ComForEn 2021

ICT Design for Community-empowered Sustainable Multi-Vector Energy Islands

Stepan Gagin, University of Passau, stepan.gagin@uni-passau.de
Sonja Klingert, University of Mannheim, klingert@uni-mannheim.de
Michael Niederkofler, Energie Kompass, niederkofler@energie-kompass.at
Hermann de Meer, University of Passau, hermann.demeer@uni-passau.de

Abstract – In this paper, a combined approach for creation of urban energy islands is proposed. It consists of technical system for multi-vector energy optimization, as well as social science solution for assembling a renewable energy community. The main challenge of proposed approach is to provide replicability of the solution because of diversity in technical architectures, business models and community engagement levels in different energy islands.

1. Introduction

Slowing down climate change in order to put a halt to climate catastrophe – this is the challenge mankind is facing today. In recent years, a wide range of technical innovations have been suggested to deal with this challenge, mainly striving towards energy efficiency but also aiming to close temporary gaps between energy demand and energy supply in order to maximize the utilization of renewable energies. This applies mainly to electricity, but all energy vectors - electricity, heat and mobility - are affected by these innovations. However, in many cases, the Jevons paradox has counteracted efficiency endeavours, i.e., the paradox situation

that efficiency gains are often more than compensated by over-consumption, stimulated by reduced cost.
In this context, the EU H2020 project “RENergetic” suggests so-called “urban energy islands” striving for local self-sufficiency while, in addition, offering energy services to the external energy grids. The energy island approach has the advantage of having clear and absolute goals, which, if taken seriously, limits the impact of the Jevons paradox, the so-called “rebound effect” because energy efficiency is a relative concept whereas an energy island either is self-sufficient or not. There is no room for rebounds.

How to reach this goal depends heavily on local characteristics of a prospective energy island, not only with regards to its geographical setting, i.e., the abundance of local energy resources, but also with regards to its inhabitants, their usage patterns and complex social ties and contracts. Therefore, an information and communication technology (ICT) based optimization solutions should be on par with needs and preferences of various user groups as well as their responsibility for the energy system that will be seen as system relevant in future active distribution grids. Self-sufficiency and, in particular, self-responsibility will thus be essential features of future energy communities at the age of renewables as an integral part of future *active distribution grids*.

These are the challenges that the RENergetic solution system addresses with a triple approach: it will offer an ICT based optimization solution, a community engagement process and corresponding tools, and it will finally boost the impact of the suggested solution set with a third pillar, a strong replication strategy. This replication strategy determines the requirements as to the modularity of those building blocks. For the RENergetic ICT system this means that it is designed as a hierarchical architecture that consists of subsystems that optimize energy supply and demand within an energy vector which is then successively optimized among energy vectors. For the RENergetic social solution the replication requirement implies that local experiences will be poured into an engagement toolbox containing engagement procedures and milestones as well as RENergetic communication building blocks.

2. Replicability as Guiding Principle

The RENergetic project has three pilot sites, the New Docks in Ghent (Belgium), the Ospidale San Raffeale in Segrate (Italy) and the University Campus in Poznan (Poland). Developing solutions that can be applied to all three sites would require a significant amount of development resources if each of the sites is looked at individually and individual approaches for each site are being made.

Therefore, the RENergetic team decided early in the project that the aspect of replicability of the solutions must be at the center of the design principles. The aim is to design generally applicable solutions that then will be replicated to each of the pilot sites. This stands true for all aspects; technical as well as legal, social and economic dimensions of each implemented solution.

A generalized view on the pilot sites has been envisioned. The human-centric approach of *user stories* [1] allows to communicate the needs of users in clear and simple phrases to get an understanding of all required features. These user stories are structured into overarching user epics to form the basis for the requirements engineering for the RENergetic solutions. These *user epics* [1] cover the electric as well as the heat domain and allow the RENergetic solutions to interact with a variety of infrastructure at the pilot and future replication sites.
With the user epics providing a frame for the requirements engineering, an abstract view on the pilot site's infrastructure, assets and automation systems must be mapped out as well. The Smart Grid Architecture Model (SGAM) [2] has been specifically designed to address interoperability issues in smart grid applications and provides a standardized method of modelling smart grid architectures. However, the SGAM framework was mainly developed with smart grids – and thus the electricity domain – in mind, and efforts to expand models to e-mobility systems [3] or general-purpose multi-energy systems [4] have only recently been published. Adopting the SGAM model and expanding it for the application in the heat domain has been a major task in the RENergetic replicability package and is one of the contributions the RENergetic projects aims to provide to the methodology of building energy islands.

In order to meaningfully utilize the RENergetic solutions, an interface between each of the sites' component layers and the RENergetic software in the function layer are defined, based on a two-layer architecture. The first layer connects to the respective RENergetic software module and is implemented by the RENergetic development team. It provides an API to the software module with a clearly defined data structure for input and output data points. The purpose of this interface layer is to work with a minimal amount of datapoints and still be able to convey the needed functionalities. The second layer acts as a docking module that connects to the pilot sites' infrastructure. In this layer the translation between the condensed datapoints of the API to actual control commands for the site infrastructure takes place. This is shown schematically in Figure 1. As this requires intimate knowledge of infrastructure and automation systems of the sites, it needs to be done within the responsibility of the respective pilot and replication sites in accordance with their technical and administrative framework. This architecture is an exact implementation of the SGAM idea of interoperability taking place on the z-axis of the system cube, while the x- and y-axis are within the sole responsibility of each pilot and future replication sites.

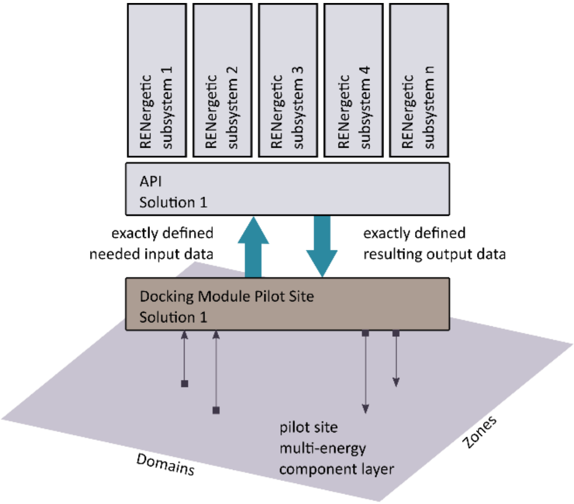

Figure 1. RENergetic interface architecture

3. Technical Solution

To realize described concept of two compatibility layers, it is decided to use OpenEMS platform [5]. OpenEMS is becoming open-source standard for energy management systems (EMS). Sometimes proprietary solutions are closed for the external communications or offer non-standardized interfaces. Utilization of OpenEMS protocols and interfaces, however, does make it possible to create adapters for existing EMS systems that meet requirements of a specific energy island.

Every energy island could have various types of devices in electrical and heating domains. To ensure alignment with most technical architectures, a modular architecture for RENergetic ICT solution is proposed. From the architecture of the RENergetic system depicted in the Figure 2Figure 2, it can be seen that ICT system consists of modules and subsystems. Modules are parts of the system that are shared between all subsystems. The data acquisition module performs data gathering from installed sensors, meters, EMS or other sources. The RENergetic portal is a mobile web application with intuitive user interface for every subsystem. The connectivity module for existing systems serves as a component responsible for pushing decisions and actions recommended by the RENergtic system to the existing hardware.

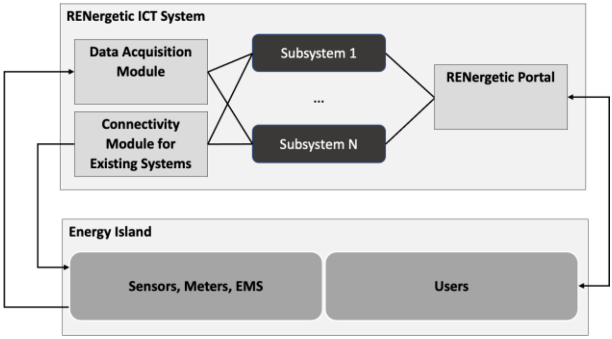

Figure 2. RENergetic ICT system architecture

Subsystems perform an optimization task in specific domain. For instance, the heat demand response subsystem performs a demand response program in central heating system. That means that final heating users (residents, office workers or students at the dormitories) could actively participate in optimization of the heat power utilization. It is done using interactive page in the mobile application with intuitive interface. The heat optimization subsystem is targeted to the heat system operators and managers. It takes into consideration all installed equipment at the energy island such as heat pump, boilers, district heating and waste heat installations. Data from installed sensors and meters, information from demand response program, as well as forecasts of future energy demand and supply are utilized by optimization algorithm. This algorithm proposes the optimal settings for the equipment to achieve desired objective, for example reducing the consumption of fossil fuels.

The electricity optimization subsystem is strongly connected to the heat optimization because many types of heating equipment also consume electricity to operate. The main concept is similar to described in heat optimization. In this domain, additionally the quality of the electricity is considered with the focus on PV installations and battery systems. The electrical vehicle demand response subsystem is a special case of demand response in electrical domain. Users of the charging stations will use interactive page, where they can indicate their preferences on charging time and level of charge. According to this information with combination of the data from forecasting algorithms and electricity optimization module, the system automatically creates a schedule for charging.

Each module could be enabled if there is corresponding equipment in the Energy Island. The overall ICT architecture is created in such a way that these modules could be utilized as separate final systems, since in many existing buildings there are already other smart control systems and user applications, which functionality sometimes intersects with proposed RENergetic system.

From subsystem descriptions, it could be seen that all of them could be considered as optimizers in the specific domain. The objectives could be a reduction of fossil fuel consumption, increase in share of renewable energy or decrease in monetary costs. As it was shown before, in some cases there is a strong connection between heat and electricity domain, so optimization should be performed jointly. RENergetic system utilizes the hierarchical optimization architecture. Figure 3Figure 3 illustrates that there are two levels of the optimization – domain-specific and global. Domain specific optimization is performed within relevant to subsystem domain, for example demand response programs that depend only on energy consumption data in one domain. Global optimizer operates on the higher-level, unifying heat and electricity domain among all optimizers, based on the demand and supply of all energy vectors.

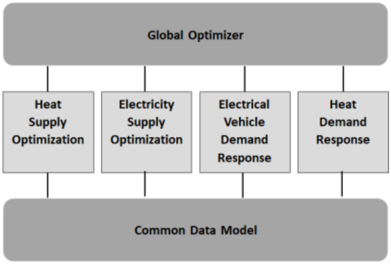

Figure 3. RENergetic optimization process

4. Social Science Solution

Many optimization systems do not need the collaboration with end users. For instance, in the case of a centralized heating system in a local heating network it is up to the energy management to implement rules of activating energy sources according to their efficiency or CO_2 intensity taking, into account capacity or ramp-up/down constraints.

However, for the case of an energy island that aims to be self-sufficient, the energy island inhabitants will have a severe responsibility for the quality of electricity inside their island, but also – due to globally increasing shares of volatile renewable energy sources – towards the external grid. It is merely not possible to strive for a decentralized power grid while taking electricity as a commodity for granted. Therefore, RENergetic not only gives the power back into the hands of the "people" as a right, but this goes with the corresponding duties and responsibility.

There are different levels of involvement, ranging from mere information over acceptance of slightly changed settings controlled by the energy island energy manager to active collaboration on a more or less day-to-day basis. This level of involvement depends on the size of the gap between through mere technical optimization achievable level of self-sufficiency of the energy island: the higher it is, the more active users need to be. Involvement is equally dependent on how the affected end-user group can control their energy usage: parameters are the duration of the stay, the size of induced energy consumption and obviously contractual power. This is why at the beginning of each user involvement there must be a stakeholder analysis. For the energy island setting, the stakeholder analysis carried through by the RENergetic team identified the following structure of generic end-users (see Figure 4): The major differentiators are the invested interest of end-users (mainly long-term vs. short-term and depending on the level of investment) and their level of control regarding the energy. All of them have specific interests, constraints and flexibilities, characteristic of their group.

The results delivered by the RENergetic ICT system need to be targeted at each end user group individually, depending on their status and options of control, but also constraint, flexibilities and interest. The area of overlap between the RENergetic ICT system and its social sciences solution is thus not only limited to the user interfaces, but beyond that the subsystems need to be designed in a way that meets the end-users' needs and control options, whenever collaboration is called for. For instance, a heat demand response system must take into account the nature of control that an end-user has over its heating device. If the heating temperature is determined centrally and the user has no control, they cannot be integrated in a demand response scheme. If, on the other hand, the heating technology was a floor heating steered by the inhabitant of an apartment, delays of several hours would need to be considered, when the end-users' active participation was required.

Currently, in the RENergetic project, a set of in-depth interviews and surveys is being executed in order to extract the main generic flexibility options and constraints of end-user groups. Obviously, the details vary from site to site, which is why the RENergetic replication package will include tools to categorize and elicit the necessary information beyond generic stakeholder characteristics and not build on specifics of the RENergetic pilots.

As shown in Figure 4, end-users may be organized in a community. This may be an informal regular gathering of students or it may be a formal "renewable energy community" (REC) according to the terms of the EU renewable energy directive RED II (2018) [6] where a group of end-users jointly owns and manages renewable energy resources with all induced responsibilities, specifically with regards to internal and external grid quality.

A community organization is a huge lever for the motivation of end-users to collaborate on collective energy actions. Behaviour changes are always viewed in the context of society, and e.g., adapting power demand or heat demand to the supply profile nowadays still is deemed unconventional and not "normal" by a vast share of the population This kind of behaviour does not correspond to current social norms, and for most people this is a major barrier towards adopting a new behaviour that enables the success of the energy island. Apart from social norms, self-efficacy is a further strong motivator for behaviour change, especially in the area of environmentally sound behaviour [6]. In the face of global climate threats, many individuals feel humbled and not able to deliver a strong contribution – which again makes them give up or due to a rising defensiveness not even start changing their behaviour. Building on these research results, the RENergetic project aims at supporting the emergence of new or the expansion of existing communities that deliver strong social identities to their community members [7]. These narratives should include realistic and measurable objectives with regards to absolute values of e.g., self-consumption, self-sufficiency or CO_2 emission to both boost self-efficacy while keeping the rebound effect in check [7]. As with the analysis of energy island stakeholders, also this will happen with replication in mind, resulting in a toolbox with communication and other engagement methods categorized according to user groups, temporal phases of an energy island community and support for building strong narratives.

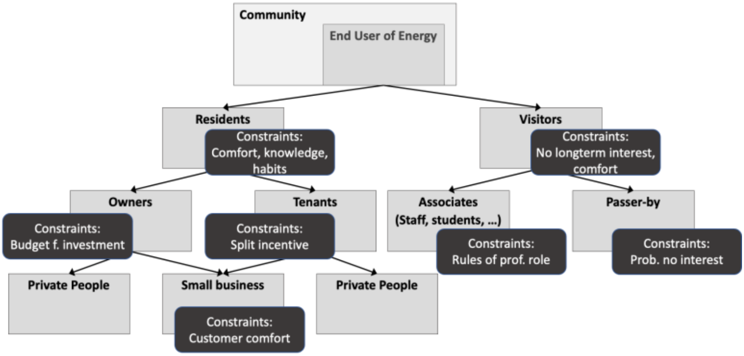

Figure 4. Generic end-user structure of an energy island

5. Conclusions

In this paper, we have outlined the RENergetic approach of energy islanding in heterogeneous environments based on cross-sectoring renewable energies. The approach consists of an amalgam of ICT solutions and far going energy community involvement. The heterogeneity, instantiated by different pilot sites, calls for a strong replicability approach. The connotation of replicability extends within RENergetic from the ICT domain, via legal and regulation frameworks all the way to requirements for end user communities. While various user target groups are investigated concerning their needs and readiness for flexibility in a cross-sector setting, a replicability across heterogeneous environments has been fostered by the concept of *user epics* that generalize the well-known concept of use cases. From an ICT perspective, a layering approach based on an implementation independent energy management system, OpenEMS, in concert with *extended SGAM*, that entails the heating domain as well as the e-mobility domain, has been pursued for *replicability* reasons. A strong point is made to call for *energy* *community responsibility* as becoming a necessary system-relevant part of future *active distribution grids* based on decentralized, renewable energy sources.

References

[1] Atlassian Agile Coach, "Agile epics: definition, examples, and templates," 2021. [Online]. Available: https://www.atlassian.com/agile/project-management/epics-stories-themes. [Accessed 31 October 2021].

[2] CEN-CENELEC-ETSI Smart Grid Coordination Group, *Smart Grid Reference Architecture*, 2012.

[3] B. Kirpes, P. Danner, R. Basmadjian, H. d. Meer and C. Becker, "E-Mobility Systems Architecture: a model-based framework for managing complexity and interoperability," *Energy Informatics,* vol. 2, no. 1, pp. 1-31, 2019.

[4] L. Barbierato, D. S. Schiera, E. Patti, E. Macii, E. Pons, E. F. Bompard, A. Lanzini, R. Borchiellini and L. Bottaccioli, "GAMES: A General-Purpose Architectural Model for Multi-energy System Engineering Applications," in *2020 IEEE 44th Annual Computers, Software, and Applications Conference (COMPSAC),* 2020.

[5] "OpenEMS - the 100% Energy Revolution needs a free and open source Energy Management System," [Online]. Available: https://openems.io/. [Accessed 31 October 2021].

[6] *Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU.*

[7] T. Bauwens and P. Devine-Wright, "Positive energies? An empirical study of community energy participation and attitudes to renewable energy," *Energy Policy,* vol. 118, pp. 612-625, 2018.

Authors

Stepan Gagin received his M.Sc. Degree in Computer Science from University of Passau, Germany, in 2021. After graduation, he continues to work at the chair of Computer Networks and Computer Communications at the University of Passau. Currently he is participating in EU research project RENergetic leading the development of ICT infrastructure for Energy Islands. His research focuses on applications of artificial intelligence in energy systems.

Dr. Sonja Klingert has been a post-doctoral researcher and project manager at the University of Mannheim since 2010. Amongst others, she had had the local lead for the EU research projects DC4Cities, ELECTRIFIC, RENergetic, and DECIDE. Before joining University of Mannheim, she was coordinator of the EU research project GridEcon at the International University in Germany. Prior to this, she worked as a researcher for the Wuppertal Institute for Climate, Environment and Energy. Her interest is in demand response, in green business models, eco-aware contracts as well as impact analysis and social issues of the energy turnaround. Sonja Klingert holds a M.S. degree ("Diplom") in Economics from the University of Karlsruhe.

DI Michael Niederkofler holds a degree of applied physics from Technische Universität Graz. He managed large international greenfield projects in the steel and raw materials industry and has worked and lived in Venezuela, Kazakhstan and China. After his international career he worked as an independent consultant for project management and internationalization. Since 2018 is the head of the Innovation Lab act4.energy, a living lab initiative with the goal of developing regional, renewable energy systems. He is working on solutions for the energy transition with a focus on demonstration and pilot projects and the replicability of results.

Prof. Hermann de Meer received his Ph.D. from University of Erlangen-Nuremberg, Germany, in 1992. He had been an Assistant Professor at Hamburg University, Germany, a Visiting Professor at Columbia University in New York City, USA, and a Reader at University College London, UK. Professor de Meer has been appointed as Full Professor at the University of Passau, Germany, and as Honorary Professor at University College London, UK, since 2003. His research interests include cloud computing, energy systems, network virtualization, IT security, smart grid, smart city, industry 4.0, digitalization of energy systems, computer networks and communications, and distributed systems.