National Centre for Energy Systems Integration

Decentralized Energy White Paper:

Adaptive Local Energy Communities

"Towards achieving energy resilience and realistic pathways to net-zero economy"

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Abstract

The decarbonization targets and the development of renewable and low carbon technologies are changing the electricity systems in UK and worldwide. The sustainable implementation of this changes in the energy markets can be achieved only if the consumers/prosumers are rightly incentivised.

Furthermore, the integration of the system, transmission and distribution network operators in the overall local energy portfolio is crucial for the successful and practical operation of the smart local energy systems (SLES).

Energy communities formed by prosumers are increasingly becoming a promising solution to delivering sustainable energy systems that promote renewable integration and active participation of end-users. Indeed, as Feed in Tariffs are being reduced and even removed in many countries, the economic interest for individual investment in renewable generation such as rooftop PV has been dramatically reduced.

A recent trend is for households to form local energy communities in order to invest together in community renewable generation assets and community batteries. The aim of such energy community microgrids is to increase the financial benefits and the local consumption. In turn, this enables the community to use more locally generated renewable generation, and shifts the market power from large utility companies to individual prosumers.

Although the number of energy communities increases consequently, there is a gap in both existing research and practice regarding what are the optimal and fair methods to redistribute the energy outputs (and hence financial benefits) from the jointly community owned assets to their members, given not all members have the same size, energy needs or demand profiles. Furthermore, there is still a need to integrate physical battery degradation and power flow (physical network/grid constraints) into community energy optimization models, which are key to building realistic distribution grid models of the energy communities.

Researchers from the UK National Centre for Energy Systems Integration (CESI) have been working intensively to address some of these challenges. CESI is an EPSRC-funded centre that aimed to reduce the risks associated with securing an integrated energy system for the UK by adopting a multi-vector approach. In this white paper, we examine the expanding range of opportunities that emerge when end-users join forces to form an energy community.

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Background

Electricity, transport and heat are the three main energy vectors that are expected to be fully decarbonized to achieve a realistic and sustainable net-zero energy system [1]. This low-carbon energy transition calls for a significant adoption of distributed energy resources (DERs) and electricity-based loads such as electric vehicles (EVs) and heat pumps.

The connection of these intermittent DERs and electricity-based loads to physical network (low-voltage grid) changes the power and increases the local voltage out-of-bounds excursion, line over-heating and congestion at the distribution grid level.

To lower these impacts, Distribution System Operators (DSO) curtails the local renewable generation and loads, otherwise DSO must resolve with expensive and lengthy traditional solution of grid reinforcement.

In addition to the challenges faced by DSOs leading to local generation and load curtailments, financial incentives for renewable energy production such as feed-in tariffs are being reduced considerably, which impacts the pace of energy transition. Hence, the current energy market settings and regulatory frameworks do not offer the right incentives to consumers for adoption of the low-carbon energy assets [2].

This is increasingly leading to a need for establishing a consumer-centric business models [3] such as local peer-to-peer energy trading markets and energy coalitions to form energy communities to optimize the generation, consumption and storage of energy within the local community, and the trade of energy and services locally and outside the community.

Problem statement

Energy community projects often involve jointly owned energy assets such as community-owned wind turbines, solar PVs and/or shared battery storage. Energy communities are a promising concept.

However, given that not all members have the same size, energy needs or demand profiles, a key challenge are:

- How these energy assets can be efficiently controlled in real time?
- How the useful lifetime of the energy asset can be modelled and enhanced?
- How the energy outputs from these community-owned energy assets should be shared fairly among community members?
- How to integrate physical energy assets degradation and power flow (physical network/grid constraints) into community energy optimization models?
- How these energy assets can be used to generate new revenue flows though participation in the energy and ancillary services markets, such as providing local demand-side flexibility services to DSO?

Smart local market solutions such as energy communities are expected to play a key role in building more decentralized, decarbonised, and democratised energy system in which consumers use more locally-generated renewable energy, and take control of their own energy supply.

Local flexibility markets are identified as a promising low-cost solution to address these grid issues as an alternative option to expensive grid reinforcement and unnecessary curtailment. A key challenge in this context is the development of smart local solutions involving local people with local demand side response, leveraging digital transformation and new local markets [4].

Solution

To address these challenges, researchers at the National Centre for Energy System Integration (CESI) have proposed various locally-tailored modelling tools, solutions and frameworks for smart local energy systems, energy communities and transactive energy models for prosumers.

Figure 1 shows the summary of various models related to energy communities and local energy markets, while Figure 2 shows the models specific to interaction of local energy markets with wider national energy markets.

Figure 1(1-3): Models specific to energy communities and local energy markets

1 Multi-stage energy community modelling

Multi-stage optimisation for energy community trading based on multi-agent systems

Multi-stage optimisation of energy and flexible demand

- Super-local: individual household
- Local community stage
- Trading with main grid

Optimisation according to differentiation in energy trading preferences

- Cost-driven prosumers
- Green and low-carbon energy prosumers
- Social prosumers

2 P2C with network constraints

Energy community modelling for P2C with network constraints

- Local community with renewable generation and battery storage
- Comparison of individual versus community assets for reduction of annual bill
- Redistribution of benefits form community assets
- Network constraints
- P2C energy trading

3 P2P automated negotiations

P2P automatic negotiation between producers and consumers without constraining the grid

- Trading for energy, power and delivery time
- Conceding rate during negotiation
- Grid validation of trades
- Smart contract implementation

Figure 2 (4-5): Models specific to interaction of local energy markets with wider energy markets

4 HEMS for wholesale energy market

HEMS control for wholesale energy market participation

- Reduce customers' energy bills: increase self-consumption by using community generation and aggregator-owned batteries
- Create aggregator revenue from participation in the wholesale energy market
- Real-time battery control
- Smart contract implementation

5 Local flexibility coordination

Algorithm for optimal coordination of local flexibility for the DSO

- Day-ahead flexibility needs forecasted by the DSO
- Market for local flexibility DSO optimisation determines optimal flexible mix
- Flexibilities are triggered in real-time as required
- Settlement based on comparison between forecasted baseline and their actual profile

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Specifically, we provide new algorithms for smart control of energy assets and redistribution mechanisms, that yield to fairer ways to divide joint gains, using the tools from multi-agent systems (distributed AI) and cooperative game theory considering the physical assets degradation and network constraints. Our works is motivated by real case studies from communities of 200 households in the ReFLEX project-the UK's largest smart energy demonstration project running on Orkney islands in Scotland [5].

The overview of the energy community model is shown in Figure 3. First, we compare the case when individual households invest in their own home energy assets versus investing in a larger jointly-owned community energy asset. Based on our case study and dataset clearly shows the benefits of a jointly-owned or pooled energy assets approach.

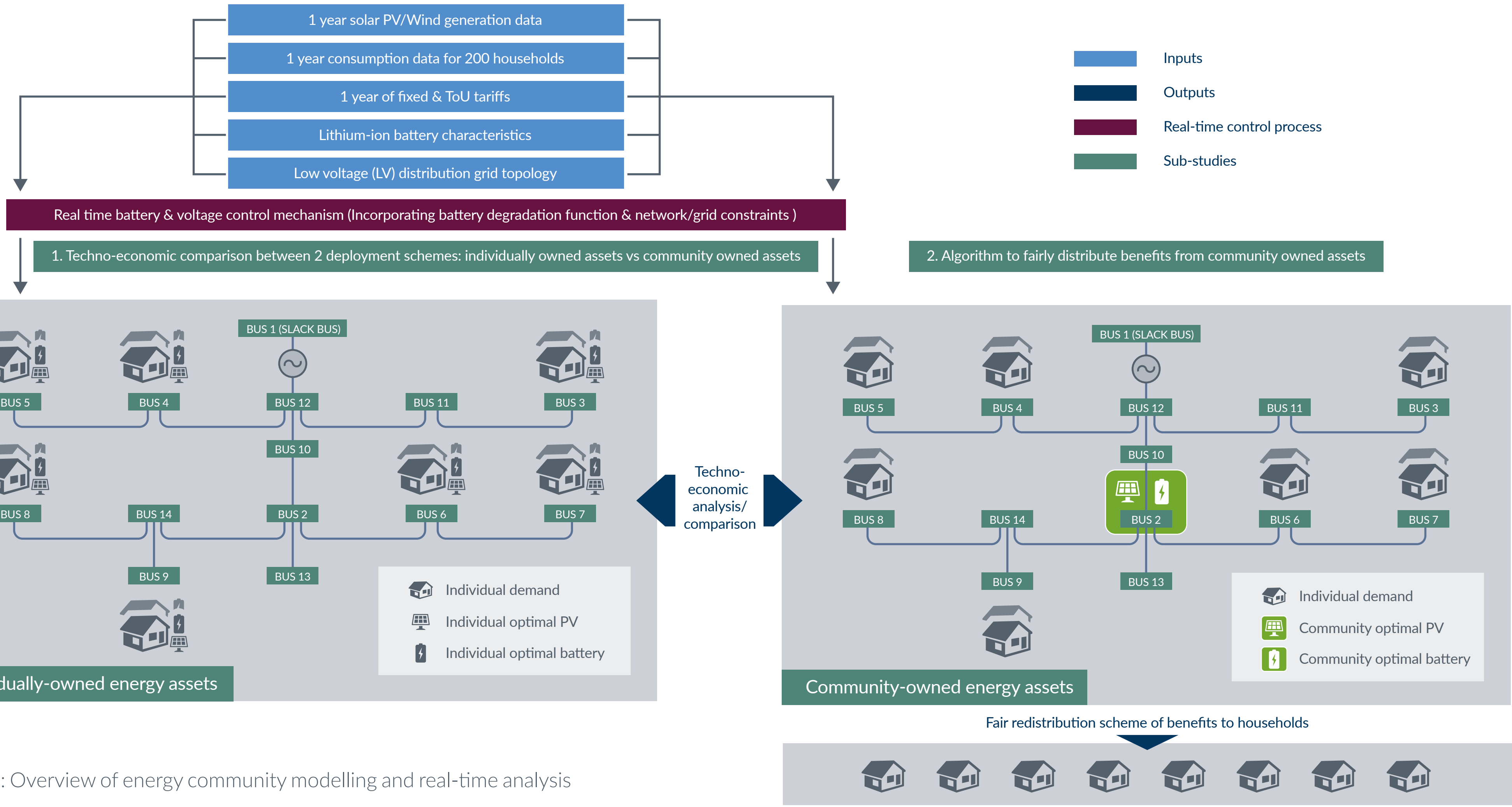

Figure 3: Overview of energy community modelling and real-time analysis

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Next, we provide several practically applicable and computationally efficient mechanism to redistribute the benefits obtained from these jointly-owned assets between homes in a fair way as shown in Figure 4.

The crossover point between the redistributed annual bill curves in Figure 4 shows that the proposed redistribution method based on marginal contribution yields to a greater reduction of the annual bill for 67% of the community households compared to state-of-the-art method.

Hence, under the proposed marginal redistribution method, more households are able to decrease their annual bills than the existing state-of-art redistribution method. Practically, having 67% of households in the community, which are mainly small consumers, also benefiting from the proposed redistribution mechanism would lead to greater social acceptance, and hence to more communities forming coalitions to invest in jointly-owned renewable energy assets.

The key findings are disseminated through publication in reputed Applied Energy journal [6] and IEEE Access [7].

The details can be assessed at:

https://doi.org/10.1016/j.apenergy.2021.116575

https://doi.org/10.1109/ACCESS.2021.3103480

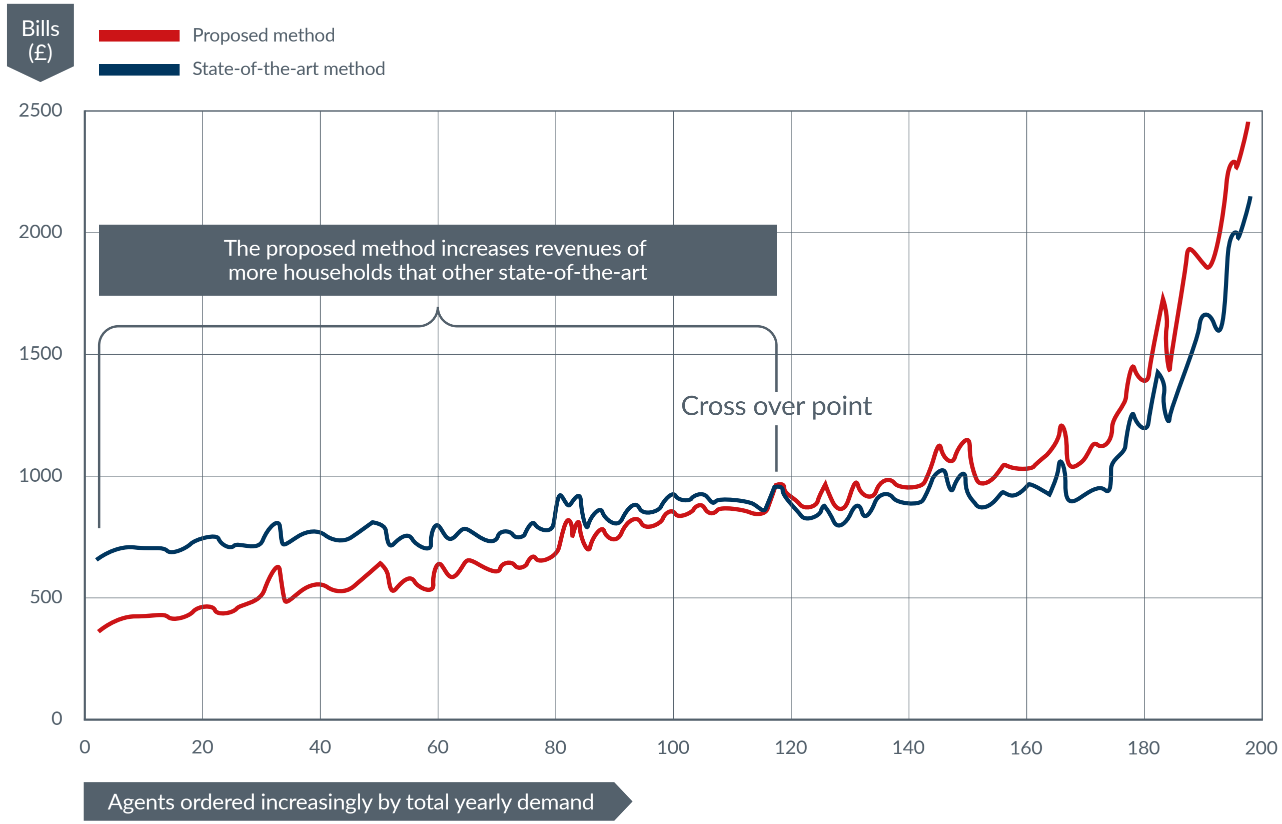

Figure 4: Comparison of the proposed redistribution mechanism with the state-of-the art methods

Conclusion

Smart local energy markets and energy community projects can support the coordination of distributed generation, demand-side flexibility and consumption in local energy systems and can incentivise active participation of end-users to energy markets.

This white paper highlights the outcome of a collaborative research between CESI and ReFLEX projects. Specifically, we have provided several modelling tools, solutions and frameworks for SLES and energy communities.

Specifically, a techno-economic modelling tools that enables real-time controls and fair sharing of renewable energy resources subjected to physical assets degradation and network constraints. Results from the techno-economic analysis show that jointly-owned assets community assets provide more savings (higher benefits) compared to distributed, individually-owned assets. These results showed the importance for determination of fair redistribution or allocation of benefits achieved in community projects.

Another key element is the need for energy communities to consider new revenue flows though participation in energy and ancillary service markets, such as providing demand-side flexibility services to the distribution system operator.

Local flexibility markets are identified as a promising low-cost solution to address the ever-increasing grid issues as an alternative option to expensive grid reinforcement and unnecessary curtailment of loads and renewable generation.

Energy communities can leverage the controllable assets such as batteries to provide reliable flexibility for the energy and ancillary services markets. In order to build this promising local flexibility market there is a need to develop a comprehensive market framework that provides coordination of the flexibility assets and services for both the distribution system and local prosumers in energy communities.

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