Optimizing Energy Communities: a Model-Based Approach

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1. Extended Abstract

Renewable Energy Communities (RECs) are a relatively new concept introduced in the EU (EU Directive 2018/2001, REDII) that empowers communities, municipalities and cities to generate, share and use sustainable energy to reduce environmental impacts and drive the energy transition. However, an ecosystem of services is needed to establish the concept of RECs in the long term. The establishment, development and operation of RECs are still associated with considerable organizational hurdles, high time expenditure and cost risks [1]. Many issues that have not yet been sufficiently investigated include considering the whole REC lifecycle, encompassing simulation and impact forecasting when setting up or extending an REC, advanced modeling techniques for simulation of RECs, as well as efficient dynamic load management during operation [2][3][4]. Additionally, RECs may have adverse effects on grid stability due to their use of renewable energy sources like solar and wind, whose intermittent and unpredictable nature can make grid management more complex, as balancing supply and demand becomes less predictable [5].

To address the challenges associated with RECs and their impact on the grid, several research questions arise:

1. How can RECs be modeled in a comprehensive, scalable and extensible way?
2. How can RECs be simulated and optimized to effectively manage their dynamic interactions over their whole lifecycle?
3. What strategies can be implemented to mitigate the adverse effects of RECs on grid stability?

In order to address these research questions, our objective is to implement a generic digital twin, adaptable to specific requirements of instance RECs (e.g. different participants, objectives, regulatory contexts), which supports all phases of an REC from conception to operation to expansion. Model-based simulation of RECs is central to our approach, beginning with the development of an REC model that incorporates parametric representations of specific characteristics like the electrical capacity of energy production, consumption, and storage devices.

In the conception phase, simulations will assess the economic, ecological, and social viability of proposed RECs by modeling prospective member behaviors using load profiles to predict consumption patterns and resource allocation. As RECs grow, this simulation will evolve to evaluate the impact of new model elements and optimize the community's configuration. During the operational phase, we will apply a combination of simulation and multi-objective optimization to enhance REC performance, allowing for the prioritization of goals such as minimizing energy consumption and maximizing local energy use while adhering to operational constraints. The optimization process will be grounded in REC simulations that predict energy production and consumption, refined through consideration of external models like weather forecasts and expected market prices. A predictive control approach will manage devices within the REC, adapting to real-time data and unforeseen events. By employing a

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multi-layer modeling strategy, we can appropriately represent RECs at different lifecycle stages. For example, a high-level model focusing on aggregate behavior is sufficient in the conception phase, but a more fine-grained model is needed for optimization in the operation phase.

By modeling arbitrary RECs, simulating various scenarios to identify optimal control strategies, and subsequently executing these controls, a comprehensive digital twin of the REC is established. Grid stabilization will be addressed through two mechanisms: first, optimization will increase internal energy consumption within the REC, reducing the amount of energy fed back into the grid. Second, our simulations will enable more accurate predictions of the energy that will still reach the grid, enabling more informed planning for grid operators.

We will conduct our research within the Design Science Methodology framework [6], which builds on the following activities:

1. `Problem identification and motivation`
2. `Definition of objectives for a solution`
3. `Design and Implementation`
4. `Demonstration`
5. `Evaluation`

The motivation and research questions at the start of this paper will guide our research. In order to define objectives for a solution, we will specify functional and non-functional requirements of an REC digital twin by reviewing existing literature, defining relevant user groups by stakeholder mapping, as well as conducting user surveys. Based on the extracted requirements, we will design a digital twin system capable of supporting RECs through their entire lifecycle. This system will encompass a flexible simulation framework, a multi-objective optimization module, an IoT-enabled control module, as well as a visualization module to promote inclusivity and engagement among stakeholders. The defined system will be implemented in iterations, and its usefulness will be demonstrated by continuous testing and integration. To evaluate our proposed system, it will be deployed in two demo RECs. Its effectiveness will be assessed through a comparative analysis, contrasting the outcomes of the digital twin simulations with real-world operational data, as well as a conclusive user survey.

In conclusion, this work contributes a novel digital twin system designed to support RECs throughout their entire lifecycle, addressing critical gaps in existing research, particularly in REC modeling, lifecycle simulation, optimization, and dynamic load management. We recognize potential challenges in modeling, simulating and optimizing RECs, as well as in scalability and real-time accuracy, especially in unpredictable environments with intermittent renewable energy, and will work to mitigate them throughout our research.

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