this not only means that there are 'holes' in the value chain but also that the networks between the actors in the value chain are not well developed. These features block knowledge development and diffusion (in networks) as well as further entrepreneurial experimentation (in spite of the positive effects of the scheme on that function). As the supply side is affected (e.g. poor supply of eco-houses; impossible to buy solar power in the market) market formation is, consequently, obstructed.

The two last blocking mechanisms affect the legitimacy of PV. By obstructing the process of legitimation, they also, by extension, constitute a blocking mechanism to 'influence of direction of search' and 'entrepreneurial experimentation'. One of these barriers is the absence of a political vision for PV sector in the government [39, 48]. Many actors in the PV and

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[25] The grid-owners are allowed to charge an annual measurement fee. ABB have built a 3kW grid-connected PV system to investigate the issues of PV electricity trade. The result is that the annual fee is so high that they actually lose money by delivering the electricity to the grid. See [57] for more information.

energy sector in general, feel that there is no long-term agenda for the energy sector and no clear vision for the PV technology. The second mechanism blocking the legitimation process are powerful advocates of larger scale and centralised technologies (nuclear and hydro) that do not believe that PV has a role to play in the Swedish energy system. These are very large actors that have a great deal of influence on Swedish energy politics and practice. Antagonising advocates can also come from stakeholder of other renewable energy sources and energy saving methods. This creates a competitive situation for the most cost efficient solution. Sweden has relatively good access to other renewable energy sources, mainly hydro power and bio energy and since PV systems are currently very expensive, they fare badly in any comparison based on current or near term costs which can lower the technology's legitimacy. A comparison based on long term potential would do the opposite. Once again, the lack of political visions for the very long term is hampering PV.

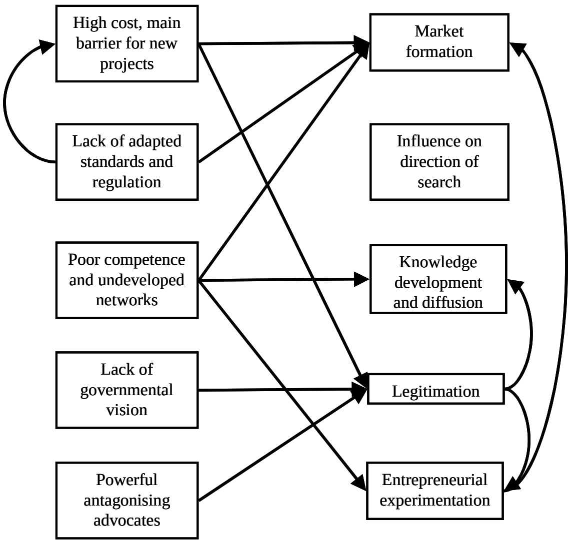

Figure 4: The effects of the major blocking mechanisms on the functional pattern

5.3 Policy measures

To counteract the blocking mechanisms there is a range of conceivable policy measures, see Figure 5. The most straightforward, overcoming the high cost barrier, is to introduce some sort of policy instrument that favours PV systems. The current support programme has managed to overcome this barrier, but there is a large uncertainty in the TIS as to what will come after it. For the actors in the TIS, it is crucial to avoid a stop and go policy[26] with its overwhelming risk to lose what has been built up. Short term programmes create a lot of uncertainty and impedes investments in knowledge formation and network building.

A longer-term market formation programme would overcome that blocking mechanism as well as the high cost barrier. It would also deal with the lack of governmental vision barrier, especially if it is combined with clear political targets for the PV technology. The problem with standards and regulations that does not fit the PV technology can be solved by 'simply' changing these so they are adapted to the PV technology as well. However, this often becomes a question of legitimacy and market power (network companies have regional monopolies) and there are many problems connected to making changes in the regulatory framework.

To manage the strong forces from the antagonising advocates, it is necessary to find and strengthen some sort of counterforce. The TIS specific advocacy coalition is a central part of this counterforce and a policy option is to strengthen it. The most important way of doing this is to induce more actors to enter the TIS. It would be particularly important to induce large, and influential, actors that can bring momentum to the legitimation process. As described earlier new entrants play a key role for the development of positive externalities and the two figures over positive feed-back loops further enhance the central role of new entrants.

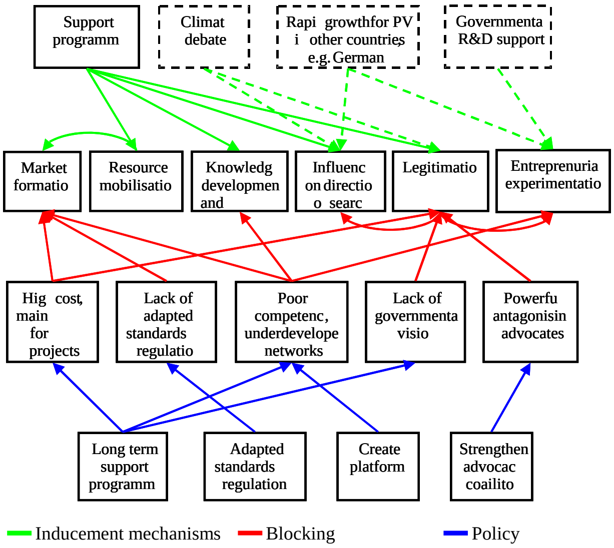

Figure 5: Blocking mechanisms and the effects of policy measures

The barrier connected to undeveloped networks among actors in the value chain is probably a less severe problem than the others in the sense that it is likely to solve itself as the market grows. Nevertheless, a cheap policy option is to facilitate this process by creating platforms where these actors can share experiences. Platforms have also been described as a place for creation of free utilities, e.g. knowledge spill-overs.

6 CONCLUSIONS

The purpose of this study was to analyse the influence of the market support programme for PV. We developed an analytical framework that allows us to evaluate the effects of the scheme on the dynamics of the technology-specific innovation system centred on PV in four different ways. A preliminary impression is that the analytical framework seems to be well suited for this kind of evaluations where the dynamics of a system is in focus.

It is clear that the support scheme already has had significant effects on the dynamics of the Swedish PV

[26] This is not uncommon in Swedish energy policy [32].

innovation system. In terms of its effect on the system's *structural components*, the most notable changes are the entry of a number of new firms, the formation of Scandinavian Photovoltaic Industry Association (SPIA) and increased expectations in the PV technology. The second point of analysis was the effects on the *functional pattern*, i.e. what is being achieved in the system. A market space has been created and together with exogenous factors, the scheme has some influence on the search for new business opportunities in PV and for a number of entrepreneurial experiments. As a consequence, knowledge development of a more applied nature has been initiated, supplementing the previous relative strength in academic research and module manufacturing. The legitimation process has also started to gain momentum, much thanks to the formation of the TIS specific advocacy coalition.

The effects on the *dynamics of the system and the occurrence of positive feed-back loops*, the third point of evaluation, are much less distinct at this early stage. However, there are some indications of linkages between functions and it is possible to identify likely future feed-back loops that can be the subject of a further assessment.

The fourth evaluation point has revealed the most notable *blocking mechanisms*. Market formation is blocked by the high cost of PV systems and lack of adapted standards and regulations. Poor competence and weak networks on the supply side obstructs entrepreneurial experimentation which hinders market formation. Weak networks also blocks 'knowledge development and diffusion'. Powerful antagonising advocates and the lack of a clear political vision for the PV technology hinders the 'legitimation' process. In turn, this has a negative impact on 'influence on the direction of search' and the 'entrepreneurial experimentation'.

These blocking mechanisms have to be weakened or removed if the TIS is to grow.

This study has identified a few policy measures that may be useful for that purpose. The most straightforward way is a new support programme that continues when the current one expires. A longer term programme, combined with clear political targets for the PV technology's role in Sweden, would be expected to deal with several of the blocking mechanisms (lack of a national vision for PV, poor competence on both supply and user side and – to some extent – high costs). Standards and regulations need to be adapted to the PV technology. Building platforms would facilitate network creation and platforms are also an ideal place for creation of positive externalities. Finally, to deal with the powerful advocates that are sceptical to the PV technology it is important to support an advocacy coalition that can become a counterforce.

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[27] However, the conclusions of this paper are not the official view of the Swedish government.

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APPENDIX I

Overview of the actors in the Swedish PV sector as of March 2006 (bold font distinguishes changes after the market formation programme).

Module manufacturers

Gällivare Photovoltaic, Arctic Solar, Scanmodule, PV Enterprise, **Sharp**

PV system entrepreneurs

NAPS, **Switchpower, Exoheat, Celltech, Flex fasader**

PV Consultants

Energibanken

Building sector

Ncc, White

Utilities

Vattenfall, Göteborg Energi, **Falkenberg Energi**

Complementary product manufacturers

ABB

Application specialists

Ekosol (detached house with PV), Schüco (roof and facade integration

Research Spin-off

Solibro, Arontis

Academic organisations*

Ångström solar center, SERC

Governmental agencies

STEM, **Länsstyrelsen, Boverket**

National R&D programme

Elforsk, SolEl

Buyers**

Malmö Stadsfastigheter, Eksta Bostads AB, Got Event, **SISAB, Municipality of Hallsberg**

Industry associations

SEAS, **SPIA**

* Research is also conducted at other universities, e.g. Chalmers, KTH and LTH

** There are many new buyers due to the support programme, these are just some of the most notable examples.