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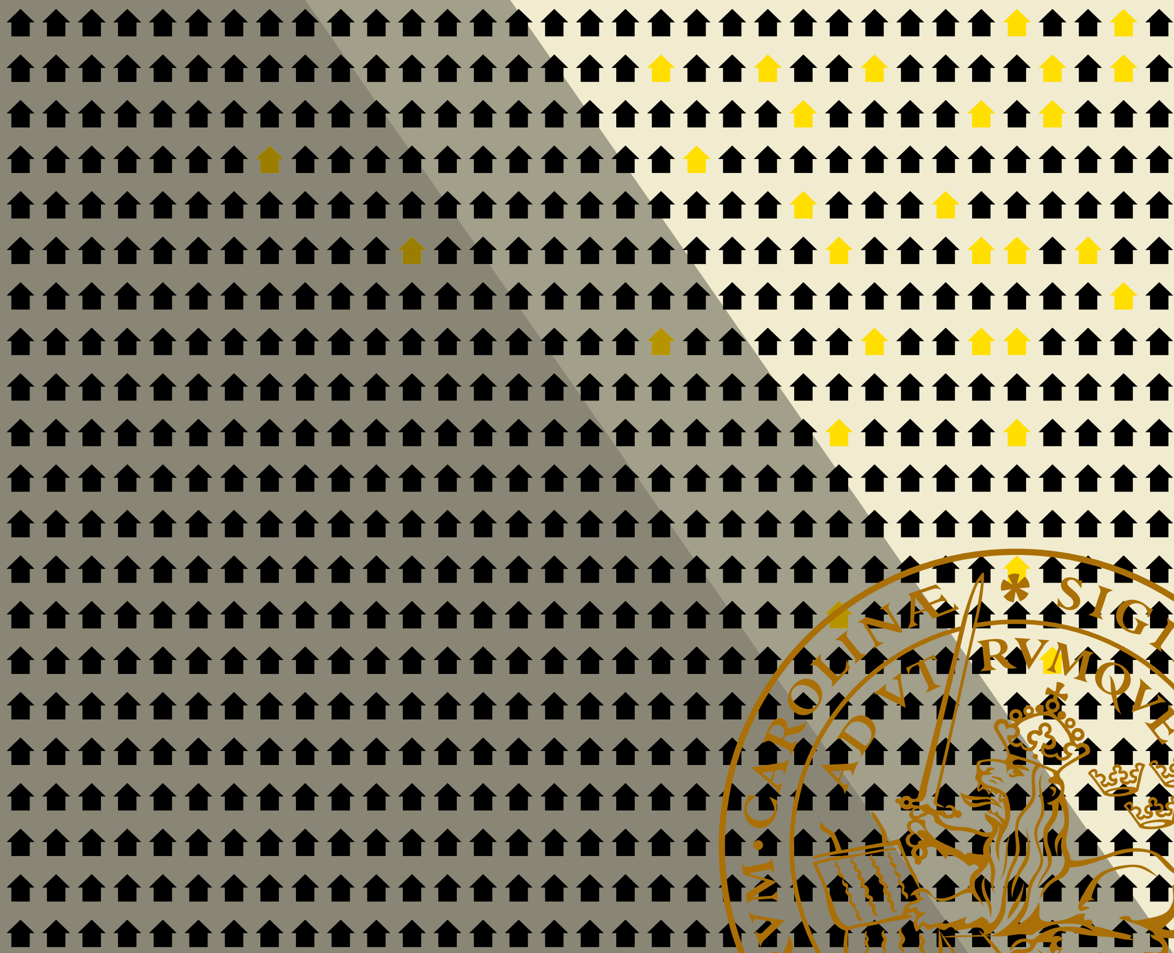

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List of abbreviations:

IRR = Internal rate of return

PPA = Power purchase agreement

PV = (Solar) photovoltaics

TGC = tradable green certificates

TIS = Technological innovation system

TPO = Third-party ownership

Keywords: Solar photovoltaics (PV), renewable energy, sustainability transitions, technology deployment, diffusion of innovations, barriers, drivers, space, technological innovation system (TIS), technology adoption, business model, peer effects

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Abstract

In order to support a sustainability transition in the energy sector, actors need knowledge about barriers and drivers to the deployment of clean energy technologies. Solar photovoltaics (PV) is a renewable energy technology that is technically mature and on the verge of becoming economically competitive in numerous regions around the world. Not least in the residential segment, PV has considerable potential. Even after residential PV has reached economic competitiveness, however, the technology might still face important barriers in the sociotechnical system in which it is to be deployed.

This thesis aims at adding knowledge about barriers and drivers to the deployment of residential PV systems. The research takes a sociotechnical systems perspective and demonstrates how the *technological innovation systems* (TIS) framework can be amended by the *business models* and the *diffusion of innovations* frameworks to study the deployment of a mature technology in a catching-up market, treating technology development and production as a 'black box'. The research is largely based on case studies and uses various modes of data collection and analysis. The bulk of the research was performed in Swedish settings on the national and local levels, although the United States, Germany and Japan were also studied. Studying these different contexts, the thesis builds knowledge about barriers and drivers on different spatial scales. The researched focused on the period between 2009 and 2014.

The results highlight various barriers and drivers in the studied contexts. On the national level, the Swedish sociotechnical system for PV deployment has been immature and infested by various institutional barriers. Swedish subsidies for PV deployment have been flawed with uncertainties, complexities and discontinuations, and there have been important uncertainties regarding the future development of the institutional set-up. The results also demonstrate how barriers in different national contexts have been decisive for what kinds of business models for PV deployment that have been viable. On the local level in Sweden, the results show how actors such as local electric utilities and private individuals have influenced homeowners to adopt PV through information dissemination and social influence (peer effects). The results can inform policymakers, firms and other actors as to how to support PV deployment.

Populärvetenskaplig sammanfattning

Klimatförändringarna är en av vår tids största utmaningar. För att utsläppen av koldioxid ska minska behöver teknologier för förnybar energi snabbt ersätta energi baserad på fossila bränslen. För att olika aktörer – såsom lagstiftare, företag, ideella organisationer och privatpersoner – ska kunna stödja en sådan omställning behövs kunskap om olika hinder och drivkrafter som motverkar respektive främjar (eller skulle kunna främja) spridningen av teknologi för förnybar energi.

Denna avhandling handlar om spridning av *solceller*. Avhandlingens mål är att identifiera och utvärdera hinder och drivkrafter som påverkar hur mycket solceller som installeras. Fokus ligger främst på solcellsanläggningar för privatpersoner i Sverige, vilket i regel innebär solceller placerade på villatak. Trots Sveriges geografiska läge på förhållandevis solfattiga breddgrader finns god potential för användning av solceller även i Sverige. Avhandlingen tar ett sociotekniskt systemperspektiv och analyserar samtida hinder och drivkrafter relaterade till regelverk, styrmedel, affärsmodeller, social påverkan och ekonomi. En rad fallstudier genomfördes, och data samlades in genom bland annat enkäter och intervjuer med nyckelaktörer. Genom fallstudier fokuserade på såväl det nationella som det lokala planet bygger avhandlingen kunskap om hinder och drivkrafter på olika geografiska nivåer.

Arbetet genomfördes som fyra delstudier, vilka har publicerats (eller ska publiceras) i vetenskapliga tidskrifter. Den första delstudien tog ett helhetsperspektiv på hinder och drivkrafter på nationell nivå i Sverige. Analysen återger ett underutvecklat sociotekniskt system för byggnadsanknutna solceller i Sverige och pekar på en rad problem vad gäller den institutionella stabiliteten. Brister i de ekonomiska styrmedlen har medfört osäkerheter och försämrad investeringsvilja inom installatörsbranschen samt en lång kö för privatpersoner att få ansökningar om bidrag beviljade. Stora osäkerheter har rått vad gäller den framtida utformningen av styrmedel och skatteregler. I vissa fall har det varit oklart hur befintliga regler ska tillämpas då dessa inte varit anpassade för mikroproduktion av elektricitet utan utvecklats för centraliserad storskalig elproduktion.

I den andra delstudien analyserades olika typer av affärsmodeller som nått framgång på tre stora solcellsmarknader (USA, Tyskland och Japan). En affärsmodell är det sätt på vilket företag skapar värde åt sig själva och sina kunder. Studien gick ut på att identifiera faktorer som skiljer sig åt mellan marknaderna och som skulle kunna förklara varför en viss affärsmodell nått framgång på en marknad men inte på en annan. De studerade marknaderna skiljer sig åt markant vad gäller vilka typer av affärsmodeller som nått framgång. Till exempel har leasing av solcellssystem varit mycket populärt i USA men nästintill obefintligt i Tyskland och Japan. Resultaten visade på att faktorer som husägares tillgång till kapital, sparkvoter, flyttmönster, egenskaper hos den nationella byggsektorn samt utformning av bidragssystem kan ha ett stort förklaringsvärde. Resultaten kan användas för att stödja spridning av solceller i Sverige och annorstädes, t.ex. genom att informera lagstiftare om hur institutionella hinder mot vissa typer av affärsmodeller kan avlägsnas, eller genom att informera entreprenörer om hur affärsmodeller kan anpassas för olika nationella kontexter.

Den tredje delstudien gick ut på att förklara skillnader i antalet solcellsinstallationer per capita mellan svenska kommuner. Intervjuer med lokala aktörer samt en enkät skickad till personer som skaffat solceller användes för att identifiera lokala faktorer i fem kommuner med särskilt hög solcellstäthet (antal installationer per capita). Resultaten pekar på att den troligen enskilt viktigaste förklaringen till den höga solcellstätheten i de studerade kommunerna är att lokala aktörer aktivt främjat solceller. Framförallt verkar lokala elnätsbolag som marknadsfört och spridit information kring solceller ha haft en stor effekt.

Den fjärde delstudien handlade om social påverkan mellan privatpersoner. En rad utländska studier har tidigare visat att varje ny solcellsinstallation ökar sannolikheten för ytterligare installationer i dess absoluta närhet, vilket indikerar att grannar påverkar varandra att skaffa solceller. Kunskapen om *hur* denna påverkan gått till har dock varit låg. En enkät skickades till solcellsägare, och uppföljande intervjuer genomfördes med utvalda respondenter. Resultaten tydde på att påverkan främst skett genom förhållandevis nära sociala nätverk (mellan släkt och vänner snarare än mellan grannar utan någon närmare relation), samt att den information som förmedlats och som ansetts viktig främst varit en *bekräftelse* på att anläggningen är enkel att använda, levererar elektricitet som förväntat och är driftsäker, samt att inga obehagliga överraskningar är att vänta. Kontakt mellan privatpersoner har således fungerat som ett komplement till professionell rådgivning, där solcellsägande privatpersoner förmedlat en trygghet som ökat deltagarnas benägenhet att skaffa solceller trots att de saknat proffsens detaljkunskaper.

I sin helhet visar avhandlingen på en rad viktiga hinder och drivkrafter för spridning av solceller. Dessa hinder och drivkrafter kopplar till såväl nationella styrmedel och regelverk som till lokala informationsinsatser och social påverkan. Genom att öka kunskaperna om hinder och drivkrafter på olika geografiska nivåer bidrar avhandlingen till bättre förutsättningar för olika aktörer att underlätta spridning av solceller.

List of papers

This thesis is based on the following four research papers (articles). The full papers can be found at the end of the thesis.

Paper 1:

Palm, A., 2015. An emerging innovation system for deployment of building-sited solar photovoltaics in Sweden. Environmental Innovation and Societal Transitions 15, 140-157.

Paper 2:

Strupeit, L., Palm, A., 2016. Overcoming barriers to renewable energy diffusion: business models for customer-sited solar photovoltaics in Japan, Germany and the United States. Journal of Cleaner Production 123, 124-136.

This paper was produced by my colleague Lars Strupeit and me in close collaboration. As regards research design, the credit goes mainly to Lars. Data collection was split between us, with me responsible for one case (Japan) and Lars for the other two cases. The literature review, data analysis and writing were performed by the two of us in close collaboration.

Paper 3:

Palm, A., 2016. Local factors driving the diffusion of solar photovoltaics in Sweden: A case study of five municipalities in an early market. Energy Research & Social Science 14, 1-12.

Paper 4:

Palm, A., 2016. Peer effects in residential solar photovoltaics adoption – a mixed methods study of Swedish users. Submitted to Energy Research & Social Science.

Content

1. Introduction

To cope with the challenge of climate change, the need for a transition to a low-carbon energy system is urgent (IPCC, 2014). Such a transition is likely to not only involve the introduction of new energy technologies, but also changes of a more social character, involving institutions, consumption behaviour, knowledge and business models (Geels, 2002; Grübler, 2003; IPCC, 2014; Kemp et al., 1998). Sociotechnical transitions of this kind have occurred several times throughout history in different sectors, but they normally take decades (Grübler, 1996), not only because of the time required to develop and refine new technological artefacts, but also because of various barriers in the sociotechnical environment in which the technology is to be deployed. Not least in the energy sector, such barriers are often severe (Unruh, 2000).

Common barriers to the dissemination of new technology include high costs, technical flaws and poor compatibility with existing infrastructure (Geels, 2002; Grübler, 1996; Kemp et al., 1998). Key reasons that new technology tends to be expensive are that production typically takes place on a relatively small scale, and that processes of learning regarding efficient production are yet to occur (Grübler, 2003; Kemp and Soete, 1992). Long periods of experimentation and learning are typically required to bring down costs and refine the performance of a new technology (Grübler, 2012; Kemp and Soete, 1992; Rosenberg, 1994).

Even after a new technology has reached economic and technical competitiveness, important barriers of a more social character typically remain, obstructing deployment of the technology. Organisational and institutional support for new energy technologies is often lacking, while existing (competing) technologies have built up such support over a long period (Bergek et al., 2008a; Geels, 2002; Grübler, 2012; Hekkert et al., 2007; Unruh, 2000). Existing institutions are often poorly aligned to new, radical innovations as the institutions were often adapted for another technological regime, and incumbent companies with vested interests in preserving the status quo will often use their (superior) financial resources and networks to hold new competitors back, e.g. through lobbying (Unruh, 2000). Besides, consumers tend to be somewhat suspicious of new technologies, and complexities and uncertainties (perceived or real, technical or institutional) can often deter potential adopters (Kemp et al., 1998; Rogers, 1983).

There is also an important spatial dimension to the dissemination of innovations. Understanding the preconditions for a transition requires an understanding of how different phenomena relate to geographical places and scales (Coenen et al., 2012; Hansen and Coenen, 2015). The spatial dimension of sustainability transitions has, nevertheless, remained underexplored (Coenen et al., 2012; Hansen and Coenen, 2015). For example, local aspects related to consumers and market formation have only been sporadically considered in the transitions literature (Hansen and Coenen, 2015).

There are various strategies that different actors can use to facilitate a transition. Various policy interventions can be used, based on economic instruments, regulatory approaches or information dissemination (IPCC, 2014). Firms can develop innovative business models that fit certain characteristics of a new technology (Bocken et al., 2014; Boons and Lüdeke-Freund, 2013). Information campaigns and lobbying can be run by non-profit organisations or others. Individuals can influence each other through social networks. Such activities can make a new technology disseminate more quickly. To enable different actors to facilitate a transition in an informed manner, a thorough understanding of the sociotechnical system in which the technology is to be deployed is needed.

This thesis is about the deployment of one specific renewable energy technology, namely *solar photovoltaics* (PV). The aim is to identify and assess *barriers* and *drivers* that obstruct and facilitate PV deployment. The thesis takes the *spatial* dimension into consideration, recognising that geographical place and scale might matter in different ways for different barriers and drivers. The scope is limited to the residential sector, i.e. to PV systems situated on the premises of private homeowners. Only grid-connected applications are considered. The thesis adopts a systemic, sociotechnical view of technology deployment, recognising that deployment depends on an interplay between aspects such as institutions, perceptions, social influence, economy infrastructure and artefacts (Bergek et al., 2008a; Geels, 2002; Grübler, 2003; Hekkert et al., 2007; Hughes, 1993; Markard et al., 2012; Unruh, 2000).

The research behind the thesis has been presented to the research community in four papers. Three of them have been published in different peer-reviewed academic journals, and the fourth is under revision. The papers are summarised one by one in section 3, and the full papers are provided as appendices.

Box 1. Background: PV technology

What is a PV system?

A PV system consists of a number of PV modules and any necessary mounting device, wiring, power inverters etc. Each module consists of a series of solar cells encapsulated into a weather-resistant shell with a transparent surface. PV systems take advantage of the photovoltaic effect, which occurs as the semiconductive material of solar cells is exposed to sunlight.

PV development and dissemination: a brief history

After its invention in the mid-1900s, PV technology found its first significant commercial market in the space industry, where the then high cost of PV was of minor concern. Subsequent niche markets include pocket calculators, early mobile phones, remote transmission stations, parking meters and holiday cottages. As a result of cost reductions and subsidies, the residential rooftop segment gained relevance in the 1990s. Global PV installations came to be dominated by a handful of countries with ambitious subsidy schemes, including Japan, Germany and the United States. In the most recent years, the global PV market has become increasingly geographically diverse.

Technical benefits and challenges of PV

Rooftop PV systems allow adopters to produce and use their own electricity. As the production is close to the user, transmission losses are kept at a minimum. PV technology is highly modular, and PV can feasibly be applied on vastly different scales (from pocket calculators to ground-mounted solar parks). A challenge of PV is intermittency (electricity is produced only when the sun shines), and an increasing share of PV in the power systems might eventually increase the need for load management.

The efficiency of most commercial PV modules in converting solar energy into electricity is around 15%, a figure that has gradually increased from around 6% in the earliest years of PV technology. This figure might not appear too impressive at first glance, but, considering the large amounts of solar energy entering the Earth, it is more than enough from a technical perspective. The global technical potential for electricity generation is several times larger for PV than for biomass or wind power (de Vries et al., 2007).

Although solar cells can be made from a variety of different materials, the world market has been dominated by cells made of silicon, which is the Earth's second most abundant element. The lifecycle greenhouse gas emissions and other externalities of PV systems are normally small in comparison to fossil fuel based electricity generation systems. The energy payback time of silicon-based PV systems under average United States and Southern European conditions is typically around two to three years (Fthenakis and Kim, 2011), and the lifetime of PV modules can be assumed to be 25 years or more (Bazilian et al., 2013).

1.1. PV deployment: barriers, drivers and space – previous knowledge and gaps in the literature

1.1.1. Barriers and drivers to PV deployment

Residential PV deployment faces substantial challenges, including issues that are general to the deployment of new technologies as well as issues that are more specific to PV, the electricity system and the built environment. While barriers are present throughout the PV value chain, this thesis focuses on barriers at work in the *deployment* phase. Deployment is defined here as the process of putting the technology into use, involving activities occurring at and around the very end of the value chain (see section 1.3 for a more detailed definition).

From a purely technical point of view, PV has been a rather mature technology for decades, performing well in various applications (Jacobsson et al., 2004). However, PV is a radical innovation in the context of national electricity systems and the built environment (Awerbuch, 2000; Schleicher-Tappeser, 2012). Compared to established electricity generation technologies, PV is a disruptive technology as it (a) can be distributed at many points in the electrical grid rather than concentrated to a few large plants, (b) can be located at the user side of the electricity meter, and (c) produces electricity intermittently (only when the sun shines). As a radical technology that requires compatibility with other systems, PV can be expected to face substantial challenges regarding compatibility with existing institutions, practices and infrastructures when deployed in a new context (cf. Kemp et al., 1998). Although there is a fair amount of literature on barriers and drivers to PV deployment, there are various relevant research gaps, of which this thesis addresses a few.

Historically, high costs of PV-generated electricity compared to electricity bought from the grid have been a dominant barrier to residential PV and other grid-connected PV applications (Arvizu et al., 2011; Jacobsson et al., 2004). Only recently have costs of PV technology become low enough for PV to compete in grid-connected applications without subsidies. These cost reductions have largely been the result of learning and economies of scale in the production of solar cells, including input materials (Candelise et al., 2013; de La Tour et al., 2013; Jacobsson et al., 2004; Neij, 2008; Nemet, 2006; Zheng and Kammen, 2014). However, this thesis mainly studies a context (Sweden) in which limited economic profitability has remained a substantial barrier.

To overcome the cost barrier, subsidies to deployment have been a common strategy and an important driver. However, not only the sheer size of subsidies is important, but also various other design aspects. For example, the remuneration can be based on the electricity production, total cost or installed capacity of a PV system, creating somewhat different incentive structures (Haas, 2003). Regardless of which strategy is chosen, the literature stresses the importance of keeping subsidies predictable (to reduce uncertainty), user-friendly (to reduce complexity) and dynamic (to be adaptable to external changes). It is crucial to keep the economic profitability (measured for example as the *internal rate of return*, IRR) of investing in a PV system predictable. Remuneration levels should thus be continuously monitored and adapted to changing prices of PV systems (Haas, 2004, 2003; Sandén, 2005). Throughout Europe, insufficient guarantees regarding the continuation of subsidies have been a common problem (Dusonchet and Telaretti, 2010). The potential of subsidies for PV adoption to drive down costs of PV technology has also been stressed, as the subsidies provide the industry with a market in which it can sell its products and thus learn how to produce and deploy PV more efficiently (Jacobsson et al., 2004; Sandén, 2005). There has, however, been a large variation in how subsidies for PV deployment have actually been designed.

An economic barrier that is particularly tangible for PV is the relatively high *upfront* cost. That is, the total lifecycle cost of PV systems is typically highly concentrated to the initial investment. The ‘fuel’ is free and maintenance costs are low, and although a PV system might be a beneficial long-term investment, prospective adopters might not be able to purchase a PV system due to difficulties in raising the necessary capital (Rosoff and Sinclair, 2009; Yang, 2010). This issue can also deter potential adopters that use a high (explicit or implicit) discount rate.

As costs of PV systems have decreased over time, other barriers than poor economic profitability have gained in relative importance. For example, various complexities and uncertainties (institutional, financial, technical) will often deter potential PV adopters (Karteris and Papadopoulos, 2012; Rai et al., 2016; Rosoff and Sinclair, 2009; Shih and Chou, 2011; Simpson and Clifton, 2015). Examples of specific institutional barriers to PV deployment that have been pinpointed in the literature are a lack of reliable installer certification and standards for technical components and grid-connection (Shrimali and Jenner, 2013; Simpson and Clifton, 2015; Zhang et al., 2015), and long turnaround times and high fees in permitting (Dong and Wiser, 2013; Li and Yi, 2014). Incumbent actors in the electricity sector that have seen their revenues being threatened by the dissemination of residential PV have often tried to influence institutions to counteract PV dissemination, with some (albeit limited) success (Hess, 2016).

Barriers to PV deployment may often be rooted in the electricity and housing systems. Barriers to new technologies tend to be most severe for “systemic technologies that require change in the outside world” (Kemp et al., 1998). For PV to achieve compatibility with buildings and electricity systems, technical and institutional change in these systems might be required. Housing and energy are also typically highly regulated, meaning that various legislative barriers might be present (cf. Unruh, 2000). Systems for electricity generation and distribution can be understood as 'large technical systems' of high complexity and inertia (Hughes, 1993). In such systems, existing institutions and infrastructures often interact to obstruct the deployment of new technologies. Legislation and other institutions in the electricity sector have typically been adapted for a technological regime (cf. Geels, 2002) of centralised large-scale facilities (Unruh, 2000). Current energy systems can be understood as being in a state of 'carbon lock-in' caused by "technological and institutional co-evolution driven by path-dependent increasing returns to scale" (Unruh, 2000), impeding radical innovation in the energy sector and conserving the status quo. Furthermore, technological change is typically slower in sectors of long-lived structures (Grübler, 1996). Only rarely does new energy technology replace existing technology through the premature retiring of existing capital stock; thus, the longevity of plants and infrastructures in incumbent energy systems holds back the dissemination of new energy technologies (Grübler, 2012).

In understanding barriers and drivers to PV deployment, it is important to understand the motives for adopting a residential PV system. In developed countries, motives have mainly related to electricity bill savings, reduced environmental impact, energy independence and a general interest in new technology (Rai et al., 2016; Schelly, 2014; Zhai and Williams, 2012). In markets where PV adoption has been a poor economic investment, concern for the environment and an interest in the technology have often been important driving forces for those few adopting PV (e.g. Palm and Tengvard, 2011).

It is recognised that business model innovation (the development of new business models or the adaptation of existing ones) could serve to overcome certain barriers to PV deployment. For example, third-party ownership (TPO) business models can address the high upfront cost of PV systems, bureaucratic hassle and concerns related to operation and maintenance (Overholm, 2015). Research on how different business models for PV deployment relate to different contextual factors has, however, been scarce.

1.1.2. The spatial dimension of PV deployment

Barriers and drivers to PV deployment can be rooted in different places and extend over different geographical scales. The production of PV system components has mainly taken place in other parts of the world than where the technology has been deployed (Huang et al., 2016; Quitzow, 2015), and the part of the value chain where development and production occur has been more global by nature than have processes of deployment. Processes occurring 'upstream' in the PV value chain, such as silicon purification and wafer production, are technologically advanced and take place in a global arena. In this part of the value chain, skilled staff has been recruited from around the world and production equipment and produced goods have been traded internationally (de la Tour et al., 2011; Huang et al., 2016). The development of institutions governing the global PV industry has been shaped by an interplay between governments and firms across national borders (Bohnsack et al., 2016). Although the actual production of PV system components and input materials has been concentrated to certain places, the sociotechnical system for the generation of PV system components has thus been rather global by nature. At the subsequent steps down the value chain too, solar cells and modules are traded globally nearly as commodities. As a consequence, cost reduction and technological improvements of PV system components have been globally pervasive, thus directly reducing barriers to PV deployment around the world.

PV deployment is an inherently more local process. Installations must be performed on-site, and the geographical focus of the actors involved typically range from the local to the national scale. Deployment in any given place is typically strongly dependent on formal institutions applying to a limited geographical area (Dewald and Fromhold-Eisebith, 2015; Quitzow, 2015), including subsidies, tax rules, building permits and rules for grid-connection.

The cost and technical performance of PV technology have thus been determined to a great extent by factors beyond the deployment context, operating at other geographical places and scales.

Although PV system installation is in itself a rather straightforward procedure, PV deployment is a complex and systemic procedure involving interaction between various actors, institutions and artefacts (Quitzow, 2015). PV deployment and production could indeed be understood as being different sociotechnical systems with different spatial characteristics, interconnected through certain linkages (cf. Bergek et al., 2015; Markard et al., 2015; Quitzow, 2015; Sandén et al., 2008). For small national deployment markets, the global PV industry could be seen as an 'external force' (cf. Sandén et al., 2008). Deployment could thus be characterised as taking place in sociotechnical 'sub-systems' (national or regional PV markets) to a global sociotechnical system for PV technology. The geographical reach of these sub-systems is presumably defined to a great extent by national borders, as the nation state is a natural upholder and enforcer of formal institutions. Although the aggregate of these sub-systems is what fuels (and is fuelled by) the global production system for PV system components, the individual sub-systems are often too small to substantially influence the global system (a counterexample is the domination of the German PV market on global demand in the early 2000s (Quitzow, 2015)).

Conventional methods for analysing technological transitions have suffered from a lack of attention to geographical aspects of the kinds described above (Coenen et al., 2012; Raven et al., 2012). The most widely used sociotechnical system approaches to understanding sustainability transitions are *technological innovation systems* (TIS) and the *multi-level perspective* (MLP) (Coenen et al., 2012; Coenen and Díaz López, 2010; Markard et al., 2012; Markard and Truffer, 2008; Weber and Rohracher, 2012). These approaches have been developed and conventionally applied to consider processes of technology development and deployment together as belonging to one and the same system. However, neither of them has been very explicit on how to deal with spatial division of labour of the kind occurring in the PV value chain (Coenen et al., 2012), although some development has occurred in this regard in parallel to the work with this thesis (Hansen and Coenen, 2015).

As stated, PV technology is mature regarding technical performance, and is reaching cost competitiveness in an increasing number of regions. Meanwhile, there are numerous potential national and regional markets around the world where PV penetration is (still) very low. These markets can be seen as potential catching-up markets, into which PV technology could be imported and deployed relatively swiftly if their internal barriers to deployment are not too severe. The potential global aggregate for PV uptake in such markets is huge, and it is thus important to understand barriers and drivers to deployment in these markets. Research on barriers and drivers to PV deployment in catching-up markets has, however, been scarce.

Various factors of a more local nature have been found to influence PV adoption rates, such as local variations in solar insolation, electricity prices (Kwan, 2012) and rules and procedures for permits, grants and grid-connection (Brudermann et al., 2013; Dong and Wiser, 2013). There is also some evidence that local organisations can overcome barriers to deployment by promoting PV through campaigns, information provision, lobbying or demonstration projects (Brudermann et al., 2013; Dewald and Truffer, 2012; Noll et al., 2014; Owen et al., 2014). As argued by Noll et al. (2014), such local initiatives are likely to have the largest impact on PV adoption rates if residential PV adoption is neither highly profitable nor clearly unprofitable. As financial aspects are neither the dominant driver nor a major barrier in such situations, the argument goes, there is more opportunity for information campaigns or seminars to make a relative difference in driving adoption rates. However, the understanding of what factors can explain local variation in PV adoption rates has been limited.

A driver with an often inherently large local component is social influence between peers, also referred to as *peer effects*. Positive word of mouth often plays an important role in overcoming barriers to the diffusion of innovations (Rogers, 1983). This is particularly true in situations where the support of a strong brand or strong marketing resources are lacking, which is often the case for small companies marketing radical innovations (Mazzarol, 2011). A number of recent studies have attempted to quantify local peer effects in terms of increased probability of additional nearby PV adoptions following previous adoptions (Bollinger and Gillingham, 2012; Graziano and Atkinson, 2014; Graziano and Gillingham, 2014; Müller and Rode, 2013; Rai and Robinson, 2013; L.-L. Richter, 2013; Rode and Weber, 2013). The results indicate that peer effects are stronger down to the zip code or street level (e.g. Bollinger and Gillingham, 2012). Some early attempts have also been made to separate *active* (through direct interpersonal contact) and *passive* (through passively observing PV systems) peer effects, although the results have remained rather inconclusive (e.g. Rai and Robinson, 2013). Pre-existing research on peer effects in PV adoption has focused on estimating the sheer magnitude of the effects, and the qualitative perspective has been lacking. The actual mechanisms underlying the peer effects have thus remained poorly understood.

There is some evidence that local organisations can take advantage of peer effects to reduce barriers to adoption. The findings of Noll et al. (2014) suggest that local non-profit organisations promoting residential PV in the U.S. have managed to leverage the impact of their activities through peer effects by engaging local individuals. A better understanding of how peer effects actually work could potentially inform organisations in how to exploit peer effects to boost PV uptake.

1.2. Objective

The objective of this thesis is to advance the knowledge on *the deployment of residential PV systems*. More specifically, the thesis aims at identifying and assessing *barriers* and *drivers* that obstruct or facilitate PV deployment in different geographical settings, taking the spatial dimension into account. Barriers include any factors in the sociotechnical system surrounding PV deployment that obstruct the deployment process, thus reducing the rate of PV adoptions. Correspondingly, drivers are sociotechnical factors that facilitate PV deployment, thus increasing adoption rates. Such barriers and drivers may relate to for example institutions, firms, economy, human behaviour, infrastructure or technology. Studying different national and local contexts, the thesis aims at building knowledge on barriers and drivers on different spatial scales. The thesis aims at answering four different research questions, one for each paper:

- RQ1 (paper 1): What barriers are present in the Swedish sociotechnical system for residential PV deployment?

- RQ2 (paper 2): How have different kinds of business models been successfully designed by firms to overcome country-specific barriers to residential PV deployment in different national contexts?
- RQ3 (paper 3): What local factors can explain geographically uneven adoption rates (as measured on the municipal level) of residential PV systems within Sweden?
- RQ4 (paper 4): How has social influence between peers (peer effects) reduced barriers to PV adoption among Swedish homeowners?

The thesis is largely based on case study methodology. Important modes of data collection were interviews and surveys, although data were gathered in various other ways as well. Both qualitative and quantitative methods were used.

The target audience includes actors that might have an interest in stimulating PV dissemination. These include policymakers, firms and non-profit organisations.

1.3. Scope

This thesis focuses on a particular part of the PV value chain, namely on *deployment*. Deployment is defined here as the process of putting the technology into use, and involves various activities taking place at and around the very end of the PV value chain, such as PV system marketing, sales, installation and adoption decision making among (potential) users. Deployment is thus the last set of processes in a series of events that lead to a PV system being commissioned. Processes taking place further upstream in the value chain, such as technology production and development, are outside the scope.

Although the terms 'deployment' and 'dissemination' are often used interchangeably, 'deployment' is in this thesis used to signal that it is activities at the end of the value chain that are alluded to. The term 'dissemination' is used here to describe the increased uptake of an innovation (e.g. the number of PV systems per capita) without alluding to any particular part(s) of the value chain. Dissemination is thus regarded here as an outcome of the combination of technology development, production and deployment.

With a focus on deployment, there is little reason to delimit the scope to PV systems based on any particular kind of solar cells. Although crystalline silicon solar cells dominate PV markets worldwide, other kinds of solar cells are in principle not excluded from the analysis. Other cell types can be produced with very different methods using different materials, but once encapsulated into modules they can typically be treated more or less as equivalents for residential applications. The deployment focus thus allows the researcher to regard PV modules as 'black boxes' converting sunlight into electricity regardless of the characteristics of its internal processes.

As regards different applications, the focus is on the *residential* segment, i.e. on systems situated in connection to and providing electricity to a particular household. Thus, larger ground-mounted installations, industrial applications and most applications on multi-family dwellings are not considered. Although people renting their homes are in principle not excluded, the current state of affairs in PV markets around the world (including the studied contexts) implies that the adopter category of interest is that of private homeowners.

Regarding *geography*, most of the research focused on Sweden, either the whole country (paper 1) or more local entities (papers 3 and 4). Only in paper 2 was the focus on markets outside Sweden, namely Germany, Japan and the United States. Paper 2 does, nevertheless, provide important lessons for Swedish actors regarding the future development of the Swedish market as this paper studies more developed markets. Papers 3 and 4 differ from the other papers in that they have a *local* focus. All research was conducted in developed countries only. Practically all households in the studied contexts are connected to the electrical grid, and the thesis thus considers grid-connected PV applications only.

Sweden was chosen as the main setting for three key reasons. First, residential PV as an investment in Sweden has been neither clearly unprofitable nor very profitable in recent years. When PV adoption offers limited (but not too poor) prospects of economic gains, various non-economic factors are presumably more likely to have a relatively high impact on adoption rates (cf. Noll et al., 2014), which makes such factors more easily observable. This makes Sweden a potentially fruitful case for studying non-economic barriers to deployment. Second, there has been a lack of research on barriers to PV deployment in catching-up markets. The aggregate of (potential) catching-up PV markets around the world offers a huge potential for PV uptake, and understanding barriers in such contexts is thus of utmost importance. Third, data for Sweden were relatively accessible as the researcher was based there and is a native speaker of the language. Paper 2 went outside the Swedish context because there was not enough empirical data to be found on the topic of interest (business models for PV deployment) within Sweden. A better understanding of business models can nevertheless be useful to support PV deployment in Sweden and other catching-up markets.

Regarding *time*, the research focuses mainly on phenomena that occurred between 2009 (when a subsidy for residential PV was launched in Sweden) and 2014. During that period and up until the time of writing this chapeau (late 2016), the studied PV markets, as well as other PV markets around the world and the global PV industry, have developed substantially. There is, nevertheless, little reason to believe that the findings of this thesis (with perhaps some minor exceptions) are less relevant at the time of finishing the thesis than a few years earlier. First, as observed by the researcher, most of the barriers to deployment in Sweden identified throughout the research remain at the time of finishing the thesis and are thus still relevant targets for policy. Second, even if the studied contexts have changed, there are numerous markets around the world that will likely face challenges similar to those encountered in the studied cases, and that can learn important lessons from them.

All papers except paper 4 adopt a systemic perspective in their respective context, considering a variety of interacting factors in PV deployment. Paper 4, being narrower in scope, focuses exclusively on social influence between peers in PV adoption.

1.4. Limitations

Some limitations of this thesis need to be recognised. First, the generalisability (external validity) of the findings is limited by the fact that the bulk of the research was focused on the Swedish context. Generalisability might be largest to similar cases, e.g. to developed countries with PV markets that are in an early stage of development and where the economic profitability of adopting a PV system is limited.

Second, the perspectives of all relevant actors are not always present. Due to restrictions in time available to the researcher, primary data could not be collected through interviews or surveys for all actors but were collected only from actors that were deemed the most relevant. In paper 1, the actors interviewed were general experts, installers and electricity companies, while primary data were not gathered for adopters and policymakers. In paper 2, primary data were obtained from companies using the business models of interest and from industry experts, but not from the companies' customers or from companies using other business models. Also in paper 3, a deeper understanding could possibly have been obtained through interviews with adopters that responded to the survey.

Third, the number of cases in the comparative case studies (papers 2 and 3) was constrained by limitations in the amount of time available to the researcher rather than by theoretical saturation (cf. Glaser and Strauss, 1967). With more cases added, the internal and external validity could have been increased, and additional insights could potentially have been reached.

Fourth, data could have been gathered to support more elaborate statistical analyses. For paper 3, data could have been collected to perform statistical analyses comparing a larger number of municipalities with regard to how various aspects correlate with PV adoption rates. For paper 4, a larger sample with secured representativeness would have made more elaborate statistical analyses possible.

2. Methodology

This section starts with a description of three theoretical frameworks that were used to guide the research. Then, the overall research design, which is based on case studies and various methods for data collection and analysis, is presented. Lastly, the interdisciplinary nature of the research is discussed briefly.

2.1. Theoretical frameworks

The research conducted for this thesis was guided by a variety of theoretical frameworks and concepts. However, three theoretical frameworks were particularly important. The rationale for choosing these frameworks is described below, after which the frameworks are outlined one by one.

As the thesis aims at identifying barriers and drivers throughout sociotechnical systems for PV deployment, the theoretical framework, or set of frameworks, used must reflect the 'whole' system. There are existing frameworks that fit this purpose quite well. In particular, the *technological innovation systems* (TIS) framework (e.g. Bergek et al., 2008a; Hekkert et al., 2007) and the *multi-level perspective* (MLP) (e.g. Geels, 2002) have been developed to analyse the development and deployment of new technologies from a sociotechnical systems perspective. These two frameworks have become dominant as analytical tools to understand (various barriers and drivers to) sustainability transitions, and, even though they have been developed rather independently of each other, they are largely focused on the same real-world phenomena and share several key concepts (Coenen et al., 2012; Markard and Truffer, 2008). Although these frameworks were not developed for any particular technology or sector, they have very often been applied to renewable technologies in the energy sector (Markard et al., 2012; Markard and Truffer, 2008).

Yet, there are differences between these two frameworks. The TIS framework is apt for studying barriers and drivers at different stages of a technology's development (Bergek et al., 2015, 2008a; Markard et al., 2012), while the MLP framework is relatively more focused on niche applications *or* regimes and less so on intermediate stages of development (Markard and Truffer, 2008). The MLP framework is more apt to explain broader transformative changes than the TIS framework, which is more focused on technology-specific matters (Markard et al., 2015; Weber and Rohracher, 2012). These differences hint that the TIS framework might be a more appropriate choice for the purpose of studying the deployment of a mature technology (PV) in an application that is not to be considered a niche (the residential application) but that has become mainstream in other geographical contexts and is expected to become mainstream also in the country or region of interest. Thus, the thesis uses the TIS framework as a starting point to analyse barriers to PV deployment (paper 1).

The wide scope of the TIS framework implies that it is not as detailed in all parts of the studied sociotechnical system. To further understand barriers and drivers to PV deployment, papers 2-4 analyse specific parts of the deployment systems. The research designs of papers 2-4 thus required the identification of the most relevant parts of these systems, as well as the identification or construction of theoretical frameworks that zoomed in on these parts.

Ideally, the TIS framework would provide adequate guidance to other frameworks that could be applied when studying certain phenomena in greater depth. This is the case for some phenomena that are within the scope of the TIS framework; for example, the TIS framework assigns significant importance to institutions, and accordingly the TIS literature refers to central literature on institutional theory, particularly to literature that deals with relationships between institutions and technological change. However, when it comes to other phenomena that occur in the TIS framework, such as the different actors involved in technology deployment and some of the 'functions' (key processes), the TIS literature does not connect as well to other literature streams. Neither does it provide guidance to any subsystems that might be analysed.

A useful analysis has, nevertheless, been performed by Foxon (2011), who identified a set of key coevolving systems relevant when analysing sustainability transitions, namely *ecosystems*, *technologies*, *institutions*, *business strategies* and *user practices*. Of these systems, *ecosystems* are regarded as external in this thesis. Also *technologies* are largely regarded as an external force, as the focus is on the deployment of artefacts that are in themselves technically mature and imported from another system. *Institutions* are crucial to a systemic analysis of barriers to deployment but are, as stated, quite well covered by the TIS framework, and paper 1 accordingly provides a thorough institutional analysis. Thus, potential areas for further studies remaining after the completion of paper 1 are *business strategies* and *user practices*. Business strategies have also been identified as crucial in bringing sustainable products to the market within the *business models* literature (Bocken et al., 2014; Boons and Lüdeke-Freund, 2013; Mont et al., 2006; Reim et al., 2015; Tukker, 2004). Furthermore, Schot et al. (2016) have made a strong case for dealing in greater depth with the role of users in the technological transitions literature.

Suitable frameworks for studying business strategies and user practices are the *business models framework* (Amit and Zott, 2001; Shafer et al., 2005) and Rogers' (1983) *diffusion of innovations* framework, respectively. Thus, these frameworks were used for papers 2-4. These frameworks fit within the scope of the TIS framework as they zoom in on real-world phenomena covered by the TIS literature. Both frameworks could be positioned relatively easily within the TIS literature as they clearly relate to core TIS concepts. What the TIS framework intends to capture by stressing the importance of firms and the function 'entrepreneurial experimentation' has a large overlap with what is described in the business models literature. The business models literature, being solely devoted to this topic, is nevertheless much more detailed on the phenomena of interest. In a similar manner, the role of users and the functions 'legitimation', 'knowledge development and diffusion' and 'market formation' of the TIS framework have a large overlap with what is dealt with in Rogers' diffusion of innovations framework.

2.1.1. Framework 1: Technological innovation systems (TIS)

The technological innovation systems (TIS) framework was developed to analyse the development, production and deployment of new technologies from a sociotechnical systems perspective (Bergek et al., 2008a; Hekkert et al., 2007). Its most common application has been to identify and assess barriers and drivers to technology dissemination in order to derive policy recommendations, often with the purpose of understanding how increased uptake of renewable energy technologies could be supported (e.g. Dewald and Truffer, 2011; Dewald and Fromhold-Eisebith, 2015; Jacobsson and Bergek, 2011; Quitzow, 2015; Sandén et al., 2008; Suurs, 2009; Suurs and Hekkert, 2009).

The TIS literature is a branch of a wider innovation systems literature, including other innovation systems approaches such as *national*, *regional* and *sectoral* innovation systems. An innovation system belonging to any of these categories can be understood as a complex system of actors and institutions involved in the development, production and deployment of new technology. Originally, the innovation systems literature focused on *national* innovation systems, which are not restricted to one particular technology but deal with the general innovative capability of a country (Lundvall, 2010). Subsequently, literature emerged on sector-specific innovation systems (Malerba, 2009) and, narrowing down, on innovation systems for specific technologies – that is, on TISs. The innovation systems literature emerged largely as a result of a frustration among certain scholars regarding how (mainstream) economics dealt with economic development; the argument was that it neglected processes of learning, institutions and technological change, and wrongfully assumed a static equilibrium (Sharif, 2006).

The rate and direction of technological change can be understood as being determined more by competition between innovation systems than between technologies (Hekkert et al., 2007). A major external force of a TIS for PV deployment is the incumbent system for electricity production, which could be understood as a sectoral innovation system, or as a sociotechnical *regime* (Geels, 2002). As stated, such incumbent systems/regimes could be expected to be locked in through various technological and institutional mechanisms, making it difficult for new and competing technologies to gain ground (Unruh, 2000).

In this thesis (paper 1), the TIS approach was used somewhat differently than in most previous TIS studies as it was applied to the *deployment* phase exclusively. Earlier TIS studies (as most other innovation system studies) have been predominantly used to study processes of development, production and deployment together as occurring in one and the same system, or they have paid less attention to deployment than to development and production (Dewald and Truffer, 2011). However, due to spatially different characteristics between different parts of the PV value chain (see section 1.1.2), a pure deployment focus was deemed the most appropriate for the present research (see also section 2.1.1.3).

In recent (post-2007/2008) TIS literature (Bergek et al., 2008a; Hekkert et al., 2007), a TIS is normally divided into one 'structural' and one 'functional' (more dynamic) part. These are outlined below, and it is briefly explained how they may relate to technology deployment. A brief account of how to think about geographical system boundaries in relation to the value chain follows, as this was an important issue in paper 1.

2.1.1.1. The structure of a TIS

The 'structure' of a TIS is normally thought of in terms of the following three categories of elements:

- *Actors*: Any organisations or individuals relevant for the development or deployment of the technology. With a deployment focus, core actors include, for example, installers and suppliers of turnkey systems and components, policymakers and (potential) adopters.
- *Networks*: Linkages between actors through which information is exchanged. In deployment, associations for installers and suppliers are frequently of high importance, as well as informal networks between adopters. Advocacy coalitions may attempt to influence policy though political networks (Bergek et al., 2008b).
- *Institutions:* Any humanly devised rules (formal or informal) affecting the development or deployment of the technology, such as laws, standards, practices or collective mind frames. For deployment, technology standards

(Ma, 2010) and popular perceptions (legitimacy) (Jacobsson and Bergek, 2004) are examples of institutions that are often important. Although institutions often facilitate deployment, pre-existing institutions may also prohibit or complicate the deployment of a new technology, often unintentionally.

While a TIS is in its early stages, the institutional set-up is usually badly aligned to the emerging technology as institutions are either not in place or are maladapted to the technology. The alignment of institutions to new technology is, however, notoriously an arduous process (Unruh, 2000), further complicated by the fact that firms "compete not only in the market but also over the nature of the institutional set-up" (Bergek et al., 2008a), a competition in which incumbent firms are often in a stronger position than the small newcomers that might represent the new technology. Furthermore, key actors might be missing or might not have gained the relevant knowledge, and networks are often lacking.

With a focus on deployment, these three categories of structural components are all likely to be as important as when the TIS framework is used to study development and deployment together. However, the deployment focus allows the researcher to focus his or her resources on those actors, networks and institutions that are the most relevant for deployment, thus creating room for a more in-depth analysis of those elements.

2.1.1.2. Functions of a TIS

Functions represent key processes that should occur in a TIS in order for the system to perform well. Functions have been described as constituting "an intermediate level between the components of a [TIS] and the performance of the system" (Jacobsson and Bergek, 2004) and as "emergent properties of the interplay between actors and institutions" (Markard and Truffer, 2008). The exact number of functions that should occur is somewhat arbitrary, and various sets of functions have been presented. The following set has (with some variation) gained recognition in the recent TIS literature (Bergek et al., 2008a; Hekkert et al., 2007):

- *Knowledge development and diffusion*, encompassing different processes of learning among key actors. As regards deployment, firms, policy makers and (potential) adopters need to gain an understanding of how to install, market, regulate, support and use the technology.
- *Guidance of the search*, capturing incentives for firms and other organisations to enter and participate in the TIS. The strength of this function is to a great extent determined by present and future *market formation* (see below) as perceived by relevant actors, not least when it comes to the deployment phase.

- *Entrepreneurial experimentation*, including various creative activities of firms. As regards deployment, innovation and variation regarding what applications and business models are employed can be important indicators of the strength of this function.
- *Market formation*, referring to activities that contribute to the creation of demand for the technology. Market formation is a crucial part of the deployment process and a prerequisite for dissemination. Barriers to market formation are often found in the institutional set-up (for example as a lack of standards or misaligned legislation) or in a poor price/performance.
- *Legitimation*, referring to changes in the social acceptance of a technology, or how good or desirable the technology is perceived to be. Legitimation through lobbying performed by activists and interest organisations was decisive for the implementation of deployment supporting schemes for PV in Germany (Bergek et al., 2008a; Jacobsson and Lauber, 2006).
- *Resource mobilisation*, reflecting the availability of human and financial capital necessary for the TIS to perform well. As regards the deployment of renewable energy technologies, the mobilisation of capital for subsidy schemes has often been crucial.

By identifying and strengthening poorly performing functions, policy interventions can facilitate the dissemination of a desirable technology (e.g. a renewable energy technology). This can be achieved by strengthening or adding drivers, or by weakening or removing barriers (Bergek et al., 2008a).

The functions have often been used to study feedback loops between production and deployment. When the TIS framework is applied to the deployment phase exclusively, such feedback loops will not be made visible. With a deployment focus, there is also a possibility that the relative importance between functions might differ from when the TIS framework is applied to a larger part of the value chain, as some functions might be more directly related to earlier stages of the value chain and others to deployment processes (e.g. 'market formation').

2.1.1.3. The spatial dimension and the case for deployment-focused TIS studies

Setting spatial system boundaries in TIS studies can be more or less complicated depending on the case at hand. While some technologies have their value chain assembled more or less entirely within one single country, others have their value chain distributed over different geographical places and scales. As stated by Hekkert et al. (2007), a technology is "hardly ever embedded in just the institutional infrastructure of a single nation or region, since – especially in modern society – the relevant knowledge base for most technologies originates from various geographical areas all over the world". The question of what part(s) of the value chain that are in focus thus has implications for the choice of spatial scope of the study.

A need for more elaborate approaches to geographical system boundary setting and spatial differentiation in TIS studies has been identified in recent publications (Binz et al., 2014; Coenen et al., 2012). The general trend towards increased global division of labour and specialisation in value chains (Antràs et al., 2012; Baldwin and Robert-Nicoud, 2014; Hummels et al., 2001; Los et al., 2015; Timmer et al., 2013) suggests that this need, if anything, will increase as technologies increasingly have their value chains distributed over different geographical places and scales. In parallel to the work with this thesis, empirical and conceptual work has been carried out by other scholars to make the TIS framework more elaborate regarding spatial differentiation (Bergek et al., 2015; Binz et al., 2014; Dewald and Fromhold-Eisebith, 2015; Gosens et al., 2015; Huang et al., 2016; Quitzow, 2015; Wieczorek et al., 2015). Empirical studies using geographically differentiated TIS approaches have been performed for PV (Dewald and Fromhold-Eisebith, 2015; Quitzow, 2015), membrane bioreactors (Binz et al., 2014) and wind power (Wieczorek et al., 2015). A spatially differentiated TIS analysis, in which deployment and production are treated as (partly) different sociotechnical systems between which linkages exist, has been proposed in recent publications (Bergek et al., 2015; Dewald and Fromhold-Eisebith, 2015; Quitzow, 2015). Such analyses could often be useful, but they are resource-intensive as the researcher has to gather and analyse data from different contexts. It is thus important that the researcher knows what to focus his or her resources on and what can be left out of the analysis. Thus, there is a case for elaborating upon whether and under what circumstances the TIS framework can be applied to deployment exclusively, treating technology development and production as a 'black box'.

PV is an example of a technology whose whole value chain does not naturally fit into one and the same geographically defined TIS. As described in section 1.1.2, the development and production of PV system components take place in a global arena, and this part of the value chain is thus better understood as pertaining to a global TIS (although it might, for pragmatic reasons, make sense to define a national TIS for these processes if the purpose is to derive policy recommendations for a particular government), while the deployment of PV is an inherently much more local activity. This can make it somewhat problematic to attempt to squeeze development, production and deployment of PV into one and the same TIS, although the TIS framework is originally intended to study all these processes together. In paper 1, this dilemma was elaborated upon, and it was demonstrated that the TIS framework is useful to study deployment separately in cases where it does not make sense to include more upstream parts of the value chain in the same TIS as deployment.

Two macro trends hint that TIS analyses focused on deployment will be increasingly needed. First, an increasing global division of labour and specialisation suggests that the production and trade of artefacts will increasingly take place in a global arena, while processes of deployment may remain more localised (which has been the case for PV, see section 1.1.2). In those cases, individual end user markets will often be small in relation to the global production system, and a pure deployment focus in TIS studies may be feasible. Second, there is an increasing availability of mature renewable energy technologies that can be deployed in new regions. This availability creates a case for more deployment-focused TIS analyses to study barriers and drivers in these catching-up markets, thus informing actors in how to facilitate a sustainability transition. Furthermore, as technologies mature, their global production systems are likely to increase in size in both absolute terms and in relation to more localised deployment systems, in which case it can be feasible to treat technology development and production as a 'black box' in relation to deployment.

2.1.2. Framework 2: Business models

In order for a technological transition to take place, not only technical but also organisational innovation is required. Not least *firms*, who are usually key actors in technology deployment, might need new strategies to overcome barriers to the deployment of radical innovations. In order to profit from a new technology, firms will often need new strategies for how to provide value for their customers and capture value for themselves – that is, new *business models* are needed. In paper 2, an analysis was made of why different kinds of business models for PV deployment have reached success in different national contexts.

A business model is, simply put, a representation of how firms create value for themselves and their customers. Customers may be private individuals, other firms or other organisations, and value may be provided in the form of services, products or a combination of both. In two widely cited papers, business models have been described as "the design of transaction content, structure, and governance so as to create value through the exploitation of business opportunities" (Amit and Zott, 2001), and the "firm's underlying core logic and strategic choices for creating and capturing value within a value network" (Shafer et al., 2005). The business models concept became prevalent around the mid-1990s in connection with the rise of the Internet (Shafer et al., 2005; Zott et al., 2011). A deployment focus is common in business model analyses, although focus can equally well be on products that are to be further processed before a finished product can be deployed.

Although there is no precise, agreed definition of a business model, the following elements are central to most definitions (M. Richter, 2013):

- *Value proposition:* the products or services offered to customers.
- *Customer interface:* the overall interaction with customers, including customer relations, customer segmentation and distribution channels.
- *Infrastructure:* the company's inner structure for value creation, including assets, know-how and partnerships.
- *Revenue model:* the relationship between the costs and revenues of the value proposition.

It is recognised in the literature that business model innovation (the development of new business models or the adaptation of existing ones) can facilitate the deployment of new technologies (Boons and Lüdeke-Freund, 2013). A new technology might not only come with some inherent attributes that call for a new or changed business model, but also the newness in itself might entail barriers that could be addressed through business model innovation. Uncertainties and incompatibilities with existing institutions could potentially be addressed through business models designed to transfer risks and transaction costs from the customer to the company, or to neutralise particular institutional barriers.

In the present thesis (paper 2), the analysis went beyond the conventional business models framework to also consider various contextual country-specific factors. This allowed the research to identify how various barriers have influenced the viability of different business models for PV deployment in different geographical contexts.

2.1.3. Framework 3: Diffusion of innovations

In the *diffusion of innovations* literature, the (potential) adopters are in focus, as well as those influencing or trying to influence their decision to adopt or reject an innovation. Thus, this framework is deployment-focused by nature, although it does not capture the full set of actors (or other factors) relevant for deployment. This section outlines the diffusion of innovations framework as presented by Rogers (1983). Rogers' framework gathers insights from a broad set of literature and has gained wide recognition. His main contribution was to put existing research together into a comprehensible yet robust package. The framework is by no means restricted to sustainability innovations or innovations in the energy sector, but is general to innovations that are or can be adopted by individuals. Elements of the diffusion of innovations framework were used throughout this thesis, particularly in papers 3 and 4.

Rogers (1983, p. 5) defined diffusion as *"the process by which an innovation is communicated through certain channels over time among the members of a social system"*. The framework focuses on processes of decision making, how different personality types relate to the inclination to adopt an innovation, and how different attributes of innovations might influence their adoption rates. Rogers used the terms ‘diffusion’ and ‘dissemination’ interchangeably. In this thesis, ‘dissemination’ is used as a general term for the uptake of an innovation (e.g. in terms of adoption rates), while ‘diffusion’ is used for processes more specifically related to communication or exchange of ideas, or to signal adherence to the work of Rogers. In this thesis, ‘diffusion’ differs from ‘deployment’ in that ‘deployment’ involves more aspects than just interpersonal communication (the difference between ‘dissemination’ and ‘deployment’ has been accounted for in section 1.3).

A key feature of the framework is the categorisation of potential adopters by some key characteristics and their role in diffusion processes. Rogers promotes a categorisation of potential adopters into five ideal types (although he concedes that in reality there are no sharp boundaries between these groups):

- *Innovators* are the first to adopt innovations. The innovator is venturesome and eager to try new ideas, leading him or her to seek social relationships with other like-minded outside their local peer group. Innovators are often seen upon with some suspicion by their peers, being perceived as ‘too’ innovative, but they can still facilitate the diffusion process by bringing new ideas into their social system.
- *Early adopters* are somewhat less innovative than innovators. They are more integrated into their local social system than innovators, and are more influential on the attitudes of their local peers. Being both relatively respected and innovative (but not *too* innovative), they are effective role models and have the highest level of *opinion leadership* (see below) among the categories.
- The *early majority* adopts innovations just slightly earlier than the average individual. This group is an important link between early and late adopters, providing interconnectedness supporting the diffusion process. Once a person belonging to this category has started contemplating adoption, his or her decision period is longer than that of earlier adopters.
- The *late majority* adopts innovations slightly later than the average individual. Adoption often comes as the result of economic necessity or social pressure. Persons in this category tend to maintain a sceptical attitude towards new ideas in general, and practically all uncertainty about the innovation must have disappeared before they choose to adopt.
- *Laggards* are the last to adopt an innovation. They are suspicious of new ideas, and their attitudes are often aligned with the practices of previous generations. Often, however, a precarious economic situation is a partial reason for the late adoption.

The decision to adopt (and keep using) an innovation is described by Rogers as an *innovation-decision process* consisting of the following five stages:

- *Knowledge,* in which awareness of the existence of the innovation and understanding of how it works are gained.
- *Persuasion*, in which a favourable or unfavourable attitude towards the innovation is formed.
- *Decision*, involving activities leading to a choice regarding whether to adopt or reject the innovation.
- *Implementation*, in which the innovation is put into use.
- *Confirmation*, in which reinforcement of an earlier adoption decision is sought, sometimes leading to a reversal of the adoption.

Innovations have different *attributes*, which are highly influential on the rate at which they diffuse in a social system. Attributes can be generalised into the following five categories, which, according to Rogers, taken together normally explain most of the variance in the rate of adoption between innovations:

- *Relative advantage* as compared to existing alternatives. In the case of residential PV, the existing alternative would for most prospective adopters be electricity from another source or another financial investment.
- *Compatibility* with for example norms, beliefs and infrastructure. As an example, residential PV benefits from a widespread belief in the perils of climate change, but may be in conflict with permitting or tax rules.
- *Complexity* as perceived by potential adopters. Although residential PV systems are typically relatively easy to acquire and use (at least from a technical point of view), potential adopters might perceive adoption and use as potentially complicated.
- *Trialability*, reflecting the possibility of testing the technology before adopting it. Residential PV suffers from low trialability, as a PV system cannot easily be installed and uninstalled for testing on a rooftop.
- *Observability*, being the extent to which members of a social system can observe the results of an adoption. While residential PV has a high observability in terms of *awareness* (neighbours will normally notice when someone has installed a rooftop PV system), lower observability of the actual results of PV adoption (production, economy, reliability) might be a disadvantage.

A key concept in papers 3 and 4 is that of 'peer effects', which captures social influence between peers (e.g. neighbours, co-workers or friends) in the adoption decision process. Although Rogers did not use this particular term, much of his framework is, as should be evident from the above account, dedicated to this topic. Peer effects can be *active* (occurring through direct communication between peers) or *passive* (occurring without direct communication, for example when someone observes a new PV installation in their neighbourhood) (e.g. Rai and Robinson, 2013). Peer effects have been observed in the adoption of a variety of technologies, such as menstrual cups among Nepalese adolescents (Oster and Thornton, 2009), electric vehicles (Axsen et al., 2009), information and communication technologies (e.g. Stewart, 2007), housing renovation (Helms, 2012) and various kinds of farming equipment (Rogers, 1983). Peer effects are often highly localised (Rode and Weber, 2013), and local peer effects for residential PV systems have been quantified in a number of recent studies (Bollinger and Gillingham, 2012; Graziano and Atkinson, 2014; Graziano and Gillingham, 2014; Müller and Rode, 2013; Rai and Robinson, 2013; L.-L. Richter, 2013; Rode and Weber, 2013). There has, nevertheless, been a lack of qualitative research on peer effects in PV adoption, and consequently the understanding of the underlying mechanisms of peer effects in PV adoption has remained poor. This gap was addressed in paper 4.

2.2. Research design

The research was mainly based on case studies carried out using qualitative methods. Data were collected through a variety of methods, including interviews (all papers), surveys (papers 3 and 4) and comprehensive internet searches (all papers). Both primary and secondary data (academic and non-academic) were used (secondary data were relatively more important for papers 1 and 2). In this section, the case study approach(es) adopted and the methods for data collection and analysis are outlined. (For a more detailed account of the research designs of each paper, see section 3 or the appended papers.)

2.2.1. Case studies

The thesis is largely based on *case studies*, i.e. empirical in-depth inquiries in single settings (Eisenhardt, 1989; Yin, 2009). Case studies are suitable to shed light on 'how'- or 'why'-questions regarding contemporary phenomena over which the researcher has little or no control (Yin, 2009). Case studies can be based on qualitative or quantitative methods, or a combination of both, and they normally make use of a variety of evidence, including documents, artefacts, interviews, and observations (Eisenhardt, 1989; Yin, 2009). Case studies are generalisable to theoretical propositions rather than to populations, and one of their important strengths is to explain causal links in complex situations (Yin, 2009).

Case studies can be based on one or more cases, which should be selected on the basis of their expected ability to provide useful information rather than to provide a representative sample of a larger universe (Eisenhardt, 1989; Yin, 2009). If the number of candidates for cases to study exceeds about a dozen, quantitative data should be collected about the cases and pre-defined criteria should be specified to select a smaller number (Yin, 2009). This strategy was adopted for paper 3.

For papers 1-3, a clear-cut case study approach was adopted, while paper 4 employed elements of case study methodology. Paper 1 was carried out as a single-case study to identify and assess barriers and drivers within one particular setting (Sweden as a whole). Papers 2 and 3, on the other hand, used multiple-case approaches to support generalisations by means of comparison between different settings.

2.2.2. Data collection and analysis

In line with the interdisciplinary nature of the research and with case study methodology, data were collected and analysed using a variety of sources and methods (Table 1). This allowed for knowledge to be added regarding various aspects of the posed research questions. The variety also allowed for triangulation, i.e. for increasing the internal validity of the findings using evidence derived from different datasets and methods (Richards, 2007). While papers 1 and 2 were exclusively qualitative, papers 3 and 4 used a mix of qualitative and quantitative methods. Paper 4 used a narrower set of data sources than the other papers. Both primary and secondary data were used. Primary data were collected mainly from interviews and surveys. See Table 1, section 3 or the appended papers for more detailed information on the data used for each paper.

Participants (interviewees and survey respondents) were selected through *purposeful sampling,* i.e. they were selected based on their expected ability to provide useful information rather than to achieve a representative sample of a larger population. Purposeful sampling is generally adequate in qualitative research (Maxwell, 2008).

Interviews were carried out in a semi-structured manner, meaning that a set of questions (an interview guide) was prepared in advance but was not necessarily followed strictly. Thus, any unforeseen and interesting matters surging during the interview could be addressed. In total, 59 interviews were performed. In addition, numerous shorter or less structured communications were performed with various actors, mainly through telephone or email. The main function of these shorter contacts was to guide the research towards relevant data sources or topics.

The interviews were analysed differently between the papers, mostly depending on their relative importance for the respective paper. For papers 1-3, interviews were not recorded but notes were taken during the interviews. For paper 4, in which interviews were relatively more important, not only notes were taken but the interviews were also recorded and (whenever the notes were not considered detailed enough) revisited and partly transcribed. Simple coding techniques were used to analyse the interviews, through which themes were identified and put into categories. This allowed the researcher to keep track of how many interviewees had made certain statements or expressed certain considerations. Some degree of interview coding was performed for all papers, although it was done most systematically for paper 4.

Two surveys were performed to collect data for papers 3 and 4, respectively. Questionnaires (see appendices A and B) were sent by postal mail to Swedish PV adopters. The response rates were 74-80% (which is to be regarded as high) and in total 130 valid responses were obtained. The data obtained through the surveys were used mainly for descriptive statistics and to guide the further research, although some inferential statistics were also performed.

Table 1. Data systematically collected for the four papers, by type and quantity. In addition to what is shown in this table, systematic Internet searches were important for papers 1-3, leading to the use of various secondary data.

<table>
<tr><th rowspan="2">Paper</th><th colspan="3">Data</th></tr>
<tr><th>Type</th><th>Actor/source</th><th>Quantity</th></tr>
<tr><td rowspan="3">1</td><td rowspan="3">Interviews (duration 0.5-1 h)</td><td>PV installers</td><td>9</td></tr>
<tr><td>Electricity companies</td><td>9</td></tr>
<tr><td>Experts</td><td>4</td></tr>
<tr><td rowspan="2">2</td><td>Interviews, marketing material</td><td>Companies (Japan)</td><td>5</td></tr>
<tr><td>Websites</td><td>Companies (U.S, Germany)</td><td>70</td></tr>
<tr><td rowspan="2">3</td><td>Survey questionnaire (appendix A)</td><td>Adopters</td><td>65 valid responses (80% response rate)</td></tr>
<tr><td>Interviews (duration 0.25-0.5 h)</td><td>Local actors (e.g. PV installers, electric utilities, municipal energy advisers)</td><td>16</td></tr>
<tr><td rowspan="2">4</td><td>Survey questionnaire (appendix B)</td><td>PV adopters</td><td>65 valid responses (74% response rate)</td></tr>
<tr><td>Interviews (appendix C) (duration 0.25-0.75 h)</td><td>PV adopters</td><td>16</td></tr>
</table>

Secondary data were collected from various sources. Documents such as industry reports, academic publications, newspaper articles and the websites of firms and other organisations were used. For papers 1-3, comprehensive Internet searches were an important tool to identify and gather data. An important data source and tool was the Swedish Energy Agency's register of applications and approvals for an investment subsidy scheme that has been available to PV adopters since 2009. The names and addresses of PV adopters obtained from this register allowed for analysis of geographical differences in PV adoption rates within Sweden, and made it possible for the researcher to contact adopters for the surveys and interviews. This register was used for papers 3 and 4.

When feasible, data were collected until theoretical saturation (Glaser and Strauss, 1967) was approached, i.e. until the marginal gain in insights obtained through additional data collection was not large enough to motivate the effort of collecting more data. There were, nevertheless, restrictions regarding the extent to which theoretical saturation could be applied (see section 1.4).

2.3. Interdisciplinarity

The research behind this thesis is *interdisciplinary* by nature. Interdisciplinarity is the combination and (partial) integration of elements from two or more academic disciplines (Boden, 1999; Klein, 2010, 1990). A broad scope alone does not necessarily imply interdisciplinarity, and neither does the mere juxtaposition of different disciplines (Klein, 1990). For interdisciplinarity to be meaningful, the strengths of different disciplines should contribute to address one and the same issue and, ideally, the disciplines should enrich each other (Boden, 1999). Although interdisciplinarity is often confused with *multidisciplinarity*, the latter term refers to the juxtaposition of disciplines without any requirements on integration (Klein, 1990). Distinctions between different branches of social science are to a large extent arbitrary and historically forged (Calhoun and Rhoten, 2010), meaning that that interdisciplinary approaches are often no more intrinsically wide-scoped or integrative than research within established disciplines.

Interdisciplinary approaches are often useful to study phenomena that are complex or that do not fit into one particular discipline (Calhoun and Rhoten, 2010; Klein, 1990; Krohn, 2010), including many policy challenges facing humanity, such as climate change and sustainability transitions in the energy sector (Bhaskar et al., 2010; Miller, 2010). The present research made use of two theoretical frameworks (TIS and business models) that are in themselves pronouncedly interdisciplinary (Pateli and Giaglis, 2007; Sharif, 2006). In addition, theories originating in sociology (the diffusion of innovations framework) were used to understand the role of adopters in PV deployment. Although these three frameworks were used largely in parallel rather than integrated with each other in the four papers, this chapeau ties the findings more closely together, thus strengthening the interdisciplinarity of the research.

3. Key findings organised by papers

The four papers studied barriers and drivers to PV deployment in different geographical contexts and using different approaches. In paper 1, a sociotechnical systems approach was used to identify and assess various barriers and drivers to PV deployment in Sweden. In paper 2, business models for PV deployment that have been successful in three important PV markets (the United States, Germany and Japan) were analysed regarding their ability to overcome country-specific barriers. In paper 3, drivers that could explain the relatively high adoption rates observed in certain Swedish municipalities were identified and assessed using a multiple-case study approach. In paper 4, social influence between peers (peer effects) was studied regarding how Swedish PV adopters have increased the willingness of their peers to adopt PV. In the following, the four papers are summarised one by one.

3.1. Paper 1 – Systems perspective on barriers and drivers to PV deployment (Sweden)

3.1.1. Background

The Swedish government has an outspoken ambition to increase the share of solar energy and other renewables in the country's energy system, and subsidies for PV deployment have been available for a number of years. As previously stated, the deployment of radical energy technologies is however a complex process that may encounter several unforeseen barriers. This calls for a systematic review of the overall conditions for PV deployment within the country. Such an analysis has previously been performed by Sandén et al. (2008), who included not only deployment but also development and production in their study. This thesis provides an updated study devoted solely to the deployment phase.

3.1.2. Objective and approach

The objective of this paper was to identify and assess barriers and drivers to the deployment of residential PV systems in Sweden. Such an analysis could result in information useful to policymakers. A technological innovation systems (TIS) approach was adopted, which is a sociotechnical systems perspective developed to analyse the dynamics of technology development, production and deployment, and to identify and assess barriers and drivers throughout a technology's value chain (see section 2.1.1). In the present thesis, however, the TIS framework was applied to the deployment phase exclusively, allowing for a more robust analysis of this phase.

Methods for data collection were comprehensive Internet searches, 22 interviews with experts, installation firms and electricity companies, as well as a number of brief communications with various actors. A large amount of secondary data, mainly identified through the Internet searches, was reviewed, including legislative texts, debate articles, organisations' websites, statistics from governmental organisations, governmental reports, etc.

The Swedish national borders were set as the geographical system boundary because they coincide with the reach of several important institutions and because a purpose of the study was to inform Swedish policymakers. Timewise, the study focused on the early 2010s.

3.1.3. Results

The analysis revealed that the Swedish TIS for PV deployment was small and underdeveloped, although the market was (in relative terms) in a state of rapid growth. Commercial actors involved in PV deployment were largely restricted to small installation companies, although electric utilities[1] and electricity retailers had also shown an increasing interest in PV systems sales and trade in solar electricity. Installation firms were typically small and with a local focus. They were often not exclusively devoted to PV technology, thus lacking the benefit of specialisation. Potentially important actors such as architects or construction companies were not

[1] In this thesis, an *electric utility* is defined as an organisation that operates an electrical distribution grid. Although the legal entity that is most directly responsible for operating the grid is not allowed by Swedish law to trade in electricity or appliances such as PV systems, a grid-operating entity and an electricity-trading entity can be (and are often) gathered within the same group of companies. The group of companies can then sell PV systems though the electricity-trading entity, while it runs the grid through its grid-operating entity. In this thesis, the term *utility* may refer to such groups of entities or to pure grid-operators. For companies engaged in electricity-trading but not in grid-operation, the term *electricity retailer* will be used.

engaged in PV deployment more than marginally. PV systems were almost exclusively purchased by the adopters, meaning that third-party ownership business models that have been common in some more developed markets were practically non-existent in Sweden. This lack of alternative business models could be a barrier to some potential adopters who would prefer to adopt PV without purchasing a system.

Overall, the most important barrier to PV deployment was found to be the poor economic profitability of investing in a PV system. This was not only because of expensive PV systems and relatively low amounts of solar influx, but also because electricity prices in Sweden have generally been relatively low by international standards. Thus, the Swedish PV market had been created and upheld by subsidies. However, the subsidy schemes in place were sub-optimally designed, impaired by uncertainties and complexities.

The most important subsidy for PV deployment has been an investment subsidy scheme available for residential PV since 2009. Through this subsidy, adopters have been reimbursed for a fixed share of their expenses for purchasing a PV system. The scheme has repeatedly reached its budget cap, after which no more applications have been approved until more funding has been added through political decisions. As the PV market was very dependent on this subsidy scheme, the reaching of the cap has led to discontinuations not only in the scheme but in the whole PV market. This has created severe problems for installation firms that have suddenly and repeatedly lost their source of revenue. It has most often been unknown to the actors if and when new funding was to be added to the scheme. The interviews revealed that, as a result of these uncertainties, installation firms have often postponed decisions regarding the recruitment of new employees, purchasing of equipment or acquiring of a more appropriate office.

Furthermore, whenever the cap had been reached, additional applications were placed in a queue to be considered if and when new funding was added through political decisions. This led to waiting times for getting applications approved gradually increasing to more than a year, creating complications not only for adopters but also for firms. The delays have resulted in extra transaction costs for installers who have often had the feeling that they have been forced to ‘sell the PV system twice’, once when the adopter contacts them before filing an application for the subsidy and again after the application has been approved.

In parallel to the investment subsidy scheme, a tradable green certificates (TGC) scheme has been in place since 2003. Through the TGC scheme, owners of PV systems and a number of other renewable electricity technologies have been granted tradable certificates for their electricity production (one certificate per megawatt-hour). Certificates have been sellable on a ‘free’ market, demand being created by legal obligations on other actors to acquire certificates in proportion to their production or use of electricity.

The TGC scheme was launched as the main Swedish policy instrument to support renewable electricity, and an important feature was its alleged ‘technology neutrality’. It has been an important driver of the dissemination of renewable electricity technologies, mainly for wind power (Swedenergy, 2012). The scheme has, however, been poorly adapted for micro-generation of electricity (e.g. in residential PV systems). Trading small quantities of certificates has been complicated, and although PV owners have formally been entitled certificates corresponding to their whole production, hassle and extra costs have made it unattractive to acquire certificates for the self-consumed part of the production. Perhaps most importantly, expensive metering equipment has had to be installed by the PV owner for certificates to be granted for self-consumed electricity. The misalignment of the TGC scheme to micro-generation is illustrated by the fact that only a fraction of the Swedish PV adopters had found it worthwhile to apply for TGCs at the time of the study. For example, by the end of 2012 a mere 10% of all grid-connected PV systems in Sweden were benefiting from the scheme (Stridh et al., 2013).

As regards the institutional set-up beyond subsidies, existing institutions were found to be fairly well-aligned to residential PV deployment in the sense that no particular barriers of prohibitive magnitude could be identified. An important barrier was removed in 2010 when PV adopters were given the legal right to connect their system to the grid at no cost. Building permits for PV systems have usually been granted without prohibitive costs or hassle, and even though there has been some variation between municipalities’ building permit policies, national regulation has kept these costs and restrictions within certain limits.

There have, however, been some barriers related to tax rules. Most of the existing tax rules of relevance were designed decades ago for a regime of centralised large-scale electricity generation, and have not always been straightforwardly applicable to micro-generation. For example, there have been uncertainties regarding whether micro-producers selling their surplus electricity to an electricity retailer are to be regarded as ‘professional’ and thereby subject to extra taxation and paper work. According to the tax agency, tax rules on the EU and Swedish levels have also prohibited net metering (the practice of subtracting any electricity fed into the grid from the consumption before applying taxes), although the tax agency’s interpretation of the rules on this point has been opposed by some actors.

A large problem has been uncertainties regarding the future development of the institutional set-up. Most importantly, future taxes and subsidies have been unpredictable, both regarding their design and at what times they would be in operation. Apart from the aforementioned uncertainties regarding the investment subsidy, there were important uncertainties regarding the planned introduction of a tax reduction scheme for PV owners[2], for example regarding the compatibility of the tax reduction with existing tax rules.

The functional analysis revealed a linear chain reaction driving deployment. 'Legitimation' had been necessary for 'resource mobilisation' of the funding used for the investment subsidy scheme. This caused 'market formation' to take off, which in turn provided 'guidance of the search' for entrepreneurs to get involved in the PV installation business. The functions not mentioned in this chain reaction ('knowledge development and diffusion' and 'entrepreneurial experimentation') were excluded because little evidence was found that these functions operated on more than a basic level. Most installation had taken place in a rather traditional manner both technically and organisationally, and the experimentation of electric utilities and other commercial actors had remained a rather marginal phenomenon. The knowledge employed by actors involved in PV deployment was rather basic (add-on PV installation is in itself not a very complicated process), and the awareness of consumers necessary for their propensity to adopt PV was rather captured by the legitimation function. Because of the deployment focus, functional feedback mechanisms from deployment to production that are often analysed in TIS studies were not made visible in this case. However, the Swedish PV market was too small to significantly affect the global PV production system and such feedback mechanisms could thus be neglected.

3.2. Paper 2 – Business models for PV deployment (Germany, United States, Japan)

3.2.1. Background

In overcoming barriers to PV deployment, firms may play an important role through organisational innovation. The development and adaptation of new and existing business models have historically often been crucial in technological transitions. As PV is a radical technology in the electricity and housing sectors, business model innovation will most likely be key to coping with various barriers. Barriers, not least related to these sectors, can vary substantially between different geographical contexts, and there is thus a need to analyse how different business models can address barriers in different PV markets. Insights into how business models can

[2] After the publication of the paper, the tax reduction has been implemented in parallel to the other schemes, meaning that there are now (December 2016) three overlapping subsidy schemes.

counteract barriers to PV deployment could be useful to support deployment in Sweden and other emerging PV markets around the world. As revealed in paper 1, the TIS function 'entrepreneurial experimentation' was rather weak in Swedish PV deployment as practically all installation companies offered the same basic sales of turnkey PV systems. In other markets around the world, however, a variety of PV business models with rather different characteristics has emerged lately. Thus, paper 2 went beyond the Swedish setting to find empirical evidence on alternative business models.

3.2.2. Objective and approach

This study aimed at analysing how different business models for PV deployment can overcome barriers in different national contexts, and how different barriers and other contextual factors affect which kind of business models that will emerge and succeed in different settings. The study compared three distinctively different business models for PV deployment that have achieved success in three important PV markets, namely in Japan, Germany and the United States. In Germany, PV systems have been purchased and owned by the user as a financial investment. In the United States, third-party ownership (TPO) business models have proliferated. In Japan, the building industry has taken a leading role by integrating PV systems into prefabricated homes. An in-depth analysis was performed regarding the characteristics of each business model and the national contexts in which they thrive. How context has mattered for the success of the different business models, and implications for policymakers and firms, were then elaborated upon.

Based on theoretical sampling (Eisenhardt, 1989), the cases were selected for three key reasons. First, distinctively different business models have succeeded in the three countries, which allows for the identification of contextual factors that might explain why a certain business model thrives in a certain context. Second, the three countries together accounted for about 45% of the cumulative global installed PV capacity at the time of the study being performed (REN 21, 2014), making them important cases to learn from regarding successful PV deployment. Third, the extensive experience of PV deployment in the three countries was instrumental for data access.

Key data sources included firms' own material, such as websites, marketing material and annual reports. Also, legislative texts, standards, research reports, academic literature, trade journals etc. were used. In the case of Japan, the possibilities to use secondary data were more restricted due to the language barrier, and interviews were thus carried out with five companies in the prefabricated housing sector and with a number of experts, using an interpreter.

3.2.3. Results

Below, a case-by-case account of the different business models and their respective contexts is given. The conclusions are then accounted for.

3.2.3.1. United States

In the United States, business models based on third-party ownership (TPO) have been highly successful, accounting for 70-90% of residential installations in important sub-markets such as California, Arizona and Colorado. In these business models, the adopter is not the owner of the PV system. Instead, the system is owned by a firm providing a full-service solution including planning, installation and maintenance. Financing is obtained through an arrangement in which firms package several projects into funds that are sold to investors.

TPO models are commonly based on either a power purchase agreement (PPA) or a lease. In a PPA, adopters purchase the electricity that the PV system generates. Certain criteria are set for the price so that it is highly predictable over a period of 15-20 years. At the end of this term, the adopter can purchase the PV system, have it removed by the PPA provider or renew the agreement. In a lease, the adopter instead pays a time-based fee for using the system, and gets to use the produced electricity without additional payments. PV leasing has been common in states in which PPA has not been allowed.

The TPO models used in the United States have successfully addressed several common barriers to PV adoption. First, they have minimised consumer transaction costs. The adopter's only point of contact has typically been the firm providing the TPO model, rather than numerous actors such as installation and maintenance firms, banks, insurers and government agencies. The TPO firm has also taken care of any administrative tasks related to subsidies, permits and grid-connection. Second, risks related to the ownership have been shifted from the adopter towards the firm. Third, the adopter has not had to raise capital to finance the system.

TPO models have addressed barriers that have been particularly prevalent in the Unites States. Homeowners in the United States have had lower savings rates than homeowners in Japan or Germany, and potential adopters in the United States have thus been less likely to be able to finance a PV system upfront without a mortgage. Furthermore, access to home equity loans has been severely restricted in the wake of the financial crisis of 2008, which has left many homeowners 'underwater' (their home mortgage being larger than the value of their home), further restricting potential adopters' ability to finance a PV system purchase. People in the United States also tend to move relatively frequently, which for many potential adopters has likely increased the relative attractiveness of immediate electricity bill savings compared to a long-term investment in their home. Lastly, transaction costs in PV deployment have been higher in the United States than in Japan or Germany, which has made it more attractive for adopters to impose them on a third party.

3.2.3.2. Germany

In Germany, PV systems have mainly been financed and owned by the adopters themselves. In the business model dominating German PV deployment, the value proposition has been based on PV adoption as a low-risk financial investment fully competitive with other investment alternatives. Adopters have been guaranteed stable revenues for 20-21 years through a feed-in tariff scheme backed up by national legislation. Policymakers have regularly monitored the cost development of PV systems and adapted the feed-in tariffs to keep the IRR of PV adoption at around 7%.

Transaction costs in PV deployment have been relatively low in Germany. Institutional alignment and local learning among practitioners since the early 1990s have led to a relatively smooth deployment process, and legal-administrative processes related to PV deployment have become among the least complicated in Europe. The absence of high transaction costs has made the third-party owner somewhat redundant as a key function of a third-party owner is otherwise to absorb transaction costs. This is likely a partial explanation for German PV adopters' preference for purchasing and owning PV systems without the involvement of a third-party owner.

As German adopters have fully financed the upfront cost, the German business model has benefited from the availability of low-interest loans especially dedicated to PV. These loans have been provided through a government-owned bank since 1999. The loans have often been supplemented by equity from the customers, and the relatively high savings rates of German homeowners have thus facilitated the business model.

Just like firms in the United States, German firms have been offering a variety of services and features to reduce uncertainties and complexity. These include comprehensive insurance packages, long-term warranties for durability and performance, as well as certification of PV system components and installers through reputable organisations.

3.2.3.3. Japan

In Japan, the cross-selling of PV systems together with other products has been widespread, particularly in the construction sector. The *prefabricated homes industry* has been leading in this regard and, as early as 2011, about 60% of all new prefabricated homes came with a PV system. The prefabricated homes sector has held around 20% of the market for new homes and 10-15% of the residential PV market. The prefabrication of homes has been dominated by around ten large companies.

The value proposition has had several advantages compared to value propositions based on add-on PV systems. PV systems sold with new homes have been less expensive for the adopter than add-on systems, and roof integration has allowed for aesthetically appealing solutions. As the adopter has already established a contact with the supplier for the purpose of purchasing a home, transaction costs have been reduced for both parties. In Japan, PV adopters who have purchased their PV system together with a new home have typically been more satisfied with the adoption than have other PV adopters (Mukai et al., 2011).

The expenses for the PV system have generally been integrated into the home mortgage, reducing transaction costs and interest rates. As a mortgage needs to be issued for the home in any case, it has been easy to expand this loan to include the PV system. From the perspective of the financial institution issuing the loan, the income generated through the PV system has enhanced the adopter's creditworthiness. Building-integration has also been a benefit in this regard as a system physically integrated into the roof cannot as easily come adrift.

A key contextual factor explaining the success of this business model is the pre-existence of a highly industrialised prefabrication sector. Built upon large volumes, automation and advanced logistics systems, Japan's prefabrication industry has seemingly been the most industrialised house-building industry in the world. Industrialisation has brought about a high degree of standardisation, benefitting PV integration. The high level of industrialisation has, in turn, sprung out of a 'scrap and rebuild' culture in which almost 90% of all homes sold have been newly produced. Homes in Japan have typically depreciated very rapidly as they have increased in age.

Unlike in Western countries, prefabricated homes in Japan have been considered to be of higher quality than site-built homes, and they have typically been more expensive and equipped with more features. The cost savings achieved through industrialisation and mass-production have generally been used to add more features to the homes rather than to reduce consumer prices. Through this so called *mass customisation*, consumers have been offered a wide variety of choices between mass-produced components, including energy devices such as batteries, fuel cells, heat pumps and home energy management systems. PV systems have neatly fitted into this pattern.

Another relevant contextual factor has been the domestic PV industry, which has been dominated by large electronics companies keeping large parts of the PV value chain within their own organisation. The Japanese PV industry has played a key role in making prefabricated PV homes become common in Japan by marketing their products intensely towards the prefabrication industry rather than directly to consumers. They have also been seeking collaboration with prefabrication companies, something that, as revealed by the interviews, the prefabrication companies have often perceived as valuable and helpful. The interviews also revealed that house producers have tended to prioritise stable long-term partnerships with PV module suppliers over lower prices or higher efficiency of the modules. Although Japanese modules have been substantially more expensive than for example Chinese modules, all house producers interviewed used Japanese modules. They motivated this choice by explaining that communication with and reliability of the module producer and its products are crucial when modules are to be customised to fit the roofs.

Also, assurances of the national government that subsidies were to be present for an extended period have been important for the prefabrication industry to work with PV integration. Changing production lines is expensive, and the house-building industry has preferred certainty that PV systems were to remain attractive for their customers before making such investments.

3.2.3.4. Conclusions

In all three cases, the studied business models for PV deployment have enabled firms to overcome typical barriers faced by prospective PV adopters, such as complexity, transaction costs, risks and access to finance. Yet, the business models have been distinctively different. The analysis suggests that the differences between them have to a large extent been the result of differences in the national contexts in which they have occurred. The importance of context implies that business models for PV deployment cannot necessarily be viably transferred from one setting to another. (For example, recent attempts to implement TPO business models in Germany have not been very successful.)

The strong presence of TPO models in the United States and their absence in Germany and Japan is not likely to only be the result of differences in consumer preferences, but also of other contextual factors. TPO models have effectively addressed issues that have been particularly prevalent in the Unites States, such as low savings rates, restricted access to capital, high mobility on the housing market and high transaction costs. In Germany and Japan, on the other hand, higher savings rates, better access to low-interest loans, lower mobility on the housing market and lower transaction costs have made PV adopters more prone to purchase and finance the PV systems themselves.

TPO models for PV deployment may gradually lose their relevance for most adopters as PV markets mature. Market maturation usually entails a reduction in transaction costs and risks, which might make it more attractive for adopters to finance and own PV systems themselves. As TPO models require more middle-men capturing their share of the lifecycle economic gains of a PV system, business models based on self-ownership have the potential to become more financially beneficial for adopters. Once other barriers disappear, self-ownership could thus become the most viable option for most adopters also in markets such as the United States. A high proliferation of TPO models could perhaps even serve as an indicator for policymakers that there are barriers that should be dealt with. TPO models could, however, still prevail in mature markets to serve certain market segments, as some adopters might value the simplicity of TPO models more than the prospects of higher long-term financial gains.

3.3. Paper 3 – Local factors and information channels influencing PV deployment (Sweden)

3.3.1. Background

On the surface, the conditions for PV deployment seem to be rather homogenous throughout Sweden, as economic and institutional conditions do not differ much between different parts of the country. Yet, PV adoption rates vary between municipalities to an extent that is beyond what could be explained by local factors such as building stock characteristics, solar influx or average income. This raises the question of whether there are unknown local drivers present in these high-dissemination municipalities that have increased local adoption rates.

3.3.2. Objective and approach

This paper aimed at identifying and assessing factors that could explain high localised adoption rates of residential PV systems in Swedish municipalities. An explorative multiple-case study approach was used (Yin, 2009). Five municipalities that stood out in terms of high PV adoption rates were studied in depth. These main cases were then compared to 50 municipalities with low PV adoption rates, which were studied in less depth. Triangulation of quantitative and qualitative methods and different data sources was used to enhance the robustness of the findings.

The main cases were selected as follows. All Swedish municipalities were ranked by their per capita PV density and by their PV density in terms of number of PV systems per detached home. Those five municipalities that occurred in the top ten in *both* these rankings were selected. As comparison cases, the 50 municipalities with the lowest per capita PV adoption rates were selected (except for one municipality that was excluded because it had very few detached homes). The case selection was thus a combination of replication (cases with the same outcome on a key variable) and a 'two tail' design (cases on either extreme of a key variable) (Yin, 2009).

Data were collected by three main methods. First, a survey questionnaire (see appendix A) was sent by postal mail to all presumed PV adopters that could be identified in the five main case municipalities. The survey yielded 65 valid responses at a response rate of 80%. The aim of the survey was to assess various local information channels that might have affected the respondents' decision to adopt PV. Second, 16 interviews, as well as a number of shorter communications, were performed with local installers, electric utilities and other key actors. Third, comprehensive Internet searches were performed to identify actors and gather other relevant information about the cases.

The data necessary to estimate municipalities' adoption rates and to contact adopters were obtained from the Swedish Energy Agency. More specifically, a register of applications and approvals for the national investment subsidy scheme (this scheme has been described in section 3.1.3) was used, containing the names and addresses of adopters. Since few PV systems had been installed outside this scheme, these data were assumed to provide a good representation of the actual number of installations.

3.3.3. Results

The results pointed to local actors promoting PV as an important explanatory factor behind the relatively high adoption rates in the five main case municipalities. This finding was corroborated through triangulation, as the three main sources of data (survey, interviews and Internet searches) pointed largely to the same explanatory factors. Common to the five municipalities was the presence of local organisations promoting solar energy from an early stage, mainly electric utilities and installation firms selling PV systems and disseminating information. The survey respondents recognised that they had been influenced to a substantial extent by these activities. Overall, the respondents rated local information channels as slightly more influential than common non-local information channels such as nation-wide media, websites with a non-local focus and non-local acquaintances. The survey results indicated that the local factors had not only *raised the respondents' interest* in PV but also *influenced their final decision* to adopt, suggesting that these factors operated throughout a substantial portion of the innovation-decision process (cf. Rogers, 1983).

The relative importance of different factors varied between the studied municipalities. Regarding this variation, the survey results were largely in line with the results obtained through the interviews and Internet searches (factors that were found to be of high relative importance in a municipality using one method were also found to be of high relative importance using the other methods). For instance, in the two municipalities with the most active local utilities, the respondents regarded utilities as more important than respondents in the other three main case municipalities did. In one municipality where installations had been largely concentrated to one zip code area in which an installation company was based, peer effects and PV installers were recognised by the respondents as relatively important. In another municipality, where a local association has realised a number of larger ground-mounted PV installations, the presence of ground-mounted PV was recognised by the respondents as important in inspiring them to adopt PV.

Local electric utilities supporting PV appeared to have been a particularly important driver elevating local PV adoption rates. Local utilities promoting PV during the period studied were found in four of the five main case municipalities, while none of the local utilities in the 50 comparison municipalities were found to have engaged in PV promotion during or before the period studied. The local utilities supporting PV in the main case municipalities had started their promotion of PV *before* the PV market started taking off, indicating causation in the direction from utilities towards increased adoption rates. The importance of utilities was also recognised by the survey respondents. Seminars attended by the respondents had (as reported by the respondents) been arranged mainly by local utilities, and 54% and 24% of the respondents agreed that their final decision to adopt PV had to some or to a large extent, respectively, been due to their utility purchasing PV electricity.

The results also indicated some causality going in the other direction. During the interviews, some representatives of PV-promoting utilities acknowledged that their organisations had been influenced to some extent by customers adopting PV or contacting them for information on grid-connection of PV, thus pushing them towards developing strategies for PV. This reveals the presence of a positive feedback loop: customers influence their utilities, which in turn influence other customers to adopt. The interviews also revealed that the utilities' engagement in PV promotion had in most cases started largely as the result of one devoted staff member (usually the CEO). These persons had, for one reason or the other, adopted a positive attitude towards PV, and had had the personal drive to win their organisation over to promoting PV.

Lastly, respondents in all municipalities recognised having been influenced by PV adopters in their proximity (peer effects), both through direct communication with adopters and by observing PV systems in their neighbourhood. These findings were strengthened by the interviews with installation companies, which largely agreed that after installing a PV system at a particular place, they would often shortly thereafter get additional requests from homeowners in the same area. These homeowners had, according to the interviewees, often been inspired by the first installation. On average, the survey respondents considered local acquaintances to have been about as influential on their adoption decision as installation firms. However, local peers whom the respondents categorised as 'neighbours' were seen as having had a rather minor influence, indicating that the peer effects had been mediated through other kinds of social relations than those between people regarding each other primarily as neighbours.

3.4. Paper 4 – Peer effects in PV adoption (Sweden)

3.4.1. Background

The results of paper 3 suggested that peer effects (social influence between peers) have been a factor in reducing barriers to PV adoption in Sweden. A number of previous studies have also quantified peer effects in PV adoption in other settings, mainly Germany and the United States (Bollinger and Gillingham, 2012; Graziano and Atkinson, 2014; Graziano and Gillingham, 2014; Müller and Rode, 2013; Rai and Robinson, 2013; L.-L. Richter, 2013; Rode and Weber, 2013). This research has mainly been concerned with estimating the increased probability of PV adoptions occurring within a small geographical area as the result of previous adoptions in the vicinity. Little, however, has been known about the inner workings of peer effects in PV adoption. Thus, in paper 4, a closer look was taken at the role of peer effects among Swedish PV adopters.

3.4.2. Objective and approach

The study took a mixed-methods approach (combining quantitative and qualitative methods) to add knowledge of the inner workings of peer effects among Swedish PV adopters. More specifically, the research aimed at shedding light on what kinds of social relations mediate peer effects, what kind of information is transferred between the peers and what emotions are evoked leading to the adoption of a PV system.

Data were collected through a survey questionnaire (see appendix B) and interviews (see appendix C) with selected survey respondents. The survey was sent by postal mail to Swedish PV adopters. To maximise the occurrence of peer effects among the respondents, adopters living in zip code areas with high adoption rates were targeted. Just like for paper 3, data for estimating local adoption rates and addresses of adopters were obtained from the Swedish Energy Agency's register of applications and approvals for the national investment subsidy scheme. All Swedish zip code areas were ranked by their number of PV systems per capita, and the survey was sent to all 92 individuals that had had their applications for the subsidy approved in the 25 zip code areas with the highest adoption rates (except for five areas that were located in the municipalities studied in paper 3, which were excluded because the adopters on those areas had recently been sent a similar questionnaire). The survey yielded 65 valid responses at a response rate of 74% (four presumed adopters returned the questionnaire informing that they had in fact not adopted). The survey was mainly built upon five-point rating scales of both unipolar and Likert type, in which the respondents were asked to rate how they perceived that seeing PV systems or talking to PV adopters in or outside their neighbourhood had influenced their perceptions of PV technology.

Telephone interviews were performed with selected survey respondents. Those 22 respondents who reported having been in contact with at least one PV adopter in their neighbourhood prior to taking a final decision to adopt (and who had provided their telephone number) were selected, and full interviews were carried out with 16 of them. The interviews were recorded, and whenever the notes taken during the interviews were not considered detailed enough, the recordings were used to complement the notes. Key data were coded in a spreadsheet.

Considering that people tend to consistently underestimate the impact of social influence on their decision making (Nolan et al., 2008), the risk of overestimating peer effects using the chosen methodology, which relied on participants' self-estimation, was assumed to be small.

3.4.3. Results

As in paper 3, the presence of peer effects was widely recognised by the participating PV adopters. Among the survey respondents, 38% reported that contact with a peer (local or non-local) had been highly important ("4" or "5" in the rating scales) for raising their interest in PV. The corresponding figure for the final decision to adopt was 35%. Among respondents who had been in contact with an adopter in their neighbourhood before they decided to adopt (28 respondents), half agreed that the contact had been highly important for raising their interest in PV, and almost half did so regarding their final decision to adopt.

The interviews revealed that the contacts had almost exclusively occurred through pre-existing and rather close social networks, such as friends and family. Contacts with PV-using neighbours to whom the respondent had no deeper relationship had been rare and of minor importance (this was also suggested by the survey carried out for paper 3). This contrasts somewhat to what has been previously believed about peer effects in PV adoption, where the role of neighbour relations has (more or less implicitly) been assumed to be important. Furthermore, even though the sample was selected based on a presumed high occurrence of *local* peer effects, almost as many respondents reported having been highly influenced ("4" or "5" in the rating scales) by someone living *outside* as *inside* their neighbourhood.

The main function of the peer effects appears to have been a confirmation that PV works as intended and without hassle, rather than the procreation of unexpected insights or the provision of more advanced information. The confirmation was strengthened by the trustworthiness of the peers, who (apart from being known by the participants) as private homeowners were in a situation similar to that of the participants, and who (as opposed to PV installers) lacked economic incentives to recommend PV adoption. The information transferred had generally not been of a very advanced character, and had mainly related to ease of use and economic performance – that PV systems worked as intended and without hassle, and that they delivered as much electricity as expected. This information had, nevertheless, been perceived as useful by the interviewees; it had contributed to reducing a general uncertainty about PV as a new and 'unknown' technology, and had increased the participants' determination to adopt. Overall, few of the contact persons had recommended PV adoption outright – rather, they had provided more 'neutral' accounts of their experiences as adopters. Almost all interviewees had seriously contemplated PV adoption and acquired some knowledge of PV before any contact with previous adopters took place, and the contacts did thus not evoke much unexpected insight.

When it comes to the role of *passive* peer effects (influence of *seeing* PV), the results indicated that these had been of minor importance. As in the survey carried out for paper 3, seeing PV systems was regarded as a relatively important influential factor. However, a closer look at the data revealed that respondents who had seen a PV system in their neighbourhood tended to regard this as influential only if they had also been in contact with an adopter. The interviews confirmed that it was when a PV system had been seen in connection with adopter contact that it had been influential, for example when visiting a PV owner that demonstrated his or her PV system.

Contacts between the interviewees and previous adopters had come about in two principal ways: either the interviewee had approached the PV adopter with the purpose of acquiring information from him or her, or the topic had come up as they had met for another purpose. Only in one case had the interviewee experienced being approached by an adopter (other than a salesperson) who appeared to have had the purpose of talking about PV. In the previous literature, it has sometimes been assumed that seeing local PV systems tend to induce people to contact the systems' owners to get more information. However, the findings of the present study did not support that such an order of events had been common in the studied setting, as almost no contacts had come about as the result (partly or fully) of the interviewee first seeing the contact person's PV system.

4. Concluding discussion

In this section, a synthesis of the findings of the four papers will first be presented. The methodological contributions of the thesis will then be discussed. Based on the findings, some recommendations for policy will also be provided, both specific advice for reforms of Swedish policy and more general advice. Lastly, some pathways for further research will be suggested.

4.1. Synthesis of findings

The objective of this thesis was to identify and assess barriers and drivers to residential PV deployment in different geographical settings, taking the spatial dimension into account. The findings of each paper have been accounted for separately in section 3. The added value of this synthesis is that it builds a larger and more coherent picture of barriers and drivers on different spatial levels, thus contributing to an improved understanding of the geography of sustainability transitions (cf. Coenen et al., 2012; Hansen and Coenen, 2015).

While the price and performance of PV technology have been largely determined on the international level, the thesis goes into depth with barriers and drivers rooted in national and local settings. By studying altogether four national PV markets, papers 1 and 2 identify and assess barriers and drivers mainly rooted on the national level, providing various examples of how institutions, industry, culture and financial aspects have affected PV deployment. On the local level, papers 3 and 4 show how local organisations and private individuals have driven PV deployment through information provision and social influence. Together, barriers and drivers rooted on all these levels determine the conditions for PV deployment at any given location. Thus, an understanding of barriers and drivers on all levels is important.

Paper 1 took a systemic perspective to identify and assess barriers and drivers in Sweden. The analysis was facilitated by the technological innovation systems (TIS) framework, which guided the research to relevant actors, networks, institutions and processes. The analysis depicts a small, underdeveloped Swedish TIS for PV deployment, albeit in rapid growth in relative terms. Limited economic profitability in PV adoption was a crucial barrier during the period studied (also including subsidies). The results reveal that the Swedish policy environment has been uncertain and complex, creating problems for different actors. The institutional barriers in Swedish PV deployment (which have been described in more detail in section 3.1.3) could be coarsely summarised as follows: First, the fact that more than one subsidy scheme for PV deployment have been running in parallel is a complexity in itself. Second, there have been uncertainties regarding when different subsidies were to be available, and on what conditions. Third, important rules, mainly related to taxes, have been unpredictable.

Even though the institutions affecting PV deployment in Sweden have mainly been national, they have not always been fully controlled by the national government. For example, Swedish rules for taxes and building permits affecting PV deployment have partly been determined on the EU and the municipal levels, respectively. Paper 1 reveals that institutions on the EU level have restricted the ability of the Swedish government to adapt rules to PV and other micro-generation technologies, resulting in institutional rigidity that has contributed to a lock-in of the incumbent energy system (cf. Unruh, 2000).

The thesis also demonstrates that country-specific characteristics of a domestic industrial sector can be important for PV deployment. Paper 2 reveals that certain characteristics of the Japanese construction sector, such as a high degree of industrialisation and standardisation, have been important for the physical and organisational integration of PV into the construction of new buildings in Japan. Those factors are rather unique to the Japanese construction sector compared to other domestic construction sectors around the world. This is likely an important explanation of why the Japanese construction sector has been highly involved in PV deployment as compared to construction sectors in other important PV markets.

The thesis also identifies barriers and drivers that vary between countries but are less confined to administrative borders. Such factors include cultural and behavioural aspects such as savings rates, homeowner mobility (how often people move), accustomedness to TPO business models (not only for PV) and priorities regarding long-term versus immediate cost savings. As suggested by paper 2, these aspects will influence what kind of business models will be most viable within a certain context, as different business models are suited to overcome different barriers to deployment. Perhaps most importantly, this relates to the ability of potential adopters to raise capital and to their preferences regarding whether to own the PV system or consult a TPO firm. Another example is real estate prices, which have developed rather differently between countries and regions, influencing homeowners' ability to finance a PV system. If the value of a home substantially exceeds the mortgage for the same home, the homeowner can often quite easily get a home equity loan to finance a PV system. This will be the situation for most homeowners in regions where the prices of homes have increased substantially in recent years. On the other hand, there are many regions around the world in which the values of homes have decreased dramatically in the wake of the financial crisis of 2008. In these regions, homeowners will typically have less opportunity of getting a home equity loan, and many of them will be 'underwater', meaning that the value of their home is lower than their mortgage. These homeowners will often find it difficult to finance a PV system, and TPO business models might then be a viable option. As argued in paper 2, this is likely a contributing factor to the success of TPO business models in California, where housing prices declined substantially after the financial crisis.

Paper 2 illustrates that certain business models can successfully overcome complexities and uncertainties faced by prospective PV adopters on the national level. It is thus noteworthy that Sweden, with its complex and uncertain policy environment, has (as was found in paper 1) lacked alternative business models such as TPO even though these have been successful in addressing complexities and uncertainties in other countries. As argued in paper 2, a lack of alternative business models (such as TPO) could be a barrier for some categories of potential adopters, and trying to explain the absence of TPO models in Sweden is thus justified. Drawing on papers 1 and 2, this synthesis allows for some remarks in this regard. A first reason for the absence of TPO models in Sweden could be the low economic profitability of PV investments; TPO models require a middle-man taking a share of the life cycle economic gains of a PV system, and the total economic gains might simply have been too small in Sweden for TPO to be viable. Second, the small size of the Swedish PV market might have decreased the likelihood of TPO models occurring as they require a higher level of organisational sophistication. Third, the Swedish institutional uncertainties have created risks of events that would affect all installations simultaneously. This contrasts to risks of events that occur independently of one another for each installation. While TPO models do not address the former kind of risk (events affecting all installations simultaneously could ruin a TPO firm), they successfully address the latter kind by spreading the risks over a large number of installations. Fourth, the Swedish housing market has withstood the global financial crisis remarkably well from an international perspective, and the prices of homes have increased rather consistently during the last decade, which has made it easier for Swedish homeowners in general to finance PV systems themselves without the need for a TPO model.

When it comes to the local level, papers 3 and 4 point to local sources of information as being an important driver of PV deployment. Local information seminars organised by electric utilities seem to have had a substantial effect in increasing adoption rates in Swedish municipalities (paper 3), and basic information transferred between peers appears to have been important in convincing Swedish homeowners to adopt PV (paper 4). Even though information channels operating on a higher geographical level, such as websites directed towards a national or international audience and media with a national coverage, were important for the decision making of the participating adopters, the findings of paper 3 suggest that local sources of information were of equal or higher importance. A substantial function of the information appears to have related to raising the interest in PV among potential adopters, indicating a lack of basic awareness.

Even though the geographical entity studied in paper 3 was the municipality, the findings point to another geographical entity of relevance, namely the area covered by the electrical grid operated by a certain utility. Different utilities have developed different strategies and attitudes regarding PV, and the results of paper 3 strongly suggest that a local utility's supportive attitude can substantially increase local PV adoption rates. Even though these effects are surely not strictly confined to the area covered by the utility's grid, the reach of the grid is likely to be of significant importance as everyone connected to the grid is a customer of the utility and thus subject to its communication. While utilities might have different roles in different countries, previous research on local sources of market formation (Dewald and Truffer, 2012) has not acknowledged the role of utilities, which might be relevant in some (though likely not all) other countries as well.

A driver with an inherently large local component is *peer effects* (social influence between peers resulting in PV adoptions). Previous research has identified substantial localised peer effects in PV deployment using quantitative research methods (Bollinger and Gillingham, 2012; Graziano and Atkinson, 2014; Graziano and Gillingham, 2014; Müller and Rode, 2013; Rai and Robinson, 2013; L.-L. Richter, 2013; Rode and Weber, 2013). Little has been known, however, about the inner workings of peer effects in PV deployment. Together, papers 3 and 4 contribute to deepening the understanding of peer effects by surveying in total 130 PV adopters and interviewing 16 of them, thus introducing a qualitative perspective that has been lacking in the previous research. Paper 3 confirms that peer effects in PV adoption also exist in the Swedish setting, and the paper provides some tentative findings regarding their underlying mechanisms. In paper 4, the mechanisms behind the peer effects were investigated more deeply. The two papers used data from different sets of participants (one set for each paper) and, as some survey items were identical or very similar for the sets, they together provide a larger sample on some aspects.

Paper 4 suggests that the main function of the peer effects was a *confirmation* from a trustworthy source that PV adoption would be a sound choice. The information transferred was generally not of a very advanced character, and related mainly to ease of use and economic performance – that the technology worked as intended and without hassle, and that it delivered as much electricity as expected. This information was perceived as useful by the interviewees, and it contributed to reducing a general uncertainty regarding PV as a new and 'unknown' technology, thus reducing barriers to adoption. Paper 4 was unique not only to the Swedish context, but also globally, as peer effects in PV adoption had not previously been studied through interviews with adopters.

The results of papers 3 and 4 suggest that the main reason (at least in the studied setting) for peer effects having a large local component is that people who are family and friends tend to live close to one another, rather than people influencing one another through more superficial neighbour relations. Both papers reveal that relations with people who the adopters perceived as 'neighbours' were perceived to have been of minor importance – instead, the influence had taken place through closer and more established social networks. The high degree of localisation in peer effects has led to an assumption in the previous literature that neighbour relations and passive influence (through passively observing neighbours' PV systems) have been important mediators of peer effects. However, paper 4 suggests that passive peer effects played but a minor role in the studied context. One implication of these results relates to the fruitfulness of different computational models of peer effects in PV deployment. Two different approaches to such models are based on social networks and geography, respectively (Bale et al., 2013; Rode and Weber, 2013). The results of this thesis indicate that the former approach might more accurately reflect the underlying processes at work.

Lastly, the thesis demonstrates how the local nature of PV deployment can create inefficiencies, at least in a small and early market such as the Swedish one. Paper 1 reveals that the installation of PV systems in Sweden has been dominated by small, local firms that have often not been exclusively devoted to PV technology, thus lacking the benefit of specialisation. This can be seen as a consequence of the fact that PV systems need to be installed on-site by the firm's staff, in combination with a small market size. Several of the installers interviewed for paper 1 expressed the ambition to become more specialised, claiming that the small market size within their catchment area would not support specialisation. With limited demand for PV systems within a reasonable travelling distance, a full-time job cannot be sustained by the demand for PV installations only. This leads to poor economies of scale on the local level, and to a lack of competition as the number of installers offering their services in any given place will be limited.

4.2. Methodological contribution

The thesis makes some contributions regarding research methodology, which will be discussed below. A first contribution relates to the application of the TIS framework. In paper 1, this framework was used to study PV deployment separately from processes occurring earlier in the PV value chain. Paper 1 demonstrates that it is meaningful to apply the TIS framework to study deployment separately in order to identify and assess barriers and drivers, and that deployment taken on its own is a complex and systemic process that motivates the use of a holistic analysis tool such as the TIS framework. The thesis argues that in cases where a mature technology is to be deployed in a catching-up market that is small in relation to the international production system for the technology in question, a pure deployment focus is motivated in TIS analyses. The value of this contribution is made evident by the fact that a pure deployment focus allows the researcher to focus his or her resources on the deployment phase, thus avoiding spending valuable time studying technology development and production, and saving him or her the effort of doing an international and spatially differentiated TIS analysis. Furthermore, increasing global specialisation and division of labour, as well as an increasing availability of mature renewable energy technologies that can be deployed in new regions, can be expected to create an increasing need for deployment-focused TIS studies (see section 2.1.1.3).

The thesis also demonstrates how the TIS framework, the business models framework and Rogers' diffusion of innovations framework can be combined to study technology deployment (see section 2.1). The latter two frameworks fit within the scope of the TIS framework and are appropriate choices when zooming in on selected parts of a TIS that relate to technology deployment. The thesis argues that the latter frameworks connect well to certain phenomena described in the TIS literature, such as certain categories of actors and the functions 'entrepreneurial experimentation', 'knowledge development and diffusion', 'legitimation' and 'market formation'. Thus, the latter frameworks could well be positioned within the TIS framework – the very concept of a 'business model', as well as various core concepts within both the frameworks, could be incorporated into the TIS framework, in some cases perhaps by replacing existing terminology. This would, nevertheless, require a deeper analysis, which is beyond the scope of the present thesis.

Another methodological contribution relates more directly to the application of the business models framework. In paper 2, the viability of different business models for PV deployment in different countries was studied. Previous literature on business models had elaborated upon how business model innovation can bring new (sustainable) technologies to the market (Bocken et al., 2014; Boons and Lüdeke-

Freund, 2013; Mont et al., 2006; Reim et al., 2015; Tukker, 2004) and upon the role of the wider sociotechnical context for shaping business models (Birkin et al., 2009; Budde Christensen et al., 2012; Casper and Kettler, 2001; Linder and Cantrell, 2000; Provance et al., 2011). The methodological uniqueness of paper 2 was that it combined the business models framework with a comparative case study approach to pinpoint contextual factors in different geographical settings. This had not previously been done for PV technology and, to the best knowledge of the authors, it had not been done for the deployment of any other technology either. The approach proved useful in understanding how different business models can overcome contextual barriers (see section 3.2.3) to technology deployment and thereby create value for adopters and firms.

Also some contributions regarding methodology to study local variations in PV adoption rates were made. For paper 3, an approach based on comparative case studies was developed to identify and assess local drivers in Swedish municipalities. A combination of a replication and a 'two tail' design (Yin, 2009) was used. Five 'main cases' (municipalities with the highest adoption rates) and 50 'comparison cases' (municipalities with the lowest adoption rates) were studied. The number of comparison cases was larger because data were scarcer for this category. The comparative element of the approach was two-fold. First, the main cases were compared to one another. Second, the two categories of cases were compared to each other. The method proved useful to pinpoint local drivers that could explain why certain municipalities have stood out in terms of high PV adoption rates. To the best knowledge of the author, there has not previously been any research on local variations in technology adoption rates using an approach including the elements described above.

Furthermore, paper 3 introduced a novel approach for dealing with differences in building stock when selecting cases for comparative case studies of geographical differences in PV adoption rates. There is often a need to take building stock into consideration when studying causal factors behind PV adoption rates, as the characteristics of the built environment (e.g. the share of detached homes) may otherwise become an important confounding variable. For paper 3, all Swedish municipalities were ranked by their PV-density using two measures: the number of PV systems *per capita* and *per detached home*. Municipalities that occurred at the top or bottom of *both* these rankings were selected. The inclusion of the latter criteria served as a control mechanism, reducing the risk of local building stock characteristics confounding the selection process (see section 3.3.2).

Lastly, for paper 4, a mixed-methods approach was developed to study peer effects in PV adoption, combining qualitative and quantitative research methods through a survey and follow-up interviews with selected respondents. Thus, a qualitative perspective that had hitherto been lacking in studies of peer effects in PV adoption was introduced. As peer effects are by nature closely related to the adopters' own thoughts and emotions, survey data arguably need to be complemented with interviews – particularly in a stage where the understanding of the effects is limited – to make sure that the survey data have been interpreted correctly and to increase the chances of identifying any important matters not identified through the survey. The method proved useful to nuance the previous understanding of peer effects in PV adoption, and continued research using this or similar approaches may be fruitful in achieving a deeper understanding of peer effects in the adoption of PV or other technologies.

4.3. Implications for policymakers, firms and others

Based on the findings of this thesis, some recommendations can be derived for policymakers, firms and other actors aiming to support PV dissemination. Below, a set of general advice will first be provided. Then, a number of more specific recommendations for reforms of existing Swedish policy will follow.

A first set of advice relates to *business models* for PV deployment (paper 2). The findings regarding the relationship between business models and their surrounding context may be useful to both policymakers and firms. Even though the research on business models was not carried out in Sweden (as was the rest of the research), the findings might prove useful to overcome barriers in Sweden and other catching-up markets.

One piece of advice for policymakers is to remove any institutional barriers that might obstruct the use of certain business models, or to provide enabling legislation for business models that have proven viable in other contexts. Preferences vary between consumer groups, and a variety of business models for prospective adopters to choose from could thus increase the overall adoption rates by satisfying the preferences of a larger number of consumers. Furthermore, a substantial number of the potential adopters will, in many contexts, find it difficult to finance and own a PV system even if a purchase would be their first choice. Any institutions hindering TPO business models may thus impose a barrier to PV deployment. This does not necessarily mean that policy has failed if all business models that have proven successful in other markets are not present in the market of interest, as it might simply be the case that the market has selected against certain business models due to differences in consumer preferences or other contextual differences that are beyond the direct control of policymakers.

When it comes to firms, the findings on business models could be informative when planning to enter new markets or targeting certain consumer segments. The findings could also guide firms in how to respond to a changing context.

A second set of advice relates to *electric utilities* (organisations operating electrical grids). Paper 3 strongly suggests that local utilities can elevate PV uptake in their area by supporting PV. Policymakers could exploit this by influencing utilities to take a supportive attitude towards residential PV. Such influence could be exercised by informing utilities about PV technology and about how other organisations have worked with PV, for instance by offering utilities' staff training as to how to best support PV deployment. A web-based platform for the provision and exchange of information directed towards utilities could be implemented (perhaps as part of a larger platform for PV information directed to a broader audience). Educating utilities might both increase the chance of them choosing to support PV deployment, and make utilities perform better in providing their customers with relevant information. In cases where a government owns a utility (Swedish utilities are, for example, often owned by local governments), the government could steer the utility towards promoting PV. Utilities could also be regulated to take a more active role in PV deployment.

Another piece of advice is to arrange *information seminars* targeting private homeowners. Such seminars could be arranged by any actor (such as utilities, non-profit organisations, local governments and installation firms) interested in supporting PV deployment. Paper 3 suggests that local information seminars have been an effective strategy to convince homeowners to adopt PV in Sweden. The effectiveness of seminars might, nevertheless, depend on context-specific factors. Two key characteristics of the Swedish PV market are that it is in an early stage of development and that there is limited economic profitability in residential PV adoption. As convincingly argued by Noll et al. (2014), there are reasons to believe that information provision has the highest prospects of being effective in markets where PV is neither very profitable nor clearly unprofitable. Awareness of PV might also be lower in early markets, in which case there is a higher need for information dissemination. The generalisability this advice might thus be more or less limited to markets that are similar to Sweden in these respects.

A last piece of advice relates to *peer effects* (papers 3 and 4). Actors with a goal to increase PV uptake could seek to make use of peer effects by involving existing PV adopters in information campaigns or marketing. This might prove a cost-effective strategy for policy and businesses even if the existing adopters are economically compensated for their involvement.

Paper 4 reveals that information obtained from peers plays a partly different and complementary role compared to other information sources, such as the advice of professionals. Peers (at least in the context studied) seem to convince each other to adopt PV by giving reassurance that adoption is indeed a sound choice, rather than through the provision of more factual information (which can be found in written sources or obtained through professional advisers). Trust is not only gained through established social relations, but also through peers being in a similar situation (as private homeowners), having actual experience as adopters, and (as opposed to firms) lacking economic incentives to portray PV in an excessively positive manner. The participation of PV adopters in information campaigns or marketing could thus be effective as a complement to other means of information provision.

There are various conceivable strategies for making use of peer effects. One suggestion is to include sessions in information seminars where visitors get the opportunity to talk to adopters, for example in Q&A sessions or group discussions. Study visits could also be organised by firms or policymakers to the premises of adopters to let attendants see their PV system and talk to them. Another option would be to have local energy advisors provide citizens with contact information to local adopters. Policymakers might even want to target certain individuals to become PV adopters if these individuals could be expected to be particularly likely to create further adoptions through peer effects. If so, the findings of paper 4 suggest that socially well-connected individuals should be targeted rather than individuals who have the most visible rooftops.

4.3.1. Reforms of existing Swedish policy

A substantial portion of the research behind this thesis relates to existing Swedish institutions, and the results thus lend themselves to some Sweden-specific policy advice. This advice does not involve increased subsidisation, but rather changes in the design of existing subsidy schemes or other advice that does not require increased public spending. The advice relates to issues that were identified in the research *and* that are still present at the time of finishing the thesis (December 2016), which includes the majority of the issues identified in the research.

Paper 1 points to several uncertainties and complexities in the Swedish policy framework that could be addressed. First, the circumstance that more than one subsidy schemes for PV deployment have been running in parallel is an unnecessary complication that creates extra administration and transaction costs for adopters, installation firms and authorities, and that makes it more difficult for (potential) adopters to estimate the economic consequences of PV adoption. At the time of writing (December 2016), three subsidy schemes are running in parallel, as the proposed tax reduction was implemented after the completion of paper 1. Second, it was – and still is – unclear for how long the different subsidy schemes will run. The total budget for PV within these schemes should thus preferably be gathered within one coherent long-term strategy with high predictability and transparency.

The most important Swedish subsidy scheme for PV deployment – the investment subsidy launched in 2009 – has been flawed with uncertainties. This issue could be addressed through some relatively straightforward reforms. First, the scheme's duration and future remuneration levels should be planned and made transparent. This could be done through the setting of certain conditions to determine the future development of the scheme. For example, it could be decided that investing in a residential PV should yield a certain economic profitability, e.g. an IRR of around 5%. Factors that influence this figure (most importantly the cost development of PV systems) should then be monitored continuously so that remuneration levels can be adapted to keep the profitability at the desired level. Once the profitability reaches the desired level without the need for subsidies, the scheme has served its purpose and should be terminated. Second, measures should be taken to mitigate the long queue of applications awaiting approval. Even though the remuneration level has been reduced to 20% since paper 1 was finished while a substantial amount of long-term funding has been added, the long queue has persisted, resulting in waiting times of up to two years as of November 2016 (Svensk Solenergi, 2016). As regards the market fluctuations caused by discontinuations in the scheme, this problem appears to have been resolved. Even if new discontinuations in the scheme would occur, the current remuneration level of only 20% in combination with reduced prices of PV systems have induced an increased share of the new adopters to purchase the system *before* their application is approved, hoping to get the subsidy retroactively. This secures a more evenly distributed demand for PV systems regardless of any discontinuations in the scheme.

Paper 1 also shows that the tradable green certificates (TGC) scheme, which has been available for PV and other renewables since 2003, has been poorly adapted to residential PV and other modes of micro-production of electricity. To adapt this scheme, the selling of small quantities of certificates could be made easier. This could be achieved for example through the provision of a user-friendly web-based trading platform, or by authorities purchasing certificates at market rates from micro-producers using an automated system (the authorities could then re-sell the certificates in bulk to other actors). Another issue is the high cost for micro-producers of acquiring certificates for self-consumed electricity, as this requires the installation of additional metering equipment. This could – if the TGC scheme is to be intended for micro-producers in the future – be solved through for example relaxed requirements on metering, certificates for self-consumption being granted on the basis of a template, or by providing PV adopters with free metering equipment. However, a burning issue is whether the TGC scheme should be intended at all for micro-production. If so, the scheme should be adapted accordingly. If not, micro-production should be formally excluded from the TGC system (any subsidisation should then be carried out by other means).

The building permit system could also be reformed. To reduce complexity, rules could be standardised between municipalities. Building permits for residential PV could also be abolished if certain criteria are fulfilled (e.g. that the panels follow the inclination of the roof). Fees could be abolished, or only be due once a permit has been approved (thus reducing uncertainty and risk for prospective adopters). Information on building permits regarding fees, requirements, administration time etc. could be provided on municipalities' websites.

As regards uncertainties regarding tax rules, it was recently (after the completion of paper 1) established that residential PV adopters are under most circumstances indeed not subject to extra taxation and related administration. Any remaining uncertainties could be mitigated by adaptation of rules in a planned, transparent manner, by clear and official statements regarding the intended direction of future reform, or by clarifying official statements regarding how existing rules should be applied.

4.4. Suggestions for further research

In this section, some possible lines of research that could be addressed subsequent to this thesis will be identified. Four potential areas of research will be discussed, one following each paper.

4.4.1. Technological innovation systems (TIS)

As argued in this thesis, there will likely be an increasing need for TIS studies focusing exclusively on the deployment phase of PV (as was done in paper 1) and other technologies. Although this thesis makes some methodological contributions in how to perform such studies (see section 4.2), further methodological development is needed. For example, methods need to be developed regarding how to set system boundaries for geography and value chain based on what phenomena interact in a systemic manner and how different phenomena relate to space. A deployment focus is also likely to have implications regarding the functional dynamics of TISs. The relative importance of different functions might change in some generalisable ways and there might be differences in which functions are important on different geographical scales. New empirical research, or re-analysis of existing TIS literature with a 'new lens', might shed light on these issues.

Conceptual work could also be done regarding how the TIS framework connects to other streams of literature. As observed in this thesis (see section 2.1), the business models framework as well as Rogers' diffusion of innovations framework both fit within the scope of the TIS framework and are useful when zooming in on certain key parts of a TIS. These, and perhaps other, frameworks could be more elaborately positioned within the TIS framework in future conceptual work.

4.4.2. Business models and their context

Paper 2 served as a first step in analysing how business models for PV deployment depend on barriers and other contextual factors in different geographical settings. The findings pointed towards a number of factors that appeared to have influenced the success of different business models in the studied markets. However, more research is needed in order to gain a deeper understanding of how and to what extent these and other factors influence the viability of different business models. As an increasing number of PV markets become mature enough to host more elaborate business models, there will be more potential cases to study. Paper 2 could also be complemented through data collection from adopters (surveys, interviews) in the studied markets or in other markets. This could shed light on adopters' motives for preferring a certain business model, and on whether any particular contextual factors influenced their preferences. Furthermore, business models for the deployment of other technologies than PV could be studied in relation to their context. This could yield valuable technology-specific as well as generalisable knowledge regarding the relationship between business models and their context.

4.4.3. Local barriers and drivers

Paper 3 was and early attempt to identify causes of locally elevated adoption rates of residential PV. There are several ways to continue this line of research. First, the adopter perspective could be further explored, e.g. through interviews with adopters in municipalities with high adoption rates. This way, a deeper understanding of factors influencing the different stages of their adoption decision process could be gained. Approaches similar to that developed for paper 3 could also be used to study other settings than the Swedish one. This could reveal to what extent the findings of paper 3 are generalisable; for example, the findings might be specific for early PV markets or for some other characteristic that Sweden shares with certain other settings. Another possibility would be to use statistical regression analyses to compare municipalities or other geographical entities with each other, using PV adoption rates as the dependent variable. This could reveal correlations not visible through case study methodology.

One finding of paper 3 was that local electric utilities supporting PV appeared to have had a substantial positive effect on adoption rates. This could be further explored in different ways. For example, it could be investigated why some utilities choose to engage in PV promotion and sales. From a purely economic perspective, promoting PV might appear as a bad decision for utilities as increased PV penetration undermines their source of revenue. Furthermore, PV sales are arguably beyond their core business. Research on incumbent companies in the offshore oil and gas sector that have diversified into wind power suggests that a key reason for this diversification has been to attract the most talented staff for use in their core business (Hansen and Steen, 2015). However, there is as yet little research on the reasons for energy incumbents to engage in renewables, and on whether and under what circumstances such engagement might be economically rational for such organisations.

Furthermore, the role (current and potential) of utilities might differ between countries. For example, utilities are typically highly regulated on the national level, which might create rather different opportunities for utilities in different countries to act beyond their core tasks (and thus to support PV). This could be researched.

Lastly, more research could be done on the role of local information in increasing PV adoption rates. The findings of paper 3 indicated that information seminars have been important in the cases studied, but little is known about what defines successful information dissemination on the local level (e.g. how an information seminar should be designed in order to spur PV adoptions). As information dissemination can be a low-cost intervention, it can (if effective) be a cost-effective way to increase PV uptake. For example, it has been argued that information dissemination has the highest potential to be effective in early markets in which PV is neither very profitable nor clearly unprofitable (Noll et al., 2014), but there is currently little empirical evidence to support this.

4.4.4. Peer effects

This thesis offers an initial attempt to understand the inner workings of peer effects in PV adoption. To build a more solid understanding of the mechanisms behind these peer effects, more qualitative empirical research is needed. Using the approach developed for paper 4 or a similar methodology combining survey and interviews appears to be a fruitful way of moving this research forward. Data could be collected from adopters, non-adopters, or potential adopters in different settings.

Depending on the exact research question and on the expected occurrence of useful information among adopters, representative or purposeful sampling could be used. For example, peer effects could often be expected to be more common in areas with high adoption rates. Thus, any given sample size could yield more useful information through purposeful sampling in such areas. As large samples are costly to manage, purposeful sampling could be beneficial in situations where a representative sample is not necessary. Future research could in those cases imitate or be inspired by the sampling strategy developed for the present thesis.

Research could also be done to find out whether and how the characteristics of peer effects vary between different contexts, such as between early and more mature markets. For example, as early adopters are generally more cosmopolite than later adopters (Rogers, 1983), peer effects might be less localised in early markets (as was the case in the studied Swedish early market).

The findings of this thesis raise some doubt as to the role of passive peer effects in PV adoption. In previous literature, these have often been assumed to be an important part of the 'total' peer effects. The importance of the passive component could be assessed by investigating the impact of PV systems' visibility. If, for example, rooftop PV systems facing roads generate substantially larger increases in local adoption rates than PV systems facing backyards, this could indicate a large passive component.

Lastly, the possibilities of utilising peer effects in campaigns could be explored. Is, for example, information provision (e.g. seminars) more effective when adopters are involved? How should they be engaged to make the highest impact: should they give lectures, be available for Q&A sessions, or take part in conversation groups? (As anecdotal evidence, small conversation groups among seminar participants were described as a very important influential factor by one of the interviewees.) Would it be cost-effective to pay them to participate? Are organised study visits to PV adopters' premises a viable strategy? Such alternatives could be investigated, for example through experiments.

5. Conclusions

This thesis identifies and assesses various barriers and drivers to the deployment of residential PV systems in different geographical contexts. Using a sociotechnical systems approach, the thesis demonstrates how the *technological innovation systems* TIS framework can be amended by the *business models* and the *diffusion of innovations* frameworks to study the deployment of a mature technology (in this case PV) in a catching-up market, treating the development and production of the technology as a 'black box'. On the national level, the analysis shows that the Swedish sociotechnical system for residential PV deployment has been immature and infested by various institutional barriers. Most notably, the Swedish subsidy schemes for PV deployment have been flawed with uncertainties and complexities, and there have been important uncertainties regarding the future development of the Swedish institutional set-up. The results also demonstrate how barriers in different national contexts have affected what kinds of business models for PV deployment that have been viable. On the local level, the results demonstrate how actors such as local electric utilities and private individuals have influenced homeowners to adopt PV through information dissemination and social influence (peer effects). The findings can inform policymakers, firms and other actors as to how to better support PV deployment.

6. References

Amit, R., Zott, C., 2001. Value creation in E-business. Strateg. Manag. J. 22, 493–520. doi:10.1002/smj.187

Antràs, P., Chor, D., Fally, T., Hillberry, R., 2012. Measuring the Upstreamness of Production and Trade Flows. Am. Econ. Rev. 412.

Arvizu, D., Balaya, P., Cabeza, L.F., Hollands, K.G.T., Jäger-Waldau, A., Kondo, M., Konseibo, C., Meleshko, V., Stein, W., Tamaura, Y., Xu, H., Zilles, R., 2011. Direct Solar Energy, in: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (Eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Awerbuch, S., 2000. Investing in photovoltaics: risk, accounting and the value of new technology. Energy Policy, The viability of solar photovoltaics 28, 1023–1035. doi:10.1016/S0301-4215(00)00089-6

Axsen, J., Mountain, D.C., Jaccard, M., 2009. Combining stated and revealed choice research to simulate the neighbor effect: The case of hybrid-electric vehicles. Resour. Energy Econ. 31, 221–238. doi:10.1016/j.reseneeco.2009.02.001

Baldwin, R., Robert-Nicoud, F., 2014. Trade-in-goods and trade-in-tasks: An integrating framework. J. Int. Econ. 92, 51–62. doi:10.1016/j.jinteco.2013.10.002

Bale, C.S.E., McCullen, N.J., Foxon, T.J., Rucklidge, A.M., Gale, W.F., 2013. Harnessing social networks for promoting adoption of energy technologies in the domestic sector. Energy Policy 63, 833–844. doi:10.1016/j.enpol.2013.09.033

Bergek, A., Hekkert, M., Jacobsson, S., Markard, J., Sandén, B., Truffer, B., 2015. Technological innovation systems in contexts: Conceptualizing contextual structures and interaction dynamics. Environ. Innov. Soc. Transit. 16, 51–64. doi:10.1016/j.eist.2015.07.003

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A., 2008a. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Res. Policy 37, 407–429. doi:10.1016/j.respol.2007.12.003

Bergek, A., Jacobsson, S., Sandén, B., 2008b. Legitimation and development of positive externalities: Two key processes in the formation phase of technological innovation systems. Technol. Anal. Strateg. Manag.

Bhaskar, R., Frank, C., Høyer, K.G., Naess, P., Parker, J. (Eds.), 2010. Interdisciplinarity and Climate Change: Transforming Knowledge and Practice for Our Global Future, 1 edition. ed. Routledge, London; New York.

Binz, C., Truffer, B., Coenen, L., 2014. Why space matters in technological innovation systems—Mapping global knowledge dynamics of membrane bioreactor technology. Res. Policy 43, 138–155. doi:10.1016/j.respol.2013.07.002

Birkin, F., Polesie, T., Lewis, L., 2009. A new business model for sustainable development: an exploratory study using the theory of constraints in Nordic organizations. Bus. Strategy Environ. 18, 277–290. doi:10.1002/bse.581

Bocken, N.M.P., Short, S.W., Rana, P., Evans, S., 2014. A literature and practice review to develop sustainable business model archetypes. J. Clean. Prod. 65, 42–56. doi:10.1016/j.jclepro.2013.11.039

Boden, M.A., 1999. What is interdisciplinarity? In: R. Cunningham (ed.) Interdisciplinarity and the organisation of knowledge in Europe, pp. 13-24. Luxembourg: Office for Official Publications of the European Communities.

Bohnsack, R., Pinkse, J., Waelpoel, A., 2016. The institutional evolution process of the global solar industry: The role of public and private actors in creating institutional shifts. Environ. Innov. Soc. Transit. 20, 16–32. doi:10.1016/j.eist.2015.10.006

Bollinger, B., Gillingham, K., 2012. Peer Effects in the Diffusion of Solar Photovoltaic Panels. Mark. Sci. 31, 900–912. doi:10.1287/mksc.1120.0727

Boons, F., Lüdeke-Freund, F., 2013. Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. J. Clean. Prod., Sustainable Innovation and Business Models 45, 9–19. doi:10.1016/j.jclepro.2012.07.007

Brudermann, T., Reinsberger, K., Orthofer, A., Kislinger, M., Posch, A., 2013. Photovoltaics in agriculture: A case study on decision making of farmers. Energy Policy 61, 96–103. doi:10.1016/j.enpol.2013.06.081

Budde Christensen, T., Wells, P., Cipcigan, L., 2012. Can innovative business models overcome resistance to electric vehicles? Better Place and battery electric cars in Denmark. Energy Policy, Special Section: Frontiers of Sustainability 48, 498–505. doi:10.1016/j.enpol.2012.05.054

Calhoun, C., Rhoten, D., 2010. Integrating the social sciences: theoretical knowledge, methodological tools, and practical applications. In: Robert Frodeman, Julie Thompson Klein and Carl Mitcham, Eds. Oxford Handbook of Interdisciplinarity. New York: Oxford University Press.

Candelise, C., Winskel, M., Gross, R.J.K., 2013. The dynamics of solar PV costs and prices as a challenge for technology forecasting. Renew. Sustain. Energy Rev. 26, 96–107. doi:10.1016/j.rser.2013.05.012

Casper, S., Kettler, H., 2001. National Institutional Frameworks and the Hybridization of Entrepreneurial Business Models: The German and Uk Biotechnology Sectors. Ind. Innov. 8, 5–30. doi:10.1080/13662710120034383

Coenen, L., Benneworth, P., Truffer, B., 2012. Toward a spatial perspective on sustainability transitions. Res. Policy, Special Section on Sustainability Transitions 41, 968–979. doi:10.1016/j.respol.2012.02.014

Coenen, L., Díaz López, F.J., 2010. Comparing systems approaches to innovation and technological change for sustainable and competitive economies: an explorative study into conceptual commonalities, differences and complementarities. J. Clean. Prod. 18, 1149–1160. doi:10.1016/j.jclepro.2010.04.003

de La Tour, A., Glachant, M., Ménière, Y., 2013. Predicting the costs of photovoltaic solar modules in 2020 using experience curve models. Energy 62, 341–348. doi:10.1016/j.energy.2013.09.037

de la Tour, A., Glachant, M., Ménière, Y., 2011. Innovation and international technology transfer: The case of the Chinese photovoltaic industry. Energy Policy, Special Section on Offshore wind power planning, economics and environment 39, 761–770. doi:10.1016/j.enpol.2010.10.050

Dewald, U.(1), Truffer, B.(2), 2011. Market formation in technological innovation systems-diffusion of photovoltaic applications in Germany. Ind. Innov. 18, 285–300. doi:10.1080/13662716.2011.561028

Dewald, U., Fromhold-Eisebith, M., 2015. Trajectories of sustainability transitions in scale-transcending innovation systems: The case of photovoltaics. Environ. Innov. Soc. Transit. 17, 110–125. doi:10.1016/j.eist.2014.12.004

Dewald, U., Truffer, B., 2012. The Local Sources of Market Formation: Explaining Regional Growth Differentials in German Photovoltaic Markets. Eur. Plan. Stud. 20, 397–420. doi:10.1080/09654313.2012.651803

Dong, C., Wiser, R., 2013. The impact of city-level permitting processes on residential photovoltaic installation prices and development times: An empirical analysis of solar systems in California cities. Energy Policy 63, 531–542. doi:10.1016/j.enpol.2013.08.054

Dusonchet, L., Telaretti, E., 2010. Economic analysis of different supporting policies for the production of electrical energy by solar photovoltaics in western European Union countries. Energy Policy, Large-scale wind power in electricity markets with Regular Papers 38, 3297–3308. doi:10.1016/j.enpol.2010.01.053

Eisenhardt, K.M., 1989. Building Theories from Case Study Research. Acad. Manage. Rev. 14, 532–550. doi:10.2307/258557

Foxon, T.J., 2011. A coevolutionary framework for analysing a transition to a sustainable low carbon economy. Ecol. Econ. 70, 2258–2267. doi:10.1016/j.ecolecon.2011.07.014

Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res. Policy 31, 1257–1274. doi:10.1016/S0048-7333(02)00062-8

Glaser, B.G., Strauss, A.L., 1967. The discovery of grounded theory: strategies for qualitative research, 4. paperback printing. ed. Aldine, New Brunswick.

Gosens, J., Lu, Y., Coenen, L., 2015. The role of transnational dimensions in emerging economy “Technological Innovation Systems” for clean-tech. J. Clean. Prod. 86, 378–388. doi:10.1016/j.jclepro.2014.08.029

Graziano, M., Atkinson, C., 2014. The Influence of Spatial Setting and Socioeconomic Profile in Urban Areas in the Diffusion of Residential Photovoltaic Systems (SSRN Scholarly Paper No. ID 2529799). Social Science Research Network, Rochester, NY.

Graziano, M., Gillingham, K., 2014. Spatial patterns of solar photovoltaic system adoption: the influence of neighbors and the built environment. J. Econ. Geogr. lbu036. doi:10.1093/jeg/lbu036

Grübler, A., 2012. Grand Designs: Historical Patterns and Future Scenarios of Energy Technological Change. Historical Case Studies of Energy Technology Innovation in:

Chapter 24, The Global Energy Assessment. Grubler A., Aguayo, F., Gallagher, K.S., Hekkert, M., Jiang, K., Mytelka, L., Neij, L., Nemet, G. & C. Wilson. Cambridge University Press: Cambridge, UK.

Grübler, A., 2003. Technology and Global Change. Cambridge University Press.

Grübler, A., 1996. Time for a Change: On the Patterns of Diffusion of Innovation. Daedalus 125, 19–42.

Haas, R., 2004. Progress in markets for grid-connected PV systems in the built environment. Prog. Photovolt. Res. Appl. 12, 427–440. doi:10.1002/pip.560

Haas, R., 2003. Market deployment strategies for photovoltaics: an international review. Renew. Sustain. Energy Rev. 7, 271–315. doi:10.1016/S1364-0321(03)00062-5

Hansen, G.H., Steen, M., 2015. Offshore oil and gas firms' involvement in offshore wind: Technological frames and undercurrents. Environ. Innov. Soc. Transit. 17, 1–14. doi:10.1016/j.eist.2015.05.001

Hansen, T., Coenen, L., 2015. The geography of sustainability transitions: Review, synthesis and reflections on an emergent research field. Environ. Innov. Soc. Transit. 17, 92–109. doi:10.1016/j.eist.2014.11.001

Hekkert, M. p., Suurs, R. a. a., Negro, S. o., Kuhlmann, S., Smits, R. e. h. m., 2007. Functions of innovation systems: A new approach for analysing technological change. Technol. Forecast. Soc. Change 74, 413–432. doi:10.1016/j.techfore.2006.03.002

Helms, A.C., 2012. Keeping up with the Joneses: Neighborhood effects in housing renovation. Reg. Sci. Urban Econ. 42, 303–313. doi:10.1016/j.regsciurbeco.2011.07.005

Hess, D.J., 2016. The politics of niche-regime conflicts: Distributed solar energy in the United States. Environ. Innov. Soc. Transit. 19, 42–50. doi:10.1016/j.eist.2015.09.002

Huang, P., Negro, S.O., Hekkert, M.P., Bi, K., 2016. How China became a leader in solar PV: An innovation system analysis. Renew. Sustain. Energy Rev. 64, 777–789. doi:10.1016/j.rser.2016.06.061

Hughes, T.P., 1993. Networks of Power: Electrification in Western Society, 1880-1930. JHU Press.

Hummels, D., Ishii, J., Yi, K.-M., 2001. The nature and growth of vertical specialization in world trade. J. Int. Econ., Trade and Wages 54, 75–96. doi:10.1016/S0022-1996(00)00093-3

IPCC, 2014. Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jacobsson, S., Bergek, A., 2011. Innovation system analyses and sustainability transitions: Contributions and suggestions for research. Environ. Innov. Soc. Transit. 1, 41–57. doi:10.1016/j.eist.2011.04.006

Jacobsson, S., Bergek, A., 2004. Transforming the Energy Sector: The evolution of technological systems in renewable energy technology. Ind. Corp. Change 815.

Jacobsson, S., Lauber, V., 2006. The politics and policy of energy system transformation—explaining the German diffusion of renewable energy technology. Energy Policy 34, 256–276. doi:10.1016/j.enpol.2004.08.029

Jacobsson, S., Sandén, B.A., Bångens, L., 2004. Transforming the energy system - the evolution of the German technological system for solar cells. Technol. Anal. Strateg. Manag. 16, 3–30.

Karteris, M., Papadopoulos, A.M., 2012. Residential photovoltaic systems in Greece and in other European countries: A comparison and an overview. Adv. Build. Energy Res. 6, 141–158. doi:10.1080/17512549.2012.672005

Kemp, R., Schot, J., Hoogma, R., 1998. Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. Technol. Anal. Strateg. Manag. 10, 175–198. doi:10.1080/09537329808524310

Kemp, R., Soete, L., 1992. The greening of technological progress. Futures 24, 437–457. doi:10.1016/0016-3287(92)90015-8

Klein, J.T., 2010. A taxonomy of interdisciplinarity. In: Robert Frodeman, Julie Thompson Klein and Carl Mitcham, Eds. Oxford Handbook of Interdisciplinarity. New York: Oxford University Press.

Klein, J.T., 1990. Interdisciplinarity: History, Theory, and Practice. Wayne State University Press.

Krohn, W., 2010. Interdisciplinary cases and disciplinary knowledge. In: Robert Frodeman, Julie Thompson Klein and Carl Mitcham, Eds. Oxford Handbook of Interdisciplinarity. New York: Oxford University Press.

Kwan, C.L., 2012. Influence of local environmental, social, economic and political variables on the spatial distribution of residential solar PV arrays across the United States. Energy Policy 47, 332–344. doi:10.1016/j.enpol.2012.04.074

Li, H., Yi, H., 2014. Multilevel governance and deployment of solar PV panels in U.S. cities. Energy Policy 69, 19–27. doi:10.1016/j.enpol.2014.03.006

Linder, J., Cantrell, S., 2000. Changing Business Models: Surveying the Landscape. Accenture Institute for Strategic Change.

Los, B., Timmer, M.P., de Vries, G.J., 2015. How Global Are Global Value Chains? A New Approach to Measure International Fragmentation. J. Reg. Sci. 55, 66–92. doi:10.1111/jors.12121

Lundvall, B.-Å., 2010. National Systems of Innovation: Toward a Theory of Innovation and Interactive Learning. Anthem Press.

Ma, Z., 2010. On Relationships between Technology Standards and Patented Technology Licensing. J. Polit. Law 3, 16.

Malerba, F. (Ed.), 2009. Sectoral systems of innovation: concepts, issues and analyses of six major sectors in Europe. Cambridge Univ. Pr, Cambridge.

Markard, J., Hekkert, M., Jacobsson, S., 2015. The technological innovation systems framework: Response to six criticisms. Environ. Innov. Soc. Transit. 16, 76–86. doi:10.1016/j.eist.2015.07.006

Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: An emerging field of research and its prospects. Res. Policy, Special Section on Sustainability Transitions 41, 955–967. doi:10.1016/j.respol.2012.02.013

Markard, J., Truffer, B., 2008. Technological innovation systems and the multi-level perspective: Towards an integrated framework. Res. Policy 37, 596–615. doi:10.1016/j.respol.2008.01.004

Maxwell, J.A., 2008. Designing a Qualitative Study, in: Bickman, L., Rog, D.J. (Eds.), The SAGE Handbook of Applied Social Research Methods. SAGE Publications, Inc, Los Angeles.

Mazzarol, T., 2011. The Role of Word of Mouth in the Diffusion of Innovation, in: Hülsmann, M., Pfeffermann, N. (Eds.), Strategies and Communications for Innovations. Springer Berlin Heidelberg, pp. 117–131.

Miller, C.A., 2010. Policy challenges and university reform. In: Robert Frodeman, Julie Thompson Klein and Carl Mitcham, Eds. Oxford Handbook of Interdisciplinarity. New York: Oxford University Press.

Mont, O., Dalhammar, C., Jacobsson, N., 2006. A new business model for baby prams based on leasing and product remanufacturing. J. Clean. Prod., Product Service Systems: reviewing achievements and refining the research agenda 14, 1509–1518. doi:10.1016/j.jclepro.2006.01.024

Mukai, T., Kawamoto, S., Ueda, Y., Saijo, M., Abe, N., 2011. Residential PV system users' perception of profitability, reliability, and failure risk: An empirical survey in a local Japanese municipality. Energy Policy 39, 5440–5448. doi:10.1016/j.enpol.2011.05.019

Müller, S., Rode, J., 2013. The adoption of photovoltaic systems in Wiesbaden, Germany. Econ. Innov. New Technol. 22, 519–535. doi:10.1080/10438599.2013.804333

Neij, L., 2008. Cost development of future technologies for power generation—A study based on experience curves and complementary bottom-up assessments. Energy Policy 36, 2200–2211. doi:10.1016/j.enpol.2008.02.029

Nemet, G.F., 2006. Beyond the learning curve: factors influencing cost reductions in photovoltaics. Energy Policy 34, 3218–3232. doi:10.1016/j.enpol.2005.06.020

Nolan, J.M., Schultz, P.W., Cialdini, R.B., Goldstein, N.J., Griskevicius, V., 2008. Normative Social Influence is Underdetected. Pers. Soc. Psychol. Bull. 34, 913–923. doi:10.1177/0146167208316691

Noll, D., Dawes, C., Rai, V., 2014. Solar Community Organizations and active peer effects in the adoption of residential PV. Energy Policy 67, 330–343. doi:10.1016/j.enpol.2013.12.050

Oster, E., Thornton, R., 2009. Determinants of Technology Adoption: Private Value and Peer Effects in Menstrual Cup Take-Up (Working Paper No. 14828). National Bureau of Economic Research.

Overholm, H., 2015. Spreading the rooftop revolution: What policies enable solar-as-a-service? Energy Policy 84, 69–79. doi:10.1016/j.enpol.2015.04.021

Owen, A., Mitchell, G., Gouldson, A., 2014. Unseen influence—The role of low carbon retrofit advisers and installers in the adoption and use of domestic energy technology. Energy Policy 73, 169–179. doi:10.1016/j.enpol.2014.06.013

Palm, J., Tengvard, M., 2011. Motives for and barriers to household adoption of small-scale production of electricity: examples from Sweden. Sustain. Sci. Pract. Policy 7, 6–15.

Pateli, A., Giaglis, G., 2007. An Interdisciplinary Research Framework to Investigate Electronic Business Models, in: Handbook of Information Technology in Organizations and Electronic Markets. WORLD SCIENTIFIC, pp. 119–135.

Provance, M., Donnelly, R.G., Carayannis, E.G., 2011. Institutional influences on business model choice by new ventures in the microgenerated energy industry. Energy Policy 39, 5630–5637. doi:10.1016/j.enpol.2011.04.031

Quitzow, R., 2015. Dynamics of a policy-driven market: The co-evolution of technological innovation systems for solar photovoltaics in China and Germany. Environ. Innov. Soc. Transit. 17, 126–148. doi:10.1016/j.eist.2014.12.002

Rai, V., Reeves, D.C., Margolis, R., 2016. Overcoming barriers and uncertainties in the adoption of residential solar PV. Renew. Energy 89, 498–505. doi:10.1016/j.renene.2015.11.080

Rai, V., Robinson, S.A., 2013. Effective information channels for reducing costs of environmentally- friendly technologies: evidence from residential PV markets. Environ. Res. Lett. 8, 14044. doi:10.1088/1748-9326/8/1/014044

Raven, R., Schot, J., Berkhout, F., 2012. Space and scale in socio-technical transitions. Environ. Innov. Soc. Transit. 4, 63–78. doi:10.1016/j.eist.2012.08.001

Reim, W., Parida, V., Örtqvist, D., 2015. Product–Service Systems (PSS) business models and tactics – a systematic literature review. J. Clean. Prod., Special Volume: Why have “Sustainable Product-Service Systems” not been widely implemented? 97, 61–75. doi:10.1016/j.jclepro.2014.07.003

REN 21, 2014. Renewables 2014 Global Status Report. Renewable Energy Policy Network for the 21st Century, Paris.

Richards, L., 2007. Qualitative Research Design, in: Readme First for a User’s Guide to Qualitative Methods. Sage Publications, Thousand Oaks Calif, p. 288.

Richter, L.-L., 2013. Social Effects in the Diffusion of Solar Photovoltaic Technology in the UK.

Richter, M., 2013. German utilities and distributed PV: How to overcome barriers to business model innovation. Renew. Energy 55, 456–466. doi:10.1016/j.renene.2012.12.052

Rode, J., Weber, A., 2013. Does Localized Imitation Drive Technology Adoption? A Case Study on Solar Cells in Germany. Working paper.

Rogers, E.M., 1983. Diffusion of innovations. New York : Free Press, 1983.

Rosenberg, N., 1994. Exploring the Black Box: Technology, Economics, and History, First Edition edition. ed. Cambridge University Press, Cambridge England ; New York.

Rosoff, L., Sinclair, M., 2009. Smart Solar Marketing Strategies. Clean Energy Group & SmartPower.

Sandén, B.A., 2005. The economic and institutional rationale of PV subsidies. Sol. Energy, ISES Solar World Congress 2003 78, 137–146. doi:10.1016/j.solener.2004.03.019

Sandén, B.A., Jacobsson, S., Palmblad, L., Porsö, J., 2008. Assessment of the impact of a market formationprogramme on the Swedish PV innovation system. DIME

International Conference "Innovation, sustainability and policy", 11–13 September 2008.

Schelly, C., 2014. Residential solar electricity adoption: What motivates, and what matters? A case study of early adopters. Energy Res. Soc. Sci. 2, 183–191. doi:10.1016/j.erss.2014.01.001

Schleicher-Tappeser, R., 2012. How renewables will change electricity markets in the next five years. Energy Policy, Special Section: Frontiers of Sustainability 48, 64–75. doi:10.1016/j.enpol.2012.04.042

Schot, J., Kanger, L., Verbong, G., 2016. The roles of users in shaping transitions to new energy systems. Nat. Energy 1, 16054. doi:10.1038/nenergy.2016.54

Shafer, S.M., Smith, H.J., Linder, J.C., 2005. The power of business models. Bus. Horiz. 48, 199–207. doi:10.1016/j.bushor.2004.10.014

Sharif, N., 2006. Emergence and development of the National Innovation Systems concept. Res. Policy 35, 745–766. doi:10.1016/j.respol.2006.04.001

Shih, L.H., Chou, T.Y., 2011. Customer concerns about uncertainty and willingness to pay in leasing solar power systems. Int. J. Environ. Sci. Technol. 8, 523–532. doi:10.1007/BF03326238

Shrimali, G., Jenner, S., 2013. The impact of state policy on deployment and cost of solar photovoltaic technology in the U.S.: A sector-specific empirical analysis. Renew. Energy 60, 679–690. doi:10.1016/j.renene.2013.06.023

Simpson, G., Clifton, J., 2015. The emperor and the cowboys: The role of government policy and industry in the adoption of domestic solar microgeneration systems. Energy Policy 81, 141–151. doi:10.1016/j.enpol.2015.02.028

Stewart, J., 2007. Local Experts in the Domestication of Information and Communication Technologies. Inf. Commun. Soc. 10, 547–569. doi:10.1080/13691180701560093

Stridh, B., Yard, S., Larsson, D., Karlsson, B., 2013. Production cost of PV electricity in Sweden. In: Proceedings for 28th EU PVSEC, 30 September 2013-4 October 2013, Paris.

Suurs, R. a. A., 2009. Motors of sustainable innovation : Towards a theory on the dynamics of technological innovation systems. Utrecht University.

Suurs, R.A.A., Hekkert, M.P., 2009. Cumulative causation in the formation of a technological innovation system: The case of biofuels in the Netherlands. Technol. Forecast. Soc. Change 76, 1003–1020. doi:10.1016/j.techfore.2009.03.002

Svensk Solenergi, 2016. Remissvar angående Energimyndighetens rapport Kontrollstation 2017 för elcertifikat – delredovisning 2 och förslag på kvoter för 18 TWh till 2030 (ER 2016:19).

Swedenergy, 2012. Elcertifikat [WWW Document]. URL http://www.svenskenergi.se/Elfakta/Elpriser-och-skatter/Elcertifikat/ (accessed 3.4.16).

Timmer, M. p. (1), Los, B.(1), de Vries, G. j. (1), Stehrer, R.(2), 2013. Fragmentation, incomes and jobs: An analysis of european competitiveness. Econ. Policy 28, 613–661. doi:10.1111/1468-0327.12018

Tukker, A., 2004. Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. Bus. Strategy Environ. 13, 246–260. doi:10.1002/bse.414

Unruh, G.C., 2000. Understanding carbon lock-in. Energy Policy 28, 817–830. doi:10.1016/S0301-4215(00)00070-7

Weber, K.M., Rohracher, H., 2012. Legitimizing research, technology and innovation policies for transformative change. Res. Policy 41, 1037–1047. doi:10.1016/j.respol.2011.10.015

Wieczorek, A.J., Hekkert, M.P., Coenen, L., Harmsen, R., 2015. Broadening the national focus in technological innovation system analysis: The case of offshore wind. Environ. Innov. Soc. Transit. 14, 128–148. doi:10.1016/j.eist.2014.09.001

Yang, C.-J., 2010. Reconsidering solar grid parity. Energy Policy, Large-scale wind power in electricity markets with Regular Papers 38, 3270–3273. doi:10.1016/j.enpol.2010.03.013

Yin, R.K., 2009. Case study research: design and methods, 4th ed. ed, Applied social research methods. Sage Publications, Los Angeles, Calif.

Zhai, P., Williams, E.D., 2012. Analyzing consumer acceptance of photovoltaics (PV) using fuzzy logic model. Renew. Energy 41, 350–357. doi:10.1016/j.renene.2011.11.041

Zhang, F., Deng, H., Margolis, R., Su, J., 2015. Analysis of distributed-generation photovoltaic deployment, installation time and cost, market barriers, and policies in China. Energy Policy 81, 43–55. doi:10.1016/j.enpol.2015.02.010

Zheng, C., Kammen, D.M., 2014. An innovation-focused roadmap for a sustainable global photovoltaic industry. Energy Policy 67, 159–169. doi:10.1016/j.enpol.2013.12.006

Zott, C., Amit, R., Massa, L., 2011. The Business Model: Recent Developments and Future Research. J. Manag. 37, 1019–1042. doi:10.1177/0149206311406265

Appendix A: Survey questionnaire for paper 3

Hej,

Hjälp till att öka kunskaperna om hur användningen av solceller kan stödjas!

Jag är doktorand vid Lunds universitet och genomför just nu en studie kring hur faktorer på lokal nivå påverkar privatpersoners beslut att skaffa en solcellsanläggning. Jag kontaktar dig då du, enligt data jag erhållit från Energimyndigheten, har en solcellsanläggning.

Jag är tacksam om du vill fylla i enkäten nedan. Det går fort, och genom din medverkan deltar du i utlottningen av två presentkort värda vardera 1000 kr på Beijer Byggmaterial. Enkäten skickas till runt 100 personer. Alla svar kommer att behandlas konfidentiellt. Jag är mycket tacksam för din medverkan.

Du svarar genom att använda bifogat svarskuvert. Portot är givetvis betalt. Jag skulle behöva ditt svar senast 16 februari 2015.

Med vänlig hälsning,

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<u>Frågor (om du är osäker, svara det du *tror* är mest riktigt):</u>

1. Innehar du ett solcellssystem?

☐ Ja

☐ Nej

Ev. övrig info:____

2. Är detta system placerat på eller i anslutning till ditt hem?

☐ Ja

☐ Nej

Ev. övrig info:____

3. Innan du på allvar började fundera på att införskaffa ett solcellssystem, **kände du till** något solcellssystem **i din kommun eller grannkommun**?

☐ Ja

☐ Nej

Om du svarade "Ja" på fråga 3, besvara frågorna 3.1-3.3 (annars, hoppa direkt till fråga 4.):

3.1 Hur var systemet/systemen i fråga 3 placerade? (Du kan välja flera alternativ.)

☐ På villatak

☐ På annan byggnads tak

☐ På mark

☐ Vet ej

☐ Annat:____

3.2 Hur fick du kännedom om systemet/systemen? (Du kan välja flera alternativ.)

☐ Jag såg solcellssystemet

☐ En person jag kände berättade för mig om solcellssystemet

☐ Annan person berättade för mig om solcellssystemet

☐ Genom massmedia

☐ Annat:____________________________________

3.3 Ungefär hur långt från ditt hem fanns **det närmaste** solcellssystemet du kände till?

☐ Mindre än 300 meter

☐ 300 meter – 1 kilometer

☐ 1 kilometer – 5 kilometer

☐ Mer än 5 kilometer

4. Innan du på allvar började fundera på att införskaffa ett solcellssystem, hade någon person i din bekantskapskrets ett solcellsystem som du kände till?

☐ Ja, en nära bekant

☐ Ja, en mindre nära bekant

☐ Nej

Ev. övrig info:____

5. Innan du på allvar började fundera på att införskaffa ett solcellssystem, kände du till om följande fanns **i din kommun eller grannkommun**:

Något företag som jobbade med installation/försäljning av solcellssystem?

☐ Ja

☐ Nej

Något företag som jobbade med solvärme?
(Installation/produktion/försäljning av solvärmeteknik/solfångare)

☐ Ja

☐ Nej

Någon organisation som jobbade med kooperativt ägda solenergianläggningar?

☐ Ja

☐ Nej

Annat?:____

6. Innan du på allvar började fundera på att införskaffa ett solcellssystem, kände du till huruvida ditt elbolag köpte el från privatpersoners solcellssystem?

☐ Ja, jag visste att mitt **elnätsbolag eller därtill kopplat elhandelsbolag** köpte solel av privatpersoner

☐ Ja, jag visste att **varken** **mitt elnätsbolag eller därtill kopplat elhandelsbolag** köpte solel av privatpersoner

☐ Ja, jag visste att det **elhandelsbolag** jag använde, vilket **inte var kopplat till mitt elnätsbolag**, köpte solel av privatpersoner

☐ Nej, jag kände inte till huruvida något elbolag jag använde köpte solel av privatpersoner

Ev. övrig info:____

Om du visste att bolaget köpte solel av privatpersoner: Bidrog denna vetskap till ditt beslut att införskaffa en solcellsanläggning?

☐ Ja, i hög grad

☐ Ja, i någon grad

☐ Nej

Ev. övrig info:____________________________________

7. *Hur <u>väcktes ditt intresse</u> för solceller?*

Gradera följande faktorer enligt hur viktiga de var för att <u>väcka ditt intresse</u> för solceller, där 1 innebär att faktorn inte alls var viktig och 5 innebär att faktorn var mycket viktig. Ringa in en siffra.

	Ej viktigt				*Mycket viktigt*
En eller flera personer jag kände och som bodde inom min kommun eller grannkommun informerade mig om solceller	1	2	3	4	5
En eller flera personer jag kände och som ***inte*** bodde inom min kommun eller grannkommun informerade mig om solceller	1	2	3	4	5
En granne informerade mig om solceller	1	2	3	4	5
Solcellsanläggning(ar) monterade på ***privatbostad*** inom min kommun eller grannkommun väckte mitt intresse	1	2	3	4	5
Solcellsanläggning(ar) monterade på ***annan byggnad*** än privatbostad inom min kommun eller grannkommun väckte mitt intresse	1	2	3	4	5
Solcellsanläggning(ar) monterade på ***mark*** inom min kommun eller grannkommun väckte mitt intresse	1	2	3	4	5
Pågående installationsarbete av solceller i min kommun eller grannkommun väckte mitt intresse	1	2	3	4	5
Ett företag som jobbade med installation/försäljning av solcellssystem där jag bor väckte mitt intresse på annat sätt än genom pågående installationsarbete	1	2	3	4	5
Ett elbolag verksamt där jag bor väckte mitt intresse	1	2	3	4	5
Ett företag/organisation som på annat sätt jobbade med solenergi inom min kommun eller grannkommun väckte mitt intresse	1	2	3	4	5
Ett seminarium/kurs/informationsträff eller liknande jag besökte inom min kommun eller grannkommun väckte mitt intresse	1	2	3	4	5
Information i rikstäckande TV eller tidskrift väckte mitt intresse	1	2	3	4	5
En hemsida på internet väckte mitt intresse	1	2	3	4	5

8. *Vad påverkade ditt <u>slutgiltiga beslut</u> att skaffa solceller?*

Hur erhöll du den information du använde som grund för ditt slutgiltiga beslut att skaffa en solcellsanläggning? Gradera följande alternativ enligt hur viktiga de var som informationskällor, där 1 innebär att de inte alls var viktiga och 5 innebär att de var mycket viktiga. Ringa in en siffra.

	Ej viktigt				*Mycket viktigt*
Kommunikation med person jag kände som bodde inom min kommun eller grannkommun	1	2	3	4	5
Kommunikation med person jag kände som ***inte*** bodde inom min kommun eller grannkommun	1	2	3	4	5
Kommunikation med granne	1	2	3	4	5
Kommunikation med företag som installerade/sålde solcellsanläggningar där jag bor	1	2	3	4	5
Kommunikation med elbolag verksamt där jag bor	1	2	3	4	5
Kommunikation med företag/organisation som på annat sätt jobbade med solenergi inom min kommun eller grannkommun	1	2	3	4	5
Besök på seminarium/kurs/informationsträff eller liknande inom min kommun eller grannkommun	1	2	3	4	5
Besök på hemsida tillhörande ett företag som installerade/sålde solcellssystem där jag bor	1	2	3	4	5
Besök på hemsida tillhörande elbolag verksamt där jag bor	1	2	3	4	5
Rikstäckande TV eller tidskrift	1	2	3	4	5
Hemsida på internet	1	2	3	4	5

Besvara de av följande frågor som är relevanta. Om flera alternativ stämmer, rangordna dessa genom att markera det viktigaste alternativet med "1", det näst viktigaste med "2", osv.

9. Om pågående installationsarbete av solceller i din kommun eller grannkommun bidragit till att väcka ditt intresse, hur fick du kännedom om installationsarbetet?
   - ☐ Jag såg installationsarbetet
   - ☐ En person jag kände berättade för mig om installationsarbetet
   - ☐ Annan person berättade för mig om installationsarbetet
   - ☐ Genom massmedia
   - ☐ Annat:____

10. Om kommunikation med en eller flera grannar eller personer du kände inom din kommun eller grannkommun bidragit till ditt beslut att skaffa solceller, har någon av dessa personer själv ett solcellssystem?
    - ☐ Ja, personen hade ett solcellssystem vid tidpunkten för kommunikationen
    - ☐ Nej, men personen var på väg att skaffa ett solcellssystem
    - ☐ Nej, och personen var inte på väg att skaffa ett solcellssystem

11. Om kommunikation med granne eller person du kände inom din kommun eller grannkommun bidragit till ditt beslut att skaffa solceller, vilken karaktär hade informationen?
    - ☐ Personen rekommenderade mig uttryckligen att skaffa ett solcellssystem
    - ☐ Personen informerade mig om solceller på ett ganska neutralt sätt (varken tydlig rekommendation eller avrådan)

☐ Personen avrådde mig från att skaffa ett solcellssystem

12. Om ett företag som installerar eller säljer solcellssystem där du bor bidragit till att väcka ditt intresse för solceller, på vilket sätt skedde detta?
    ☐ Reklam
    ☐ Jag hörde talas om företaget ryktesvägen
    ☐ Jag kände en person verksam inom företaget
    ☐ Information på företagets hemsida
    ☐ Tidningsartikel, radio- eller tv-inslag
    ☐ Annat:____

13. Om en aktivitet såsom ett seminarium e.d. inom din kommun eller grannkommun väckt ditt intresse eller fungerat som informationskälla, besvara gärna följande frågor efter bästa förmåga:

    - Vem var arrangör?:

      ____

    - Hade aktiviteten någon särskild målgrupp? Vilken?:

      ____

    - När och var ägde aktiviteten rum?:

      ____

14. Om du kände till ett solcellssystem i din kommun eller grannkommun innan du på allvar började fundera på att införskaffa ett solcellssystem: **Hur troligt är det att du hade skaffat ett solcellssystem om du inte hade haft denna kännedom?**
    ☐ Det är troligt att jag ändå hade skaffat ett solcellssystem
    ☐ Det är då mindre troligt att jag skaffat ett solcellssystem
    ☐ Vet ej

15. Har du något mer att tillägga?:

____

____

____

____

____

Eventuellt kommer jag att vilja kontakta dig för att ställa någon följdfråga. Kan du tänka dig att bli kontaktad? Lämna i så fall ditt telefonnummer här:______________________________

Tack för din medverkan! Lägg enkäten i det bifogade svarskuvertet och glöm inte att posta ☺.

Appendix B: Survey questionnaire for paper 4

Hej,

Hjälp till att öka kunskaperna om hur användningen av solceller kan stödjas!

Jag är forskare vid Lunds universitet och genomför just nu en studie kring hur faktorer på lokal nivå påverkar privatpersoners beslut att skaffa en solcellsanläggning. Jag kontaktar dig då du, enligt data jag erhållit från Energimyndigheten, har en solcellsanläggning.

Jag är tacksam om du vill fylla i enkäten nedan. Det går fort, och genom din medverkan deltar du i utlottningen av ett presentkort värt 1000 kr på Beijer Byggmaterial. Alla svar kommer att behandlas konfidentiellt. Jag är mycket tacksam för din medverkan.

Du svarar genom att använda bifogat svarskuvert. Portot är givetvis betalt. Jag skulle behöva ditt svar senast 25 maj 2015.

Med vänlig hälsning,

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Instruktioner:

- **Om du är osäker, svara det du *tror* är mest riktigt**
- **Du väljer själv hur du vill tolka ordet ”grannskap”**
- **Om någon annan person än du i ditt hushåll varit den drivande i att skaffa solceller, be gärna denna person fylla i enkäten istället**

<u>Frågor:</u>

16. Innehar du ett solcellssystem?

☐ Ja

☐ Nej

Ev. övrig info:____

17. Hur är detta solcellssystem placerat?

☐ På/vid mitt hem

☐ På/vid mitt fritidshus

☐ Annat:____

18. Vilket år beställde du installation av systemet (när skrevs kontraktet)?

Svar: År____

Nedan följer två grupper av påståenden, där du graderar olika faktorer efter hur viktiga de var som inspirationskälla för ditt beslut att skaffa solceller. Den första gruppen (fråga 4) handlar om vad som väckte ditt intresse för solceller – alltså vad som inspirerade dig i ett tidigt skede av beslutsprocessen. Gruppen därefter (fråga 5) handlar om vad som påverkade ditt slutgiltiga beslut att skaffa solceller – alltså vad som inspirerade dig i ett senare skede.

19. Hur ***väcktes ditt intresse*** för solceller? (Ringa in en siffra)

	Ej viktigt				*Mycket viktigt*
Person ***bosatt i mitt grannskap*** (men utanför mitt hushåll) informerade mig om solceller	1	2	3	4	5
Person jag kände som ***inte*** bodde i mitt grannskap informerade mig om solceller	1	2	3	4	5
Jag ***såg*** solcells- eller solvärmesystem i mitt grannskap	1	2	3	4	5
Någon ***berättade för mig*** om solcellssystem ***som fanns i mitt grannskap***	1	2	3	4	5
Jag ***såg pågående installationsarbete*** av solcells- eller solvärmesystem i mitt grannskap	1	2	3	4	5
Någon ***berättade för mig*** om installationsarbete av solcellssystem som pågick i mitt grannskap	1	2	3	4	5

20. Vad ***påverkade ditt slutgiltiga beslut*** att skaffa solceller? (Ringa in en siffra)

	Ej viktigt				*Mycket viktigt*
Person ***bosatt i mitt grannskap*** (men utanför mitt hushåll) informerade mig om solceller	1	2	3	4	5
Person jag kände som ***inte*** bodde i mitt grannskap informerade mig om solceller	1	2	3	4	5
Jag ***såg*** solcells- eller solvärmesystem i mitt grannskap	1	2	3	4	5
Någon ***berättade för mig*** om solcellssystem ***som fanns i mitt grannskap***	1	2	3	4	5
Jag ***såg pågående installationsarbete*** av solcells- eller solvärmesystem i mitt grannskap	1	2	3	4	5
Någon ***berättade för mig*** om installationsarbete av solcellssystem som pågick i mitt grannskap	1	2	3	4	5

21. Såg du något av följande i ditt grannskap innan du definitivt bestämde sig för att skaffa solceller? Du kan markera flera alternativ.
    - ☐ Solcellssystem
    - ☐ Solvärmesystem
    - ☐ Solenergisystem av okänd typ (jag vet inte om det var solceller eller solvärme)

22. Denna fråga besvaras av dig som markerade något av alternativen på fråga 6 (om du inte markerade något på fråga 6, gå direkt till fråga 8). Ringa in en siffra.
    Att se solcells- eller solvärmesystem i mitt grannskap…

	Instämmer inte alls				*Instämmer helt och hållet*
…gav mig en mer positiv bild av solceller	1	2	3	4	5
…ökade min benägenhet att tro att solceller kan vara en investering med låg risk	1	2	3	4	5
…ökade min benägenhet att tro att solceller kan vara tekniskt tillförlitliga	1	2	3	4	5
…ökade min benägenhet att tro att solceller kan vara ekonomiskt gångbara i svenskt klimat	1	2	3	4	5
…ökade min benägenhet att tro att solceller kan tillföra mitt hus estetiska värden	1	2	3	4	5
…bidrog till att jag skaffade solceller tidigare än vad jag annars skulle ha gjort	1	2	3	4	5

23. Hade du kontakt med någon solcellsägare i ditt grannskap innan du definitivt bestämde sig för att skaffa solceller?
    - ☐ Ja
    - ☐ Nej

Om du svarade ”Ja” på fråga 8, besvara då frågorna 9-12. Annars, gå direkt till fråga 13.

24. Vid denna kontakt fick jag information om… (du kan markera flera alternativ)
    - ☐ Ekonomisk prestanda hos solceller
    - ☐ Tekniska egenskaper hos solceller
    - ☐ Bidrag som kan fås för solceller

☐ Annat:____

25. Vilken relation hade du främst med denne solcellsägare? (Välj ett alternativ.)
☐ Granne
☐ Vän
☐ Släkting
☐ Annat:____

26. Ringa in en siffra för varje påstående nedan.
Att kommunicera med solcellsägare i mitt grannskap…

	Instämmer inte alls				*Instämmer helt och hållet*
…gav mig en mer positiv bild av solceller	1	2	3	4	5
…ökade min benägenhet att tro att solceller kan vara en investering med låg risk	1	2	3	4	5
…ökade min benägenhet att tro att solceller kan vara tekniskt tillförlitliga	1	2	3	4	5
…ökade min benägenhet att tro att solceller kan vara ekonomiskt gångbara i svenskt klimat	1	2	3	4	5
…ökade min benägenhet att tro att solceller kan tillföra mitt hus estetiska värden	1	2	3	4	5
…bidrog till att jag skaffade solceller tidigare än vad jag annars skulle ha gjort	1	2	3	4	5

27. Var kontakten med solcellsägare till någon hjälp för dig i din beslutsprocess att skaffa solceller? Hur?:

____

____

____

____

28. Tror du att du själv har påverkat någon i ditt grannskap till att skaffa solceller? Ringa in en siffra för varje påstående nedan (om du känner dig alltför osäker kan du lämna tomt).

	Instämmer inte alls				*Instämmer helt och hållet*
Att jag har pratat med personer i mitt grannskap har lett till att någon i mitt grannskap har skaffat solceller	1	2	3	4	5
Att personer i mitt grannskap har sett mitt solcellssystem har lett till att någon i mitt grannskap har skaffat solceller	1	2	3	4	5

29. Gör en uppskattning efter bästa förmåga: Hur många veckor tog det från att du på allvar började fundera på att införskaffa en solcellsanläggning tills dess att du tog det slutgiltiga beslutet att införskaffa en solcellsanläggning?
Svar:____________________________________veckor

30. Har du något mer att tillägga?:

____

____

____

____

____

Eventuellt kommer jag att vilja kontakta dig för att ställa någon följdfråga. Kan du tänka dig att bli kontaktad? Lämna i så fall ditt telefonnummer här:________________________________

Tack för din medverkan! Lägg enkäten i det bifogade svarskuvertet och glöm inte att posta ☺.

Appendix C: Interview guide for paper 4

For paper 4, interviews were of a relatively higher importance than for the other papers. Thus, the interview guide used for paper 4 is provided in the following. The guide was developed somewhat during the research process, and guides that were somewhat different from that presented below were thus used for the earlier interviews. The guide was not strictly followed, but a semi-structured interview technique was used.

Questions for all interviewees:

Kan du berätta om hur du fick idén att skaffa solceller?

    När fick idén?

    När skaffade solceller?

Hur fick du information om solceller?

    Alternativen nedan:

    Ekonomi (bidrag, försäljning av överskottsel)

    Dimensionering, orientering (platt på tak eller upplutade)?

    Prestanda? (Produktion, livslängd, miljö)

    Regler? (Bygglov, nätanslutning?)

    Användarvänlighet?

Questions for interviewees that had been in contact with previous adopters:

Du uppgav i enkäten att du hade pratat med någon som hade solceller innan du bestämde dig för att skaffa egna – kan du berätta lite om det?

Vad hade du för relation till personen?

Vad berättade personen?

Rekommenderade han/hon solceller?

Upplevde du att den information du ville ha matchade den du fick?

Fick du någon ”aha-upplevelse”?

Hur påverkades din attityd till solceller av kontakten?

Fick du din bild av solceller bekräftad?

Vem tog upp ämnet solceller – du eller han?

Sökte du upp honom/henne?

Varför?

Direktkontakt? Mejl/chat?

Hur mycket visste du om solceller innan kontakten?

Hade du funderat på att skaffa solceller innan kontakten?

Hur var personens råd vad gäller:

Kvalitet?

Trovärdighet

Trevligt att interagera med personen?

Lätt att förstå?

Hade personen mycket tid att prata?

Hur var personens råd i jämförelse med råd du fick från andra håll (installatör, elnätsbolag, etc.)?

Fick du samma typ av info från dessa källor?

Hur nära varandra bor ni?

Vad brukar ni prata om?

Hur skulle du beskriva personen?

Kön

Ålder

Utbildning/jobb/kvalifikationer

Personlighet

Jämför med att andra större investeringar, t.ex. att köpa en bil, vilken roll spelare råd från personer i din omgivning vad gäller solceller?

Skulle du ha *velat* ha mer kontakt med tidigare solcellsägare?

Trialability?

Questions for interviewees that had seen PV in their neighborhoods

Du uppgav i enkäten att du sett solceller i ditt närområde innan du bestämde dig för att skaffa egna solceller – kan du berätta lite om det?

Hur var den placerad?

Kände du dess ägare?

Fick du veta att han/hon hade solceller genom att se dem?

Kände du till något om dess ägare?

Visste du om det var solceller eller solvärme du såg?

Om nej: när fick du veta vad det var?

Hade du funderat på att skaffa solceller innan du såg anläggningen?

Kommer du ihåg vilka tankar du hade efter att ha sett anläggningen?

Vad var viktigast: att se solceller eller att prata med solcellsägareägare? I vilka faser av beslutsprocessen var de viktiga?

<u>Questions for all interviewees:</u>

Din ålder?

Din sysselsättning/utbildning?

Beskriv ditt grannskap

Finns mycket kontakt mellan grannarna?

Har du mycket kontakt med andra i området?

Hur länge har du bott i ditt hus?

Vilka investeringar/förbättringar har du gjort medan du bodde där?

Vart vänder du dig vanligtvis för information/stöd när du gör sådana förbättringar?

Varför vänder du dig dit?

Har du vänt dig till andra *mer* för PV?

Varför/Varför inte?

Skulle du ha vänt dig mer till andra om du känt personer med kunskap?

Mer än för andra investeringar?

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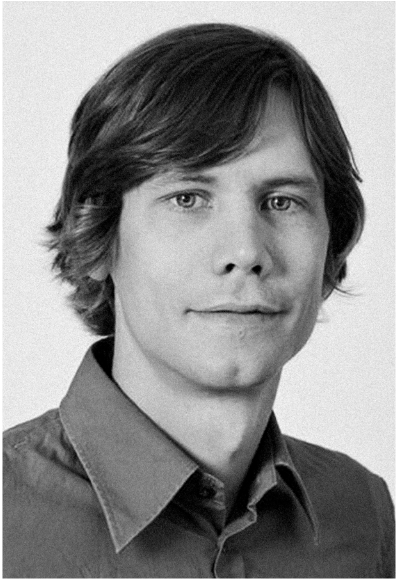

Solar photovoltaics (PV) is a renewable energy technology that converts solar irradiation into electricity. PV is technically mature and has a huge potential to offset fossil fuel generated electricity worldwide. PV is currently reaching cost-competitiveness in an increasing number of regions around the world, not least in residential (rooftop) applications, where it allows homeowners to produce their own electricity. Residential PV does, however, face various barriers within the sociotechnical system in which it is to be deployed. This thesis investigates barriers and drivers to PV deployment in different geographical contexts, thus providing knowledge on how to facilitate a sustainability transition in the electricity sector.

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