Co-Evolution of Smart Energy Products and Services:

a Novel Approach towards Smart Grids

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***Abstract*— In this paper we present our project on interdisciplinary evaluations of existing smart grid environments regarding (1) the technical performance of smart energy products and services, (2) end users perceptions, (3) stakeholder processes and (4) market aspects. Our evaluations are based on data and information originating from real life pilots and demonstration projects in the field of smart grids in residential areas in the Netherlands and in Austria. The so-called CESEPS project is executed in the European ERA-Net Smart Grids Plus program. CESEPS stands for Co-Evolution of Smart Energy Product and Services. Its main objective is to support the development of smart energy products and services for local smart grids that better respond to the demands and concerns of all stakeholders in terms of performance, cost, reliability, safety and robustness, sustainability and energy-efficiency, and end users' comfort. Besides comparative data analyses and user surveys, this three year project comprises simulation activities to model existing and innovative smart grid energy products to evaluate their feasibility, given the aspects above mentioned. In this paper our approach will be explained and illustrated by several examples of ongoing subtopics of research and knowledge dissemination among stakeholders in the smart grid sector.**

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Keywords*— *residential smart grids; products; services; end users

I. INTRODUCTION

The integration of intermittent renewable energy sources and decentralized energy production in existing electricity grids is a technical and organizational challenge. After technical aspects, the second biggest challenge in smart grids development is to understand consumer behavior in future grids as social acceptance and a more active role of energy consumers are of great importance for the success of smart grids. To overcome these challenges we suggest a co-evolutionary approach through which technology, marketplaces, emerging user needs and their adaption, as well as needs of stakeholders in business and governance will be merged. In biology, co-evolution is the term for a long-term process by which several organisms evolve together while adapting to – and in time, changing – environments. Organisms make use of other organisms by building partnerships or by living on or in them, and have to adapt to their environments and to these relationships. These adaptations result in future

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generations with features more suitable for survival, often by improved mutual relationships – different organisms working better together- and sometimes these changes are that large that the next generations are so different that they may become different species. In applying this co-evolutionary thinking to the mid- and long-term development of smart grids, in this project the ‘smart grid’ is seen as an environment and its energy technologies, ICT solutions, end users, and other stakeholders as complementary organisms having to collaborate to make the smart grid function as intended: flexible, energy-efficient, reliable and robust, sustainable, and cost-effective. In that sense the co-evolution of multiple compatible smart grid technologies are put in the context of society and product development from a process perspective.

Till now the introduction of the smart grid concept has been merely technical and has led to about 250 smart grid pilot projects in Europe [1-2]. According to the International Energy Agency [3], a smart grid is an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users. Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimizing costs and environmental impacts while maximizing system reliability, resilience and stability.

This project focuses in particular on residential smart grid projects in two countries, namely Austria and the Netherlands, which both have a different profile in relation to the share of renewables in electricity consumption. For instance, with just 5.5% the Netherlands shows one of the lowest shares of renewable energy in whole Europe while Austria is one of the front runners with on average 75% of renewable energy and in some areas even 100% thanks to a high penetration of hydropower and wind energy. It can be easily understood that these differences may result in different expectations and other technical specifications and operation of smart grid projects.

In the Netherlands, an increase in the number of smart grid pilot projects has been witnessed since 2008 resulting in more than 30 Dutch pilot projects running at present, half of them in residential areas. In Austria these developments resulted in a similar number of projects. In these projects new energy technologies are put into practice including photovoltaic systems, in-home energy displays, smart appliances, electricity storage and electric vehicles, and energy services such as billing, energy trading and energy management. Various new energy-related products and services, see Figure 1, such as smart meters, smart appliances, e-vehicles, and in-home automations are being offered in residential smart grid pilot projects. These products and services are expected to support the active participation of end users in balancing energy demand and supply in the electricity network. One well-known project is *PowerMatching City* in Groningen, which explores a smart grid from the perspective of energy technologies, ICT (PowerMatcher), end users and markets. Lessons learned from smart grid pilot projects such as *PowerMatching City*, *SmartLowVoltageGrid* in Austria, *Smart Region Köstendorf and Eberstalzell* in Austria or *Your Energy Moment* in the Netherlands will support the present research.

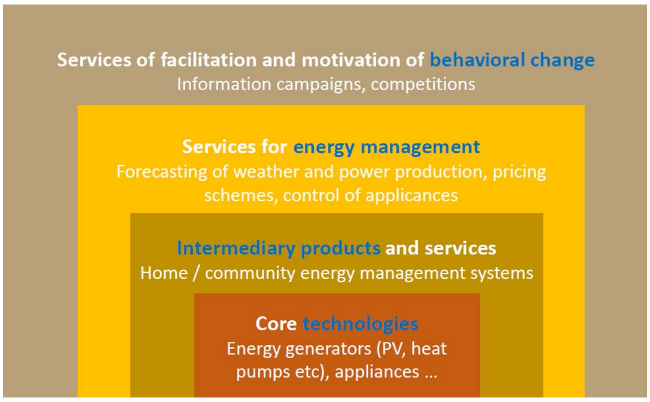

Fig. 1. Conceptual framework for residential smart grid products and services.

Previous studies have concluded that separate energy technologies usually perform well, however to improve the functioning of the whole smart grid environment, the combination of energy technologies in one integrated system should perform also well. From that perspective end users need to be taken into account in the design of products and services that support active user involvement. The end users are empowered in the production and management of energy, and insights from other stakeholders involved in residential smart grid pilots are needed to complement existing experiences. These studies are relatively limited due to their low number of participants and therefore low statistical relevance. Moreover there is a lack of evaluations of the marketplace of energy and energy products and services in smart grids from end users and multi-stakeholder perspectives. Due to the limited information, the development and performance of various energy-related products and services that could support a better participation of end users in future residential smart grids development are rather behind compared to other industries that develop technology-based products such as the ICT mobile sectors.

From a theoretical point of view the energy performance of smart grids at the low voltage level mainly depends on three factors: technical aspects, financial aspects, and human aspects. Technical aspects such as the configuration of an energy system, local climate and weather conditions, the appliances installed and the construction of dwellings are usually taken into account in the development of new smart grid projects. This also applies to financial aspects such as the type of pricing of electricity (dynamic or time-of-use), investment costs, and O&M costs. On the other hand human aspects are usually given insufficient attention during the preparation phase of new smart grid projects. They include the interaction of residential end users with smart energy products and end user behavior towards energy efficiency, local production of sustainable electricity and trading of electricity. So far, understanding of residential end users’ behavior in smart energy systems results from post-evaluative research in existing smart grid pilots that serve as Living Labs. In recent years, consumer research in the field of smart energy systems mainly focused on the technical feasibility and functioning of intelligent networks. Only a small part of this research [4-8] considered the evaluation of the energy balance of households and the interaction of end users with smart energy and the necessary smart grid product-service combinations. This type of research has been explored only to a very limited extent; of the 219 EU projects in the field of smart grids which have been undertaken since 2001 only 8% is in the category of 'home application - customer behavior' [2]. Within this category of projects the focus is on smart meters, energy saving, and a smaller proportion on electric vehicles. Much of the research has a top-down approach in which the experiences of energy suppliers and energy distribution companies are the key element. Experimental research on end users in smart grid pilots and their needs and wishes as energy customers has been performed in only two projects with an emphasis on the analysis of monitoring data of energy flows in domestic smart energy systems. In the Netherlands, only two out of thirty smart grid pilots have been subjected to in-depth consumer research, and only one research activity exists in the field of multi-stakeholder analysis of smart grids. Also in Austria a couple of customer-orientated research pilots (*Consumer2grid*, *SmartWebGrid*, etc.) exist, but in general these projects lack sufficient consumer focused evaluations. Therefore it is very likely that our research will fill a void of knowledge and experiences in the smart grid research sector in Europe and probably also elsewhere.

II. Our Approach

To overcome the challenges and limitations that arose in the previous studies, we proceed with a co-evolutionary approach through which technology, marketplaces, emerging user needs and their adaption, will be merged using the *three layer research model* for Smart Grid environments which is presented in Figure 2.

A. Technology

Smart grids host a large number of diverse energy technologies and ICT. In the framework of our research project we have selected a limited number of technologies, based on their relevance and impact in the local smart grids that will be evaluated and validated in more detail. These are smart grids' safety aspects and overall network reliability regarding their energy and power flows, energy-efficiency, local sustainable energy production and consumption, demand side management by self-consumption of energy generated in the smart grid pilot, forecasting techniques and mutual trading of energy with neighbors, controlled charging of EV by renewable energy sources and patterns of use.

B. Marketplace

Existing smart grid energy products and services will be evaluated as well as new solutions will be created in order to shape changing energy market structures with a focus on the 'good design' for energy products that support safe and reliable operation of local smart grids, demand side management and electric mobility in smart grids with a high penetration of renewables. From the perspective of energy markets, the microeconomics of smart energy products and services will be evaluated in terms of in terms of return on investments, Net Present Value and levelized costs of electricity in relation to real-time pricing versus time of use pricing. In particular in the field of e-mobility financial comparisons will be made between electric charging and consumption of fuels in cars equipped with a combustion engine.

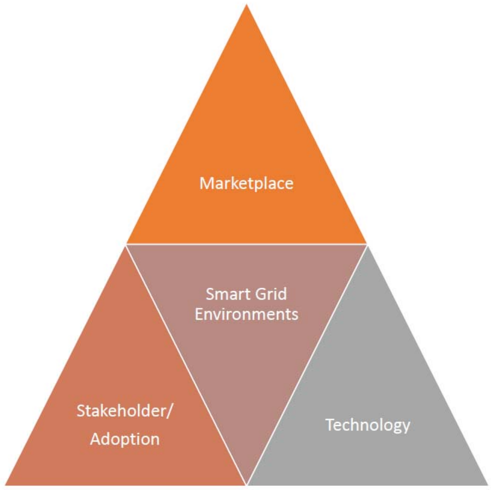

Fig. 2. The *three layer research model* which is applied in our project.

C. Stakeholders/Adoption

Adoption of end users such as individual persons and communities is a significant issue which regards new features in smart grids such as demand side management, exchange of energy with other end users, a high penetration of renewable energy at a local level, the required flexibility for prosumer interactions and e-mobility. By interviews and observations of all smart grid stakeholders (both end users and utilities, policy makers, network operators et cetera) their experiences, expectations and modes of interaction between them, will be captured to understand the acceptance, preferences, and practices occurring during the pilot projects. Information resulting from these studies will subsequently be applied in co-evolutionary development of smart energy products and services.

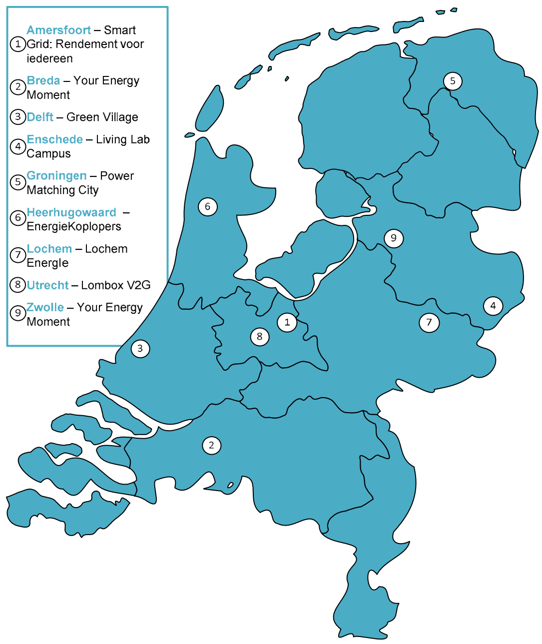

Fig. 3. Map of the Netherlands with various locations of smart grid pilots which are evaluated in our project, see also [9].

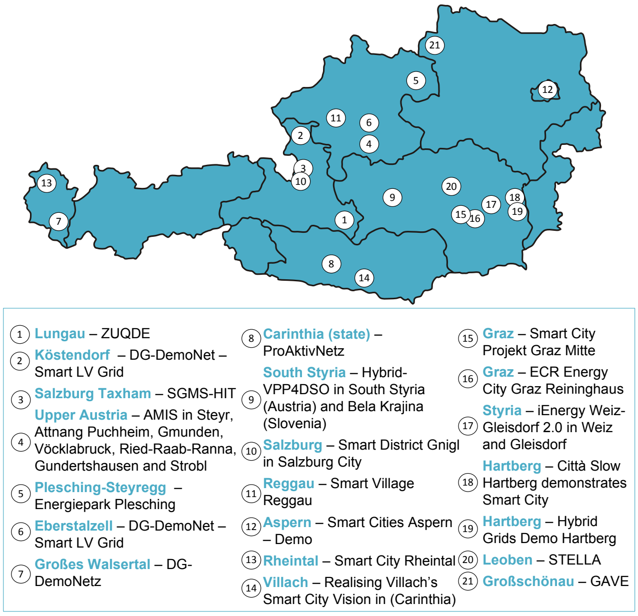

Fig. 4. Map of Austria with various locations of smart grid pilots which are evaluated in our project, see also [10].

CESEPS aims at developing knowledge about the actual performance of technologies in local smart grid pilots by monitoring and evaluating data from these projects and executing measurements on site. Complementary to the experimental approach, theoretical modelling of energy performance of smart grid technologies and their interaction will be established. The role of stakeholders and end users in local smart grid pilots will be explored by gaining insights into their needs and wishes for smart energy products and services, the needed changes in their energy practices, and contextual barriers encountered.

To realize these objectives, existing smart grid environments will be explored by evaluating the performance of energy products and services as well as end users perceptions and stakeholder processes. The research in this project will perform a comparative validation of smart grid technologies and concepts in more than four existing demonstration projects in the Netherlands under the umbrella of the *Smart Energy Collective* of DNV GL, such as *PowerMatching City*, *Your Energy Moment*, and pilots in the cities of Heerhugowaard, Lochem and others (see Figure 3) and in six ongoing pilots Austria called *E-mobility on Demand*, *PlanGridEV*, *iWPP-Flex*, *EcoGrid EU*, *Hybrid-VPP4DSO*, *IGREENGrid*, and others (see Figure 4).

Adding to existing smart grid pilots, we will develop innovative technological concepts for e-vehicles with fuel cells, smart solar charging and other charging solutions within the framework of the *Green Village* of TU Delft, the *Living Lab Campus* of University of Twente and *Vehicle2Grid* in Utrecht, see Figure 3.

Besides comparative data analyses and user surveys this three year project comprises various simulation activities to model existing and innovative smart grid energy products, using transient and static modelling, with time scales ranging from microseconds to 15 minutes.

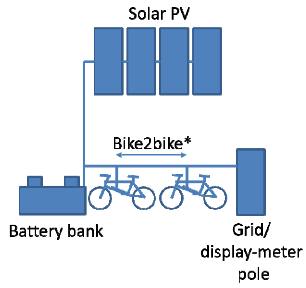

Fig. 5. Scheme of the envisioned solar charging station at UT's campus.

III. Preliminary Results

This project started in March 2016. Below, preliminary research results and approaches are presented.

A. *Connecting Smart-Grid stakeholders*

The increasing share of renewable energy sources, together with the 2020 and 2030 targets for the reduction of greenhouse gas emission in the EU created the need of innovations in the EU energy system. Besides new technologies, active involvement and collaboration among stakeholders are equally important [8]. This collaboration and communication between involved parties will reduce the risk of undesired circumstances such as poor quality of the electricity supply, congestion, lack of stability, impossibility to cope with demand, etc. One of the objectives of CESEPS is the creation of a Knowledge Community that will bring together stakeholders, such as consumers, energy providers, smart grid developers, city planners, policy makers, product designers and researchers, with the aim of generating and disseminating common tools for planning, integration and operation across the energy system. The results of our work may therefore contribute to an optimized grid planning and design at European level, more efficient transnational trading, and new business opportunities. For this purpose several workshops have been organized yet.

B. *Designing solar charging stations for e-vehicles*

In the recent years the number of electric bikes in the Netherlands has risen exponentially. Currently more than 15% of the Dutch citizens owns an electric bike. As these bikes are co-powered by batteries, they need to be charged regularly. Opportunities can be found in a charging system based on solar energy as a result of three factors: 1) steady improvements in performance and reduction of cost, for the solar cells technology, 2) the growing social awareness, consensus and support for sustainable products and services, and 3) the possibility to extend the learning points to solar charging stations for electric cars.

To get a properly functioning charging station that will deliver energy to the user when needed, the sizing of the solar panels and energy buffer is crucial. Furthermore, understanding end users' riding and charging behavior is critical for the optimal design of the station. In our approach, this understanding is gained via a survey established the e-bikes owners on the *Smart Living Campus* of UT. The outcome of the survey is then used for a) its technical information, as input for the modeling and simulations of the solar charging station, see Figure 5; b) its behavioral information, to set up solar charging stations which meet the users' needs. Based on the reliability of the power supply and the levelized cost of electricity, preliminary results show that – per e-bike – a charger is composed of a 160 Wp photovoltaic system with MPPT, a 100 W converter, and a 700 Wh Li-ion battery bank when used in a climate like in the Netherlands.

C. Utrecht smart grid pilot

The Utrecht smart grid pilot originated from the project *Smart grid: Profit for Everyone*, which focused on developing innovative business cases for services in a smart grid environment [11]. One of these cases was identified to be a shared car service based on vehicle to grid technology where electrical demand was met by locally generated photovoltaic solar power. In this project, detailed analyses were made on electricity usage in a large set (100+) of households that were equipped with solar panels. Our first analysis made use of power measurement data (for 297 evenly distributed days, every 10 seconds, 79 households in the Dutch cities of Amersfoort and Utrecht) provided by DNV GL, which was one of the partners in the *Smart grid: Profit for Everyone* project. Using MATLAB battery simulation and Net Present Value (NPV) analysis, the average optimal storage size in the case of net metering abolishment for end users owning solar panels was determined to be 3.2 kWh. There was much variation between the households, with optimal battery sizes ranging from 0.5 kWh to 7 kWh. Subsequently, we determined what the impact of these optimally sized batteries would be on the neighborhood electricity demand. The impact on the peak power was limited (at a decrease of 5.7%), while the impact on the average four-hour evening load was larger at a decrease of 22%. However, when the batteries were controlled to minimize stress on the grid, the impact would increase to -32% and -39%, respectively. These findings make collaboration between households and other stakeholders (e.g. net operators or retailers) very attractive, which is line with the focus of our project. Moreover, we found that increasing battery sizes above the optimal storage size would not result in large decreases in the NPV of the batteries, further increasing attractiveness of investments of external parties in residential batteries of end users, see Figure 6.

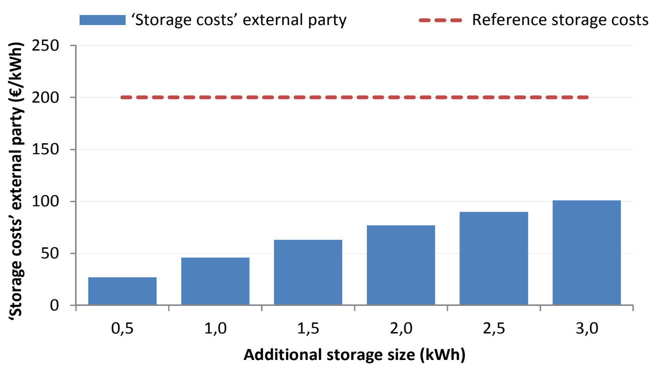

Fig. 6. Possible investment costs of storage. Here, the x-axis represents the additional storage size above the optimal storage size per household. The y-axis represents the average decrease in NPV per kWh of increased storage.

D. Research of a medium voltage distribution networks with integration of photovoltaics, electric vehicles and EES

Smart Grids are in the triangle of conflicting priorities between (a) *classic distribution networks* with single consumer installations and unidirectional downward load flow, (b) *closed distribution networks*, which are autonomous or autarkic consumer networks consisting of several consumer buildings and power-generating systems and can operate either grid-connected or isolated, and (c) *individual prosumer installations,* which are on the one hand single consumer installations and on the other hand, (difficult to predict) local electricity producers that can operate both, as an island or network coupled (autonomous and autarkic consumer).

Thus, planners and distribution system operators (DSO's) are challenged today with a high amount of alternative decentralized large and small energy generation (PV, small hydro, wind power), an increasing electric energy consumption by e.g. electric vehicles (EV's), conditioners and heat pumps as well as an increasing number of large and small electrical energy storage systems (EES). With these changing conditions in electricity generation, consumption and load flow, the distribution networks are faced with power quality problems especially at midday with a high PV-infeed, extremely high grid loads in the evening because of charging the batteries of electric vehicles, load managing systems or other installations not coordinated with the grid operators.

In a first step in this study a medium voltage distribution network with PV and electric vehicle integration is systematically examined by performing steady state load flow scenarios to verify the feasibility, the influence on the reliability of the system and the economic impact on the grid and the consumers. In a second step the impact of large electrical energy storage systems (EES) in the medium and low voltage distribution grid is analyzed technically and economically regarding the possible solutions of the medium voltage network [12].

E. Users' involvement in smart grids development

Currently, there are more than 30 smart grids projects in the Netherlands which also involve renewable energy production. A closer view shows that these projects differ widely regarding the role of households in project and energy management (Figure 7). Generally, energy and grid companies undertake smart grid experiments with financial support of national and local governments. In addition, some local energy users' cooperatives have started smart grid projects. These alternatives represent different and perhaps competing development pathways regarding the role of users in a renewable energy transition.

An exploratory literature search pointed out that very few studies have been undertaken about the involvement in and acceptance of smart grids by electricity users. Current ideas about users' acceptance of smart grids are based on predictive models predominantly, depicting users as rational, isolated individuals. These yield a limited understanding of their experiences, values, energy-intensive daily practices and relations with other users and other stakeholders.

By investigating the involvement of households and their relations with other stakeholders in a set of widely differing pilot projects, we will be able to assess as well as support the social learning and innovation process of smart grid developments in a responsible manner.

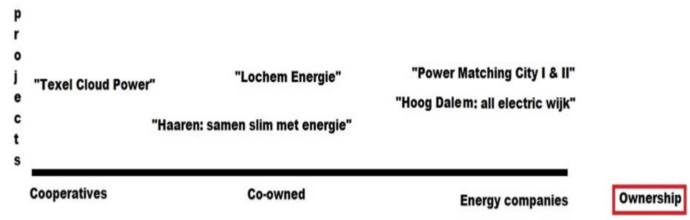

Fig. 7. Examples of Dutch smart grids pilots projects

IV. Conclusions and Outlook

In this paper we have presented our interdisciplinary research project on the exploration of existing smart grid on the basis of (1) the technical performance of energy products and services as well as (2) end users perceptions, (3) stakeholder processes and (4) market aspects. From the preliminary research results and approaches it was concluded that at the moment there exists still a lot of opportunities to generate new knowledge regarding the interaction between end-users and smart grid technologies as well as improved smart energy products and services. In the forthcoming three years we therefore will continue to execute our project with the intention to develop user-centered approaches toward Smart Grids technologies, to increase knowledge about appropriate energy product-service combinations, by data sharing and data analysis of existing smart grid pilots.

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Disclaimer

The content and views expressed in this material are those of the authors and do not necessarily reflect the views or opinion of the ERA-Net SG+ initiative. Any reference given does not necessarily imply the endorsement by ERA-Net SG+.

References

[1] JRC, Joint Research Council European Commission, Smart Grids Projects Outlook. 2016, Online: http://ses.jrc.ec.europa.eu/smart-grids-observatory

[2] JRC, Joint Research Council European Commission, Smart Grid Projects in Europe: Lessons learned and current developments, 2011, European commission, The Netherlands.

[3] IEA, International Energy Agency, Technology Roadmap Smart Grids, OECD/IEA, 2011, Paris. Online: https://www.iea.org/publications/freepublications/publication/smartgrids_roadmap.pdf

[4] D. Geelen, A. Reinders, D. Keyson, Empowering the End-User in Smart Grids: Recommendations for the Design of Products and Services, 2013, Energy Policy, 61, pp 151-161.

[5] G.P.J. Verbong, S. Beemsterboer, F. Sengers, Smart grids or smart users? Involving users in developing a low carbon electricity economy, 2012, Energy Policy 52, pp 117–125.

[6] M. Wolsink, The research agenda on social acceptance of distributed generation in smartgrids: Renewable as common pool resources, 2012, Renewable and Sustainable Energy Reviews 16, pp 822– 835.

[7] C.B.A. Kobus, R., Mugge, J.P.L. Schoormans, Washing when the sun is shining! How users interact with a household energy management system, 2012 Ergonomics 56:3, pp 451-462.

[8] U. Obinna, P. Joore, L. Wauben, A. Reinders, Insights from stakeholders of five residential smart grid pilot projects in the Netherlands, 2016, Journal of Smart Grids and Renewable Energy 7, pp 1-15.

[9] Netbeheer, Map of Dutch Smart Grid Projects, 2016, Online: http://nbn-assets.netbeheernederland.nl/p/32768/files/Poster%20Intelligente%20Netten%20Netbeheer%20Nederland.pdf

[10] Smart Grids Austria, Map of the Austrian Smart Grid Projects, 2016, Online: http://www.smartgrids.at/modellregionen.html

[11] Website: www.smartgridrendement.nl (last accessed July 8, 2016)

[12] M. A. Lagler, master thesis: Computer-based analysis of an urban 20 kV medium-voltage network, 2015, Institute of Electrical Power System of TU Graz, Graz, Austria.