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Convergent and divergent learning in photovoltaic pilot projects and subsequent niche development

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A proposed strategy to facilitate the use and development of radical new sustainable technologies is the creation of niches. Learning in these niches and the social embedding of learning experiences can stimulate changes in existing sociotechnological regimes. Pilot projects in which new technologies are used may form part of these niches. This article describes the results of a Dutch research project involving photovoltaics on learning within pilot projects and subsequent actions of the participating parties. The central questions are whether and how internal processes, such as open and creative negotiations, foster learning and how such learning relates to subsequent niche developments. The study suggests that pilot projects could encourage both convergent and divergent learning, depending on whether participants' learning experiences and expectations of the new technology start to align. Although the two types of learning can coexist, they seem related to different process conditions. The implication of these findings is that the management of pilot projects to contribute to regime change involves strategic choices about stimulating either the opening or the closing of the novelty's interpretative flexibility.

KEYWORDS: learning, technological change, solar cells, renewable energy resources, development projects, management

Introduction

Renewable energy technologies such as photovoltaics (PV) can play a major role in the move toward sustainable energy provision and use. At the same time, the relatively new approach of strategic niche management (SNM) offers a policy instrument for challenging existing sociotechnological regimes and thus stimulating increased application of radical sustainable technologies (Raven, 2005; Schot & Geels, 2008). Originally developed in the Netherlands, the SNM approach can also serve as an analytical framework. Notable examples of early work on SNM include Rip (1989) and Schot et al. (1994; 1996).

The starting point is that large-scale application of a radical new technology is possible only if severe bottlenecks can be overcome. The existing sociotechnological regime—the rules according to which existing technologies are considered self-evident (become locked-in)—typically hinders the introduction of novel technologies. Changes are therefore required in scientific knowledge, engineering practices, production processes, product characteristics, competencies, established user preferences, infrastructure, and so forth (Schot et al. 1994).

The conceptual idea of SNM, which aims to overcome lock-in, is grounded in quasievolutionary theories of technological change in which variation

and selection are no longer seen as independent processes and in related notions of technology assessment that aim to manage technological development (Schot, 1992). Historical research confirms that initially many ultimately successful technologies were applied in small isolated parts of the market, so-called market niches (Schot, 1998). These are small application domains in which a novel idea already has some specific advantages over the established technology, although the innovation and its associated user preferences require further development (Hoogma et al. 2002). In these niches, incipient technologies have the opportunity to mature while new ideas evolve about their meaning, user preferences, desirable product development, needed infrastructure, and unexpected effects. The development and specification of these ideas are called learning processes. If market niches do not come into existence spontaneously, but a new technology is expected to have high societal advantages, then a government or company could create a protected niche by providing shelter (e.g., through the provision of a subsidy) to facilitate the process of bringing a technology into actual use.

Scholars of SNM regard niches as potential starting points for sociotechnological regime change, although they have typically assumed that the chance to contribute to such transitions is quite small. The central dynamic is considered to be niche branching,

a process in which niches arise and grow, while a specific new technology is applied in an increasing number of market segments. It is a coevolutionary process in which changes in the knowledge of actors, user preferences, and infrastructure occur in tandem with consistent changes in technology. Geels (2002) provides the example of the substitution of sailing ships by steamships, which started in small niches such as inland waterways and ports and for mail transport. The complete substitution of sailing ships ultimately came with mass emigration from Europe to the United States and the opening of the Suez Canal (which was not amenable to sailing ships).

In the early SNM literature, the main transition dynamic of regime change is thus regarded as an incipient technology that ultimately substitutes for an incumbent technology via a process of niches branching out, growing, and eventually replacing the regime. This process occurs if the niches align with, and are strengthened by, changes in the regime that are induced by pressure from external developments at the macro-scale (or landscape) level, such as an economic crisis, a natural disaster, or a particular demographic change (Weber et al. 1999; Kemp et al. 2001), with the consequent destabilization of the incumbent regime.

More recent analysis of transition processes has focused on interactions among developments at the three different levels of analysis: the micro-scale niche, the meso-scale regime, and the macro-scale landscape (Raven, 2005; Smith, 2007; Schot & Geels, 2008). In response to the critique that the niche approach overemphasizes micro-scale developments as the core locus of change, Geels & Schot (2007) developed a typology of ideal typical transition pathways. In addition to the substitution trajectory, they, for instance, distinguish pathways in which niche innovations are adopted as add-ons to the existing regime. In each of these pathways, it appears that both an opening of new opportunities (by a proliferation of niches) and a closing down (with one or a few niches becoming dominant through a process of selection) play roles.

Questions persist regarding the relationship among deliberate protection of niches, learning, niche branching, and regime change. Furthermore, the analytical framework of the niche approach remains based mainly on conceptualization of past regime shifts that came about without any intervention (or niche management, as we would say now). We are also unable to draw many conclusions from existing, deliberately managed niches (for instance, from subsidized experiments with new forms of sustainable transportation) because they have not had the time to contribute to regime change (Hoogma, 2000; van Mierlo, 2002; Raven, 2005). Whether the historic

processes around autonomous niche development and regime change can be taken as starting points for deliberate niche management therefore remains to be seen. In this regard, there is a need for more empirical elaboration and testing of the niche approach.

Recent work on sociotechnological innovation pleads for more research on learning in niches and the wider influence of these protected spaces (Schot & Geels, 2008; Smith et al. 2010). In this article, learning is the key concept for understanding niche developments from a micro-level perspective. I propose to address learning by probing into a protected niche, and even further down to the level of single pilot projects, to clarify whether and how it is possible to deliberately foster learning in and around such projects to stimulate niche development with the ultimate aim of contributing to regime change (cf., Brown et al. 2003). It is assumed that the success or failure of pilot projects in the sense of learning is neither merely reliant on external prerequisites—such as subsidy programs, pressure from policy measures, and so forth—nor simply dependent on the characteristics of the novelty and the way it is applied in the project. The aim is to discover whether social processes internal to the pilot projects, such as network formation and negotiation, have a significant influence on learning. It is also of interest for the management of pilot projects to know whether such learning indeed influences subsequent niche development via further actions of the participating actors. For reasons explained in the next section, the analysis focuses on convergent learning, which occurs when diverse actors “develop visions on solutions and problems that complement one another, and change their roles and goals in close association with each other” (van Mierlo et al. 2010a).

The central questions of this article are:

- What internal processes influence convergent learning and further actions in and around pilot projects involving the actual use of PV in housing?
- What is the relationship between learning in pilot projects and subsequent niche development via actions of the participants?

I first define the central concepts and discuss the analytical framework in the following section. The third section describes PV in housing, the applied technology at the center of the analysis. This discussion is followed by descriptions and a comparative analysis of four PV pilot projects in the Netherlands with particular attention devoted to their learning processes and their conditions for learning. In the final section, I draw conclusions on the management of pilot projects and niches.

A Framework for Analyzing Innovation in and around Pilot Projects

Niches appear in many forms, but practical experiments, as well as protection measures, are often integral to such innovation-facilitating spaces (Hoogma et al. 2002). However, not all experiments and projects for learning and innovation can be evaluated from the perspective of the SNM approach. To distinguish these experiments from others, such as experiments in the laboratory that hardly trigger learning on social aspects like user preferences and division of roles, the term pilot projects is used. I define a pilot project as an initiative of a group of diverse actors to apply a new, radical technology in practice (with or without protection) in a specified market segment that at least one of the relevant actors views as promising. In cases where end-users are not involved during the development phase of the project, they become engaged in the near-natural context once the technology is applied.

For analytical purposes, a clear distinction must be made between a single pilot project and a niche that may consist of a several such initiatives, various experiments, and other activities and processes. A pilot project is bound in place and by a particular set of participants, and these boundaries are quite clear to the relevant actors. For this reason, Brown and her colleagues prefer to refer to such activities as “bounded sociotechnical experiments” (Brown et al. 2003; Brown & Vergragt, 2008). Furthermore, the actual application of the technology requires a tangible form of cooperation, since a diversity of actors must come to some kind of agreement to proceed (van Mierlo, 2002). Such collaboration is not necessarily the case for the interaction of actors within a niche around several experiments. It is consequently important to investigate the negotiation process inherent in a single experiment and its role in the development of the niche.

Participants in pilot projects have the opportunity to learn. In addition, further niche development may occur in a very specific way, for instance, if the participants are encouraged to apply a new technology in a subsequent project.

To clarify the influence of the internal processes among participants in a single pilot project on learning and further actions, I investigated several pilot projects in the same protected niche. I did so with the aid of an analytical framework that was, on one hand, focused on the desirable effects of pilot projects and, on the other hand, the conditions for learning. The latter provided insight into the management of pilot projects that aim to contribute to regime change.

Direct Effects of Pilot Projects

To enable evaluation of the pilot projects, criteria were formulated to empirically examine each initiative at the project level. In line with the niche approach, as well as the work of Brown et al. (2003) and Brown & Vergragt (2008), learning in projects is the starting point of the analysis. The three criteria of direct effects of pilot projects are convergent learning, organizational adjustments, and repeated use.

In the context of the empirical cases, most of the participants engaged with a new technology with which they were not previously familiar. What does that mean from a learning perspective? Most literature on learning in niches and innovation projects focuses on what is called second-order learning, which is distinct from first-order learning (Hoogma et al. 2002; Brown et al. 2003; Smith, 2007; Brown & Vergragt, 2008; van Mierlo et al. 2010b). First-order learning involves gaining experience about how to do things better within the framework of pre-existing goals and assumptions; it alone would not contribute to regime change. In contrast, more demanding second-order learning occurs when basic aspirations, values, and assumptions become the subject of learning. Such learning is assumed to be essential for regime change. Both learning concepts apply to individuals, homogeneous groups, and organizations and were originally developed to study the adaptation of organizations to changes in the environment (Argyris & Schön, 1996). However valuable they may be, this article proposes another concept of learning to evaluate PV pilot projects, namely convergent learning, because it sheds light on learning among people from a diversity of organizations and groups with heterogeneous roles, problem definitions, aspirations, and values.

Convergent learning entails aligning project participants’ interpretations and actions about how to apply the new technology, to divide the roles in project development, to handle risks, to manage the project, to finance extra costs, to respond to complaints, and so forth. This concept of convergent learning is useful because a pilot project resembles a negotiated agreement between several different types of actors put into action (Drake & Donohue, 1996). Successful negotiations require the development of relatively stable interdependence messages early in the process and shared interpretations, or at least an alignment in meaning (Dewulf et al. 2009). Conversely, when disputants cast the issues in incompatible ways and fail to create an acceptable joint framing, conflicts are often perpetuated (Salipante & Bouwen, 1995).

Moreover, the concept is relevant for analyzing a project’s influence on further developments over time. What lessons were learned and what conclu-

sions were drawn for subsequent activities and about the future of the new technology? Again, alignment is central given that every transition becomes coordinated at some point via the synchronization of visions and the interconnection of actors' practices and roles (Callon et al. 1992; Geels & Schot, 2007). The terminology of convergent learning illuminates the prospect of complementarity among the fundamentally different assumptions and values of the various project participants. They do not necessarily come to share a completely common view during the learning process; it suffices if their perspectives overlap partially or are mutually supportive. The concept is inspired by Grin & van de Graaf's (1996) idea of congruency, that heterogeneous actors in a policy network may come to regard a particular line of action as a meaningful solution to a problem differently experienced by each of them. In a pilot project, heterogeneous participants may come to convergent learning, operationalized as the development of complementary visions on the desirability and feasibility of the (future) use of the novelty in a certain application domain and their own roles in its further development from their respective (changing) aspirations and values.

The second direct effect relates to the idea that the formal and informal rules guiding actions in innovation projects are initially diffuse, broad, and unstable (Schot & Geels, 2008), while niches consist of an emerging community in which rules gradually become more specific, shared, and stable. It is assumed that rule changes as a direct effect of pilot projects are restricted by the actors that are involved in them and by the limited scale. It is for this reason that organizational adjustment is the central criterion used, assuming that a successful project leads participants to adapt their internal organization in such a way that it advances their own and other actors' engagement with the new technology (van Mierlo, 2002). A participating energy company, for example, might decide to rescind restrictive rules on feeding back PV electricity into the grid, thereby making it easier for individual households to take advantage of the technology.

Direct additional application of the technology, for instance in follow-up initiatives, is another desirable effect of a pilot project. This idea is inspired by, but does not completely follow, Rogers' (1995) concept of adoption: a decision to make use of one innovation out of several possibilities. I analyze the action following such a decision as repeated use of the novel technology in new projects.

Conditions Conducive to Learning and Subsequent Niche Development

This study defined three criteria for identifying beneficial learning conditions that expose the ways in which project managers can stimulate convergent learning, organizational adjustments, and repeated use in pilot projects: heterogeneous network formation, open and creative negotiation, and network management.

First, heterogeneous network formation is seen as an initial internal condition for learning. Callon et al. (1992) provide a relevant perspective on network formation, suggesting that technoeconomic networks around new technologies should fulfill different functions—those of science, technology, use, regulation—and mediate among the actors performing these activities. The network of participants in a PV pilot project certainly consists of actors with different functions and roles, such as investing, subsidizing, developing products, using the products, providing advice to users, and so forth. I investigated to what extent the network around a pilot project was heterogeneous, in the sense of the diversity of functions fulfilled by the participants, who came from both existing regimes and a potential new PV regime.

Second, as suggested earlier, the participants in a pilot project have to come to an agreement and a form of coordinated action to be able to apply the technology. Therefore, the analytical framework deployed here is based upon a theory, principled negotiations (or consensus building), that elaborates on negotiations fostering deep learning and innovation (Fisher & Ury, 1993; Susskind et al. 1999; Innes & Booher, 2010; see also van Mierlo et al. 2010b). The central focus of this perspective is on high-quality agreements that meet the desires and priorities of all actors, are based upon knowledge and expertise, and often are more innovative than regular accords (Innes, 1999). In addition, the negotiations required to reach these agreements have important secondary effects like fostering learning, building new and trusting relationships, and forging novel practices and rules.

These agreements can be reached in negotiation processes that are self-organizing in the sense that there is consensus about the process rules. Because participants discuss their respective stakes and other aspects that are usually taken for granted, these negotiations creatively ensure that the resulting agreement is more than just a division of the cake. Moreover, they are open: participants gain insight into their partners' interests, motivations, points of view, and so forth. These characteristics are summarized in the condition of an open and creative negotiation process.

The final condition is network management. It is assumed that managing a pilot project that aims to stimulate an innovation process differs significantly from traditional forms of project planning or operational steering, both of which tend to focus on preset goals, efficiency, and content (van Mierlo et al. 2010a). Project managers should take the characteristics of complex networks into account, as well as the nonlinearity of negotiation processes (de Bruijn & ten Heuvelhof, 1995; de Bruijn et al. 2010). If the managers of the PV pilot projects take demonstrable action to form a heterogeneous network and facilitate open and creative negotiations, they are presumed to be managing the network.

The Emergence of a Protected Niche for PV in Housing

Many products can be made and several social functions can be fulfilled with PV. From an historic point of view, the first niche for PV emerged when solar panels were used in outer space. Since the 1980s in the United States and the 1990s in other industrialized countries, PV has been portrayed as a sustainable alternative to electricity produced with fossil fuels. The United States, Germany, Japan, the Netherlands, and other countries developed government programs to stimulate both development and use of PV (see, e.g., Jacobsson et al. 2004).

In the Netherlands, a White Paper released in 1990 proclaimed that in two decades grid-connected PV could become the most important sustainable energy option (Ministerie van Economische Zaken, 1990). Prior to this document the national government did not expect PV to be relevant for Dutch energy provision, but upon its release a target was set to save two petajoules (PJ) of fossil fuels per year by 2010 with PV systems. Between 1994 and 2000, the government saw new housing as the most promising market segment for PV, given the abundant roof space available and its accessibility via developers that build large housing projects. With a sizable budget for a special learning program, Dutch policy aimed to investigate under what conditions a large-scale introduction of PV in housing would be feasible (Novem, 1994; 1997) during a period when the costs per kilowatt-hour (kWh) for PV were about ten times the consumer price for customary electricity generation. For the learning program, Novem, an organization that acted on behalf of the Ministry of Economic Affairs, provided a project subsidy to large organizations because intervening in a market of numerous private households was expected to be managerially too complex. Energy companies in particular could receive a subsidy if Novem was convinced that the proposed projects would be useful for learning about

the technical and social bottlenecks and possibilities of PV. A major condition was that large solar systems would be integrated into the roofs of buildings for aesthetic reasons. In addition, the government expected that saving regular roofing material would reduce the costs for the PV systems in the long term. As a consequence, the learning projects were targeted toward new housing developments. For the Netherlands, where local governments allocate land to project developers, this meant that governments and developers were both involved in these initiatives. It became the role of architects to integrate PV into the design of the new homes.

At the start of the learning program in 1990, there was only one house in the Netherlands with a large autonomous PV system on the roof. This system was built by a solar energy enthusiast committed to demonstrating that PV was suitable in the country during a period when the national government still assumed it was not feasible. In addition, PV was being installed in approximately 25 privately owned homes with grid-connected systems and a further ten rental homes that were part of a project pursued by an electric utility company (van Mierlo, 2002). From these sparse beginnings, the learning program had, by its termination in 2000, financially supported the realization of about 150 projects (Verhoef et al. 2001). Thousands of PV houses were built with the aid of the learning program and a new subsidy for small PV systems. Over the course of the decade, the previously dominant role of energy companies was reduced; ownership of the systems shifted from the energy companies to the residents and project developers began on their own initiative to apply for subsidies for PV housing projects. The power capacity of all grid-connected PV systems in the Netherlands was almost 9 MWp (megawatt-peak) in 2000 and increased further to 89 MWp in 2010 (Statistics Netherlands, 2012).

Although this amount was still far from the hundreds of MWp needed to reach the national policy goal, the Netherlands in 2004 came to occupy fourth position among European countries in terms of PV capacity per inhabitant. However, between 2003 and 2010, the annual added volume of PV fell dramatically due to a political shift in the country. The government reframed earlier subsidies for PV as being cost ineffective compared to wind energy and as stimulating free riding (Negro et al. 2009). As a consequence the Netherlands dropped in 2010 to fourteenth position among European countries. However, in the same year the Dutch PV market rose again in response to a temporary new subsidy, but its future prospects remain highly uncertain because of the incessant inconsistency in Dutch energy policy.

The learning program in general followed the course advocated by SNM scholars and provided room to learn in practice about a radical new technology in heterogeneous networks. Even though the learning program came to an end long before any signs of a regime change, it provides a useful opportunity to look more closely at the learning processes among the many actors, including PV companies, housing developers, and energy companies, that were closely involved in these large pilot projects.

With the idea of applying and integrating large PV systems in buildings, the radical, challenging character of PV became obvious. In the words of Geels (2004), niches are increasingly radical as they deviate more from the rules of the dominant regime. All sociotechnological regimes consist of a plurality of explicit and implicit principles of how to produce and use the new technology embedded in norms and values, physical infrastructure, formal regulations, consumption patterns, and so forth. If integrated into buildings, PV becomes an energy-production unit as well as a building element that requires new standards and procedures and changes in existing rules in both domains.

Decentralized energy production with renewable energy demands drastic changes in the relationship between energy companies and their customers, who used to be end-users and now become producers. To make grid connection possible for feeding back surplus PV electricity at times of high production, Dutch energy companies had to develop norms for the required quality of the PV-produced electricity and the return rates (van Mierlo, 2002). Technological developments across production, distribution, and energy use—such as a redesign of the grid for dynamic demand management, new forms of transportation power, and large-scale energy storage—are needed for decentralized renewable energy options (Huberty & Zysman, 2010). Unruh (2000) speaks of a carbon lock-in, a vicious cycle in which governments allow new generation capacity and grid expansion, thus increasing availability of cheap electricity that, in turn, encourages consumption and development of new applications and end-use technologies. Governments are then inclined to approve yet more capacity to meet the expanding demand. Unruh (2000) ob-

serves that policy makers typically do not recognize this lock-in. This is manifest in the perpetuation of laws that discourage carbon-saving technologies and the problems that governments encounter when trying to discontinue subsidies for fossil-fuel energy production.

Moreover, efforts to integrate solar panels into the design of new housing projects and into the physical structure of individual homes interfere with the physical surroundings, impose conditions on the building and architectural quality of the panels, and require combining the knowledge and competencies of electricians, contract builders, architects, and others. The installation of large PV systems into housing therefore prompted confrontation between the PV industry and the energy and building regimes in the pilot projects.

The Four PV Pilot Projects

Investigation of the process conditions for learning in pilot projects and the further actions of participants is based on a comparison of four housing initiatives with PV in the Netherlands. Completed between 1995 and 1998, these initiatives formed the first phase of a series of large pilot projects, which are comparable in the sense that they all commenced during the same period and were all part of the same protected niche—PV in new housing projects. Given this more or less similar context, comparing the projects allows for study of the influence of internal processes on learning and subsequent actions of the participants.

There were, of course, important local differences among the four pilot projects. Table 1 provides an overview. In two of the projects, the systems were owned by the residents while in the other two schemes ownership was in the hands of the energy company. Three of these projects—in Amsterdam, Apeldoorn, and Amersfoort—involved large roof-integrated systems. In these efforts, each PV system was meant to produce at least 50% of the annual electricity use of an average household. The fourth project, also in Amersfoort, involved mounting one alternating current (AC) solar panel on the roofs of hundreds of houses. It was the first time that such a

Table 1: Characteristics of PV projects studied.

Characteristics	Amsterdam	Apeldoorn	Amersfoort	AC project
Initiated	1991	1991	1993	1994
Effective dates	1996	1996–1998	1995–1996	1996
Number of PV houses	71	94	50	217
Total power (kWp)	250	219	110	22
Costs (mlnimum in €)	2.4	2.3	1.1	0.2
Subsidy (%)	49	58	50	0
PV ownership	energy company	residents	energy company	residents

small PV system had been applied in the Netherlands.

The extensive files of the project managers provided the start of the empirical research for three of the pilot projects and offered a useful way to analyze the chronology of important events, the times of formal decisions, and the arguments used by participants. The direct effects of the pilot projects were analyzed in detail by means of in-depth, semi-structured interviews with all the participating actors, including the managers of the energy companies, architects, and key representatives from the PV suppliers. In total, 43 interviews were conducted with several respondents (the project managers and representatives of the PV supplier) involving more than one session.

Learning a Great Deal in Amsterdam

When the energy company in Amsterdam took the initiative to apply PV in a new housing project in 1991, just the one other example (with PV panels integrated in the roofs of ten rental homes) was available in the country to serve as inspiration. The announcement by the Dutch government that it wanted to subsidize large PV projects stimulated this scheme. The energy company's motives were to experiment with this promising new technology and to fulfill its legal environmental obligations. By fortuitous circumstance, the energy company was already in contact with the local government, which was then in the process of designing an environmentally friendly new housing development and for which implementing PV seemed an attractive addition. The municipality of Amsterdam decided to organize a competition for project developers and their architects to create a plan for a new housing project including PV. The energy company formulated a long list of prerequisites for the application of PV, such as the generation capacity (in kWp), the tilt, and the orientation of the solar panels. A requirement was that the systems would be physically integrated into the roofs.

There were numerous confrontations between the vested and new actors around these prerequisites as well as other matters. According to the energy company, the project developer and the architect neglected the requirements with respect to optimal production of PV electricity, such as the orientation and the tilt. Discussions took place both during the design stage and the construction phase. There was, among others, a huge debate about the height of the chimneys and the shadows that they would cast over the solar panels, thereby decreasing efficiency considerably. In a similar vein, the energy company and the only Dutch PV producer at the time, Shell Solar Energy, paid scant attention to the difficulties and the relevant knowledge of the project developer and architect. According to the project leader from the mu-

nicipality, "The energy supplier had no experience with building projects, the process. They hadn't thought about the social consequences, about the reasons for a project developer to participate in such a project" (Heere, 1996). More fundamentally, the desire on the part of the energy company to achieve an optimal yield conflicted with the values of the project developer and the architect (as well as with the values of the municipality) regarding building aesthetics and residential density.

For example, it took almost a year before the energy company was willing to pay for the additional time that the architect needed for the design due to its newness and difficulties with the physical integration of PV, such as knowledge of tilt and orientation and material characteristics. Another problem concerned the sizes of the panels, which did not fit the standards common in building projects and were not as tolerant of adverse weather conditions as other material alternatives. Despite an earlier technical test of the integration technique, rain started to leak into the houses immediately after they had been built, probably because of problems in the connection between the regular roof material and the solar panels. In the end, an expensive approach involving the installation of a watertight subroof proved to be the only reliable and acceptable solution.

It required nearly six years to complete this large PV housing project and at first sight the effects were slight. Only two of the participating actors changed their policies and procedures: Shell Solar Energy employed a building expert and started to cooperate with electrical engineers and Novem decided to manage the projects on the basis of criteria rather than involvement in all project discussions. Hence, only the participants whose main interest was in PV were induced by the pilot projects to undertake organizational adjustments relevant for the introduction of PV. In addition to these two actors, only the architect continued to work with PV in subsequent projects, as he was convinced of the possibilities for PV in housing developments despite its high costs. He also changed his vision on housing fundamentally when he decided to put "room for nature" at the core of all his new projects. The rest of the participants perceived the project as a single, stand-alone venture.

In line with the conceptual assumption that without an open and creative negotiation process a pilot project will not lead to the desired effects, there was little sign of convergent learning in this project. Except for Novem, Shell Solar Energy, and the architect, none of the participants believed that PV was sufficiently mature to be applied in new housing developments. The energy company no longer saw an active role for itself in such initiatives; instead, it decided to start a test with small systems in existing

housing. The visions of the participants did not come much closer, except for their opinion that the PV houses were beautiful and that future residents needed to be financially involved with the PV systems. All relevant actors, except for Novem, stated explicitly that they had not learned from one another.

However, if one looks at the project in more detail, an interesting effect can be seen. Although the participants did not learn in a convergent way, all of them learned broadly about many aspects of PV in new housing: financial, technical, aesthetic, and social. The energy company learned about the accurate placing of chimneys, leakage problems, electrical requirements, financing, building processes, and division of responsibilities in the event of problems. Although Novem still expected energy companies to take an active and initiating role in large PV projects, the energy company itself had come to a different conclusion. The project developer learned, among other things, that he should take shadowing into account and that a roof should have margins without PV. The municipality learned that, although the houses were attractive, PV was too expensive to be applied and that the residents should derive personal benefits from the PV systems attached to their houses. In sum, almost all lessons were actor specific, and in some cases contradictory.

Several Project Managers in Apeldoorn

Shell Solar Energy, in collaboration with a project developer, took the initiative for another large PV project. The company wanted to show that the national goal of realizing 250 MW of PV in 2010 could best be reached by pursuing large PV projects in housing. It also sought to gain experience with these sizeable PV projects. Together with two other energy companies, Shell Solar Energy formulated the general prerequisites and identified the feasibility of a large project with about 100 PV houses. A project group was formed that started looking for a suitable location somewhere in the Netherlands. It took about two years to find an appropriate site and two years longer to complete the terms of reference among the collaborating companies about preconditions, planning, and financing, which were never actually signed. It was the project developer who finally contacted the municipality of Apeldoorn, where the PV objective fit the planning of a new housing estate called Energy Zone.

Because of long, drawn-out financing problems, the project developer at some point threatened to build the houses without PV with the aim of forcing the decision-making process. In the same period of stagnation, which was partly due to employee turnover at the one energy company that remained involved, Shell Solar Energy wrote a memo arguing

that the energy company should participate more actively in the project. So, in a way, the PV supplier took the initiative to manage the project.

Except for one of the architects involved, the participants assessed the negotiation process in quite negative terms. As the energy company's project leader formulated it, "After the conclusion of the project, the fights remained in my head" (Bergsma, 1998). The energy company and particularly the project developer were dissatisfied with one another's roles, and almost all participants claimed that others were insufficiently interested in PV. With respect to the decisions taken, many participants felt that they had had to forego some of their own aspirations. One point of discussion concerned the payback rates for the residents, who in contrast to the Amsterdam residents would own the PV systems. The energy company suggested the same payback rates as those nationally set for wind energy. Since these were lower than the regular price households paid per kWh, the project developer did not agree and as a consequence let future residents pay less for the PV systems (9% of the total direct costs). Additional problems occurred during the building of the houses. It proved difficult to connect the solar panels to the edges of the roofs, and, because of their weight and large size, the panels bent a little and ran the risk of breaking. Moreover, when finally realized, the PV systems suffered from problems with the invertors and other technical parts.

The Apeldoorn case demonstrates how, despite an unsatisfactory negotiation process, problems can be overcome if participants other than the project leader manage the process at moments of conflict or stagnation. This seems all the more important since, in spite of the difficulties, the project had substantial effects. All participants learned about a wide range of aspects and, above all, after the completion of the project, were convinced that PV systems could be applied in new housing. Some learning experiences were shared, such as the conclusion that residents should have access to the PV electricity themselves and that the installation should be better prepared. Most learning experiences, however, were so diverse that the participants could not easily conceive of a collaborative follow-up project. The energy company learned most about division of responsibility in the development and ownership of the PV systems, the PV supplier learned most about the strict rules in the building sector, and the project developer learned about how to finance such a project. Contradictory conclusions were drawn about the color of the solar panels (beautiful versus ugly), the realization of such a project in practice (complex versus simple), and the best phase to become concrete about financing (early

on versus after participants have become really motivated).

Besides the PV parties, several other participants undertook organizational adjustments. The energy company, for instance, formulated its own quantitative goals for the application of PV and developed new financing instruments to capitalize on the willingness of some clients to pay for clean energy. The project developer started cooperating in the national PV covenant, and one of the architects joined a working group to study cost-reduction measures. In line with these positive effects, most of the parties participated in follow-up projects in several application domains, including both new and existing housing and new office buildings.

A Quite Principled Negotiation Process in Amersfoort

In Amersfoort, the initiative to integrate PV systems into rental houses was taken by the energy company, which had a budget for energy-saving projects that would be supplemented with a subsidy from Novem. The network around the pilot project was formed on the basis of several existing bilateral contacts. Because of these prior connections, the participants trusted one another to some extent at the start. The energy company was already involved in meetings organized by the municipality about guidelines for the infrastructure of a large sustainable housing estate. This area was also opened up for environmental experiments, an opportunity the energy company gladly embraced. The housing association, which was already interested in passive solar energy, was willing to cooperate because of the opportunity it provided for approaching the energy company about extra energy-saving measures.

From the outset, the energy company paid considerable attention to interactions among the various PV-project participants; for instance, a working group for communication was formed involving many of them, including the municipality. The participants agreed on a code of conduct to inform one another about their communication activities. Furthermore, at several stages the energy company asked the participants to join a midterm evaluation. Points of discussion were, among others, the size of the invertors (one per seven houses), whether to use thermal solar energy as well, and the specifications of the contracts between the housing association and the residents who would not own the PV systems. Also, participants discussed many aspects of the original design of the houses, given their influence on the yield, until the designs were satisfactory to all concerned. When the contract builder made clear why he did not have confidence in the selected integration technique, although it had been tested, the project

group decided to change it. The building-and-use phase faced numerous complications because of a lack of contact between the energy company and the contract builder and insufficient knowledge on the part of the builders about the requirements for PV, such as ventilation. Moreover, neither the inverter system nor the profiles for the integration of the solar panels proved to function well. So, as in Amsterdam, a water-tight subroof was needed.

The energy company's project manager tried to facilitate a process of coproduction and obviously succeeded considering the remarks of other participants. For instance, the project manager of the housing association observed, "I joined the group and aspired to get the feeling 'we are doing this together.' It went perfectly...even though a lot of problems arose. Everybody had a very good attitude. If we were in a dip, we said 'hold on'" (Meijrink, 1996). Most of the participants stated that they were very satisfied with the roles and the positive, cooperative attitudes of others.

In light of these process conditions, the pilot project in Amersfoort proved to have desirable effects. Many new actors who became involved in the project learned extensively and in a convergent way. They all became convinced that it was possible to develop new housing projects with PV in the—by then—existing situation. They also shared many learning experiences, such as that more attention needed to be paid to the connections between the components of the PV system and the house; that one central stakeholder should coordinate the handling of residents' complaints; and that it was important to involve the contract builder earlier in the process, that is, during the design rather than the construction phase. Since many of these issues were thoroughly discussed during the joint midterm evaluations, they seem to have supported convergent learning. In addition, the project led to some actor-bound learning as well, experiences not mentioned at all by other participants. Novem concluded that it was too early for prefabricated installation, the energy company resolved that it should control the building requirements, and the contract builder expected the prices to drop soon because of the existence of several PV suppliers. The architect and contract builder did not agree on the tilt, because the tilt that was best for PV production, and therefore preferred by the architect, allowed rain into the houses.

A large follow-up project planned from the outset of this first PV initiative in Amersfoort, as well as several nearby PV undertakings by the energy company, offered the participants the opportunity to partake in subsequent activities, which all of them did with the exception of the housing association. In these initiatives, the Amersfoort project contributed

to niche splitting in several directions: from housing to utility building and from rental houses to owner-occupied houses.

Little Special in the AC Project?

The AC project, which entailed the installation of a single solar panel on each of 217 houses, arose from an initiative of a project developer who wanted to have an innovative image. By his own account he noted that, “One square meter of solar cells means nothing of course. It is the banner [status symbol] to your house though” (van Mil, 1997). The project developer wanted to build in the aforementioned estate in Amersfoort, where the municipality required some sustainable energy measures. Other parties were not interested in the option of just one solar panel (in this case an AC module) per house. Since these small systems hardly contribute to the average yearly electricity use of a household, the Dutch government by then considered them to be an inefficient use of free roof space. Also, integrating PV systems physically into buildings was believed to be more appealing aesthetically than adding an AC module to regular roofs. Moreover, at that time, none of the large actors involved in stimulating PV was interested in exploring a private market, given the high costs per kWh. The project developer, however, assumed that, because the price of the module was relatively small, integrating it into the price of the whole house would not be an obstacle for buyers.

Although this type of application diverged significantly from the leading ideas about the value and application of PV in the Netherlands at the time, and the associated techniques for AC modules still had to be developed, the project challenged few rules of the existing building and energy regimes. The AC modules were easy to add to the original design of the houses because they were small and did not have to be integrated. Traditional building relationships were sufficient to pursue the project. The developer served as the manager for the whole project, including installation of the PV panels, and the supplier of the AC modules, again Shell Solar Energy, was selected after comparison of several offers. In this case, the PV supplier was consequently not involved directly in the building project, nor was the energy company, which only formulated the conditions to connect the AC modules to the electricity grid. At the request of the project developer, a consultant undertook the search for a suitable PV application and the technical preparations. During construction, just a few problems with the AC modules became apparent and, as far as is known, there were no special challenges during the use phase.

There were just a few bilateral contacts regarding PV; in fact, there was nothing like a collective, open,

and creative negotiation process among the participants. Still, the AC project had considerable effects. All participants became convinced that AC modules could be applied in housing, and several saw how straightforward it was to do so. A negative shared lesson was that the AC modules were visually unattractive, among other things because they did not cover the whole roof. In addition, some participants had their own, mainly technical, learning experiences. Compared to the other projects, the various actors learned very little regarding project management, relations among participants, and interactions with residents.

The project developer, one of the architects, and the consultant all pursued other subsequent projects with private PV systems in new housing developments. The initiative also stimulated actors that had been only indirectly involved, or not at all, to consider approaching a private market with AC modules. The four AC modules concept—the idea to cover 10% of the average electricity consumption of a household with a few panels—arose nationally and was embraced not only by Shell Solar Energy but also by Novem and some energy companies that had not been previously interested. The project thus triggered organizational adaptations not only by the project developer but also by several external actors. In 2000, thousands of existing houses had a small PV system as an add-on, paid for by the residents and subsidized via large-scale projects initiated by Greenpeace and energy companies. Private customer interest, however, remained lower than proponents had anticipated.

Process Conditions Differentiated

Comparison of the process conditions in the projects is revealing (see Table 2). A first finding is that a heterogeneous network of participants and associated people was formed around all four PV pilot projects. In all of these initiatives, actors from the existing building regime were involved (project developers, housing associations, contract builders, architects, local authorities, and residents), and in three of them also an actor from the energy regime (the energy company). Actors from the potential new PV regime (the PV suppliers and, in most cases, Novem) participated as well.

However, an open and creative negotiation process was reflected in only one project. In Amersfoort, the participants engaged actively, solved problems collaboratively, handled public relations together, and were open toward one another. This was also the only project in which the energy company, functioning as the project manager, paid serious attention to social processes as a result of network management.

Table 2: Process conditions (*in italics: process condition not or hardly present*).

Condition	Amsterdam	Apeldoorn	Amersfoort	AC project
Heterogeneous network	Actors from the building sector, energy company, local authority, and PV parties.	Actors from the building sector, energy company, local authority, and PV parties.	Actors from the building sector, energy company, and PV parties.	Actors from the building sector and PV parties.
Ambitiousness of pilot project	Very high	High	High	Low
Open and creative negotiation process	<i>No one felt ownership of the process. A lot of conflicts, not really resolved, mutual incomprehension. Choices and decisions tolerated without participants being convinced.</i>	<i>Some participants did not feel ownership of the process. Some important participants unsatisfied with process. Choices and decisions merely tolerated.</i>	<i>Special approach of project, partly developed by participants. Open negotiations, not really creative. Satisfaction about decisions.</i>	<i>No special procedure. No multilateral negotiations, just bilateral. Decision-making process was conventional.</i>
Network management	Mostly management of content.	Hardly any network management; instead, management by a number of actors.	Several characteristics of network management.	Traditional project management.

In the other projects, negotiations were not open and creative at all, nor were there obvious signs of network management. In the AC project, however, there was no need for deliberation among the relevant parties because the application of PV in the building project was no challenge at all. The manager of the AC initiative was the project developer, as is usually the case. The way he wanted to apply the PV systems was technically and socially quite simple, because the systems were small and could be installed as add-on components and the costs were nominal compared to the prices of the houses. No special procedures or innovative arrangements (other than technical) were needed. Hence, the extent to which the envisioned project-specific application of the new technology challenges the rules in the incumbent regimes—which I term the ambitiousness of the pilot project—was rather small. It shows that it is not necessarily a technology itself that is radical in the sense that it is confronted with structural barriers in the existing regime; rather it is the characteristics of the envisioned market and the degree to which it diverges from existing regimes that determine whether a novelty is radical or not. It seems plausible, then, to take the ambitiousness of the pilot project into account as a feature that determines the need for open and creative negotiations to stimulate learning.

The projects in Amsterdam and Apeldoorn did challenge many existing rules: by striving to apply large systems in many houses at once, by having the energy company serve as the PV project manager in addition to the overall project manager, and by inte-

grating the PV panels physically into the buildings. A confrontation between vested and new interests took place, as shown in the conflicts about the importance and possibilities of an optimal yield from the PV systems, the implementation problems that occurred because of the lack of knowledge on the part of the PV supplier and the building parties about one another’s procedures and norms, and the tensions about the division of responsibilities and core competencies among the energy company, building parties, Novem, and the PV supplier. In these cases, principled negotiations would have been necessary for convergent learning. However, the negotiations were not open and creative. The PV parties, the building parties, and the energy companies found themselves working on an interdependent basis, without really wanting to be. In Amsterdam and Apeldoorn, there was actually no agreement on the process, the roles of the participants, and so forth. They accepted others’ decisions without really being convinced, or simply ignored them.

Notwithstanding the similarity between these two projects, there was one important difference. In Amsterdam, the participants (except for the energy company as the PV project manager) were quite passive, whereas in Apeldoorn the project developer and the PV supplier variously took over the role of project manager from the energy provider at moments of impasse. This management by a number of actors appeared crucial for the relative success of the projects, as the next section shows.

Table 3: Direct effects on pilot-project participants (*in italics: no or little effect observed*).

Learning Mode	Amsterdam	Apeldoorn	Amersfoort	AC project
CONTRIBUTING TO REPLICATION IN THE NICHE				
Convergent learning	<i>No shared vision about the future. No shared learning experiences.</i>	Shared, rather global future vision. Some shared learning experiences.	Shared, specified future vision. Many shared learning experiences.	Shared future vision. Some shared learning experiences.
Organizational adjustments	<i>Adjustments conducted by only two PV parties.</i>	Adjustments conducted by five participants.	Adjustments conducted by five participants.	Adjustments conducted by two actors from the existing regimes.
Repeated use in same market segment	<i>Architect only building party that became involved in new pilot project.</i>	Almost all participants undertook new projects.	Almost all participants undertook follow-up projects.	Almost all participants involved in new projects.
CONTRIBUTING TO NICHE SPLITTING				
Divergent learning	Participants learned much about diverse subjects with several contradictory learning experiences.	Participants learned much about diverse subjects with some contradictory conclusions.	Many actor-specific learning experiences, one contradictory.	<i>Some actor-specific learning experiences, none contradictory.</i>
Exploration of different market segments	Test in new potential market segment: existing houses by energy company.	Use in office sector, existing houses, and others.	Use in office sector and other ownership relations.	<i>No repeated use or tests in different market segment.</i>

Direct Effects under the Influence of the Process Conditions

In a comparison of direct effects (convergent learning, organizational adjustments, and repeated use), three out of the four projects were successful: Apeldoorn, Amersfoort, and the AC project. In contrast, the Amsterdam initiative displayed none of the predefined desirable effects. However, when we look at the implications of this project more closely, it becomes clear that, even though no convergent learning took place in Amsterdam, some learning actually did occur. In fact, all the participants learned a great deal about the possibilities, value, and constraints for PV in housing. Their learning experiences were, however, very diverse and did not lead to complementary visions about the desirability and possibilities for the future of PV in new housing developments. It seems useful therefore to consider divergent learning as a direct learning effect, separate from convergent learning. Whereas convergent learning means that visions and actions around a novelty align because of experiences in the pilot project, in the case of divergent learning various changes occur in participants’ thinking, but they are purely actor-bound, sometimes deviating from, and at times even contradicting, one another. In conflict situations, divergence can be treated as a continuation of the status quo, but in innovation processes, the emergence of divergence can be seen as an articulation or learning process. So with divergent learning, participants’ visions change

without the coherence needed for subsequent coordinated actions.

Defined as such, divergent learning is observable in three of the four cases to a greater (Amsterdam and Apeldoorn) or lesser (Amersfoort) extent. In the AC project, by contrast, there was convergent learning about the application of PV in new housing developments since there was alignment of the learning experiences of the participants about a restricted set of subjects, but there was no additional divergent learning.

A similar distinction between diverging and converging effects was found across repeated uses in the same potential market segment or in another one. The AC project stimulated several participants to use PV again, but only in the same application domain (i.e., types of buildings, ownership conditions, type of PV system), whereas participants in the other projects started using PV in other application domains (Table 3).

Divergent learning and use in other domains seems to approximate what Bijker (1995) called the interpretative flexibility of an artifact. This terminology means that diverse actors and groups interpret the technology in varying ways as a solution deriving from their own problem definitions, leading them to explore it in disparate ways. In a similar vein, convergent learning, organizational adjustments, and repeated use in the same domain relate to what Bijker calls closure—a reduction in the diversity characterizing a new technology due to negotiations and coalition building. The coexistence of convergent and

divergent learning in two projects suggests that the process of closure within these projects was not complete at the time.

In sum, whatever the differences in the quality of the negotiation process and the network management, all projects were relatively successful. At this point, the discussion turns to a more detailed analysis of the relationship between the process conditions and the learning effects. In each pilot project, the formation of the network was heterogeneous. Since this result is in line with theoretical assumptions, it is still assumed to be a general condition that requires further research.

Other conditions were dependent on the kind of effects considered desirable and the ambition of the pilot project. Divergent learning took place in all of the ambitious projects, so challenging many regime rules may be a condition for this type of learning. For convergent learning, heterogeneous network formation sufficed in the more mundane AC project. For the projects that challenged many rules (Amsterdam and Apeldoorn), an open and creative negotiation process and network management were great advantages for convergent learning. However, these factors cannot be seen to constitute vital process conditions. In Apeldoorn, management by a number of participants appeared to replace these conditions to a greater or lesser degree.

Conclusion

This article has sought to provide insight into the process conditions for learning and follow-up actions by and among the participants of pilot projects with a new technology. Both these effects are relevant from the viewpoint of innovation and regime change. How did the participants give meaning to their experiences in the design phase of the pilot projects and the construction of the buildings, and did their visions align and motivate them to participate in similar subsequent initiatives? The following discussion summarizes the main findings of the empirical case studies and identifies some consequences of this work, both with respect to theoretical perspectives on the role of pilot projects in regime change and to the formulation of strategies to enhance niche development by protecting specific application domains.

Internal process conditions in the PV pilot projects influenced learning among the various parties involved in the new housing developments. It is apparent that the importance of process conditions depends on 1) the kind of learning (convergent or divergent) and 2) the ambitiousness of the pilot project.

An unexpected outcome of this study is that the pilot projects differed in the degree to which they challenged prevailing rules in the incumbent energy

and building regimes. The level of ambition seemed to act as a sort of intervening factor. In the three challenging projects, a greater number of process conditions was required to reach success in terms of convergent learning and follow-up actions than in the more routine project. Furthermore, high ambition may have been an important process condition for divergent learning. These results suggest stimuli for interactive learning in innovation processes that go beyond the better-known ones of external crises and surprises, bringing in new knowledge and diverging perspectives, trust and reciprocity, and feelings of urgency and interdependency (Argyris & Schon, 1996; Aarts & van Woerkum, 2002; Leeuwis, 2004; van Mierlo et al. 2010b).

These observations raise many questions about the scope of the findings from the selected PV cases. Additional research is needed, for instance, regarding whether divergent learning can also occur in relatively mundane projects. The process conditions for learning may depend on the application domain and the stability of the relevant regimes. Moreover, the process requirements for subsequent actions, which are essential for regime change, most certainly reside not only within the pilot projects but in the direct context as well. The relationships between second-order learning—the central concept used in innovation studies—and convergent and divergent learning are unidentified and call for further inquiry (see also Schot & Geels, 2008).

However, comparison of the PV case studies provides strong evidence for the value of distinguishing convergent from divergent learning as important processes in pilot projects that aim to contribute to regime change. Moreover, the clustering of opening and closing effects justifies formulating the implications of the findings for pilot projects and niche development.

At this point, it is instructive to return to the notion of niche branching. According to the niche approach, niche branching is a key feature of the successful introduction of radically new technologies. No distinction is made between the splitting of a niche toward another potential market segment and replication of a niche (in the same market segment) in another geographical area. Niche branching can mean both. As Hoogma and his colleagues (2002) observe, “This process of niche branching includes the emergence of new application domains and the creation of a bandwagon effect through replication of the niche elsewhere.” However, the term chosen—branching—suggests that splitting is regarded as the main process.

Evaluation of the PV pilot projects indicates that niche splitting and replication in a niche are different processes. Given the results of this study, they may

well be accompanied by different types of learning in and around pilot projects and seem to have different process conditions as a consequence. Convergent learning, the type of learning that is the most promising for regime change from a theoretical point of view, was found in the PV projects related to replication in a niche and not to niche splitting. So it is all the more relevant to specify analytically types of learning and types of niche development and their respective process conditions, and to study the role of these processes in the interaction of the projects with the regime and in diverse transition paths at a more general level (Geels & Schot, 2007; Smith, 2007; Klerkx et al. 2010).

The pilot projects in Amersfoort and Apeldoorn seem to have the characteristics of what Smith (2007) calls intermediate projects, given that the PV niche and incumbent energy and building-regime actors mutually adapted their visions and rules. The AC project can be seen as a typical example of a translation process in which lessons and newly developed practices in the pilot project were easily transferred into the existing regimes, albeit not because of their flexibility but because of their relatively low level of ambitiousness.

For the management of pilot projects, and probably niches as well, the results of the study entail some strategic choices. A first choice is whether the ambitiousness of a pilot project, or a series of pilot projects, will be high or low. This choice is strategically relevant because, on the one hand, high ambition may be deemed necessary to avoid an exclusive focus on incremental changes and, on the other hand, it may hinder reaching desirable effects in a pilot project because of inherently high risks due to uncertainty about the amount and availability of resources, actions of competitors and suppliers, future changes in policy, and so forth (Meijer & Hekkert, 2007).

A second choice is whether or not to aim deliberately at the opening or closing of interpretative flexibility associated with the new technology. Opening seems a more likely impact of an ambitious pilot project because, as in the case of PV in new housing developments, it does not require a deliberative and creative process or an engaged management style in the same way that closing does. However, some niches (like PV in housing) are protected, with the aim of stimulating a specific application domain that is expected to have potential in the long run. In those cases, aiming to stimulate participants to apply the technology again in the same domain may be at least as important as having them explore other application domains. The challenge then is to encourage ambitious projects to come to closure by providing the necessary additional process conditions.

The management of pilot projects and niches is thus not merely a matter of imitating the dynamics of spontaneous historical regime changes that start with the emergence and branching of market niches in small application domains where the new technology is expected to have advantages in the short run. Rather, the historical lessons about the natural routes toward regime change must be drawn on in thoughtful and flexible ways.

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