Scaling up sustainable energy innovations

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\textbf{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 coconcomitant 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.

\section{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 Commission, 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 grids. 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, 2011a).
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, 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.
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