‚Replicating' smart grid experiments: a socio-technical analysis

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Abstract
The latest survey of smart grid pilot projects in the European Union includes 950 different cases (Gangale et al., 2017). A key question for the further transformation of the electricity grid is how to go beyond such experiments and pilot projects, how to aggregate and communicate experiences, how to draw lessons, how to scale up and disseminate the new findings and set-ups emerging around the digitalisation of the electricity grid.

In our paper we will draw on results from an ongoing ERA-NET Smart Grid Plus project "Replicability Concept for Flexible Smart Grids", which studies smart grid pilot projects in Austria, Switzerland, Germany and Sweden. We ask the question, whether or to which extent these experiments can contribute to the development of smart grids in other places, particularly through solutions which raise the flexibility of the local energy system in integrating volatile renewable energy sources.

In this paper we suggest a scheme of analysis which is sensitive to the specific institutional, geographical and stakeholder contexts of the smart grid pilot projects on the one hand and the different contexts at the places where outcomes of the experiments are supposed to be taken up.

1. Introduction

Smart grids are perceived to be an essential element of future sustainable energy systems. Such electricity networks are characterised by a pervasive deployment of intelligent (i.e. ICT based) communication, monitoring and management systems which enable a two-way flow of both information and power exchange between electricity suppliers and customers (Sigrist et al., 2016). These grid technologies are the basis for a range of applications and services. In particular, the flexible shifting of electricity loads of households or industry helps to match electricity demand with a fluctuating electricity supply due to a large share of intermittent renewable energy sources. Demand response measures and the building up of storage capacities also reduces peak loads in the electricity grid and in combination with a more local matching of demand and supply might reduce the need to up-grade the low- and medium voltage grid system despite growing electricity demand and a more distributed and volatile renewable electricity generation. These new developments are expected to radically change the local electricity system and markets, especially at local grid level (Gangale et al., 2017). Local electricity grids, which, by many actors, are still considered as a means for the one-way flow of centrally generated energy, will increasingly become an infrastructure for more complex tasks and energy logistics.

However, how such a future grid will be organised in practice, which technological configurations it builds upon, which services and incentive structures will be offered to its users, which new actors will become part of the electricity system (e.g. storage providers) and how the role and relations of old and new actors will be changed, is still in flux and a broad range of possible configurations of smart grids at urban or at household level is currently under investigation in various pilot or demonstration projects (WEF, 2010). The latest survey of smart grid pilot projects in the European Union counts 950 different cases (Gangale et al., 2017).

A key question in this situation is thus how to move beyond pilot projects and complete the transformation to a more active, flexible and sustainable grid system. Obviously, this is not only a question of 'getting the technologies right'. Energy grids and their functionality are deeply intertwined with regulations and other institutional structures (e.g. ownership structures, tariff systems), the types and networks of actors who operate the grid or supply electricity, the social practices and cultures of energy use, or the models and cognitive frames of actors and stakeholders, including the business models and interests of companies participating in the energy system. Studies of the scalability and replicability of smart grid technologies, i.e. the potential of implementing technologies from pilot projects for the whole electricity system or parts of it, even if carefully done and insightful, thus necessarily fall short of capturing the dynamics of electricity system transformation and the requirements of moving from limited smart grid pilot projects to a full scale smart electricity grid.

The question of how to scale up and replicate smart grid projects has been taken up in several research projects from a socio-technical perspective (e.g. Naber et al., 2017; van Winden and van den Buuse, 2017; van Doren et al., 2018). These contributions mostly investigate different patterns of up-scaling, factors driving the upscaling process, and the contribution of these up-scaling processes to a long-term smart grid transition. In this paper we will build on these analyses, but instead of focusing on patterns and long-term transition dynamics, we will zoom in on the next phase of pilot projects and discuss preconditions of replication and growth of these experiments. Given the complexity and local embedding of such smart grid projects, a replication in a strict sense obviously is not possible and implementing the same type of project somewhere else will always involve some elements of translation, or in other words, dis-embedding projects from place-specific conditions and re-embedding them in a new context.

In this paper we aim for a better understanding of these processes and will develop a typology of context conditions which are relevant to understand the local embedding of smart grid pilot projects. Based on two empirical case studies we will then try to identify critical contextual elements of smart grid projects, which are a pre-condition for the type of project and its replication. Certain smart grid pilot projects may e.g. critically depend on spatial-geographical preconditions such as highly densified urban contexts, or on certain institutional preconditions such as time-variable tariff schemes or organisational structures like the unbundling of grid operators and energy providers, as is the case for most electricity grids in EU-countries. Without these preconditions the same type of project (or particular use cases as we will point out later) will not be replicable in other places.

The typology and analysis we suggest allows for a better assessment of the replicability potential of smart grid experiments and provides guidelines for the dissemination of results gained from such pilot projects. Furthermore, it may help to compare the portfolio of existing pilot projects and identify contexts of smart grid application, which have not been sufficiently studied yet and would require further testing and development. Not least, a better understanding of the replicability of smart grid solutions developed in pilot projects and the institutional or regulatory conditions, they require, may inform energy and innovation policies, which aim at more supportive context conditions of smart grid applications.

In the following chapter, we will discuss previous literature on the replication and up-scaling of smart grid experiments and develop our analytical framework for identifying critical context conditions for the replicability of smart grid projects. In chapter 3, we will then apply this analysis to two empirical cases – a smart grid project in Hartberg, Austria, and one project in Malmö, Sweden. In our concluding discussion in chapter 4, we will then discuss the applicability of the concept to further cases and its potential to support the move beyond pilot projects.

2. Analysing context conditions for the replicability of smart grid pilot projects

Much of the discussion on the replication and up-scaling of smart grids has a predominantly technical focus – although usually acknowledging the importance of regulation or market design. As Sigrist and colleagues (2016) point out in a comparative analysis of smart grid demonstration projects in the European Union (GRID+ project, Sigrist and Rouco, 2012), scalability and replicability are the two qualities of smart grid pilot projects which reduce barriers for the growth and reuse of the solutions tested. They conclude that scalability as the "ability of the system to maintain its performance and function (...) when its scale is increased" (p. 2), requires a modular design, because centrally organised systems cannot be easily increased in size. Replicability in turn, which "denotes the property of a system that allows to be duplicated at another location or time" (p.2), they conclude, largely depends on standardisation and interoperability. Only if a smart grid solution is interoperable with existing grid infrastructures at other places, and the solutions as well as interfaces are sufficiently standardised (ideally allowing for plug-and-play applications), does it have a chance to be replicated at a variety of other places from an engineering perspective. In both described circumstances of replication and upscaling, they identify economic factors (e.g. the economic viability of scaling up small-scale solutions, and some market-related institutional factors (e.g. similarities of market designs along with regulations which define the role of different actors, tariff structures etc.) as factors for the viability of business models and replicability of solutions (see also May et al., 2015). As a final factor, stakeholder acceptance is pointed out as a precondition to make projects larger or replicate them.

2.1. Socio-technical concepts of up-scaling

However, from our socio-technical perspective and the empirical evidence gathered in the ReFlex project, social, economic or institutional factors are not discussed in sufficient depth and differentiation in these technology-oriented analyses. Techno-economic performance of a smart grid solution is an important precondition for economic viability, but not sufficient for successful diffusion or upscaling. In a socio-technical perspective, which takes the entanglement of new technological configurations with a range of socioeconomic and cultural dimensions seriously, the question of replication and upscaling becomes more complex. Moreover, the replication and up-scaling of solutions from pilot projects needs to be integrated in a broader perspective of systemic change to live up to the longer-term aim of transforming the existing electricity grid, also beyond the replication and economic success of specific smart grid solutions. Such an attempt is e.g. undertaken by Naber et al.

(2017), who put these questions into a broader context of socio-technical transitions. Table 1 gives an overview of the different processes of up-scaling they define in a transition context.

Patterns of upscaling (based on previous studies).

Pattern of upscaling	Description
1. Growing	The experiment continues and more actors participate, or the scale at which technologies are used increases
2. Replication	The main concept of the experiment is replicated in other locations or contexts
3. Accumulation	Experiments are linked to other initiatives
4. Transformation	The experiment shapes wider institutional change in the regime selection environment

Table 1: Different patterns of up-scaling smart grid experiments (source: Naber et al., 2017)

These patterns closely follow concepts of strategic niche management (Schot and Geels, 2008; Smith and Raven, 2012), where radically new socio-technical configurations initially take form and gain strength in protected niches such as publicly subsidised pilot or demonstration projects. Niches contribute to processes of social learning, the formation of social networks, and the alignment of expectations of different actors. Through processes of interlocal learning (Geels and Raven, 2006), the variety of local experiments contributes to the development of a global niche. Under certain conditions, when dominant socio-technical regime structures (in our case, the current organisation of electricity grids supported by specific regulations, rules and incumbent actors) come under pressure, e.g. through climate change and the need to integrate a high share of renewables or through new technological developments such as the pervasive use of ICT, such niches may challenge and eventually overturn socio-technical systems such as the electricity system. In analogy to these niche development processes, smart grid solutions might find their way into a global niche or even become part of a modified or transformed regime. Pilot projects may grow in size (e.g. include additional actors or households) and may be replicated in other places. Eventually, these projects may be aggregated, e.g. through the work of intermediary organisations, which facilitate the knowledge flow and learning across smart grid pilot projects and may finally transform current structures of the electricity grid. Analysis of a variety of case studies shows that replication often does not mean to repeat an entire experiment, but that mostly parts (e.g. technologies, routines, institutions) of a project are replicated and circulated between multiple contexts.

Also, other researchers have suggested socio-technical concepts to better understand and categorise scaling-up processes. Van Winden and van den Buse (2017) identify three types of upscaling in their review of literature:

(a) roll-out mainly refers to manufactured smart city products and service innovations and their scaling up on the market (market roll-out) or in organisations (organisational roll-out);

(b) expansion refers to increasing the size of existing smart city projects (such as mobility platforms); and

(c) replication refers to the implementation of solutions developed in pilot projects in other contexts (other organisations, other parts of the city, other cities).

In general, such types of upscaling include spatial dimensions (geographical enlargement), intertemporal dimensions (expanding duration and continuity) and attempts to influence institutional environments to accommodate to the upscaling process. Particularly the last element bears similarities to the 'transformation' pattern of upscaling in Naber et al. (2017). Van Winden and van den Buuse (2017) put particular emphasis on conditions and drivers for up-scaling processes, and they identify four main issues, which are largely in line with Sigrist et al. (2016):

(i) prospects of economies of scale, which provide a strong incentive to firms to scale-up projects;
(ii) managing the interplay of exploration and exploitation activities and the different competencies related to this at firm level (see also Hansen and Mattes, 2018) as a precondition for up-scaling;
(iii) meeting the challenge of knowledge transfer (particularly tacit knowledge) is a key issue for transferring new solutions to other contexts and replicate them;
(iv) as well as the conditioning role of regulatory, legal and policy frameworks, when projects are replicated in other places. (van Winden and van den Buuse, 2017)

Key lessons of their research are (1) the need to design pilot projects already in a way which makes it easier to scale them up, and (2) the sensitivity of smart grid technology projects with respect to social, cultural, political, institutional and behavioural contexts. By taking the social, cultural and institutional local structures and relations (despite a highly complex, intervowen and networked society) into account, also regional theories and theories on urban competitiveness have increasingly payed attention to the "place-basedness" of local experiments, policies and implementation projects in the last decade (see e.g. *Friedmann 2002, Camagni 2009).* We will come back to several of these issues in our own conceptual approach below.

A further distinction of up-scaling patterns is made by van Doren et al. (2018) regarding cases of urban low-carbon initiatives. Here a horizontal pathway of scaling up, which refers to the spatial growth of initiatives and includes replication, diffusion or other ways of scalar expansion, is distinguished from vertical pathways of scaling up, which rather focus on 'structural learning' and institutional change and includes related terms such as translation, mainstreaming or institutionalisation (p. 178). A strong performance in horizontal upscaling (replication) is seen to significantly increase the chances of vertical up-scaling or institutional change. Vertical scaling up can also mean a successive embedding of smart grid projects in wider institutional fields (regional, national, international) which in this process are adapted to meet the requirements of smart grids (see also van Doren et al., 2016). In relation to Naber et al. (2017) the horizontal expansion means remaining in the same niche, while horizontal up-scaling means going beyond the niche and transform regime structures.

Summing up, current literature, on the replication/scaling-up of pilot projects or sustainability initiatives, makes a main distinction between (A) different forms of scaling-up within given institutional and socio-cultural contexts, and (B) more far-reaching up-scaling strategies, which involve different forms of system transformation and institutional change. The first category includes different scaling-strategies such as the expansion of pilot projects, the replication of smart grid solutions in new contexts, or the roll-out and diffusion of new products and services. A key tenet of these studies is the importance of socio-cultural, institutional, political and economic contexts as a pre-condition, incentive and shaping factor of up-scaling processes. In our further analysis, we build on the insights provided from this literature and particularly, focus on the replication and transfer of smart grid solutions to new places and contexts. At this level, existing studies are not specific enough and do not sufficiently spell out how the change in context conditions should be taken into account and which context conditions are of particular relevance for the replication and wider diffusion of smart grid solutions developed in pilot projects.

2.2. Contextual conditions for the replication of smart grid solutions

In our following conceptual framework and analysis of empirical cases we are thus mainly interested in, how solutions developed in smart grid pilot projects can be taken up and replicated in different places. Such a spreading of smart grid solutions can be seen as a first step towards a transformation of the whole electricity grid and wider institutional changes at national or international scale. However, as pointed out above, such a replication rarely means implementing an identical smart grid project somewhere else. Rather, certain elements or solutions developed within a smart grid pilot project are transferred to new contexts, a transfer which often requires some level of translation or adaptation of these solutions. In relation to smart grid pilot projects it is crucial to ask: Which elements and solutions of the pilot project can be replicated somewhere else? Which context dimensions are critical for the replicability of these solutions? If these critical context conditions are not matched at the new place where a smart grid solution should be implemented, the solution in question is either not applicable, or in some cases framework conditions might be changed to accommodate the smart grid.

On this behalf, a scheme of analysis has been developed, which is sensitive to the specific institutional, economical, technological, geographical and stakeholder contexts of the smart grid pilot projects on the one hand and the different contexts at those places where outcomes of the experiments are supposed to be taken up.

The first question we have to ask is: Which elements of the smart grid pilot project are expected to be transferred to another place? In principle, the range stretches from highly standardised technical products, such as a new monitoring or visualisation device, which can be widely disseminated, to the whole set-up and configuration of a pilot project which can be implemented in a similar way somewhere else. While the first case will mainly require some technical preconditions to ensure the operability of a technical device in a new context (see the above mentioned criteria set up by Sigrist et al., 2016), the much more complex set-up of a pilot project will be transferrable only under very specific circumstances. But even in the case of a technical device, the interesting question is often, how it is actually used and embedded in a broader socio-technical smart grid context.

As an intermediate and sufficiently flexible level, we thus suggest 'use cases' to describe the socio-technical transfer of smart grid solutions. Here we can build on existing methodologies to describe use cases as part of IT systems for software developers and system architects (see ISO/IEC 19505-2: 2012) and further adapted to the design of smart grid systems (Gottschalk et al., 2017). Even in software development such use cases comprise detailed descriptions of functionalities and actions related to specific software solutions ('storylines' and 'scenarios' about the type of actors involved, their behaviour and action etc.), however these mostly remain at a micro-level. We go beyond this and include different type of context dimensions, which are needed to understand certain smart grid applications. Such a use case might be e.g. the implementation of a home energy management system to optimise the self-produced electricity from a PV system in a household. Apart from its technical set-up and implications for the use of household appliances, a description would also comprise business models, regulatory preconditions and more. Such basic socio-technical configurations, including a solution to particular problems and needs, social practices of use as well as relations to wider cultural and institutional contexts, appear to be a practicable level to analyse the socio-technical requirements and pre-conditions for transferring solutions tested in pilot projects to other contexts.

In this replicability approach we take the following dimensions into account, when analysing a use case as socio-technical configuration:

- Technological dimension: Which are the functionalities of the technological components and the whole system relevant for the use case (e.g. grid infrastructure, energy sources, storage equipment, loads)
- Spatial-structural dimension: In many cases geographical characteristics such as climate zone and landscape are crucial for the implementation of certain smart grid solutions. Also the spatial scale of the pilot project may play a significant role for its replicability. In certain scale-specific cases the possibilities for up-scaling are limited.
- Mission and macro-economic dimension: What are the key (long-term) missions, vision and non-commercial strategies and policies of public and private actors implementing the specific smart grid solution? (e.g. commitment to climate reduction goals, sustainability development goals …) What are the macro-economic effects (benefits and costs) of a solution for third parties?
- Micro-economic dimension: Which are the relevant market and contractual relations? (e.g. between energy supplier and customer, between grid operator and flat owner, between grid owner and grid operator etc) Which are the key economic actors (including customers) involved? What is the value added for the economic actors driving the use case?
- Actor constellations: Which actors are involved in the use case and how? What is the concrete ownership structure? Which stakeholders are relevant? What are their positions and are their controversies involved? Are certain actor groups explicitly or implicitly excluded?
- Institutional dimension

For the institutional dimension we particularly refer to the 'field' concept of Beckert (2010)[1], which allows to analyse the dynamics between three social forces (a) institutions (mostly formal), (b) social networks and (c) cognitive frames:

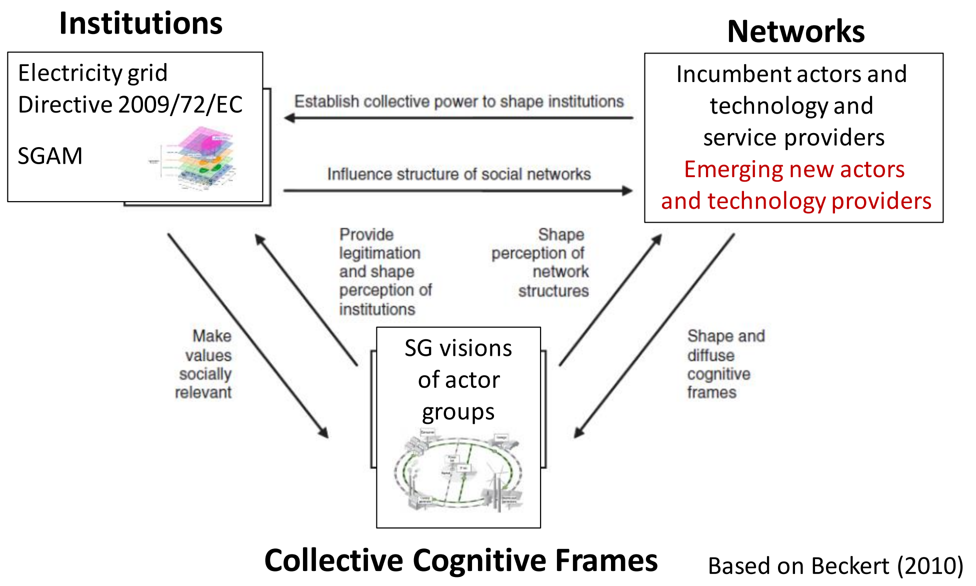
a. Formal institutions include legislative regulations, ownership and possession rights, market rules of the involved markets, organisational structures, technical standards, as well as formally agreed strategies;

[1] Although, Beckert (2010) focuses on markets and economic institutions, the concept can also be used as a general concept for institutional dynamics, e.g. as in the EU project CRESSI where the field concept was applied to social innovation (Nicholls et. al 2018 forthcoming, Nicholls and Ziegler 2017 - https://www.sbs.ox.ac.uk/sites/default/files/research-projects/CRESSI/docs/CRESSI_Working_Paper_2_2017rev_Chp2_April17.pdf)

b. Social networks of incumbent and new actors involved in the use case and stakeholders affected by it or influencing its context. This is going beyond the role of individual actors, which are dealt with separately (see above);
c. Cognitive frames, as the "culturally shaped meaning", which collectively shape the way formal institutions, habits and practices are built on (e.g. mental models of how energy systems and markets shall look like, locked-in social practices influencing energy consumption, or acceptance criterial for new market rules or privacy risks of end-user groups).

The figure below shows the interaction of those three social forces giving examples from the field of energy. This e.g. helps to identify lock-ins and contradictions between the existing regime with its formal institutions and dominating social networks and newly emerging and often competing cognitive frames between niche players and incumbents. Through this concept, we can also analyse in how far, in the case of the concrete cognitive frames behind the term "smart grid" and "flexibility", which might be (in)compatible with standards or regulations within the current energy regime.

Figure 1: Field concept describing the dynamics of institutionalisation



Beyond a descriptive mapping of these dimensions and the use case, a crucial question for further transfer is the 'criticality' of these dimensions or elements of it for a transfer of the use case. Often solutions only function under particular regulatory preconditions (e.g. the possibility of time-variable tariffs), ownership structures (e.g. ownership by the municipality), social network characteristic (e.g. hierarchical versus distributed power) or spatial characteristics (e.g. dense settlements). Our mapping of relevant context conditions and use case descriptions can be used to systematically identify preconditions for the replicability of smart grid use cases. At the same time, it can be useful to analyse in an early phase of new pilot projects, which lessons and solutions from existing projects can be integrated in the new set-up. To illustrate the applicability of our suggested analysis and further flesh out more details, we turn now to two empirical cases of smart grid pilot projects and the conditions for their replicability in other contexts.

3. Analysis of the use cases from the demo sites Hartberg and Malmö:

The uses cases analysed are both related to the flexible energy management of RES-based energy systems in the context of increased volatility of energy generation. Thus, the solutions developed in the pilot projects, are not intended to test single components independent of the systemic nature of the solution. In the case of Hartberg, the demo site is Ökopark Hartberg, a business park in the industrial zone of the small town, in Austria, aiming at energy system integration with smart grids. In the case of Malmö, Sweden, the demo site is the new smart city district of Hyllie in Malmö, where a platform for the smart integration of district heating and electricity system infrastructures has been developed.

3.1. The case of Ökopark Hartberg

In the case of Hartberg, evidence was gathered through semi structures interviews, a site visit and workshop with representatives of the municipality, the Stadtwerke and partners in the local pilot project together with the international ReFlex project team, in November 2016. We summarize our description of the case along the dimensions listed earlier in table 1 below.

Spatial-structural dimension	The demo site in Hartberg, is a business park "Ökopark Hartberg" with office buildings, a cinema and museum. It is situated in a region (Styria) which is having significant forest resources. Stadtwerke Hartberg and its different affiliated organisations are 100% owned by the City of Hartberg. As Stadtwerke they operate the grid and are also the local (almost monopolistic) provider of electric energy. One of the particularities of the demo site is that the business park is also run by the Stadtwerke, thus they have a close relationship with end-users: firms renting the offices, aquarium in the entertainment complex (cinema/museum), owner of electric cars charging their cars. Due to its neighborhood with a biobased CHP on the campus of the business park, Ökopark Hartberg's could be seen as a local micro-grid. The energy infrastructure includes the biobased CHP, low-energy buildings, PV for E-mobility charging. Thermal heat comes from the CHP and electricity is made available through the local grid of the Stadtwerke. Among other solutions which are tested, a direct-line peer-to-peer solution is tested in a pilot between the heating system of the aquarium as permanent load potential and the PV-charging station, to make use of excess electricity and to test the economic potential of peer-to-peer electricity exchange.
Micro-economic dimension	The business model of the Hartberg Stadtwerke and their innovation approach wanted to use the Businesspark as a testbed for their concept for optimized energy management, including PV supported E-mobility charging stations. At the same time Ökopark should also be an attractive campus for local firms. Apart from income generated through rents, urban and regional policies are strong drivers, following a clear mission, are key for understanding the case.
Mission dimension	The city of Hartberg has a vision and commitment to protect the climate (since 25 years member of the provincial network fore climate protection) and become CO2-neutral. The development of the Ökopark is related to and since its start the management of the Stadtwerke was personally taking care of the implementation of the related city strategy. Ökopark is also aimed at hosting research and firms dealing with environmental-technologies engaged in greening of the economy, thus playing a role in regional and economic development.
Formal	With respect to formal institutional settings, ownership of the grid and it's

Institutional framework	possession are two main factors. In this respect, Hartberg's local grid is owned by the municipality and operation is managed by its own energy utility, Stadtwerke Hartberg. Another institutional aspect is the legal framework for organising grid operation and energy supply. Stadtwerke, mostly occurring in Germany and Austria, are a peculiarity in the European context, as with less than 10.000 customers, grid operation and energy supply can be organized in a bundled organizational context. A third institutional dimension, to be highlighted here, is that of the energy regulation and the room it provides for contractual arrangements. In general, the energy regulator is aiming to set the rules for the monopolistic grid operator's rights on the one side and on the other side, its obligations. An example from the Ökopark is the above mentioned set up of a direct line for peer-to-peer exchange of electricity. Under Austrian regulation, the monopolistic distribution system operator has the right to forbid two grid-users to exchange energy through the electricity grid or to build a direct line. Thus, many aspects of the pilot project, need exceptional contractual arrangements between different businesses in unbundled structures. This would either increase the transaction costs, making the potential business model of the use case less attractive, or at all impossible.
Collective Cognitive Frames	With respect to collective cognitive frames, the importance of a vision and mission became evident during the site visit. It became obvious how strongly the vision for the eco-business park influenced the historical development of the demo site, as a picture of the vision is exhibited in the business park itself.
Social networks involved	With respect to social networks involved, the close collaboration between, municipal owner, energy utility and organisations in the ownership of the Stadtwerke or the municipality acting as end-user allows for experimenting. The interviews also showed the importance of a care-taker role to orchestrate the complex network of stakeholders and actor groups in the city. In our case, the management of Stadtwerke took this role continuously over several years, particularly linking municipal policy making with the local business sector and the various actors in the Stadtwerke.

Table 1: Contextual characteristics of the smart grid use case in Hartberg, Austria

The use case to be replicated in this case study deals with the local energy management in business parks. For replication and upscaling, one of the critical conditions seems to be the "bundled" context as Hartberg's local grid is operated by its own energy utility, Stadtwerke Hartberg, which is also the energy supplier at the same time. Basically, in the Austrian and German context, this size of the use case could also be replicated in bundled setting, however, then it would be limited to municipalities / grid operators with a rather small size and not suitable for (larger) upscaling. For other countries outside of the EU with less restrictive legislation on separation of grid operation and energy supply services, such as Switzerland, this limitation to upscaling in size would not become an obstacle to the replication of the business park use-case itself. In an "unbundled" context with an operator of the electricity grid in charge of connecting a business park, which does not share the same goals as the electricity supplier, the use case becomes more complex to become successful. Even more challenging is the situation when a third energy company providing heat to the business park, which would require a quite sophisticated collaborative business model.

Another aspect which needs to be taken into account in replication is that, on the demo site, the business park is also run by the Stadtwerke. Thus, not only do they have a have a close relationship with end-users as grid operators and customers in an energy supply contract (electricity, heat and electric cars charging) but also as landlord to tenant (firms renting the offices, operating of the entertainment complex (cinema/museum), renting space in a car park).

Furthermore, another success factor in this case is the rather long-term perspective and support by a clear sustainability vision and mission statement. For replicating a sustainable business park model such as in Hartberg, the visioning and orchestration of a shared mission to achieve a working collaborative business model would become a key success factor and need to become a core part in a co-creation process during a replication project.

The case of Hyllie, Malmö

Similar to Hartberg, a combination of methods was used in Hyllie. We used semi-structured interviews with project managers, two site visits, workshop with key stakeholders in the ReFlex-project in October 2017, along with document studies of municipal plans and project descriptions.

In the new urban district Hyllie in the city of Malmö, Sweden, a smart grid platform has been implemented which in the longer term will integrate both, the electricity and the district heating grid. Currently, the system is mainly applied to manage heat loads of the district heating system by using building structures for heat storage.

Hyllie is Malmö's largest development area and will in the final phase comprise around 9000 new homes and an almost equal number of office spaces. Hyllie is seen to be a 'lighthouse' for Malmö's target to become 100% renewable by the year 2030. Further aims and procedures on the way to become Öresund region's most climate-smart city district have been laid out in a climate-contract between the city of Malmö and the companies VA Syd and EON as well as in the Hyllie Environmental Programme (HEP). The aim for Hyllie is to provide 100% renewable and 'recovered' energy by 2020, sourced by a large proportion from local sources; develop a sustainable local transport system based on electricity and gas; create an integrated energy system of electricity, gas, heating and cooling; and reduce energy consumption by connecting energy-efficient buildings to a smart grid and facilitate a climate-smart lifestyle.

Dimension	**Description**
Technological dimension	The system is applied to manage heat loads of the district heating system by using building structures for heat storage. To date, the smart electricity grid features have only been incompletely developed (a limited number of smart home equipped apartments). The most advanced smart grid feature which has been implemented is a 'smart district heating grid platform' which allows to manage district heating loads through demand side measures. In the longer run the aim is to develop a smart grid platform operating across the heat and electricity grid. The main feature of the smart district heating system is a smart residential gateways (control box with mini-computer) connected to the building management system in district heat supplied buildings and allowing to use the

	building structure as a heat storage by slightly overheating the building in advance of an expected peak demand and using the stored heat during the peak hours. The raised heating temperatures are at a level where they go unnoticed by residents in the building. The technical challenge beyond building a smart control platform has been to make the residential gateways compatible with different types of building energy management systems. In the longer run, the residential gateways can be used to provide other types of smart grid functionalities to the buildings and households.
Spatial-structural dimension	Smart city district Hyllie is a newly built city district (still under construction) located in Malmö, the third largest city and municipality in Sweden, located in the south, across the strait from Copenhagen. The surrounding areas are farmland with fertile soil and a long history of agriculture. The expansion of the city is thus easy due to the flat land, although the existing highways and railroads are obstacles for the district heating system expansion. The flat land and proximity to the coast makes the area suitable for wind power, at the same time wind power expansion is limited by the high agricultural value of the land surrounding Malmö.
Micro-economic dimension	The energy infrastructure has been privatised since 1991 and is now owned by the German company E.ON which also owns energy companies with predominantly district heating in roughly 20 other Swedish municipalities. The municipality and energy company are however cooperating closely on many issues, and especially in the Hyllie project - EON as the owner of the district heating system and heat provider, and municipal or private building developers and owners. In terms of contractually relations, there is a difference between district heating and electricity. District heating customers are passive users. If living in multi-dwelling buildings the heat cost is included in the rent, and residents cannot choose another heat provider. In electricity, the customers can choose whom they buy their electricity from, but the grids is monopolised. In district heating, grid and production is not separated. The use of the building management system for managing heat loads is decided in agreement with the building owners and so far does not involve any fees and financial compensations from either side. Key economic actors are thus the municipality, building developers (public or private), energy companies (mainly E.ON) and customers. Customer incentives are rather limited as they are passive in terms of the technological configuration.
Mission and macro-economic dimension	Part of the effort to develop this climate-smart district is a pilot project for Smart Grids funded by the Swedish Energy Agency. The aim is to deploy an integrated energy system in Hyllie which optimizes the interaction between local and central production using the smart grid and offering smart home functionalities to its residents. From the Swedish Energy Agency´s perspective, the pilot project is a part of a wider strategy to develop smart grids in Sweden, as part of a sustainable transition in order to facilitate the technical development but also in the end to make smart grids into an export industry. From the perspective of Malmö municipality, the main goals are developing the urban district of Hyllie. The main vision is: ”With communication in the centre, Hyllie shall be a driving force for growth and sustainable development of the new Malmö – a place that crosser borders and is facing outward with the whole world as the arena”. Sustainable development and the mitigation of climate change are key elements of the vision, and the smart grid development is regarded as a part of that aim.

	The macro-economic effects are based on reduction of peak production – thus reducing costs due to climate emission taxes and fuel prices. A broader installation of load management would have further potential and is currently implemented also in existing residential areas in Malmö and other Swedish cities. The smart district heating system has so far turned out to be the only smart grid application in Malmö with a viable business case. Managing the district heating loads by shaving off peak loads allows for a more efficient use of the district heating grid system and reduced need to expand its capacity
Actor constellations	The model is embedded in a broad partnership of the municipality, E.ON as the owner of the district heating system and heat provider, and municipal or private building developers and owners. A foundation for these collaborative relationships is the Climate Contract and Hyllie Environmental Programme as well as a long tradition of collaborative public-private partnerships for the provision of different types of infrastructure services in Malmö municipality. Most buildings in Hyllie and Malmö are connected to the district heating system. The Swedish Energy Agency is a key partner in terms of funds for the pilot; they supported the project with 47 million SEK (4,4 million Euros) in 2011. The users are not much involved in this process, they are rather seen as passive but crucial for the load management – but the users are not active in the process.
Institutional dimension	The electricity market in Sweden is liberalized with competition in production and sales, but monopolized for transmission and distribution. The district heating infrastructure is still integrated with one supplier who also owns the grid. Although competition may occur if all parties agree, this has not been implemented anywhere yet in Sweden. Regulations are strict and significant standardisation has occured in the district heating sector throughout the 20th century, meaning that the differences between different electric systems or DH-systems are not that large. From the national perspective the smart grid development is supported in various ways, through institutional channels as well as informal.

Table 2: Contextual characteristics of the smart grid use case in Hyllie, Sweden

In terms of the potential for replication, the use case in question in Hyllie is thus a smart grid platform for the load management of district heating with an IT infrastructure for control and prediction of heat loads and special devices interacting with the building energy system to store heat in the building structure in advance of peak load of the district heating system. Despite a number of technical limitations (control infrastructure needs to be built up; interfaces with building energy management systems and their technical specifications need to be developed and are currently not commercially available), only few of the contextual conditions listed in table 2 appear to be critical for replication or upscaling of this smart grid solution. Obviously, such solutions are only relevant for cities with district heating systems (and preferably in situations where a reduction of peak loads is useful, e.g. by reducing the need to increase the capacity of heat pipes despite expansion of the DH system) and only buildings with an energy management system can be integrated. Integration of grid ownership and supply are a precondition, but this is usually the case with district heating systems. Public ownership is not a requirement, but a cooperative relationship with building owners is of importance because they have to voluntarily accept the installation of such a system in their building without financial benefits (otherwise the business case for this solution might be in jeopardy). It is thus also of advantage to have only a limited number of building owners as contract partners in the supply area. As has already been tested by E.ON the system is scalable and can be expanded to further parts of the city and it can also be applied to the existing building stock.

4. Discussion and conclusions

The analysis of our two cases of smart grid demonstration projects makes clear that the replicability of solutions developed within these projects, i.e. their contribution to the development of smart grids in other places, depends on a combination of technical and non-technical (social, institutional, economic) factors. Currently available analytical concepts, as described in this paper, lack several dimensions. Nevertheless, some of these more technology centred contexts provide a good starting point for further analysis. An example is the standardised use case description (see ISO/IEC 19505-2: 2012) adapted to the design of smart grid systems by Gottschalk et al. (2017), which allowed us to delineate appropriate cases of smart grid solutions under conditions of practical use.

However, when analysing such use cases as socio-technical configuration, further dimension need to be added to assess the potential and conditions for replication. In our analysis we have identified five additional dimensions which appeared to be essential to better understand and assess the replicability of solutions from pilot projects: a spatial-structural dimension, a mission dimension and the three social dimensions taken up from Beckert's field concept (Beckert, 2010), i.e. formal institutions, social networks and cognitive frames. As those social forces are integrated in a dynamic relationship, they take the structures of social relations and relational patterns into account as well as they are the constraining rules and norms that influence the structure of social networks and cognitive frames of individuals by making values socially relevant. Furthermore, they refer to legitimation through collective power and commonly shared meanings and interpretive material (making sense of society and its actions). Following this notion, those dimensions not only allow for an analytical approach to replication and upscaling, but also establish a frame for the evaluation and identification of success factors for replicating smart grids experiments.

The analysis of the two case studies from Malmö/Hyllie in Sweden and Ökopark Hartberg in Austria structured along the different dimensions of the socio-technical configuration of smart grid use cases demonstrates the applicability of this approach. Making these dimensions explicit in the use case analysis provides a basis for further reflection and analysis of the potential to implement these use cases in other contexts. While the possibility of replication was hardly influenced by certain dimensions (e.g. the ownership structure in the case of smart district heating grid load management), other dimensions turned out to be highly critical (e.g. certain regulatory contexts) for the implementation of these solutions.

In the end, the analysis of use cases as sketched out in this paper, is supposed to support processes of transfer and learning across different sites of smart grid applications. In transition studies such processes have been conceptualised as inter-local learning (Raven and Geels, 2010) and identified as key elements of the growth and upscaling of socio-technical niches. Replication and upscaling of smart grid experiments can be seen as targeted, problem-solving attempts of learning from one experiment and transferring the (successful) elements of this demonstration project to another site. As with other examples of technology transfer between different contexts (see e.g. Ulsrud et al., 2018), the contextualized nature of such experiments requires elements of decontextualization and recontextualization in the process of replication and upscaling. Thereby, *contextualization* refers to the act or process of putting information or specific factors into context (making sense of information from the situation or location in which the information was found), while *decontextualization* occurs when those factors become separated from their social, cultural and institutional context. However, if we view context as a process rather than as a static concept (see Gumperz 1982[2]), this allows the actors who replicate the smart grid experiment to create, maintain, and change what contextual factors are relevant to them (important for the process of recontextualiation when upscaling or replicating), whereas we need to consider that it is never one single context but usually a multiplicity of contexts (as of set of actions, stakeholders and preconditions) that changes due to interaction.

In terms of replication and upscaling, both described case studies showed the importance of a care-taker role as well as political/strategic support to orchestrate the complex network of stakeholders and projects in the city as well as to ensure continuous development of follow-up initiatives and the shaping of the socio-technical framework for upscaling and new experiments. Obviously, such strategies of replication and implementation of solutions in other places are just one step in moving beyond pilot projects and more fundamental changes of the contextual conditions, which have been treated as stable in our analysis, are needed for a socio-technical transition of the electricity system. Nevertheless, the spreading and replications of solutions developed in pilot projects are a crucial step on this way and require the development of more nuanced replication strategies than we can observe today.

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[2] In language and communication studies, Gumperz (1982) was one of the first to define contextualization in relation to discourse analysis.

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