Assessment of the impact of a market formation programme on the Swedish PV innovation system

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Abstract

A technological innovation systems model is used to assess the effects of a policy intervention in order to inform future interventions. The proposed evaluation methodology is a four-step procedure: First system boundaries are set. Second, based on collected data, we make a description of how the structure and size of the technological system changed in the period, in terms of the component categories artefacts, actors and rules (including knowledge and institutions). Third, we investigate causal relations in the innovation system in terms of functions. The functions relate the change of structural components to the structure itself as well as to external forces. We also look for chain reactions and positive feedback that reinforce growth. Forth, we assess the relative contribution to the functional dynamics (and thus structural change) of the intervention we are to evaluate.

1 Introduction

Until 15 May 2005, support from the Swedish government to the PV sector was largely limited to research. 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.[1] According to oral statements from representatives of the party that took the initiative, the 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].

An evaluation of such a market support must go beyond just looking at the added PV capacity, i.e. goal number 1, or the technical performance of added capacity. In order to assess the impact of the support on goals 2 and 3, ideally, we would wait for 10-20 years and see how the market and industry develops. However, if the underlying purpose of the evaluation pursued, is to inform policy makers on how coming policy programmes could be designed to, in effective ways, stimulate a further development at this point in time, this is not a suitable strategy. We are required to make an *early* evaluation, and thus we need a methodology that identifies processes that are precursors to manifest market and industry growth. A theoretical approach that captures such processes is the Technological innovation system (TIS) framework [3-5]. Variants of this framework has earlier been used to describe processes of industry formation around emerging technologies [e.g. 6, 7, 8] and for scenario construction used for policy assessment *ex-ante* [9]. The TIS framework has, to our knowledge, not previously been used explicitly for evaluation of a specific policy intervention *ex-post*. Arnold [10] observed that "...a systems world needs systems evaluations" and that there is lack of such. In this paper we develop the TIS framework into a systems-based policy evaluation tool and test the methodology on the case of the Swedish PV deployment programme.

The proposed evaluation methodology is a four-step procedure: First system boundaries are set. Second, based on collected data, we make a description of how the structure and size of the technological system changed in the period, in terms of the component categories artefacts, actors and rules (including knowledge and institutions). Third, we investigate causal relations in the innovation system in terms of functions. The functions relate the change of structural components to the structure itself as well as to external forces. We also look for chain reactions and positive feedback that reinforce growth. Forth, we assess the relative contribution to the functional dynamics (and thus structural change) of the intervention we are to evaluate.

To these four steps we may add two steps that use the evaluation to foresee coming development and implications of future interventions. First, we assess the prospects for further development by identifying strong and weak functions, and the underlying cause for strength and weaknesses, i.e. we analyse inducement and blocking mechanisms. Second, based on identified weaknesses and the understanding of the functional dynamics, effective new policy measures are suggested.

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[1] In the spring 2008 the cap of SEK 150 million was taken away and the PV support was integrated in a larger support program for energy efficiency in buildings with a cap of two billion. It is however not clear is this will result in a major increase since PV projects compete with many alternative investments within the program.

2 Technological Innovation Systems and assessment of intervention

We are here interested in the early growth of the production and use of a new technology and how the growth is affected by policy. Such a growth process is socio-technical and systemic by nature, i.e. it is contingent upon the build up of a number of technical as well as social components that are linked in various ways. Systemic innovation processes are now being systematised in different theoretical frameworks (see for example Geels et al [11] and Markard and Truffer [12] for reviews). We will here follow and partially further develop the Technological Innovation System (TIS) approach [3, 4, 13]. Following Bergek et al [4] and Hillman and Sandén [9] we make a model of the TIS made up of *structural elements* of a technological system and aggregated change processes called *functions*. In this paper we will make clear that these functions explain the causal relationships producing a technological system. For clarity we here use the term 'Technological System' for the agglomeration of structural elements such as artefacts, firms and regulations directly related to the technology. The Technological Innovations System, the TIS, is a more theoretical construct describing growth of that system.[2] The functions then describe how the technological system changes under the influence of both endogenous forces (stemming from actions and structure of technological system itself) and exogenous forces (Figure 1). An external stimulus may set in motion a process of cumulative causation, governed by positive internal feedback.[3]

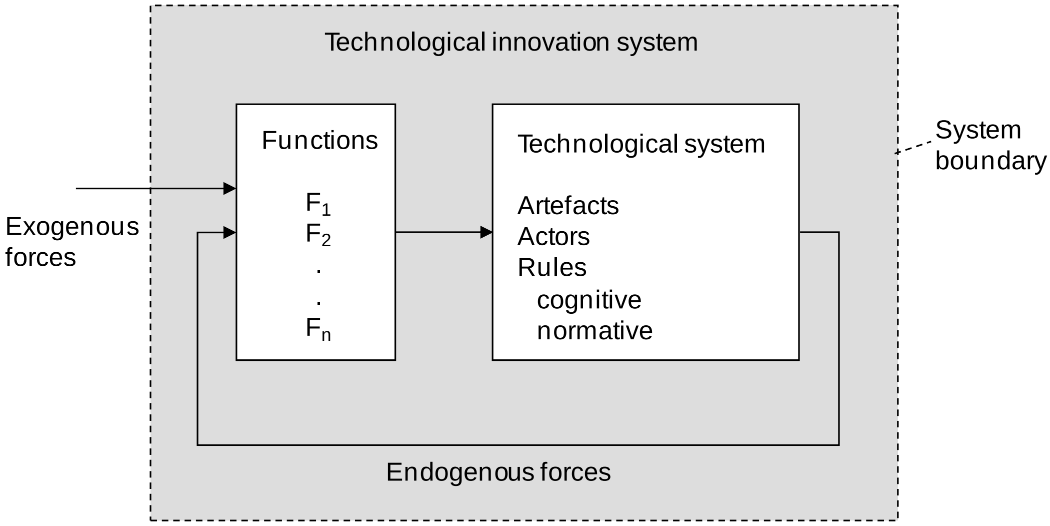

Figure 1 The innovation system can be described by a set of n innovation system functions (F_i) that correspond to the creation of the structural elements in the technological system. Functions determine how the structure develops, while the functions are determined by the structure (endogenous forces), as well as by exogenous forces stemming from structures and events outside the system boundary.

[2] This definition of the technological innovation system tries to bridge the gap between earlier versions coming from the tradition of national innovation systems, where the innovation is produced by a more static and already existing innovation system, and a more dynamic view that puts a lot of stress on how the system produces itself.

[3] This model of change might appear very mechanistic. The mechanistic character is however somewhat superficial, since some of the most important change mechanisms rely of 'soft' variables such as attitudes and conceptualisations of the world, and in early phases the system is very sensitive to initiatives of individuals, that is processes at a system level that is not fully covered by the model.

2.1 System boundaries

To define our object of study we need to draw a system boundary. We suggest that system boundaries for TISs need to be made in at least four dimensions: technology, value chain, time and geography.

To define the technology under study we need to specify both how it is made and what it is used for. The upstream part of a value chain: the material, knowledge and processes required to produce the technology specifies it. So does the downstream application domain. To exemplify, the technology boundary in this study enclose the group of PV technologies as a whole. Other choices are possible, such the wider groups of renewable energy technologies, building components or semiconductors or the narrower group of thin film PV.

The technology boundary thus defines the width of the bundle of value chains. We also need to specify how far the studied system extends in both directions along the value chains. In our case for example, we exclude raw materials producers but at least in principle include all other actors from producers of cells and producers of knowledge to buyers of solar electricity.

In the case presented below we focus on the rather narrow timeframe from 2005 when the market programme was put in place to early 2008. A shortcoming with a narrow timeframe is that it makes longer term processes and slower feedback mechanisms invisible. To capture a larger part of the dynamics and identify what the studied intervention adds to the system we extend the time frame to the beginning of the 1990s.

In this study we use a national system boundary. This is by no means the only possible choice, but it relates to the purpose of informing Swedish policy makers. The choice of system boundaries needs to be coupled to the purpose of the study and what kind of decisions it is supposed to inform [14].

This leads us to the distinction between real and modelled (arbitrary, imagined) system boundaries. A real system boundary distinguishes a group of components that are interacting intensively internally but substantially less with surrounding elements [15]. To put it differently there is no (or little) circular interaction (feedback) between internal and external elements on the same time scale as between internal components. A human body or a firm are examples of systems with a real system boundary. Modelled system boundaries are set by the modeller and can but do not have to coincide with real boundaries. The modelled system boundaries of TISs are unlikely to be as real as those enclosing human bodies or firms. However, depending on how they are set, they may enclose a more or less real system.

In, Jacobsson et al (2004) we also used a national system boundary and described the evolution of the German PV system from the late 1970s to 2000 [7]. That system was to a large extent nationally contained, i.e. while being open to external influences, German module and cell production, knowledge development, and market expansion were to a large extent interdependent and coevolved. The Swedish PV system, on the other hand, is a small system at the fringe of large international PV industries and markets (this description is actually a result of this study). The implication of this is that a lot of interaction can (and do) take place across the national border. Thus, when we apply a national system boundary it is by no means a system boundary that frames a real system, i.e. where interactions among the components within the system are much more frequent than the exchange across the system boundary. On the other hand, since the Swedish system is small in comparison to the surroundings one can assume that there is little feedback between the Swedish system and the surroundings, i.e. the Swedish TIS is affected by the PV world but the PV world is not affected by the Swedish system. Here we apply a national system boundary since we primarily are interested in system reactions to national policy and since there are no (or negligible) repercussions in the surroundings we believe it is fruitful to work with this boundary.

We can make similar observations regarding the technology boundary. There are for examples interactions between the Germany PV and wind TISs and between the systems around a bundle of alternative fuels in Sweden [4]. With wider system boundaries, geographically or technologically, we could capture more interaction processes at higher levels but we would also risk losing in detail and miss processes at low levels. One possible methodological extension is to work with different systems boundaries in parallel.

Finally one should notice that Swedish policy and regulation directed at PV is part of the system. Hence, developments that change the prerequisites for new regulation that in later periods could lead to market and industry growth should be monitored. Unfortunately, that also makes our analysis part of the system. When we make a recommendation for future policy we contribute to legitimisation or de-legitimisation in the system. In fact, already when we interview people we affect and are affected by the system that we study.

2.2 Structural elements and relational properties of a technological system

The literature on economics of innovation and science and technology studies has identified a number of structural elements that constitute a technological system; see e.g. [7,20,21]. We here group them into three main categories: artefacts, actors and rules. In a system, these elements are linked in various ways.

Physical artefacts do not only include the technology in focus but also machinery to produce the technology and complementary products. Artefacts may be hard-linked to make up larger artefacts (e.g. components in a PV-installation) or more loosely linked in networks connected via standardised interfaces (e.g. cars and petrol stations or PV-installations and electricity consuming devices connected via the electricity grid or transportable energy storage).

Similarly, *actors* may be organisationally hard-linked into firms and other organisations (forming actors at a higher level), loosely linked via markets or, as an intermediate form, be linked in networks [22]. Firms (and other organisations) are found within the whole value chain. Other organisations include universities, industry associations, NGOs and government bodies. Taken jointly, these make up the actor base of the system.

Rules define what actors and artefacts are able to do and what they ought to do. There are cognitive as well as normative rules.[4] Rules can be embedded in actors and technical artefact or codified in symbolic systems.

We distinguish three major types of cognitive rules. The first is what we may call the knowledge base of the technological system. It constrains what actors are able to do, e.g. produce or install PV panels. This *technical knowledge* has an instrumental character and can normally be captured by correlations and cause-effect chains: If A then B. It says something about the future and it is the future of limited systems that are stable over time and have performance that can be repeated and thus verified. Some technical knowledge is codified in symbolic systems (articles, patents or more general, text, drawings, etc.). Technical knowledge is also found as competence within actors: as explicit knowledge or more experience based tacit skills within individuals [17] or as procedures and routines within organisations [18]. A share of this technical knowledge is also embedded in artefacts.

[4] This reflects the old philosophical dichotomy between how things ‘are’ and how they ‘ought to be’ [16].

Technical knowledge is constantly transformed from one type to another: General formalised knowledge is turned into practical skills and particular artefact designs and practical experience is generalised into formalised knowledge.

A second part of the cognitive dimension has to with statements of the future performance of large and complex systems. They can also be framed by the schemata “if A then B” but cannot be tested and verified in the same way as technical knowledge. This part of the cognitive dimension could be labelled *expectations*.

A third part of the cognitive dimension is the structure of the symbolic systems, such as the differentiation and meaning of concepts. *Conceptualisation* also go beyond empirical testing, but will, unlike expectations, never be proven right or wrong, but shape what can be thought and understood.

The normative dimension regulates interactions between actors and defines what actors and artefacts should or should not do. These rules include hard *regulations* (controlled by juridical systems) and norms or *attitudes* (controlled by social systems). Also normative rules may be codified in symbolic systems, or embedded in people, organisational routines and artefacts (e.g as standards).

The cognitive and normative dimensions are not always easily separated. Taken jointly they influence decisions and actions in the form of frames [19, 20] or paradigms [21]. In earlier papers on TIS the term ‘*institutions*’ has been used instead of ‘rules’. In the terminology used here ‘institutions’ then have included not only the normative rules but also all cognitive rules with the exception of technical knowledge.[5] An alternative subdivision is then technical knowledge (codified and tacit) and institutions (regulations, attitudes, expectations and conceptualisations).

A given set of structural elements can form different kinds of systems depending on how they relate to each other. The relationships create a system property. An important system property is *positive external economies*. According to Carlsson [38] the main function of a technological innovation system is “to capture, diffuse, and magnify spillovers, some of which are the result of intentional acts of individual actors, while some occur as a result of largely unintended interaction”. Positive externalities (spillovers) can be viewed as links between actors and other elements. To exemplify: developed technical knowledge can be proprietary or accessible to many; favourable regulation such as subsidies can be reserved for a limited group or for a broader set of actors; and technical infrastructure can be open to many or a few. *Specialisation* of artefacts, actors and rules is a similar relational system property. It makes the system more fine tuned and efficient and the specialisation of actors increase the speed of learning and cost reduction. In a sense, specialisation is the opposite of positive external economies, since it reduce overlaps.[6] The scope for positive external economies and specialisation increases with system size.[7]

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[5] This also appears to be the definition used by Scott [18], with the small difference that Scott also includes organisational routines in ‘institutions’.

[6] A systemic solution to making use of specialisation as well as positive external economies at the same time is ‘modularity’ and hierarchical organisation [16, 17].

[7] The importance of positive external economies becomes clear if we envision the difference between entering a newborn and a mature system. The first actors in the system can find little knowledge; the understanding of, and attitudes towards the new technology among suppliers, customers and regulative bodies are not favourable; and regulation and surrounding technical systems do not fit the technology. When the 50th actor enters the system, these structures have changed, and a number of positive externalities in the form of available knowledge, favourable attitudes and compatible legal and technical structures are present, making progress less difficult.

It is relatively easy to get and verify empirical data on how stocks of artefacts and actors change. Codified knowledge is accessible via publication and patent databases and changes of codified regulations are publically available. Changing expectations, conceptualisations and attitudes are harder to detect but can be observed indirectly by means of discourse analysis or more directly in interviews and surveys. The formation of informal actor networks can be indirectly detected by data on meetings of different kinds, and higher skill levels and the development of organisational routines are made explicit in lower costs. Unfortunately, costs are not that easy to trace. Qualitative empirical data of all kinds can be gathered via interviews with knowledgeable people in the field.

2.3 Functions of innovations systems

The term ‘function’ has been used with somewhat different meaning in different strands of the innovation system literature. Sometimes the functions denote what is done by an identified group of actors within the system [22]. Here we stick to a somewhat different interpretation. The functions describe what is required to build up the system. They are thus functions of a more abstract innovation system (Figure 1). Not only actors but also artefacts and rules as well as external events may contribute to the functions of the TIS.[8]

The number of and delineation between functions is somewhat arbitrary but should cover the creation of all structural elements of the technological system as well as important emergent properties of the structure. Bergek et al. describe a set of eight functions [4]. They were initially constructed based on a slightly different conceptualisation of TIS, but they are easily adapted, to the framework presented here. Three functions capture actor participation: ‘Influence of the direction of search’ describes the incentives and pressures for firms on the supply side to participate in the system, ‘market formation’ captures the entry of users, and ‘resource mobilisation’ reflects the participation of educational and financial organisations, such as universities and venture capital firms. ‘Materialisation’ denotes the establishment of artefacts. ‘Development of formal knowledge’ refers to creating and tapping a research-based knowledge pool, whereas more applied, diverse and tacit knowledge comes out of ‘entrepreneurial experimentation’ by firms and other actors. Finally, ‘legitimation’ is a process that leads to an alignment of institutions, i.e. changed expectations, conceptualisations, attitudes and regulation.

The eighth function ‘creation of positive external economies’ is somewhat different in character. As discussed in Section 2.2, it can be viewed as adding links between actors and other elements, such as technical knowledge or attitudes, or better, as a second dimension (width) of the other functions making the created new elements available to more actors. We could here also add a ninth function, ‘specialisation’, describing a different kind of relational development in the system.

Empirical evidence at the functional level can be used to foresee future changes of the structure. For example, we would look for the combined internal and external forces affecting ‘direction of search’ or ‘materialisation’. Since functions are partly linked via the build up of

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[8] If one would make a mathematical model of the innovation system the functions would be differential equations: $\frac{dy_i}{dt} = f_i(y_1, \ldots, y_n, z_1, \ldots, z_m, \varepsilon)$, where y_i represent internal structural properties, z_i represent external influences and ε is a stochastic perturbation. This interpretation opens for System Dynamics modeling of innovation systems. Due to the instability of innovation system and difficulty with parameterization, such models are unlikely to add much to the predictive capacity of innovation system studies. However, formal models are useful for developing conceptual clarity and as tools for illustration and education [23, 24].

structural components, historical development can to some degree be described as chain reactions in the system. Such chain reactions have been termed ‘motors’ of innovation [22]. Based on such observations, one can speculate upon future chain reactions. The system is however, never deterministic due to influence of external events and agency (the free will of actors to act or pass).

2.4 Distinguishing the effect of the market support from other stimuli

In experimental science there are normally non-affected systems to compare with. This is not the case when interventions in large socio-technical systems are to be assessed. There is no baseline system or control group to compare with, nor can the intervention be repeated in a similar system. Hence it is virtually impossible to determine with certainty what development that resulted from specific intervention, and what would have happened anyway as a result of other stimuli. What we can do is to monitor what happened during the period compared to before, and what happens in other countries and in other technology domains. We also need to substantiate our claims with reasonable arguments about mechanisms. We need to carefully observe exogenous sources of impact on the Swedish system and differentiate between impact of the subsidy programme and other Swedish policies that were in place during the studied period. There could also be (are likely to be) synergies between different interventions and stimuli. The functions allow us to analyse such interactions.

3 The Swedish PV innovation system: assessment of the response to a governmental intervention

3.1 System boundaries

We follow the system from the early 1990s to mid 2008, with focus on the period with investment support, i.e. after May 2005. We use Sweden as geographical boundary for the system (see discussion in 2.1). We include technologies using the photovoltaic effect to produce electricity from sunlight (solar cells, solar photovoltaics or PV), with focus on grid connected systems, most of them mounted on buildings. In principle, we include the whole value chain but do not follow all supply chains (such as manufacturing of glass and cables) to their origins. In practice we exclude what is not PV specific. In this study ‘PV specific’ is not precisely defined with a sharp cut off, e.g. when PV value chains declines below a certain market share of input goods. Due to the small size of the system, we do not see this as a major problem.

We use the main value chain: cells, modules, installation of systems and solar electricity to organise our description of the system. Complementary value chains (for example for balance of system components such as PV system inverters) are not very visible. The main reason for this is not our description but the lack of activity in these value chains in the Swedish system.

3.2 Collection of data

Data was mainly collected from 80 semistructured interviews from August 2005 to December 2007. For details see references [25, 26]. Additional data comes from databases and various written sources.

3.3 External forces

Before examining change in the system we identify some external forces affecting the development. A major hampering force is the existence of a mature system already producing electricity, based on technologies that differ from solar cells in many respects. Swedish electricity supply comes to more than 90% from centralised nuclear and hydro power plant. Thus there is a technological regime that is likely to be unfamiliar with or even hostile towards PV and solar electricity [27, 28]. Development of other electricity technologies such as wind power may change the stability of the regime [29]. Nevertheless the impact of the regime is likely to be a rather stable force during the period. Also, the positive impact from generic knowledge development in physics and chemistry changes slowly. However, there are two positive external forces that changed rapidly in the period. The world market for solar cells grew from 1.3 GW in 2004 to 4.3 GW in 2007 and the media attention to climate change grew dramatically between 2005 and 2007 (Figure 2). This needs to be accounted for in the analysis of the impact of the investment subsidy.

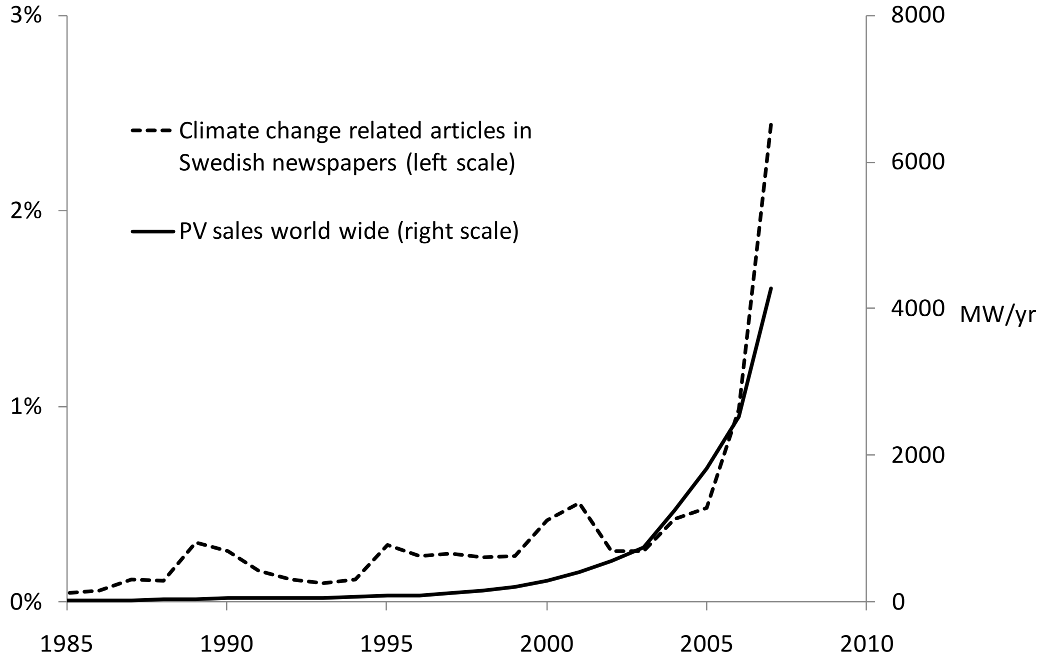

Figure 2 Indicators of two forces, external to the Swedish PV system. The global PV markets grew by on average around 40 % per year in the period 1996-2006 and by 69% between 2006 and 2007 (full line, right scale). The interest in climate change and thereby also in carbon neutral technologies is indicated by the percentage of articles in Swedish newspapers in the database "Artikelsök" dealing with climate change in any respect. The media interest started in the late 1980s but boomed between 2005 and 2007 (dotted line, left scale).

3.4 Structural change in the technological system

Cells: academic research and spin-offs

The Swedish trend in PV research follows the international upswing in PV research from the late 1990s and since 2000 the relative activity in PV research in Sweden is in parity with the relative PV activity in the global research community (Figure 3). Notably, there is no research on silicon cells.

To date (August 2008), there has been no solar cell production in Sweden. Research on solar cells started at The Royal Institute of Technology (KTH) in Stockholm in the 1980s. The research centred at one type of thin film cells (CIGS).[9] Key researchers moved to Uppsala University in the 1990s to form Ångström Solar Centre together with two other research groups. In 1995 Nordic Solar Energy AB was formed as a spin-off from the research on CIGS cells. It got funding from EU and public funds in Sweden but had little success in attracting private risk capital and gaining interest from Swedish industry. In 2003, a new spin-off company, Solibro AB, was founded. Still the interest from large Swedish firms and venture capitalists was low and 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 functions as a manufacturing development centre but the cells are produced in Germany. Solibro GmbH started production of cells in Thalheim, Germany, in May 2008.

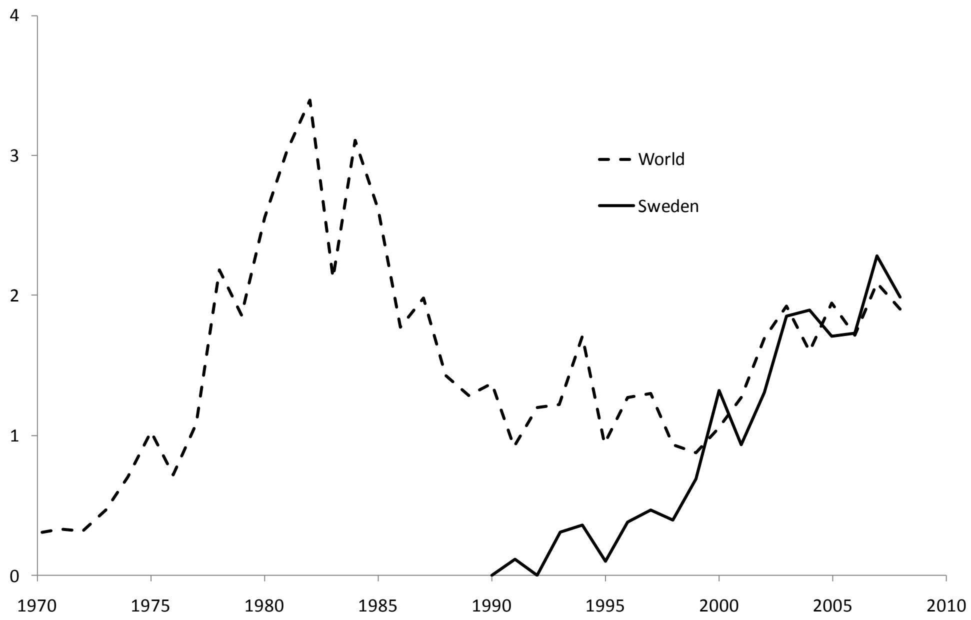

Figure 3 Percentage of all publications in the database Scopus related to solar cells. Since 2000, the Swedish academic system is as engaged in solar cell research as the rest of the world.

Midsummer AB, a company founded in 2004 plan to start production of CIGS cells in 2008 based on a different production concept than Solibro. The company is not a spin-off from Swedish research but develop cell production based on knowledge from CD and DVD production in the US. When Midsummer started out, they also had a hard time attaining financial resources. The company managed to get money from one Swedish authority (Vinnova) and the EU. The funding from the EU made it possible for them to acquire some risk capital. In 2008, the situation is reversed. According to a firm representative, they now get one call from venture capitalists a week.

Besides CIGS, there is research on two other thin-film technologies in Sweden. In the early 1990s researchers in physical chemistry in Uppsala started collaboration with Michael Grätzel on dye-sensitized solar cells (the 'Grätzel cell'). In recent years, part of the research on dye cells moved to KTH and some work on dye-cells has also been done at Chalmers University

[9] CIGS is short for copper indium gallium diselenide.

of Technology in Göteborg and at the Institute Swedish industrial research group (Swerea IVF). The third branch of Swedish thin-film PV research started in the late 1990s with research on polymer solar cells at Linköping University and at Chalmers. Bibliometric data reveal that research is now spreading to Lund University. There is yet no spin-off company based on any of these younger technologies.

The research spin-off Arontis Solar Concentrator AB started out as a non-profit research project. They do not develop cells but make solar concentrating PVT (photovoltaic thermal) systems, which produce both electricity and hot water. Arontis have many links to Swedish universities. Arontis does not consider the Swedish market to be of great importance in terms of volume, but of value as a base for demonstration projects [30].

Modules: export companies

The production of PV modules in Sweden was 75-80 MW in 2007 (Figure 4), or about 50 times the amount sold in Sweden the same year (Figure 1). All the five producing companies put together modules from silicon cells. The first module producer, Gällivare Photovoltaics (GVP) was founded in 1991 when the local mining industry made massive layoffs [31]. The Government put up 35% of the investment cost. An economist with experience from the European solar cell industry became CEO. In 2002, GVP was bought by the German firm, SolarWorld AG. When the modules now went to SolarWorld, two of the former major customers of GVP, Naps Systems (in Finland and Sweden) and Alfasolar in Germany, set up a second company, Arctic Solar, in GVP's old buildings. The former production manager of GVP now runs Arctic Solar. The former CEO of GVP moved to southern Sweden and started PV Enterprise. In 2003, also the Norwegian firm REC set up its module factory ScanModule in Sweden. In the end of 2006, n67 Solar, a firm belonging to a Danish consortium, set up a factory in northern Sweden, less than 50 km from GVP and Arctic Solar in Gällivare. Since 2003, production volumes have increased rapidly, mainly due to the aggressive expansion of ScanModule (Figure 4). While ScanModule get cells from the mother company in Norway, the expansion of for example PV Enterprise has been blocked by the silicon bottleneck and the fierce competition for silicon cells on the world market [32].

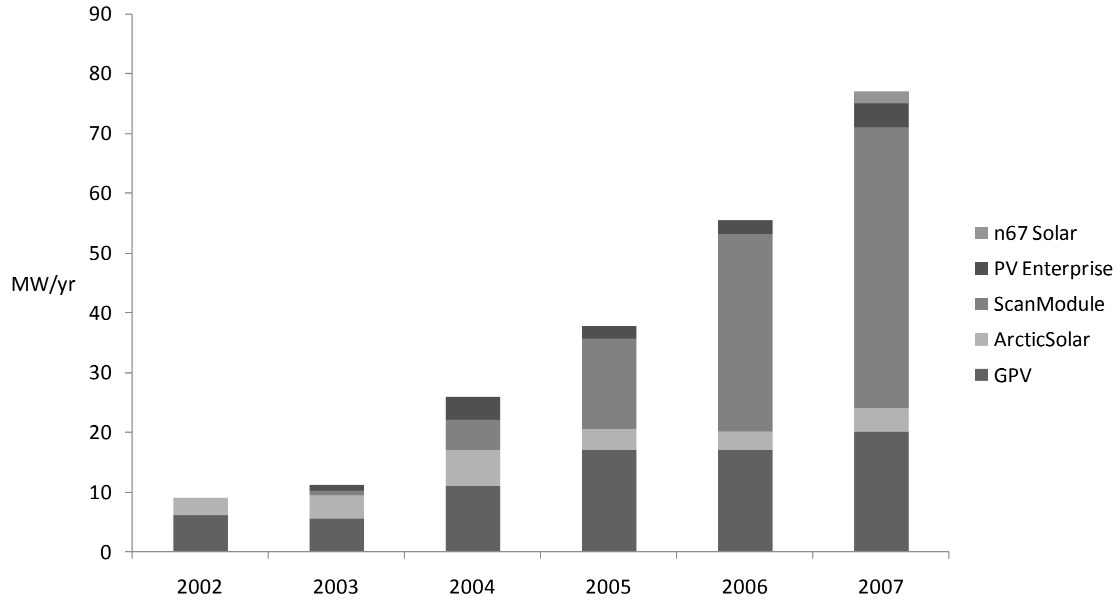

Figure 4 The production of PV modules in Sweden 2002-2007. Prior to 2002, Gällivare Photovoltaics was the only producer.

While the bulk of the production goes to high volume markets abroad, there are Swedish supplier-buyer networks between module manufactures and installers, mainly between Arctic Solar and Naps, and GVP and Switchpower (see below) [33, 34]. Recently, the Swedish investment company Bore Wind with shares in Switchpower, bought 65% of GVP. According to an interview in Photon, the two companies located in Gällivare help each other whenever there is lack of material or personnel [31], an example of positive externalities emanating from a local network. Links between these companies and universities are week, but initiatives are taken to establish cooperation on product quality [35].

PV system installation

Since the beginning of the 1990s there was a stable market for PV for off-grid applications between 0.2 and 0.3 MW per year (Figure 5). A few grid connected systems, mainly demonstration projects, were installed prior to 2005. In 2005, when then subsidy for PV installations in public buildings was in place, the PV markets in Sweden changed dramatically.[10] In 2007, the market for grid connected systems had reached above 1 MW (Figure 5). In parallel to market growth, new actors entered the system. In 2004, there was one firm doing system installations (turn-key entrepreneur), in March 2006 there five, and in November 2007 eight [26]. Some of these were new companies. Others were roofing, facade or solar heating companies that diversified into PV installations. Between 1997 and 2004, there was one small consultancy firm working with pre studies, project management and inspection. In March 2006, there were three and in November 2007 there were six, including some large engineering consultancy firms. In the end of 2007, also two of the larger firms working nation-wide with electrical installations had gained experience with PV installations [26]. Modules were supplied from Swedish as well as foreign firms. Two large multinational module retailers have established PV divisions in Sweden since the introduction of the market formation programme. One of these is Sharp, a world leading PV module producer. 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. Balance of system components such as inverters have been imported, since there are no domestic suppliers. A solar energy technician programme started in 2006, initiated by the entrepreneur behind Arontis (see above). The programme mainly focuses solar heating systems, but also includes PV [26].

Almost all installations are placed on existing buildings and there is little involvement of construction companies and architects. One architect firm that was involved in a demonstration project prior to the investment support has taken a role as educator. An architect at the firm has written a book on solar energy in architecture and urban planning [36], and they arranged field trips to PV installations in other countries for professionals in the construction sector. The interest seems to increase. The trip in 2006 had 32 participants, while the trip in 2007 attracted 72 [37]. A seminar series for architect students financed by the Solel programme at Elforsk (see below) were held at three universities in autumn 2006 to spring 2007. It was appreciated by students to learn about the difference between concepts such as 'power' and 'energy' and 'solar electricity' and 'solar heating'. Hence knowledge is increasing from a very low level, where basic conceptualisation is a first step. Besides this singular event, courses that include solar cells not common in the curricula of architect and civil engineering students [38]. Lund University has an elective course in solar energy for architects.

[10] 70% of the total installation cost is reimbursed by the Government.

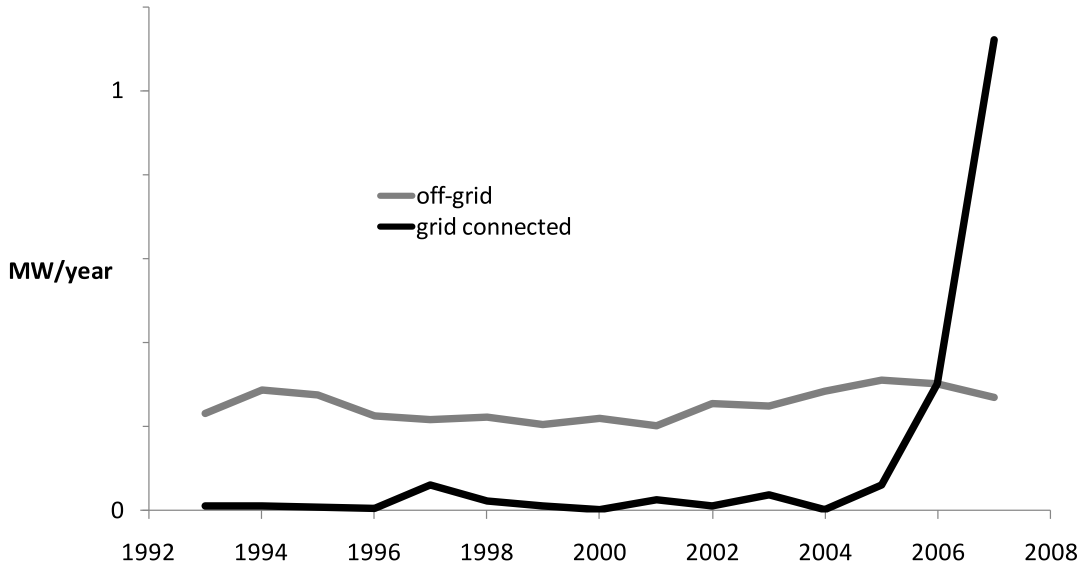

Figure 5 PV markets in Sweden 1993-2007 [39].

The investment subsidy directly targets the system buyers and the number of grid-connected PV installations in Sweden built outside of the investment subsidy are negligible [39]. The system buyers receiving the investment subsidy are (as the support demands) mostly public organizations such as universities, churches, museums and health care centres. The City of Malmö stands out as the most active buyer. At first, the focus was mostly on energy savings but it shifted towards making Malmö a centre of excellence for solar energy and using their top position in PV Sweden to create publicity, marketing Malmö as a city of renewal. In order to spread the knowledge about solar energy technologies in Malmö, the City has initiated the foundation of a non-profit organization, Solar City Malmö [40]. A similar initiative “Sunrise in the west” is taken in Western Sweden. In contrast, there has been no noticeable coordination in the City of Stockholm. Here, an additional support has been granted from the City, making investments almost free of charge for the individual investor.

The public procurement act has implied a considerable amount of administrative work, increasing the cost and time delays of projects and new firms without reference installations haven’t been able to entry the market. The novelty of the technology has also resulted in time delay in getting building permits. In some cases, the National Heritage Board has rejected installations.

A primary node in knowledge development around installation of PV systems is the SolEl programme at Elforsk. The programme started in 1995. Initially, it was instituted by the electricity companies and the Energy Authority to follow what happened in the field. Lately, a broad variety of stakeholder has become involved, including architects, construction companies and module producers.

Solar electricity

No market for solar electricity has emerged. There is no solar electricity sold in Sweden, neither from domestic installations, nor from installations abroad. Hence, there are no solar electricity consumers besides those owning PV installations. Most installations are designed not to supply a surplus to the grid. Suppliers of solar electricity are entitled to sell green electricity certificates. Due to the low price of certificates and the high cost of metering, only four solar electricity installations were covered by the certificate system in 2007, corresponding to less than four percent of the installed PV capacity. The attitudes towards solar cells and the expectations of their future appear to be low within the larger utilities. A representative from a solar industry organisation states that Vattenfall, the state own giant, has not shown any interest and that they are not very friendly towards distributed power sources [33]. In a publication it is concluded that solar electricity is not a competitive alternative for energy companies in Sweden [41]. Nevertheless, at least one local utility has demonstrated an interest in selling solar electricity [42]. A small company that are selling PV systems to consumers offers help to their customers with arguments in communication with grid owners [43].

In fact, a substantial share of electricity consumers appears to be willing to pay a premium price for solar electricity. In a survey comprising 11 575 house owners, 29% were willing to pay the double electricity price (about 0.2 Euro/kWh) or more for 100 kWh of solar electricity per year [44].

Cross cutting actors, networks and rules

In the autumn of 2005, Switchpower, one of the new PV installation firms, took the initiative to form the Scandinavian Photovoltaic Industry Association (SPIA). The group forming SPIA thought that the older solar energy association SEAS was too focussed on solar thermal and did little lobbying to improve the situation for PV. However, SPIA remained small and some actors saw SPIA as being too close to some companies. In the spring, SPIA and SEAS merged into Svensk Solenergi, which is more of an industry association and less of an NGO compared to SEAS, and has a broad representation from the value chains of solar electricity and solar heating. Some fifty companies are members. Svensk Solenergi, as well as its predecessors has approached the Swedish government to lobby for a continued support of the solar cell market post 2008.

There are no official goals for solar cells. The Government has not taken any clear position. Instead the rhetoric is that policy measures should be ‘technology neutral’. The focus is on energy technologies that could have a large impact on the Swedish energy system until 2020. There also seems to be no clear view on the relationship between energy, environmental and industrial policy. Nevertheless, in the fall of 2007, one motion from an individual parliamentarian was handed in to the Parliament, which argued for increased support of the solar cell industry.

The attitude towards solar energy in general is very favourable among the public. In a yearly survey, solar energy has been the energy source that most people in Sweden want Sweden to invest more in. Since the survey started in 1999 until 2006, the belief in solar has been stable. Over the years, between 77% and 83% answered that they thought Sweden should invest more in solar energy.[11]

The awareness of solar cells on the public arena can be indicated by media presence. There was a notable increase of articles in Swedish press in 2007 (Figure 6).

[11] Solar energy was not included as a separate category in the survey of 2007 due to lack of space.

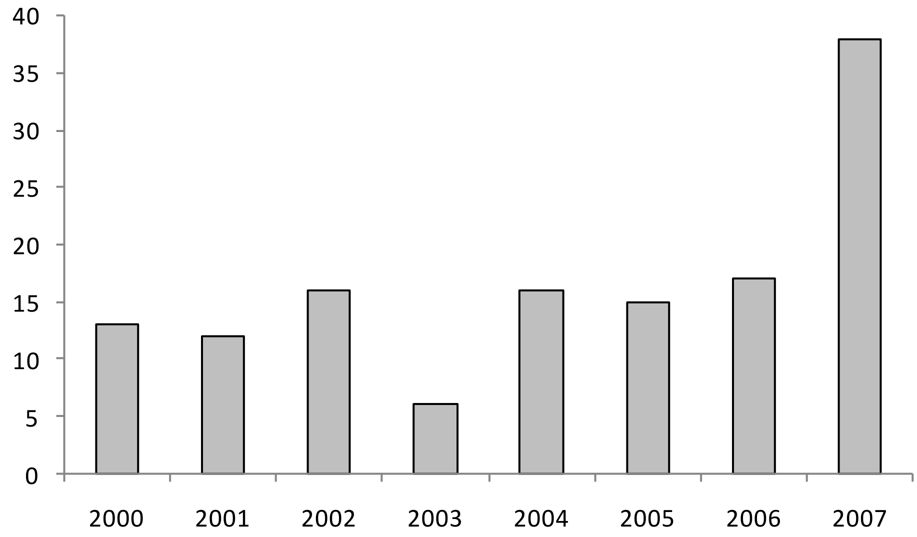

Figure 6 Articles about solar cells in Swedish newspapers and magazines.

3.5 Functional dynamics

The functional dynamics differ between the subsystems surrounding cell development, module production and system installation. There exist links between the subsystems, but they are weak. The subsystems are all dependent on external forces.

The cell development subsystem

An ambition to follow the international development within solar cells and the general increased interest for the environment in the 80s and 90s shifted the direction of search of some researchers with competence in microelectronics, photoelectrochemistry and conducting polymers and access to laboratory equipment towards the solar cell application. The knowledge production and physical infrastructure for knowledge production has continually expanded thanks to increased supply of resources from Swedish funding agencies and the EU. An exogenous cause for the increased funding is the growing interest in renewable energy technology as a solution to global energy and environmental problems and an expected opportunity for new industry and jobs. An endogenous cause is the legitimacy of PV (awareness, expectations, attitudes) transferred from universities to agencies directly through emerging networks and indirectly via media. The networks are further established when former students from these research departments take positions within agencies. The movements of graduated PhDs and the success of existing PV research groups to attract funding stimulates other universities to diversify into PV research which in turn broaden the competence base and fertilize knowledge production. A growth loop (motor) for knowledge production is created, stimulated by exogenous factors, but upheld by internal feedback.

The researchers have also engaged in entrepreneurial experimentation leading to practical knowledge and materialisation of production processes and cells. The prime example is Solibro. The lack of legitimacy for PV in Sweden made it difficult to find risk capital and interest from large firms with production know-how. In Germany, on the contrary, a decade and a half of public market support had created experienced and finically strong producers and different expectations of the future of PV [7]. Thus the weakness of the Swedish PV system – small industry, no market and low legitimacy made it impossible to attract the resources in Sweden necessary for expansion. With German capital and competence materialisation is now taking place in Germany. However, the creation of a development lab in Sweden enables further knowledge production in Sweden. The success of Solibro to attract the largest solar cell producer in the world has probably increased the legitimacy of PV in Sweden also among investors and entrepreneurs outside the knowledge production network.

Midsummer is partly a different story. The entrepreneurs behind Midsummer, were guided towards PV by the visibility of the development in Japan [45]. They apply competence from a different area, CD production in the US, illustrating a case of spill-over between technological innovation systems [4]. Also this company had a hard time to attract Swedish capital in 2004. Financial support from abroad (once again) in terms of EU funding changed the situation and increased expectations around the company. The interest from investors in 2008 can be traced to the rapidly growing global PV markets and to the increased legitimacy of PV in Sweden. Within the company, they see Midsummer as being independent of the Swedish market. They plan to sell their first cells to a module producer in Asia. However, they now have some connection to Swedish university research. They collaborate with researchers at Chalmers University of Technology where one scientist at Chalmers University of Technology is now working full time with research related to Midsummer. This illustrates a different pathway for how a general knowledge base and physical research facilities can be brought into a specific technological system and how a small company can initiate research they cannot do themselves.

The lack of a production industry obviously creates a problem for research in the sense that PhDs cannot find qualified jobs outside academia in Sweden. Hence, it becomes more difficult to attract students. On the other hand, graduated students become a resource pool for other PV subsystems and if they leave the Swedish PV system completely they may bring back important know-how to the Swedish PV system at a later stage. They could also function as ambassadors for Swedish PV research in other countries - as was the case in the acquisition of Solibro by Q-cells - or for PV technology in general in non-PV industries.

In conclusion, the subsystem has been dependent on resource supply from abroad, but the growth of the system (research networks and spin-offs) in combination with the growing interest for climate change and the growing world market for PV has contributed to the legitimation function and raised expectations for PV in Sweden. This, in turn, seems to affect resource mobilisation. Knowledge is supplied to an international research community and the materialised products are hitherto produced outside Sweden and sold at international markets. However, the system creates a pool of people with in depth knowledge of PV technology.

The module manufacturing subsystem

PV module manufacturing started as a way to create jobs. Resources were supplied by the Government and the mining industry. Off-grid applications in Sweden provided a first market in the 1990s. Knowledge about production initially came from people with experience from production in other countries. The first company, GVP, has seeded further entrepreneurial experimentation and the start up of two of the other four module producers. One the remaining two (n67), set up the factory in the vicinity of GVP, possibly guided by the local knowledge base and positive externalities. The growing world markets have driven a scale up of production. The Swedish market accounts for approximately 1% of sales. Financial resources for scale up were mainly supplied by investments of German, Norwegian and Finnish firms. Knowledge development is produced within these industrial networks, and links to universities are scarce. Material input in the form of cells is imported. For firms like PV Enterprise that is not part of a larger vertically integrated company group, cell shortages on world markets have become a blocking mechanism for scale up.

When Bore Wind with shares in the installation company Switchpower, were guided to buy 65% of GVP it was an example of how a small actor in one part of the value chain may influence the development of larger actors in other parts of the chain, and generally how search processes are enriched when the nodes in a network increase.

In conclusion, the success story of Swedish module manufacturers illustrates the importance of having a seed that can react to and make use of external processes. The functions producing growth of the subsystem is now to a very large extent dependent on exogenous factors. However, new links to a Swedish user and investment context is being established.

PV system installation and use

The market support clearly contributed to market formation and made many new buyers enter the system. Prior to the market support, there was one system installation company, NAPS, and one consultant, Energibanken. These had been involved in the few grid-connected demonstration projects Sweden had before 2005. The two persons running Energibanken, came out of the research group that had started PV research at KTH in the 1980s which illustrate the versatile role of universities in technological systems. The competence of these two companies was essential to get the market going. The growing market guided the direction of search of new entrepreneurs and existing firms in related industries. The new actors actively tried to convince potential buyers to invest in systems. Networks between actors were created. Knowledge spread via meetings held by the Solel programme at Elforsk, and by others. With contributions from the new actors, Solel published guidelines for architects and installers, and thereby contributed to positive external economies. Towards the end of period, the increasing number of firms led to specialisation. Practical knowledge increased to some extent with the increasing number of projects. However, the number of projects is far too few to allow for more specialisation and cost cuts through repetition.

Materialisation was made possible by the existence of a mature industry abroad. Some of the modules were provided by firms like GVP and Arctic Solar, but others were imported via companies like Sharp and Schuco. Balance of system components like inverters had to be imported.

The increasing number of installed solar cell systems increased the visibility and thereby the legitimacy of the technology. More people came into contact with the technology and got experience from it. This effect was propelled with the emergence of organisations like Solar City Malmö and ‘Sunrise in the west’, that arranged seminars combined with solar cell sightseeing. This in turn is likely to further guide the direction of search of a broad range of actors. The entry of new actors also fertilised the PV lobbying and legitimation process in Sweden directly through the creation of SPIA and later, Svensk Solenergi. Svensk Solenergi is now a network with actors from the whole value chain.

Entrepreneurial experimentation is hampered by limitation of the support to public buildings. Likewise, the short timeframe have practically excluded integration in new buildings and thereby the entry of architects and construction companies. This entry is further blocked by the lack of education and low level of knowledge about PV among architects and civil engineers.

The interest from the public could have provided a market for solar electricity and thereby an expanded market for PV installations. The regulations around electricity feed-in and the low interest from utilities has hitherto blocked this. However, the market formation programme has lead to an articulation of this problem. Regulation changes are under way. Research is also started to investigate the potential for a solar electricity market.

3.6 The effect of the investment subsidy

The subsidy has had a very small effect on cell development and module manufacturing. The market created ended too soon for cell development and was too small to be of importance for module production. If designed differently the program could have become a test bed for Swedish cell technology (entrepreneurial experimentation) and fostered stronger collaboration between Swedish cell research and module manufactures (external economies based on stronger networks). The subsidy has not been able to create a market for solar electricity. However, it has spurred a market for solar cell systems and radically transformed and developed that part of the value chain. The subsidy has lead to identification of regulative problems with PV installations (building permits) and with solar electricity feed-in.

The materialisation of PV systems in Sweden, the development of new organisations such as Svensk Solenergi and Solar City Malmö and the strengthening of old organisations such as the Solel program have affected the availability of knowledge. This increase of artefacts, actors and networks, together with the relative success of Swedish module producers and solar cell spin-offs, and together with external forces such as increased concern for climate change and rapidly growing PV markets in the world, has led to an increased legitimacy of PV in Sweden. Expectations are higher. It is impossible to estimate the relative contribution of the different factors. Further, there is a multiplication effect. The external forces need to be interpreted and articulated in Swedish arenas. There are now a growing number of people that are able to tell about external trends to a Swedish audience. No matter the relative contribution of external and internal causes, the growing legitimacy – positive attitudes, expectations and familiarity - has most certainly changed the prerequisites for future policymaking, investment decisions and direction of search.

To conclude the goals of the subsidy was 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. First, the actual installed capacity seems to become somewhat less than 7.6 MWp. This is from our perspective of less interest. Second, according to our analysis the subsidy has enhanced the prerequisites for further diffusion. The number of actors and their competence has increased. However, further market formation is very dependent on continued market support. The increased legitimacy partly coming as a result of the subsidy has enhanced the prospects for such a policy intervention. Further, the subsidy has set in motion a search for a solar electricity market based on consumer willingness to pay a premium price. Third, a PV industry is growing, to a large extent independent of the support. The support has filled in parts of the value chain, but parts are still missing such as the construction industry, and links between many parts of the value chain are weak. The support has affected the legitimacy of PV and search processes, which is likely to benefit all parts of the value chain, e.g. through access to capital. However, the negative contribution to legitimation from the large electricity utilities is not yet balanced.

3.7 Recommendations for policy: Continue to support solar cell use and connect the subsystems.

The Swedish system for solar cell use and production will never be independent of the development outside of Sweden. However, the Swedish system needs to be developed enough to be able to make use of external forces. To continue a development of the PV use in Sweden a continued market support of some sort is needed. To stimulate new actors to enter and explore new opportunities, it needs to be long term, include private investors and provide incentives for the building industry to take action. To exploit academic research in next generations of thin film technology in Sweden, the expectation and awareness needs to be increased among investors. This can be done be supporting networks, but also indirectly by the proposed market support and by declaration of a solar energy vision. A vivid market could also provide a testing ground for new technologies. To sustain the growth of the module producers, it could be wise to support links upstream to cell development and university research, to prepare for possible future shifts in technology from crystalline silicon to thin films. Supporting links downstream could induce development of new applications. It is not only links to the construction industry that are of interest. Also other industries such as the automotive industry could provide new markets and room for mutual learning.

4 Final remarks

The task was to assess the effects of a policy intervention. There is not a Sweden without the policy intervention to compare with. And we cannot wait to see what happens in 20 years from now. In the end social processes can never be fully explained, and policy interventions will to a large extent always remain an art based on the experience and worldview of politicians. However, by using a systems model to assess the policy intervention we have been able to trace some facts and relations of relevance for the stated goals of the intervention. We understand more than we did before the investigation. By applying the model to more cases we believe that the methodology can be refined and more can be learnt about the relative strength of the causal relationships in growth processes.

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