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Scaling up sustainable energy innovations

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ABSTRACT

Current electricity grids do not fit the needs and challenges of the 21st century, such as the need to transition to renewable energy sources and the variability in power supply concomitant with such energy sources. In this context, smart electricity grids have been proposed as a solution. A large number of pilots and experiments have been set up, but a key challenge remains how to upscale them. Upscaling is critically important to enable a wide-scale integration of renewable energy sources. This paper mobilises literature on the strategic management of experimental niches to explore the upscaling of smart grids in the Netherlands. On the basis of existing literature, a typology of four different patterns of upscaling is proposed: growing, replication, accumulation, and transformation. The relevance of this typology to understanding upscaling of smart grids is explored in a comparative qualitative case study design. On this basis we argue that the building of broad and deep social networks is important for growing and replication; articulating and sharing expectations is important for replication; and broad and reflexive learning processes are critical to transformation and replication. The paper concludes by arguing that these findings can provide important guidelines for future energy innovation policies.

1. Introduction

The idea of the traditional power grid is to deliver electricity from a few central generators to a large number of consumers (Fang et al., 2012). However, these hierarchically and centrally controlled power grids do not fit the needs and challenges of the 21st century (Güngör et al., 2011). Especially the large-scale introduction of renewable energy sources (e.g. wind and solar) into the grid, leading to fluctuating production, the increase of local energy production resulting in multi-directional flows of electricity, and new increased loads (e.g. from electric vehicles and heat pumps) are great challenges for the current electricity grid (Verbong et al., 2013). A new concept of next generation electric power system has emerged, namely the so-called 'smart grid', which can be defined as "*a system that includes a variety of operational and energy measures including smart meters, smart appliances, renewable energy resources, and energy efficiency resources*" (Federal Energy Regulatory Commision, 2008, p. 17). In such an integrated system, information and communication technologies (ICTs) provide communication capabilities absent in traditional power grids. Smart grids are believed to increase the electric power quality and reliability, reduce greenhouse gas emissions, facilitate the expanded deployment of renewable energy, and provide cost reductions for all users along the energy value chain (Fang et al., 2012; Güngör et al., 2011; Schwister and Fiedler, 2015; Verbong et al., 2013).

Smart grids are a central element in European energy policies. For instance, in 2009 the European Commission established a Smart Grid Task Force to help shape EU smart grid policies and smart grids have received substantial support in European funding programs (Mosannenzadeh et al., 2017). As one of the EU member states, the Netherlands early on acknowledged that smart grids are to play a crucial role in energy transitions (CE Delft and KEMA, 2012; Taskforce Intelligente Netten, 2010), and initiated several programmes to experiment with smart girds. One of these programmes is the Innovation Programme Smart Grids (IPIN), which was established in 2009 by the Netherlands Enterprise Agency (RVO) and commissioned by the Ministry of Economic Affairs. The aim of the programme is to accelerate the diffusion of smart grids in the Netherlands (RVO, 2015a; Taskforce Intelligente Netten, 2010). Sixteen million euro was made available for this programme and since 2012, a total of 12 smart grid pilot projects have become part of this programme (RVO, 2011a). In September 2015 the IPIN finished. Most pilot projects had demonstrated positive techno-economic evaluations. For example, a pilot project in the island of Texel showed that households saved on average 5.1% on electricity and 10.3% on gas during the trial period (Hobbel and Rienks, 2016; RVO,

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2015b). Another project, the 'Powermatching City' pilot, showed that the benefits of smart grids for the Dutch consumer market could amount to as much as € 3.5 billion (DNV GL, 2015; RVO, 2015c).

However, despite such promising techno-economic performances of smart grids, a widespread transition to smart grids has not yet happened in the Netherlands. Innovation studies literature has indeed long recognised that techno-economic performances are important but not sufficient for successful diffusion or upscaling. For this reason, this paper is concerned with understanding the socio-institutional challenges of the transition towards smart grids. In doing so, this paper develops and tests an analytical typology of upscaling on the basis of socio-technical transition theory, and in particular strategic niche management (Kemp et al., 1998; Van der Laak et al., 2007). Hence, the contribution of this paper is not only empirical and policy-relevant, but also conceptual in developing a framework that can be useful for future research on upscaling of sustainable innovations. Despite a few notable exceptions (e.g. Jolly et al., 2012; Seyfang and Longhurst, 2015), little is known about how experiments scale up and which processes are important for the upscaling of experiments. The research question of this paper is: *How and why have smart grid experiments of the Innovation Programme Smart Grids scaled up in different ways?*

The remaining part of this paper is structured as follows. Section 2 reviews relevant literature and develops a theoretical framework for analysis. Section 3 discusses the methodology. Section 4 presents results and Section 5 compares across cases. Section 6 concludes and provides suggestions for further work along the lines of the analytical framework provided in this paper.

2. Upscaling smart grid experiments: a typology

Smart grid experimentation occurs in the context of wider sustainability transitions in the energy system. A transition can be defined as *"a society-wide change that involves fundamental and interrelated changes in technology, organisation, institutions and culture"* (Van den Bergh and Kemp, 2006, p. 1). Hence, transitions do not only require new technologies, but changes also occur in elements such as regulations, user practices, infrastructure, and symbolic meaning (Geels, 2002). To get a better understanding of the complex dynamics of transitions the Multi-Level Perspective (MLP) has been developed (Geels, 2002). The MLP framework builds upon evolutionary and social constructivist approaches to innovation and distinguishes three levels: niche, regime and landscape. There is a nested hierarchy between these layers, which means that regimes are embedded within landscapes and niches within regimes.

The MLP has been elaborated in more detail elsewhere (Rip and Kemp, 1998). The focal level of the MLP is the socio-technical *regime*, which refers to the incumbent socio-technical configurations and dominant way of realising a societal function (Smith et al., 2010). Regimes usually change incrementally, but more radical innovations can take place at the *niche* level. Niches are protective spaces that shield radical innovations from too harsh selection pressures in the regime, such as fierce price competition (Geels and Schot, 2007; Smith and Raven, 2012). Niche innovations are initially unstable socio-technical configurations with lower performance and are more expensive. In this way niches provide space for learning processes and building support for the innovation. Finally, the *landscape* level refers to the exogenous context of a socio-technical system. Landscape changes usually take place slowly and may end up taking decades, and are behind the direct influence of niche and regime actors (Geels, 2004).

The Strategic Niche Management (SNM) approach has been developed to further understand and govern processes of niche creation (Schot and Geels, 2008). SNM is not a simple technology push approach – which would argue that a focus on technical designs suffices. Sustainable development requires interrelated social and technical change. Thus, in niches not only the technological design, but also (new) institutions can be tested and developed. SNM distinguishes three critical processes that are important for successful development of a niche: *social network building, articulation of visions and expectations, and learning processes*. A key aspect of strategically managed niches is to design socio-technical *experiments* in such a way that they contribute positively to these three processes. Experiments can be defined as: *"inclusive, practice-based and challenge-led initiatives designed to promote system innovation through social learning under conditions of uncertainty and ambiguity"* (Sengers et al., 2016).

In the early phases of an innovation, the network of actors involved with the innovation in question is often fragile. Actors' commitments to the niche are at this point limited, because actors do not yet have vested interest and withdrawal does not result in large losses. Experimentation in projects brings new actors together and new social networks emerge (Raven, 2005). A social network is important to create support for the technology, facilitate interactions between stakeholders and provide necessary resources. Social network building contributes to niche development when, first of all, the network is *broad,* meaning that multiple actor types (firms, users, policy makers, academics, entrepreneurs, scientists, etc.) are included. The inclusive character of social networks is important, as multiple kinds of stakeholders facilitate the articulation of multiple, potentially conflicting views. Second, a network contributes to niche development when the network is *deep*, which means that actors should be able to mobilise commitments and resources within the networks (Schot and Geels, 2008). Large firms that support the incumbent technology often have enough resources to support the niche. However, these firms may slow down the development, because of vested interests in the incumbent technology.

Actors participate in experiments on the basis of visions and expectations, which provide legitimacy to invest time and money in a technology that does not yet have market value. Particularly when the technology is still in its early developments, *expectation articulation* is important to attract attention, resources and new actors (Schot and Geels, 2008). Furthermore, expectations provide direction to learning processes and contribute to successful development of the innovation when they are *robust*, which means that they are shared by many actors – the power of expectations increases when they are shared between people (Van Lente, 1993). Expectations also contribute to niche development when they are substantiated by tangible results from experiments. When more experiments, research reports, experts, and specialists support the actors' expectations, the *quality* of the expectation increases (Hoogma et al., 2002).

Learning processes are crucial because they enable adjustment of the technology and societal embedding to facilitate diffusion. A good learning process is *broad*, which means that it is not only directed to the accumulation of data and facts, but also focuses on the alignment between the technical (e.g. technology, infrastructure, and industrial development), and the social (e.g. user context, regulation, societal impact) (Van der Laak et al., 2007). Furthermore, a good learning process is *reflexive* (second-order learning) which means that there is willingness to change direction if the technology does not match the underlying assumptions. This means that learning is not just about instrumental learning about technological solutions, but also concerns learning about underlying assumptions and values; it is about changing the frame of reference and ways of looking at problems or solutions (Byrne, 2009).

These SNM processes are not isolated, but they interact with and influence each other (Geels and Raven, 2006; Raven and Geels, 2010). Nevertheless, niche innovations are rarely able to transform an established regime without broader forces and processes. Transitions come about through interactions between the three levels of the MLP: niches build up internal momentum, landscape changes put pressure on the regime and the regime gets destabilised and *windows of opportunity* are created for the niche innovations (Schot and Geels, 2008). When the key internal niche-development processes are present in the niches and when niches experience favourable external conditions in the regimes and landscapes, niche innovations can diffuse more widely into society

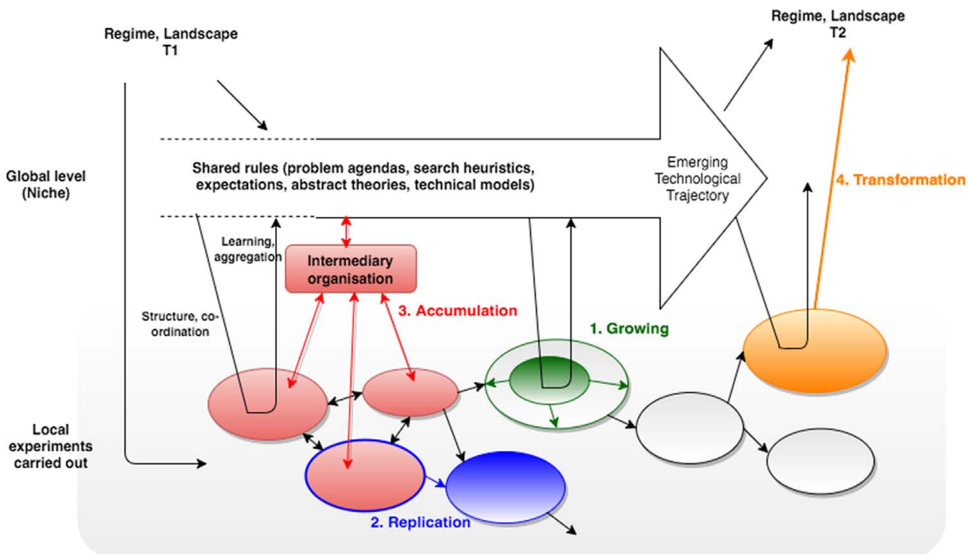

Fig. 1. Patterns of upscaling and the emerging technological trajectory (adapted from Geels and Raven (2006)).

(Seyfang and Longhurst, 2015). This means that the internal processes in the niche are important, but that they are not the only pre-condition for transitions (Van der Laak et al., 2007).

Based on previous SNM studies, we propose a typology of patterns through which experiments can scale-up and diffuse innovative solutions. Upscaling of experiments is important: when activities increase, experiments can add to an emerging field at the 'global' niche level (Fig. 1). When local experiments are compared and lessons aggregated, the rules at the global niche level become more articulated, stable and specific (Schot and Geels, 2008). This increases the potential of the niche to influence the current regime and eventually achieve a transition.

We distinguish the following upscaling patterns. *Growing* refers to a dynamic in which an experiment continues and more actors participate in the experiment or market demand increases – the experiment grows in size or activity. *Replication* takes place when the main concept of an experiment is used in other locations. When the experiment is replicated in other geographical locations or contexts, (local) knowledge of the initial experiments can be used in other locations. *Accumulation* means that an experiment gets linked to other experiments. In this process, intermediary organisations play a key role in facilitating interaction between experiments that exist simultaneously (Hargreaves et al., 2013; Kivimaa, 2014). This is important because when the lessons learned in experiments at different locations are compared and aggregated, the experiments can contribute to a more stable technological trajectory at the global niche level (Geels and Deuten, 2006). The last pattern we propose is *transformation*. This pattern does not refer to geographical or physical scaling but refers to the levels in the MLP (Raven et al., 2010). It means that the experiment shapes wider institutional change in the regime selection environment (Smith and Raven, 2012). Table 1 provides descriptions, a case example and selected literature references for each pattern.

In the next section, we discuss the research design to use this typology for empirical research on scaling up smart grids in the Netherlands.

3. Methodology

The research design uses a multiple-case study approach in combination with a qualitative data collection strategy. An explorative grounded theory design was chosen (Glaser and Strauss, 1967). This means that empirical data from the cases was collected, with the initial framework of upscaling derived from the literature review acting as a focus device, and then compared against each other, to explore and eventually refine the typology. To ensure internal validity of the qualitative research, we used three tactics proposed by Yin (2003): 1) Interview data was compared with secondary data, which means that multiple sources of evidence have been used; 2) the researchers established a chain of evidence by deriving interview questions from the conceptual framework, recording the interviews, and using citations from interviews in the analysis and conceptual interpretations; and 3) draft reports have been sent back to respondents to determine whether raw data was rightly interpreted.

Four IPIN experiments were selected for in-depth analysis (Table 2) on the basis of three criteria. Firstly, to allow comparability, only smart grid experiments concerning households were included in the sample. Secondly, the sample included both smart grid experiments that substantially scaled up and experiments that featured only limited

Table 1
Patterns of upscaling (based on previous studies).

Pattern of upscaling	Description	Example from our case studies	Selected literature reference
1. Growing	The experiment continues and more actors participate, or the scale at which technologies are used increases	PowerMatching city is growing and has the goal to scale up the pilot to 500 households	Jolly (2010), Jolly et al. (2012) and Seyfang and Longhurst (2015)
2. Replication	The main concept of the experiment is replicated in other locations or contexts	Your Energy Moment Zwolle is replicated in Breda	Jolly (2010), Jolly et al. (2012) and Seyfang and Longhurst (2015)
3. Accumulation	Experiments are linked to other initiatives	PowerMatching City Groningen is joining the Green Deal: Smart Energy Cities, in which it is linked to other experiments	Geels and Deuten (2006), Hargreaves et al. (2013) and Kivimaa (2014)
4. Transformation	The experiment shapes wider institutional change in the regime selection environment	PowerMatching City Groningen and Your Energy Moment Zwolle played a crucial role in achieving institutional change	Geels (2004), Raven et al. (2010) and Smith and Raven (2012)

Table 2
Selected experiments (cases) for the analyses.

Name	Location/City	Duration
1. Your Energy Moment	Zwolle	2012–2016
2. Cloud Power Texel	Texel	2012–2014
3. PowerMatching City (II)	Groningen	2011–2015
4. Smart Grids in Sustainable Lochem	Lochem	2012–2015

upscaling. Thirdly, the sample included smart grid experiments that were expected to scale up in different ways to identify whether different patterns of upscaling require different conditions in terms of SNM processes. For each case an individual case description and analysis was written. After the individual reports, the cases were compared with each other and cross-case patterns were identified in an iterative process (Yin, 2003).

Data collection took place between December 2015 and April 2016. Data about the experiments was collected through semi-structured interviews with project partners and analysis of project documents (e.g. project plans, evaluation reports, project presentations, and factsheets). A total of twelve interviews were held with project stakeholders, and three additional interviews were conducted with two different employees of RVO and one person from the ministry of Economic Affairs, who were all closely involved in the management of the innovation programme. These interviews resulted in additional insights about the goals, expectations and results of the IPIN, which were used as background information for the research. Additionally, two other Dutch smart grid professionals were interviewed (Fig. 2). With professionals, we mean individuals who in their daily work are frequently involved with smart grid developments, including their technical development, policy support and field testing. Also two smart energy congresses were visited during the research period. A generic semi-structured interview was used, which means that the researchers used a guide with topics and fairly specific questions (Bryman, 2008). Appendix A shows the semi-structured interview script that was used for the interviews with the project stakeholders. Questions did not always follow exactly the order in the way outlined in the schedule, and interviewees had a leeway in how to reply during semi-structured interviews (Bryman, 2008). In this way, it was also possible for the researchers to ask other relevant questions when appropriate.

For data analysis we used similar procedures as described by Seyfang and Longhurst (2015). Interviews were recorded and transcribed. Subsequently, project documents and the interview

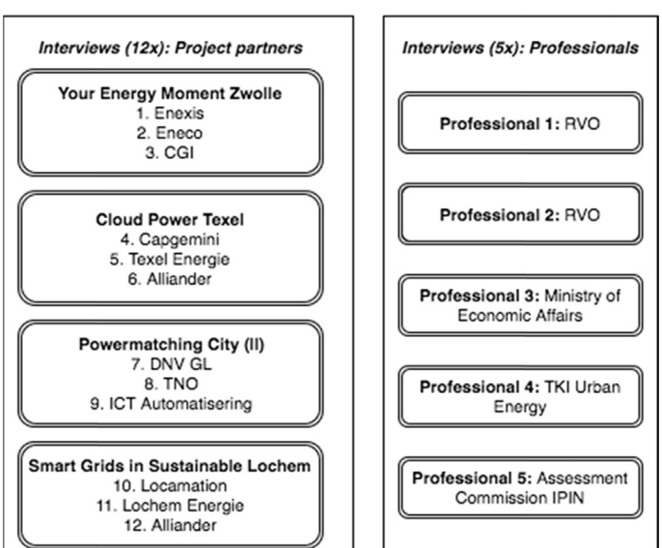

Fig. 2. Overview of conducted interviews.

transcriptions were coded. First, the patterns of upscaling for each experiment were determined. Table 3 gives an overview of indicators that were used to determine the upscaling performance of the experiments. The values for upscaling were assigned using a three-point scale: no upscaling (-), low upscaling (+), and high upscaling performance (++).

Second, the processes and activities that took place in the individual experiments were analysed. In the first place, clearly irrelevant data were not labelled and excluded for further analysis. Thereafter, an open coding strategy was used in order to identify the full range of explanations for upscaling. However, right from the beginning SNM concepts were used as sensitizing concepts to direct the analysis, meaning that raw data was compared with the theoretical background discussed in the theory section. The concepts gave a sense of reference and direction along which to look as they gave an idea of important aspects that might be relevant to understand and interpret upscaling dynamics (Blumer, 1954). Appendix B gives a brief overview of how interview segments were coded. Based on our interpretation of the qualitative data, we scored the SNM processes by using a five-point scale. Table 4 gives an overview of how values were assigned to the indicators, and Textbox 1 gives an extract of how qualitative data from (interview) texts were interpreted and rated by the researchers. The scoring is a relative ranking. Hence, these numbers represent the relative differences between the cases rather than representing absolute values. This scoring is meant to support and communicate the interpretative analysis of the material rather than being input into statistical analysis or other quantitative techniques. As such the table allows readers to quickly see the relative differences between the cases in terms of processes relevant to understanding upscaling performance. We do not claim objectivity, but use the scores as communicational devices.

Finally, after the individual case analyses, cases were compared with each other. A summary table with the cases and their ratings on the concepts and upscaling performance was created, which formed the basis for cross-case pattern matching and interpretation.

4. Results

4.1. Your Energy Moment (Zwolle)

In 2012 Enexis (grid operator) initiated the experiment Your Energy Moment (YEM) in Zwolle. The experiment was set up to gain more experience in a real-life environment with technical, economic and social options for creating flexibility and increased sustainability in energy consumption (RVO, 2011b). Households received several smart technologies, such as smart meters, home energy management systems (HEMSs), smart washing machines and dryers, and solar panels (Enexis, 2014). EV charging stations were placed in the neighbourhood, and dynamic pricing was used to provide economic incentives to consumers. The project consortium consisted of five other partners: SWZ (housing association), Eneco (energy supplier), CGI (ICT consultancy firm), Flexicontrol (product and service supplier), and Eindhoven University of Technology (TU/e).

The experiment expanded through several phases. In 2012 the experiment started with about 100 households; at the end of 2015 almost 200 households participated. Furthermore, the pilot has been replicated in Breda. In Breda, mainly the same technologies are used as in Zwolle, but heat pumps were added to the configuration. Moreover, an apartment block became part of the experiment. Several elements of the original experiment in Zwolle, such as particular technologies and concepts are replicated elsewhere, and further developed in other experiments (rather than replication of entire experiments). Therefore, *replication* performance was ranked high. YEM Zwolle did not become part of other innovation programmes or smart energy initiatives, and thus no *accumulation* and aggregation through other innovation programmes than the IPIN took place. According to the interviewees the

Table 3
Indicators for upscaling performance.

Pattern of upscaling	No upscaling	Low upscaling	High upscaling
Growing	No growth of the experiment *(-)*	Small (less than doubled) growth of the experiment *(+)*	Experiment at least doubled in size (participants) and/or activities *(++)*
Replication	No replication of the experiment *(-)*	Experiment is replicated once *(+)*	Experiment is replicated several times *(++)*
Accumulation	No accumulation *(-)*	Experiment is active in at least one experimental programme, next to the IPIN *(+)*	Experiment is active in more experimental programmes *(++)*
Transformation	Experiment did not result in institutional change *(-)*	Experiment is mentioned by the interviewees to be instrumental to institutional change (regulative, normative, cognitive) *(+)*	Experiment is mentioned by the interviewees to be the key-driver to institutional change *(++)*

Table 4
Indicators and values for the concepts of the theoretical model.

Process	Indicator	Description	No – Yes
1. Social network building	Broad	The network consists of actors from different domains	1 2 3 4 5
	Deep	Resource commitment of the members is high	1 2 3 4 5
2. Articulation of visions and expectations	Articulation	Expectations are clearly articulated between the members	1 2 3 4 5
	Robustness	Expectations are shared by the members	1 2 3 4 5
	High Quality	Expectations are substantiated by on-going experiments, researches, and experts	1 2 3 4 5
3. Learning Processes	Broad	Learning took place on several dimensions	1 2 3 4 5
	Reflexive	Assumptions about the underlying problem definition, function or desirability of a smart grid are questioned	1 2 3 4 5

experiment played a crucial role in achieving institutional change (*transformation*). The experiment led to a cognitive change in thinking about the energy system by the energy suppliers, grid operators, technology firms, and users. Furthermore, the experiment was chosen as support project of the European Electricity Grid Initiative (EEGI). However, to achieve a change in institutions one interviewee mentioned that it is also important to collaborate with firms from other experiments. As one interviewee said:

> ***"It is not just this project. Actually it is a combination of the projects that results in transformation. You can see it as separate projects that together 'complete the puzzle'." (#1)***

Internal niche processes were well managed in the YEM Zwolle pilot. Different types of partners joined the experiment and as such the

Textbox 1: scoring extract

CASE A

"We said on purpose, let's do this project just with partners from industry. So, there was no involvement of public organisations or a research organisation because we think the market should take the lead."

(Social network broadness: 1)

"Learning was particularly of technical nature, as more technologies and services had to be developed than thought beforehand […] So, although firm X conducted a survey about user preferences, most learning was on the technological dimension […] Learning about economic models was also less successful, as the system was not working properly." **(Broadness of learning processes: 2**)

CASE B

"We had a very good mix […] there was involvement of an IT company, a small supplier of consumer products […] University X conducted some research of both technical and social nature […] The grid operator and energy supplier were involved, as they are responsible for energy supply in this area. […] And the municipality conducted some lobby activities to participate in a national energy programme."

(Social network broadness: 5)

"We really learned on a lot. The grid operator learned how their network reacted on such a concept and developed some technical and financial models for smart energy systems […] University X developed demand response models, and research organisation Y developed a new flexibility protocol and did research about user preferences […] Firm Y tested the roll out of sensory. […] Furthermore, several legislative barriers were identified." **(Broadness of learning processes: 5)**

EXPLANATION:

In **Case A** only firms from industry were involved. Besides that, learning was especially of technical nature. However, some research about users was conducted and they tried to learn on the economical dimension. Therefore, social network broadness is rated with a 1, and broadness of learning processes is rated with a 2. In **Case B** actors with multiple backgrounds joined the project, both small and large, and regime outsiders and firms from the established energy regime. Furthermore, learning was broad as it took place on multiple dimensions (technical, social, economic, regulative). Therefore, network broadness and broadness of learning processes were interpreted as high and both rated with a 5.

social network was ranked as rather broad. Large incumbent regime companies were involved, as well as a large ICT consultancy company, a small entrepreneurial firm supplying products and services for energy management, academics and researchers, and a housing association. One interviewee confirmed the necessity of a broad network:

"By setting up pilots with multiple partners, the different interest had already been taken into account during the design of the pilot, which makes it more likely that the design of the experiment is interesting for everyone when it ends." (#3)

At the beginning of the experiment, clear agreements had been made about the resources every partner committed to the experiment. Moreover, some partners were prepared to invest additional money, indicating high levels of commitment (Enexis, 2014). Furthermore, Enexis received additional public support for the experiment in Breda. Hence, enough resources were available, and therefore the *social network* was ranked as quite deep.

The experiment had a clear target: establish a technical working system, and test whether and how consumers can be influenced to use energy at the 'right' moments. Partners had their own expectations to participate in the experiment. However, because they clearly *articulated their expectations in regular meetings* everyone could meet their own expectations. As one interviewee argued:

"I think it has been very good that in the beginning a lot of time has been used to see what the various interests of partners were […] Eventually, the partners understood and respected each other, which resulted in a great cooperation." (#2)

The experiment resulted in overall shared and positive expectations. Most partners decided to continue with the pilot and expand activities elsewhere. Although some firms faced difficulty in finding a market for their products and establishing positive business models, the participating firms gained market visibility. So, the YEM Zwolle experiment contributed to the development of a relatively robust (positive) *expectation* about smart grids. The quality of *expectations* also increased through the experiment, which provided tangible evidence of success to them. Furthermore, other Dutch smart grid experiments played a role in shaping and supporting these expectations:

"Also other projects shape these expectations […] For example, we also participated in the PowerMatching City pilot, and we compare those results with the pilot in Zwolle". (#1)

Learning took place on several dimensions. Especially, a lot of learning on the social dimension occurred. Researchers from TU/e and Enexis conducted research about user behaviour. The most important result was that people shifted their energy consumption, by using (smart) appliances, to moments when more energy was available. Furthermore, they learned that standardization is needed for smart energy products, as most products are not compatible with each other. Another important lesson from the pilot was that it is essential to enthuse consumers and involve them in product and service development:

"It is essential to involve the users, as energy is a low interest product […] By involving them right from the beginning, attractive and understandable products and interfaces can be created." (#2)

The research outcomes resulted in the publication of at least ten scientific papers, and some articles in newspapers and journals (Enexis, 2014). Technology firms learned how to set up smart energy and home automation systems, and Eneco learned how to set up a billing system. Moreover, partners gained experience with the preparation of market models, and lessons about regulatory changes were learned. Overall, it can be concluded that *learning* was very broad. These lessons were acknowledged to be important for upscaling:

"The knowledge and experiences gained within the project are of great value for the realization of future smart grid projects." (#2)

Learning also occurred about the functioning of the smart grid. During the pilot consumers could chose a cost-conscious or a sustainable profile. To the surprise of the participating partners, almost every consumer chose a cost-conscious over a sustainable profile – challenging some of the underlying assumptions of the experiment (*reflexive learning*). One interviewee said:

"I was really surprised that as many as 80–90% of the households preferred a cost-conscious profile over a sustainable profile." (#1)

Another unexpected result (according to the interviewees) was that consumers preferred to start the washing machines themselves (by using 'common sense') and that people were limitedly interested in the use of smart appliances.

4.2. Cloud Power Texel

Texel municipality wants to become energy self-sufficient in 2020 by using sustainable energy (RVO, 2011c). In this context, Texel Energy, a local energy cooperative, initiated the experiment Cloud Power Texel, which involved 300 households. The Cloud Power concept is developed by Capgemini (consultancy firm) and facilitates local energy communities to tune their energy demand based on the available local energy supply by using dynamic pricing (Capgemini, 2012). Capgemini and Texel Energy collaborated with Alliander (network operator) and two suppliers, Quby and Siemens (RVO, 2015b). The main goal of the experiment was to examine how a self-sufficient community could function and how its energy flows can be monitored and accounted for.

Although the goal of the municipality is to become entirely self-sufficient in 2020, no *growth* of the experiment has taken place yet on Texel. The experiment is also not *replicated* in other areas. However, Cloud Power Concept proved its value and Capgemini is looking for other places (outside the Netherlands) to implement this concept (Capgemini, 2012). The experiment did also not become part of other innovation programmes nor has it been coupled to other experiments. This means no *accumulation* and aggregation by other innovation programmes has taken place. Although no physical upscaling has been realised yet, the experiment resulted in some small institutional changes. Interviewees indicated that results of the experiment shaped ways of thinking about energy use and supply amongst participating consumers and firms. Furthermore, the identified legislative barriers in this experiment contributed to a change in regulation. However, interviewees acknowledged that such change is (often) not the result of one experiment and that sharing of experiences, collaboration, and lobbying with several initiatives is needed to achieve this.

Regarding the management of niche processes, the *social network* was not very broad. Mainly actors from industry were included, but no actors from research institutes or universities. Also involvement of other energy suppliers that are active on Texel was limited, and they did not want to work together. Another point mentioned by two interviewees is the importance of continuity in the network composition. During the experiment several changes of actors in the consortium took place. This complicated project continuation:

"It helps when no changes in the project team occur […] otherwise you will lose momentum to go through." (#6)

For upscaling, additional resources are needed. However, these resources were not available and this was partly caused by a lack of investment power. Alliander made most investments during the experiment, but they first wanted to test other concepts in different locations before investing in a next phase of the Texel experiment. Hence, the *social network* was not deep. Although the firms invested in the experiment as initially agreed, the additional resources that were needed to scale up were not available.

The partners joined the experiment with different *expectations*, which were clearly articulated in weekly meetings and within a transparent organisational structure. Most expectations were met and the experiment was of value for most partners. It demonstrated that it was possible to better balance energy, which facilitated that the community could become more self-sufficient. However, the experiment also showed that it is difficult to achieve positive business cases in the Netherlands and Capgemini does not expect to successfully sell the concept in the Netherlands. The experiment also showed that people became more aware of their energy use and that they were willing to postpone their energy use to times when there is more local energy supply and prices are lower. However, because of several technical limitations, no hard statistical judgement could be made about energy shifting (Hobbel and Rienks, 2016). Hence, expectations could only be partially confirmed by tangible results.

Because expectations were articulated well among partners, an overall positive shared expectation about smart grids emerged. However, as one interviewee mentioned, upscaling requires different expectations:

> ***"For the pilot, Cloud Power Texel it was really the goal to test the concept, how can we let it work properly. However, for upscaling you need different goals from those you had in the initial project." (#5)***

There was no clear vision about how to scale up and which partners are prepared to invest resources in a next phase. Furthermore, the absence of a positive business case and lack of urgency for smart grids decreased the will to invest in a follow-up project. Eventually, the *lack of a shared vision* on how to scale up resulted in the experiment being abandoned. As two partners stated:

> ***"The things that we wanted to test have been tested […] therefore, it is not interesting for us to do additional investment in the project on Texel." (#4)***

> ***"One of the learning points for us is to think and communicate in an earlier phase about a how to continue […] Now, everyone has just brought this project to a successful end, but then there was really not a follow-up plan." (#5)***

Learning took place on several dimensions, but most learning was of technical nature. The experiment showed that some technologies did not function properly and other technologies were needed to create a robust system. However, a solution was not achieved for this problem, mainly because of a lack of resources. On the social dimension learning was about how users interact with the HEMS and how people can be motivated to use energy at different moments. Besides that, learning on the regulatory dimension took place. The experiment showed that current legislation and taxes on sustainable energy are not supportive for smart grid concepts. Furthermore, the experiment showed that there is need for standardization, as one interviewee mentioned:

> ***"Standardization is just a precondition for the development of smart grids. Beforehand we searched for a suitable standard and then the question was: which one of the five hundred?" (#4)***

Another lesson was that a common market model is needed that dictates how flexibility can be allocated and what the roles of different actors are in the new situation. According to the interviewees all these lessons are crucial for scaling up an experiment:

> ***"The lessons that have been learned are crucial in order to scale up anyway […] When you scale up you do not start all over again, but you take the valuable lessons with you." (#5)***

Learning was mostly of first-order nature. However, there was also some learning about the underlying assumptions (*reflexive learning*) of a smart grid. Project partners experienced that consumers were more willing to contribute to a sustainable society than was expected beforehand, even when the economic savings are tiny.

4.3. PowerMatching City II (Groningen)

Between 2012 and 2015, the PowerMatching City (PMC) II experiment has been running in two residential areas in Groningen. The experiment was an expansion of PMC I, which was the first smart grid experiment in the world. The experiment was initiated by DNV GL, that formed a consortium with eight other partners: Enexis (grid operator), TNO (research institution), Gasunie (gas infrastructure company), Essent (energy supplier), ICT Automatisering (ICT company), Delft University of Technology, TU/e, and the Hanze University of Applied Science. Within the experiment several technologies like energy monitors, CHP units, heat pumps, solar panels, EVs, and smart meters and devices have been used. The PowerMatcher, a smart grid device, was used to efficiently balance demand and supply between sources and appliances in the local smart grid. To stimulate people to use energy at other moments, dynamic pricing and two smart energy services were developed. The main aim of the experiment was to gain experience in attaining optimum capacity management in a smart grid, and aligning energy services to the demands and requirements of households (RVO, 2015c).

PMC II is *growing* under the name PowerMatching City to the People. The goal of PowerMatching City to the People is to scale up the pilot to 500 households. This experiment is also part of the 'Green Deal Smart Energy Cities', which aims at the use of smart energy concepts within 100.000 buildings in the Netherlands (Consortium Green Deal Smart Energy Cities, 2015). Eleven other experiments joined the Green Deal, which is a form of *accumulation*. The experiment has been replicated several times. The Smart Energy Collective (SEC) has been established, which conducts several experiments partially based on PMC. Furthermore, DNV GL has replicated the project concept in several other countries, and several partial technologies and concepts are replicated in other experiments:

> ***"What you see is that components of PowerMatching City are further developed in other projects. Take the PowerMatcher, which is now also used in Denmark and in Heerhugowaard." (#8)***

Furthermore, replication within a new social network can be observed. For example a new experiment is initiated in a business area in Groningen, which is (partly) a succession of PMC (Redactie Emerce, 2016). Multiple partners from several prior experiments participate in the new experiment and combine their knowledge, competences and technologies to develop a new smart grid system in an industrial area. The experiment also played a key role in achieving institutional change (*transformation*), which is indicated by several prizes that PMC won. The project had a profound impact on how people think about the energy system and the pilot was an important incentive to initiate other Dutch smart grid initiatives.

In terms of managing niche processes, the *network* was very broad. Both incumbents and regime outsiders were involved in the pilot. Furthermore, a lot of knowledge was available in the network, as one research institute and three academic organisations participated. Also the involvement of the municipality was important, as it played an essential role in the lobbying process for joining the Green Deal. The network was quite stable with few changes. The consortium originated from prior collaborations, which increased trust, and let to better understandings between the partners. This means that social proximity[1] was high, which is especially important for network building in early phases of niche development (Coenen et al., 2010). During the experiment, enough resources were available, and clear agreements were made about how much time, money, and knowledge each firm should invest. Moreover, additional subsidies became available for upscaling and new firms were attracted, which increased resource availability.

[1] *Social proximity* is based on friendship, kinship, or mutual experiences, and refers to mutual trust between members (Coenen et al., 2010).

Therefore, it can be concluded the network was very deep.

One of the successes of the experiment was that there were no contradicting interests, because *expectations* were clearly articulated at the beginning and during the pilot. Every partner could meet his goal, and at the same time everybody contributed to the experiment. One interviewee argued:

"It was very great that we had one goal for PowerMatching City II, that was to show what the value of such a system is, and everybody supported this […] So there were no conflicts of interests, which made the concept quite strong." (#9)

Furthermore, an overall robust (positive) expectation about smart grids emerged. PMC I led to positive expectations about the technical possibilities of smart grids and PMC II showed that it is possible to shift the energy use of consumers. Moreover, PMC II showed that more flexibility in energy demand was available in households than expected, and benefits for the Netherlands range from 1 to 3,5 billion euros (DNV GL, 2015). The positive outcomes of the experiments led to increased expectations and firms developed a shared vision for follow-up experiments. One interviewee emphasized the power of expectations:

"Expectations were really important to continue, with PowerMatching City we had a worldwide ground-breaking experiment, which made continuing the experiment definitely worthwhile." (#7)

Additional subsidies fuelled the expectations to initiate other economic viable pilots and accelerated the upscaling process. Expectations were of high quality because they were supported by tangible results from the experiments, researches, and experts in the smart grid field.

In PMC I *learning* was mostly related to technical issues, but in PMC II social learning played a central role. The experiment also resulted in some new innovations, like smart scooters. Most lessons on the social dimension were gained by end-user research conducted by the universities and Essent, and some lessons about regulation that are needed for smart grids were learned. Several scientific publications originated from these studies. The most important outcomes were that consumers can be controlled by offering price incentives, and technologies offered to consumers should be simple and transparent. Furthermore, the experiment showed that users are really important for smart grid development:

"The end-user has an extremely important role for upscaling, he or she eventually decides whether to buy a product or to subscribe to a service that is needed." (#9)

Much was learned about the economic value of smart devices. Flexibility profiles have been developed for several technologies. These flexibility profiles have been used as input for several future energy scenarios, and in this way the total value of flexibility in the Netherlands was calculated. Another lesson was that it is important to develop a market model that describes how and by whom flexibility should be allocated.

"During the pilot it became clear that the allocation of flexibility should be done much more formal. However, as we were already this far we just recommended it for future pilots, and that is where USEF[2] continued." (#7)

To achieve positive business cases, an interviewee argued for the importance of standardization, because it will reduce costs of installing and running smart devices and services:

All products have their own smart appliance standard, which is modified in such a way that technologies from different vendors are compatible in the pilot. However, outside the pilot they do not work together, and thus consumers cannot buy compatible products.: (#8)

Hence, learning processes were very broad in PMC II and considered crucial for upscaling, as one interviewee said:

"These lessons are crucial for upscaling, because you never replicate a project one at one, but you take the important lessons with you." (#7)

During the experiment, reflexive learning also took place. It was shown that consumers preferred the 'smart energy saving' service to the 'together pleasantly sustainable', which was not expected beforehand:

"I expected that they (the services) would be in balance. So, that there would be more people who wanted to work 'green' together and less people would 'watch their pennies'." (#9)

Furthermore, in the beginning users preferred the use of (automated) smart appliances. However, when they became more experienced with the system it gave them more satisfaction to manually control smart appliances. Additionally, it was shown that for the use of smart appliances trust in the functioning of the technology is important. When people lose trust in smart appliances it is difficult to regain it (DNV GL, 2015).

4.4. Smart Grid in Sustainable Lochem

In 2012, the experiment *Smart Grid in Sustainable Lochem* started. The experiment was initiated as a citizens' initiative, with the aim to stimulate the residents of Lochem to use less energy, generate their own electricity by solar panels, and to exchange electricity between each other (RVO, 2013). With an application that was developed during the experiment, residents had insights in their current use and generation of electricity. Furthermore, experiments with (smart) EV charging were conducted (RVO, 2015d). In the context of the pilot, a consortium was founded under the name IN4Energy. Five organisations joined this consortium: Lochem Energie (local energy cooperative), Alliander (grid operator), Locamation (control technology developer), Eaton Industries (automation service and product developer) and the University of Twente. The main goal of the pilot was to gain practical experience with the integration of decentralised generated sustainable energy in an existing electricity grid (Tubben, 2013). The experiment gradually grew and eventually 163 people participated. Moreover, the scale of technologies used in the pilot increased. The experiment started with a car-sharing concept with four EVs, which has grown to seven EVs (RVO, 2015d). Also the use of solar energy systems increased. Next to *growth*, key concepts of the Lochem experiment have been *replicated* in another smart grid experiment, the Houthaven project in Amsterdam. The experiment in Lochem did not become part of another innovation programme next to the IPIN and therefore no *accumulation* and aggregation of knowledge took place. The experiment was mentioned to play an instrumental role in *transformation*, as consumers became more aware of energy generation and consumption and the grid operator learned new things about the energy system. Furthermore, some legislative barriers have been identified and shared with policymakers, which is important to change regulative institutions.

Regarding the management of niche processes, the *network* was rather broad as several types of organisations joined the pilot, including both actors from the existing energy regime and regime outsiders. Other partners included an organisation that represented the interests of consumers and a research institution that brought in knowledge and conducted research. Furthermore, interviewees mentioned close cooperation with the municipality of Lochem. However, small entrepreneurial firms were mostly lacking. Moreover, communication between partners was sometimes complicated, as firms came from

[2] The Universal Smart Energy Framework (USEF) is a framework consisting of a set of rules, role descriptions, implementation guidelines, and a market control mechanism for decentralised energy markets, with the goal to accelerate large-scale implementation of smart grids (Boer and Verhaegh, 2016).

different industries that use different languages:

> ***"When we talked about data platforms, we both seriously thought that we were talking about the same thing. Until sometime in the measurements, after a few months, we found out that we were talking about two really different things." (#12)***

There were clear agreements about how much resources each partner should invest. However, when additional investments were needed most partners expected that the grid operator should make the investments. Furthermore, the experiment was expensive and for upscaling additional resources were needed that were difficult to get. Some parts of the experiments, like the EV sharing concept can be scaled up as the business case is positive, but this does not apply for most other concepts:

> ***"This project was of course heavily subsidized [...] If you cannot get any subsidy for a follow up project than at least not all parts of the project can be scaled up." (#11)***

In the Houthaven project, Alliander participated with several other firms, which made additional resources from other firms available. However, resource availability in the Lochem experiment was relatively low, especially when the experiment ended because the consortium was not willing to invest in a next project phase. Hence, the network cannot be characterized as very deep.

During the experiment *expectations* were well articulated and therefore it was possible for every firm to meet its expectations. Lochem Energie increased in member size, and more than eighty people installed solar panels on their roofs and four collective solar parks have been established. Eaton and Locamation developed and further improved technologies, and gained experience with their implementation. However, Locamation expected to install more of their sensors during the pilot. Alliander gained knowledge about the effect of solar energy and EVs on its network and the implementation of the (MPARE) in-home display, and the university conducted research about user behaviour and improved its models.

Although everyone could meet its expectations and both project partners and users were enthusiastic, there was a lack of a clear vision about the future activities for the experiment in Lochem:

> ***"We have gained a lot of insights in the technology: what happens and how. But the next step – how to go on with each other is extremely difficult. How to continue... we really do not know. " (#12)***

At the end of the experiment it was not clear which activities from the pilot should be scaled up and who wants to contribute to this. Moreover, upscaling is not expected to be feasible without additional subsidy. A lack of a robust vision for upscaling between partners was missing. It takes a lot of time to set up a follow-up plan, because the interests of all partners must be kept in mind. This does not mean that the experiment will not continue in the future, as one interviewee said they are still in the decision phase:

> ***"That is the point where we are now, we just finished, the end reports are just submitted and there is actually still no real decision on a sequel." (#11)***

Some *expectations* were based on the outcome of the experiment. For example, the success of the EV pilot fuelled the expectation for EVs and legitimated to continue with this concept. However, as the roll-out of technologies took more time than expected, not everything could be tested as initially hoped for. Eventually no flexible tariffs have been used, which made it impossible to see how users respond to such incentives. Furthermore, there was a lack of (experiences with) smart technologies for in-home use. So, some but not all expectations were substantiated by outcomes of the experiment, hence, the quality of *expectations* was limited.

In the experiment the partners learned on several dimensions. However, learning was more focussed on the technical dimension because most technologies were still underdeveloped:

> ***"Technologically we still had to overcome a lot of challenges to at least let the chain work." (#12)***

Locamation, Eaton, and the University of Twente learned most about technical solutions for their products and models. Alliander gained experience with different methods for EV charging. The most important lesson for Alliander was that technologies were inefficiently connected to the grid. The University of Twente conducted some research about human behaviour and Lochem Energie learned about user behaviour in workshops and meetings they organised. University researches published several (scientific) publications. Additionally, learning took place about economic models. Lochem Energie established several business cases for collective solar parks and Alliander conducted some economic studies in cooperation with the University of Twente about the options and costs for grid improvement. Furthermore, some regulative lessons were gained about barriers for the establishment of collective solar parks. Also, a stress test was conducted to see to what extent the grid could be overloaded. Other lessons were that there is need for standardization and that there is a lack of a sense of urgency for smart grids in the Netherlands. As one interviewee said:

> ***"Here in the Netherlands, who cares at the moment? There is a big gap between the people form the energy world, who have the knowledge and realise the impact, and the big crowd who has no idea." (#12)***

Moreover, the experiment demonstrated that more experience is needed with market models to achieve a robust and smart energy system in the future. It can be concluded that learning took place on several dimensions and therefore *learning processes were pretty broad.* Although, most learning was of first-order nature, also some reflexive learning occurred. One interviewee mentioned it was surprisingly that users were mainly driven by economic values, represented by the following quote:

> ***Another outcome was that when you look at what motivates people, you could definitely see that it clearly needs to be brought back to finances. Eventually, it is important for the people that they 'experience financial benefits'." (#11)***

However, as no flexible tariffs have been used it was not possible to learn about the effect of financial incentives on energy shifting. So, although some reflexive learning took place, it was a relatively small part of the pilot in Lochem.

4.5. Cross-case comparison

Table 5 presents an overview of the upscaling performance and the rating of the individual concepts and indicators. By adding the values assigned to each concept (per experiment) the *total experiment activity score* is obtained. The *total upscaling performance* is obtained by counting '+' values. Here it must be noted that these values are based on an interpretation of qualitative data. As such, they are not objective assessment but meant to communicate this interpretation in a stylised way and serve as interpretative instrument to compare patterns across cases.

By comparing the upscaling performance with the total experiment activity, a clear relationship can be noticed – pilots with a high experiment activity score have a higher upscaling performance. Based on this analysis, we now turn to a discussion how processes shape upscaling and which processes are in particular important for different patterns of upscaling.

The building of a social network is important and the findings suggest that it is in particular important for *growth* and *replication*. As was shown in the case of YEM Zwolle, a broad network is important to design a successful pilot that already considers the interests of a wide

Table 5
Interpretative ratings for each experiment.

Concept	**Indicator**	**Rating (1–5)**			
Experiment:		***Your Energy Moment***	***Cloud Power Texel***	***PowerMatching City Groningen II***	***Smart Grid in Sustainable Lochem***
1. Social network building	Broad	5	2	5	4
	Deep	4	1	4	2
2. Articulation of visions and expectations	Articulation	4	4	4	4
	Robustness	3	2	4	2
	High Quality	4	3	4	3
3. Learning Processes	Broad	4	3	5	4
	Reflexive	4	3	4	2
Total experiment activity		28	18	30	21
Upscaling performance					
1. Growth		+	–	+ +	+
2. Replication		+ +	–	+ +	+
3. Accumulation		–	–	+	–
4. Transformation		+ +	+	+ +	+
Total upscaling performance	5	1	7	3	

range of actors. This ensures that the pilot is also interesting for most stakeholders in a successive upscaling phase. Furthermore, a broad network increases resource availability and the potential for innovation and learning. YEM Zwolle and PMC show that the involvement of small entrepreneurial firms is especially important for innovative in-home solutions. Next to a broad network, PMC shows that continuity in the project network is important as this increases trust between partners, which is crucial for a sequel. Growth and replication require additional resources, making a deep network crucial. In the Lochem and Texel pilot, there was a lack of resources for upscaling, but in PMC and YEM Zwolle partners were prepared to invest in an upscaling phase. Besides that, PMC and YEM Zwolle received additional subsidies for a sequel and in an upscaling phase their social network expanded, which also increases resource availability.

Articulation of expectations is crucial in upscaling. The findings suggest that they are especially important in terms of contributing to *replication*. The cases show that articulation of expectations is important for different partners to understand and respect each other's interests, which increases the potential for partners to meet their initial expectations. However, another finding is that the articulation of expectations is not sufficient for upscaling. In order to scale up it is important that a robust expectation emerges *between* partners. This was the case for YEM Zwolle and PMC, because in both experiments a relatively positive expectation about smart grids arose that was shared between project partners. Shared acceptance of these expectations provide legitimacy for actors to invest time and effort into experiments and in this way firms can create a constituency and shared vision for upscaling. Furthermore, the communication of positive expectations outside the experiment is important to attract new partners in a replication phase. There are several ways to diffuse expectations (e.g. by publications, demonstrations, media attention.). So, articulation of expectations and social network building are interrelated, which corresponds with earlier SNM findings (Geels and Raven, 2006; Raven and Geels, 2010).

Learning processes are essential in upscaling and in particular for *transformation* and *replication*. Learning processes can reduce costs and are important for replication because a new experiment is never set up in exactly the same way as the initial experiment – a new smart grid experiment will be adapted to the lessons that have been learned in prior experiments. For example, YEM Breda uses several concepts that have been used in YEM Zwolle, but additionally, some concepts have been further developed and some new technologies are used. This corresponds with findings of Hoogma et al. (2002), who showed that in an ideal situation, experiments produce results, actors learn from this results, and make adjustments to improve technology or societal imbedding. Second-order learning is especially important to achieve institutional change as it involves the questioning of the underlying assumptions and desirability of a smart grid. The outcomes of such a reflexive learning process can lead to a change in institutions. For example, YEM and PMC showed that users prefer saving costs to being sustainable. This influences how actors arrange (new) experiments. In this process, aggregation activities (e.g. publication and diffusion of experiments' findings) are important. In this way, empirical descriptions of local practices can be presented, enabling comparison of local practices. Additionally, lessons from experiments can inform niche outsiders and promote support for the smart grid niche. The findings also suggest that for successful learning it is important to have a broad social network. Experiments with a broad social network (e.g. PMC and YEM) represented higher forms of reflexive learning.

5. Discussion

Although SNM was already well suited to analyse internal niche dynamics, this study suggests that SNM is also (partly) able to explain the upscaling performance of experiments. The research shows that experiments that are well managed in terms of the SNM processes are more successful regarding the upscaling of their activities. In particular, our results suggest that particular relations between internal niche processes and different patterns of upscaling exist (Fig. 3). The building of a social network is in particular important for growth and replication; articulation of expectations is especially important for replication; and learning processes are particularly important for transformation and replication. Future research can identify whether these relationships are maintained for other cases.

Some uncertainties of the research are worth to discuss. First, the research was dependent on the interpretation or perceived reality of the interviewees. Sometimes, partners from the same experiment had different ideas and interpretations of upscaling and how well processes were managed in the projects. Besides that, the research is dependent on the interpretations of the data by the researchers. As such, complete objectivity of the results cannot be claimed, but triangulation between multiple data sources allowed us to limit potential interpretative biases as much as possible. Second, external validity is the possibility to generalize findings to other cases and domains (Yin, 2003). A multiple case study design increases generalizability, as it allows comparison of analytic conclusions across a range of contexts. However, the small sample size cannot ensure high external validity. Nevertheless, the main purpose of the research was not to reach a generalised cause-and-effect explanation, but to get a better understanding of the complexity of project upscaling in particular cases. Third, the timing of the study is

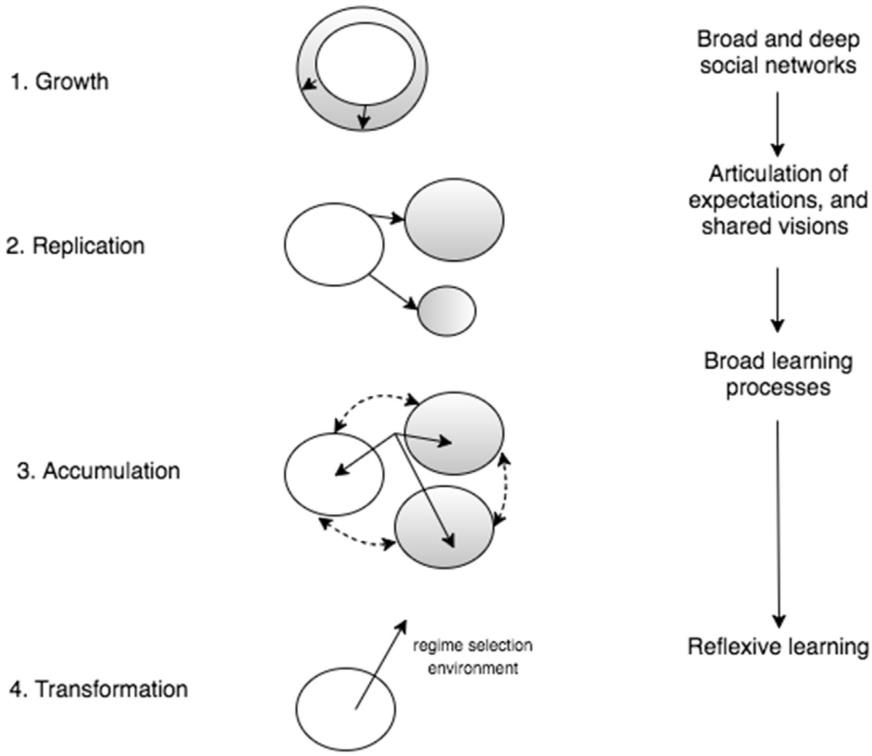

Fig. 3. Patterns of upscaling and relations with strategic niche management processes.

another limitation. Most experiments just finished and experiments that have not yet scaled up may in the future still scale up. Some interviewees mentioned that they are still in the decision phase of how to continue with the project. Finally, for some pilots it was not possible to get the (final) project reports because of confidentiality reason, or reports were not yet finished. This might have resulted in a lack of some relevant data.

6. Conclusion and policy implications

In this research four smart grid experiments of the IPIN have been analysed with the SNM approach. Experiments were regarded to be successful when they scaled up their activities. However, how experiments can scale up and influence established regimes is not well known in transition studies. From existing literature, we identified four patterns of upscaling: growth, replication, accumulation, and transformation. We highlight the following conclusions and recommendations.

First, we found that all patterns of scaling are relevant (in varying degrees) in the experiments. YEM, PMC, and Smart Grid in Sustainable Lochem represented growth and replication. Accumulation was only represented in the case of PMC and all experiments contributed to transformation. Hence the first conclusion is that this research confirms the usefulness of the typology for analysis of upscaling sustainable innovations such as smart grids. Future research may demonstrate the applicability and usefulness in other empirical domains.

Second, our empirical research results in some further specifications of this typology. The research shows that replication is often not a completely linear process of replicating an entire experiment, but that mostly parts (e.g. technologies, routines, institutions) of a project are replicated and circulate between multiple contexts. In this way components get further developed and transformed. One explanation for this is that a smart grid can be seen as a particular kind of innovation, i.e. a configurational technology, which means it is a system that does not consist of a single technology or artefact, but of different components that can be arranged in several ways based on the context of application (Fleck, 1993; Peine, 2009). This research shows that components (e.g. smart appliances, protocols, dynamic pricing) are replicated in subsequent experiments and get further adapted and integrated in smart grid systems. Furthermore, the research shows that also replication is possible within a new actor network. In this way, new partners share technologies, experiences and knowledge from previous experiments and recombine them to set up new experiments.

Third, the findings of the research also have important implications for the establishment of smart grid experiments and innovation programmes. First of all, the research shows that experiments that are well managed in terms of the SNM processes have a higher potential to scale up. Hence, a recommendation for future energy policy and innovation programs following from this research is to explicitly use SNM for the design of smart grid experiments and initiate innovation programmes with the SNM approach in mind. For example, experiments can be improved by involving a broad range of actors, creating an environment in which expectations can well be articulated and broad and reflexive learning processes are initiated, and by early involvement of users. This may enhance the potential for experiment upscaling.

Finally, another important implication is that to achieve a change in the institutional environment, experiments should collaborate and lobby with each other. Intermediary organisations can also play an important role in this process (Hargreaves et al., 2013; Kivimaa, 2014). For further research it is worthwhile to study how experiments cooperate, how knowledge sharing between different pilots can be improved, and what the role of an intermediary organisation can be in facilitating such exchanges of experiences.

Appendix A. Semi-structured interview script

Interview script: project stakeholders

Theory	Concept	Dimension	Interview questions
General questions and questions regarding upscaling			– What was the goal of the project? – How and by which parties was the project initiated? – What was the role of your organisation during the project? – What was your role during the project? – How did the project scale up? (*Explaining different patterns of upscaling when needed*) – What are important processes for upscaling? – What are barriers for smart grid development and projects upscaling?
Strategic Niche Management (SNM)	**Social network building**	Broad	– Which (type of) partners were involved during the project? – Did the size of the project network increase or shrink? – How was the interaction between parties? – What was the role of the different parties (in the consortium)? – How does the social network formation influence upscaling?
		Deep	– Were there enough resources available during the project? – Were there resources available for upscaling? – Who provided which resources?
	Articulation of visions and expectations	Articulation	– What were your initial expectations about smart grids? – How did your expectations evolve? – How have expectations been articulated between parties? – How did expectations influence upscaling?
		Robustness	– What were the expectations of other parties? – Did an overall shared expectation about smart grids emerge within the project network?
		High Quality	– On which experiences/lessons were the expectations based? – How were expectations substantiated?
	Learning processes	Broad	– What were the learning targets for the experiment? – What type of learning occurred in the project? – What were the most positive and negative expectations? – How was learning organised?
		Reflexive	– Did new assumptions or expectations regarding smart grids emerge? – What were the most surprising results of the pilot?

Appendix B. Coding of interview segments

Examples of interview (transcript) segment	Created code	Theoretical background
On the one hand, technology development, so technical components. However, a much more important element of the pilot was the social aspect. So how users behave and react on certain incentives.	Focus on technical learning and social learning	SNM: Technical and social learning
So, what we learned was that people actually used their energy at different moments	Shift in energy pattern was noticed	SNM: Learning: user behaviour
Research was the same in both pilots. But what you clearly see, is that in YEM Breda additional technologies were used like heat pumps	New technologies/ innovations in a replication phase	Upscaling typology: replication
What we saw is that growth was difficult because we used dynamic prices for grid operation that from a legal perspective was not possible outside the pilot	Legislation is a barrier for upscaling	Barriers for upscaling
Uhh, But yeah it is still quite a search how to make money with this concept. Subsidies are still needed.	Difficult to achieve profitable business case	Barriers for upscaling
Uhmm, yes, but it is not only this project that achieves transformation, but actually all the projects that are conducted contribute to this.	Collaboration and information exchange is important for transformation	Upscaling typology: transformation
I would not say it that way, actually it is the combination of projects that are needed for transformation	Collaboration and information exchange is important for transformation	Upscaling typology: transformation

However, that are all commercial parties, that are heavily looking how to achieve a positive business case	Difficult to achieve profitable business case	Barriers for upscaling
I think it was very good, that beforehand we all clearly knew what the final goal of the project was, and that there was at least a joint goal.	Development of a shared vision is important for upscaling	SNM: (shared) Expectations
Yeah, that was really great, we published at least 20 scientific articles	Capture and share lessons/ learning processes	SNM: Learning
The consumer is extremely important for this (upscaling), because in the end he or she has to change their behaviour or buy things.	Users' perception is essential for upscaling	SNM: Learning: user involvement
And an open source approach is really important for upscaling, because otherwise everyone is re-inventing the wheel. It should be simple to interconnect different components with each other	Open source standards are important for upscaling	SNM: Learning: standardization

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