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An assessment of operational economic benefits of renewable energy communities in Belgium

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An assessment of operational economic benefits of renewable energy communities in Belgium

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Abstract. Renewable Energy Communities (RECs) are anticipated as key means to restructure the energy system in the European Union. However, there are still many open questions regarding the needed conditions that would allow their extensive roll-out. Here we propose a techno-economic model to assess the conditions needed by RECs to operate in an economic beneficial way in the Belgian context. The results indicate that while user type, user consumption and electricity tariff design are important, they are not as important as the amount of installed flexible technology, e.g. heat pumps or electric vehicles, to reduce operational costs. In scenarios with high penetration of flexible technologies the annual operational costs of the REC can be up to 17 % lower than the operational costs of the business-as-usual situation.

1. Introduction

Renewable Energy Community (REC) has become a recurring term linked to the energy transition towards more sustainable cities and energy system. RECs allow a wider range of actors, such as private citizens, citizen organization as well as small and medium enterprises to become active participants to the energy transition. Favorable conditions are created for individuals to become energy prosumers with the right to consume, sell or store renewable energy on their premises and within their community. Although the recast of the Renewable Energy Directive [1] provides an enabling framework for RECs on EU level, the specific definition and local enabling conditions still depend on the transposition at the individual EU member states level. While there are member states making considerable progress on this, there are still many open questions regarding needed conditions that would allow an extensive roll-out of RECs [2]. While Flanders (Belgium) is home to one of the pioneers within energy cooperatives (ecopower), it still lacks a specific legal framework for RECs and has tariffing structures that are unfavorable for REC economic feasibility [3]. In this study we assess alternative configurations of RECs in order to understand the conditions needed to assure their operational economic benefits in the Flemish context. The configuration of the REC is varied in three main factors that can impact the economic benefits: 1) different combination of consumer/prosumer that will constitute the community; 2) the type of electricity tariffs implemented; and 3) the energy production, conversion and storage technologies to be included. A set of scenarios for different types of users, tariffs and technology mix has been defined. The scenarios are the input for a model that optimizes total operational cost of an energy community. Finally, to analyze the benefits for a REC for each scenario, we compare the operational cost for three different levels (business-as-usual, single-user and REC) of optimization.

2. Data and model descriptions

2.1. Data

We rely on data collected from 10 RECs around Flanders to construct a generic REC that resembles the local conditions. A total of 22 different electricity power consumption profiles with hourly time-step over one-year horizon provided by the Flemish distribution system operator, Fluvius, were used. Eleven of them are from residential consumers connected to the low-voltage (LV) grid, while the other 11 are a mix of commercial and public buildings linked to the medium-voltage (MV) grid. Nine of the residential profiles represent single-family houses and the other 2 are apartment buildings. The mix of buildings connected to the MV grid is composed by: a bank office, a sheltered housing, a library, an extracurricular school, two local shops, a community centre, a secondary school with its sport halls, a supermarket and a tennis club. Heating and cooling demand data were not available, hence they were simulated in TRNSYS based on building type, usage and outside temperature. One heating profile per category was simulated for the residential buildings, while both heating and cooling demand were simulated for all the commercial and public buildings. These heating and cooling demand profiles were then transformed in electric consumption of heat pumps using the outside temperature and the variable coefficient-of-performance of the devices. Regarding EV, two different charging demand profiles were used: one for LV users and one for MV users. Charging demand for LV buildings is based on a synthetic profile generated based on a fixed daily demand of 7 kWh and a fixed charging schedule, while the EV charging profile for MV buildings corresponds to actual measurements from public charging stations located at the parking areas of the campus of the Vrije University Brussel, a Flemish University. PV energy generation profiles are estimated using a standard generation profile based on the average weather profile for Flanders, which are scaled based on specified installed capacities.

2.2. Scenarios and assumptions

Following a collaborative and iterative approach with representatives from academia, REC pilots, engineering companies, banks and grid operators we proposed a total of 135 scenarios that results from the combination of five REC user configuration scenarios, three technology scenarios, three tariffs design alternatives and three levels of optimization to evaluate the potential operational economic benefits of the generic REC. The gathered and simulated energy consumption profiles were used to build five different REC configurations based on the distribution of their total energy consumption (see Table 1). The aim of using different REC user configuration scenarios was to identify the potential impact of different combinations of LV and MV users on the potential economical gain.

Table 1. REC configurations

REC Scenario	1	2	3	4	5
LV consumption (%)	100	70	50	30	0
MV consumption (%)	0	30	50	70	100

Furthermore, assets are assigned per user (Table 2) and asset maximum capacities are fixed per technology (Table 3). The values in both tables defer for low voltage and medium voltage users. We created three different scenarios for technology penetration for the two buildings categories. Technology scenario 1 and 2 were designed to test optimistic future scenarios of technology usage based on the stakeholder insights from the Flemish market, while scenario 3 represent the average of 10 REC pilot sites involved in Flemish project ROLECS.

Table 2. Technology penetration ratio and capacities

Technology scenario	PV (% of users)		HP (% of users)		EV (% of users)		BESS (% of users)	
	LV	MV	LV	MV	LV	MV	LV	MV
1	50	50	33	33	20	33	0	0
2	50	50	33	100	20	100	50	50
3	40	20	20	20	50	10	30	10

Table 3. Technology capacities

Technology scenario	PV cover factor (% of consumption)		HP capacity (kW)		EV charging power (kW)		BESS capacity (% of PV capacity)	
	LV	MV	LV	MV	LV	MV	LV	MV
1	100	20	2.5-4	14-288	3.5	55	0	0
2	100	20	2.5 4	14-288	3.5	55	50	50
3	50	20	2.5-4	14-288	3.5	55	80	60

Three electricity tariffs alternatives are proposed. The main focus is to test the impact of moving from a purely volumetric tariff towards a more capacity based one. For doing so we identified the final cost split of an electricity tariff from [4]: 28 % represents the commodity, 18 % the DSO tariff, 7 % the TSO tariff, 17 % the VAT and the remaining 30 % are fees and taxes. Since in Flanders there are various suppliers and prices of electricity vary, we take an average of prices of the current kWh based tariff [5]. Our reference scenario consider a day/night tariff with peak prices between 7 and 22, and off-peak prices the rest of the day and the weekends. The average prices used for LV buildings are 28 c€/kWh for peak times and 21 c€/kWh for off-peak times. Prices for MV buildings are 50 % of the LV tariffs. These considerations lead to the following tariffs: i) 100 % of the cost is kWh-based ii) The DSO tariff (18 % of the total) are kW-based iii) All the costs except VAT and taxes (53 % of the total) are kW-based. The first tariff is the reference and common scenario in Belgium, the second scenario represent the planned tariff for 2022 in Flanders [4], while the third one represents an additional potential future scenario. We introduce a capacity tariff of 50 €/kW/year in the second scenario which scales to 147.2 €/kW/year in the third one. MV tariffs are 50 % of LV tariffs also for capacity. Injection price is fixed for all type of buildings and tariffs, with a revenue of 3.5 c€/kWh.

Finally, the proposed group of users with varying technologies and tariffs are analyzed within three levels of energy cost optimization:

(i) Business-as-usual (BAU): no optimization at all
(ii) Individual building optimization (IBO): optimization at building level and no energy exchange between different buildings
(iii) REC optimization: optimization at community level with possibility of peer-to-peer energy exchange

In the BAU scenario, electrical energy balance is calculated at every time step for every building. Heat pump usage match the hourly heating/cooling profile, as the EV charging pattern follows the hourly charging demand. In the LV cases, EV charging starts at 7pm until the daily demand is met. No BESS is included in this scenarios as no optimization on assets scheduling is introduced. For the IBO, heat pump consumption matches the simulated daily demand but it is optimized hourly to match 24 hours energy demand profiles. The same concept applies to EV charging, the only difference is that we apply a time-window constraint on the EV charging hours for the LV buildings, which forces each user to charge the car only between 7 PM to 7 AM. The RES optimization uses the same principle for technology as IBO taking into account the energy use/cost optimization is on the energy community level and allows for optional peer-to-peer exchange. The peer-to-peer structure follows the community-based market concept [6], where a consumer inside the REC has a possibility to buy energy either from the supplier or from community member. The buying price of electricity is the same regardless of where the electricity is coming from. The difference lays in the revenue that the prosumer gets from injecting into the REC instead to sell back to the main grid. In fact, the energy part of the tariff (28 % in our case) does not go to the DSO but stays inside the community which will reduce the net cost for the community compared to interaction with the grid only.

2.3. Mathematical model

The mathematical model presented in this section is the generalized model for the REC optimization scenarios. BAU and ISO represent simpler optimizations, due to no BESS or no peer-to-peer exchange. In those cases respective part of the equation becomes zero. The objective function minimizes the total annual electricity consumption cost of the REC:

$$min \sum_{\substack{b\in B,\\ t\in T}} (P_{t,b}^{im} \cdot \lambda_{t,b}^{ext,im} - P_{t,b}^{ex} \cdot \lambda_{t,b}^{ext,ex}) \cdot \Delta t + \sum_{\substack{b\in B,\\ m\in M}} (P_{m,b}^{p} \cdot \lambda_{b}^{p}) + \sum_{b\in B} C_b^{int} \tag{1}$$

The first summation term represents the total annual net cost for the energy exchange between the community and the grid, which is simply the difference between the cost of importing energy and the gain for injecting energy back to the grid. All the variables are indexed over the hourly time set T and the buildings set B. $P_{t,b}^{im}$ and $P_{t,b}^{ex}$ represent the power imported and exported from/to the grid for every timestep t and building b, while $\lambda_{t,b}^{ext,im}$ and $\lambda_{t,b}^{ext,ex}$ are the tariffs in €/kWh for importing an exporting energy respectively. Finally, Δt is the difference between two timesteps to convert power into energy. The second summation term constitutes the annual cost for the monthly peak consumption. $P_{m,b}^{p}$ is the peak power imported from the grid for month m and building b and λ_b^p is its associated cost in €/kW. Finally, the last term is the sum of the peer-to-peer exchange costs C_b^{int} for each building.

The peer-to-peer exchange cost for each building is calculated in a similar way as for the energy exchange between the community and the grid:

$$C_b^{int} = \sum_{t\in T} (Q_{t,b}^{im} \cdot \lambda_{t,b}^{int,im} - Q_{t,b}^{ex} \cdot \lambda_{t,b}^{int,ex}) \cdot \Delta t \tag{2}$$

where $Q_{t,b}^{im}$ and $Q_{t,b}^{ex}$ are the imported power from the community and exported power to the community of each building b at timestep t. $\lambda_{t,b}^{int,im}$ and $\lambda_{t,b}^{int,ex}$ are the internal tariffs for purchasing and selling energy inside the community. The power balance for exchange among buildings in a community is assured for every hour as defined in Eq. 3:

$$\sum_{b\in B} (Q_{t,b}^{im} - Q_{t,b}^{ex}) = 0 \tag{3}$$

Moreover, the power flows of the exchange with the grid and the exchanges inside the community needs to be balanced with the power flow $p_{t,b}$ of each building:

$$p_{t,b} - Q_{t,b}^{im} - P_{t,b}^{im} + Q_{t,b}^{ex} + P_{t,b}^{ex} = 0 \tag{4}$$

The power flow of each building $p_{t,b}$ is a power balance per building b in timestep t:

$$p_{t,b} \;=\; l_{t,b} \;+\; p_{t,b}^{hp} \;+\; p_{t,b}^{cool} \;+\; p_{t,b}^{ev} \;-\; p_{t,b}^{pv} \;+\; p_{t,b}^{ch} \cdot y_{t,b}^{ch} \;-\; p_{t,b}^{disch} \cdot y_{t,b}^{disch} \tag{5}$$

where $l_{t,b}$ represents the base load consumption of the building, $p_{t,b}^{hp}$, $p_{t,b}^{cool}$ and $p_{t,b}^{ev}$ are the power demand for heating using the heat pump, the power demand for cooling using the heat pump and the electric vehicle charger. $p_{t,b}^{pv}$ is the power output of the solar PV installation, while $p_{t,b}^{ch}$ and $p_{t,b}^{disch}$ are the charging and discharging power of the battery. $y_{t,b}^{ch}$ and $y_{t,b}^{disch}$ are the binary variables ensuring that the battery is not charging and discharging at the same time (Eq. 6). Heating and cooling loads of the heat pump and electric vehicle all have their own demand to be met (Eq. 7).

$$y_{t,b}^{ch} \;+\; y_{t,b}^{disch} \;=\; 1 \tag{6}$$

$$\sum_{i \in I^d} (p_{i,b}^{j} \cdot Y_{i,b}^{j}) \;=\; d_{d,b}^{j} \tag{7}$$

where I^d is the set containing the 24 hours of each day d during the year and j is indexed over the set $\{hp, cool, ev\}$. $Y_{i,b}^{j}$ is the hourly availability of asset j and $d_{d,b}^{j}$ is the power demand of asset j during day d for each building. Each of the flexible assets hourly power output is limited by its maximum output m_b^j (Table 3):

$$p_{t,b}^{j} \;\leq\; m_b^j \tag{8}$$

Eq. 9 represents the energy balance of the battery, where $e_{t,b}$ is the energy stored in the battery at the hour t for building b, l^{batt} is the static loss of stored energy between each timesteps, η^{ch} and η^{disch} are the charging and discharging efficiencies.

$$e_{t+1,b} \;=\; (1 - l^{batt}) \cdot e_{t,b} \;+\; \Delta t \cdot (y_{t,b}^{ch} \cdot p_{t,b}^{ch} \cdot \eta^{ch} \;-\; y_{t,b}^{disch} \cdot p_{t,b}^{disch} / \eta^{disch}) \tag{9}$$

In addition boundaries for the charging and discharging powers of the battery as well as a minimum and maximum state-of-charge are introduced.

3. Results

All the results for the individual building optimization and REC optimization are presented as % of total cost of the business-as-usual case in Table 4. For IBO and BAU results, the sum of each individual user's annual energy consumption cost was taken to be compared to the total cost of REC. When looking at difference between tariffs, tariff 3 gives the best result for every scenario and in general a tariff based more on capacity leads to a reduction of total annual energy consumption costs. Variation in use of flexible technologies have the most impact on the operational economic benefits of both individually optimized buildings and REC. The scenarios where technologies with flexible loads, such as heat pumps, EVs and BESS, are included allow for preferential shifting of the loads to times with lower electricity tariffs. The impact of use of flexible technologies is visible in decrease of costs for REC scenario 4 and 5 (majority of MV users) in technology scenario 2. While these REC scenarios in combination with technology scenario 1 and 3 lead to the lowest cost reductions, in combination with technology scenario 2 (more flexible technologies) the highest cost reduction is achieved. This shows that share of flexible load technologies used and base load building energy consumption have a bigger impact on total costs than ratio between LV and MV buildings participating in REC. Finally, for all the scenarios it is visible that REC leads to the lowest annual energy consumption costs, with maximum cost savings of 17 %, even though in most cases the economical benefit over the IBO configuration is not substantial (between 0 % to 7 %). Moreover, it is important to keep in mind that the operation of a REC will have additional costs (e.g. IT infrastructure for peer-to-peer exchange) which are not included in this study.

Table 4. Cost comparison for all scenarios (in bold scenarios with at least 10 % cost reduction)

	REC scenario	IBO (% of BAU cost)			REC (% of BAU cost)		
		Tariff 1	Tariff 2	Tariff 3	Tariff 1	Tariff 2	Tariff 3
Technology scenario 1	1	96.00	95.34	93.53	92.12	91.22	**86.55**
	2	96.56	95.88	93.96	92.28	91.28	**87.22**
	3	97.28	96.71	95.06	92.86	91.89	**88.52**
	4	97.94	97.41	95.86	93.30	92.46	**89.89**
	5	99.25	98.83	97.55	97.72	97.38	96.37
Technology scenario 2	1	95.87	94.59	91.44	93.33	91.89	**87.82**
	2	95.15	93.39	88.68	92.60	90.63	**85.26**
	3	96.65	95.22	91.43	94.33	92.70	**88.34**
	4	95.78	93.62	**87.36**	94.13	91.82	**85.16**
	5	95.12	92.15	**82.79**	95.09	92.12	**82.76**
Technology scenario 3	1	98.10	97.18	94.93	97.19	96.21	93.79
	2	98.33	97.49	95.34	97.49	96.58	94.29
	3	98.78	98.15	96.47	98.16	97.47	95.65
	4	98.84	98.22	96.52	98.37	97.70	95.87
	5	99.43	99.07	97.95	99.42	99.07	97.95

4. Conclusions

The key factor to create economic benefit in the operation of a REC is the amount of available flexible technologies. Based on our analysis, the cost benefit is optimal when flexible assets are utilised with a capacity tariff that further exploits the possibility to shave peaks in demand. The best case can reach up to 17 % of cost reduction compared to the business-as-usual case. While variation of different LV and MV users in the REC did not have significant impact, their effect was mainly due to their level of energy consumption and not the consumption behavior. The rather specific model presented in this study will be further extended to address on one hand the impact of needed investment in the flexible technologies by individual or community and on the other hand the potential benefits of use of different mechanisms of peer-to-peer exchange within a REC.

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