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Pricing of exchanges within energy communities. Application to the MeryGrid case.

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Pricing of Exchanges within Energy Communities

Application to the MeryGrid case

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Abstract

With the energy transition, and in particular the development of renewable energy and storage systems, new electricity local market models arise, such as energy communities. An energy community consists of an association of entities, where each entity can produce, sell and distribute energy among the community. The objective of this work is to study energy communities and in particular how exchanges within the community could be priced to guarantee the viability of the community. To achieve this objective, we first study the legislation in Belgium and in Europe, present some existing energy communities and summarize some pricing models proposed in the literature. Finally, we apply one of these pricing models to a test case inspired by the Belgian energy community MeryGrid in order to study how each participant benefits from the community with this pricing model and what is the impact of some parameters in the model on the behaviours of the participants. In particular, we compute the value of the storage system for the community and estimate the gain for the storage owner in order to check if the storage investment in the community was profitable.

Keywords: energy community, exchange pricing, MeryGrid

Résumé

Avec la transition énergétique et en particulier le développement des énergies renouvelables et des technologies de stockage, de nouveaux modèles de marché local d'électricité émergent. Parmi eux se trouvent les communautés d'énergie. Une communauté d'énergie est une association de plusieurs entités qui produisent, fournissent et distribuent l'électricité au sein de la communauté. L'objectif de ce travail est d'étudier les communautés d'énergie et en particulier comment les échanges au sein de la communauté pourraient être tarifés de façon à garantir la viabilité de celle-ci. Pour atteindre cet objectif, nous commençons par analyser la législation en Europe et plus particulièrement en Belgique. Nous présentons également les projets de communautés énergétiques. De plus, nous présentons certaines méthodes de tarification des échanges (ou partage des gains de la communauté) proposées dans la littérature scientifique. En particulier, nous étudions un modèle de marché interne local que nous appliquons à une communauté énergétique belge, MeryGrid. Nous analysons notamment la valeur de la communauté pour ses participants, l'impact de certains paramètres du modèle sur cette valeur ainsi que la valeur actuelle nette de l'investissement de l'unité de stockage sous différentes conditions.

Mots-clés: communautés d'énergie renouvelable, tarification des échanges, MeryGrid

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Chapter 1

Introduction

With the energy transition, and in particular the development of renewable energy and storage systems, new models of electricity production and consumption fostering local production arise. Among these models, one can find energy communities. An energy community consists of an association of entities, where each entity can produce, sell and distribute energy among the community. The entities can be for example small or medium enterprises, individuals or public authorities. This definition is broad in scope and we will see throughout this work several examples of energy communities.

Energy communities are recent local market models, few of them exist around the world. Therefore several questions arise around them. How to form them? How many entities should be in the community? Can one leave the community easily? How to organize the community? How to ensure the reliability of this system? Should the community still be connected to the public grid? Will it use the public grid or develop a private local grid? How to share the bills (e.g. maintenance) between the participants? How to define the pricing of exchanges within the community?

In this thesis, we are particularly interested in this last question. Indeed, correctly defining pricing methods is primordial for the development of energy communities. First of all, if the pricing is not well defined, it can lead to the collapse of the community. Indeed, the pricing must be such that it guarantees the viability of the community, that is each member benefits[1] from the community and also does not feel disadvantaged compared to the other members; otherwise

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[1] Note that a benefit could also be simply environmental (Steg & Vlek, 2009), not only monetary, and people could stay in the community simply because of the local energy consumption and the decarbonization offered by the renewable energies. However in this work, we focus on monetary benefit.

the member could leave the community. Furthermore, pricing can be used to encourage wanted behaviours (Bergman et al., 2009; Gautier & Jacqmin, 2019), such as developing renewable generation.

In order to study possible pricing methods within energy communities, we begin with a study of the current legislation and existing projects in Europe, with a focus on Belgium more particularly. In particular, we present the proposed pricing policy when it is available. The objective is to study at what stage of their development energy communities are. We also review the literature about exchange pricing (or gain sharing) within energy communities.

Then we apply one exchange pricing method to a realistic test case in order to better understand this pricing policy. The test case is inspired by the Belgian energy community MeryGrid, located near Liège. We first perform a sensitivity analysis on some parameters of the model, such as the community operator tariff, the storage tariff and the capacity of the storage system in order to understand their impact. We also analyse the impact of the storage system on the value of the community and estimate if the storage investment in the community is profitable in an horizon of twenty years with the given pricing system.

This report is organized as follows. Chapter 2 describes the trends in Europe and more specifically in Germany and France, which are pioneers regarding energy community legislation. It presents some existing projects in these countries as well as the regulation framework. Chapter 3 focuses on Belgium, presenting the legislation in the three Regions and some current and future pilot-projects. Chapter 4 reviews the scientific literature about exchange pricing. Chapter 5 presents the test case studied in Chapters 6 and 7. Chapter 6 is a sensitivity analysis of the exchange pricing model. It studies in particular the impact of some parameters of the model on the benefit of participants[2]. Chapter 7 studies the impact of the storage unit on the value of the community and the return of investment of the storage system owner. Finally, chapter 8 concludes and proposes some future works.

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[2] The content of this chapter led to a publication (Duchesne, Savelli, & Cornélusse, 2019).

Part I

Energy communities in Europe and in the literature

Chapter 2

Energy communities in Europe: regulations and projects

In this chapter, we present a recent directive of the European Union concerning energy communities. Then we focus on two European countries in particular, Germany and France which are pioneers in the matter. We present first how they propose to develop energy communities based on their regulation and then some illustrative projects in these countries. The objective is to study at what stage of their development energy communities are.

2.1 Regulation from the European Union

The concept of energy communities has existed in Europe for a long time, mainly in the form of energy cooperatives of citizens who sell the produced electricity but do not directly consume it (see REScoop.eu (n.d.) for examples of energy cooperatives in Europe). It took years before these citizen's initiatives led to actual regulatory framework where they could directly consume the electricity they produced.

In 2016, the European Union (EU) published the Winter Package "Clean energy for all Europeans" in order to achieve the objectives on energy and climate defined during the Paris' Agreement in 2015. As part of this package, the EU proposed, in the end of 2018, a second version of the Renewable Energy directive (RED II) establishing, among other things, a regulatory framework for renewable energy communities.

In this directive (Art. 2), renewable energy communities are defined as follows:

‘renewable energy community’ means a legal entity:

a) *which, in accordance with the applicable national law, is based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity;*

a) *the shareholders or members of which are natural persons, SMEs or local authorities, including municipalities;*

a) *the primary purpose of which is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits;*

If we analyse this definition, we notice that it is flexible enough to correspond to the different laws and projects among the countries of the European Union. However, purposes of renewable energy communities are listed and enforced: the control of the communities must stay local and the incentive of the communities must not be only financial.

This directive also provides some rules about energy communities (Art. 22). For instance, the Member States of the EU should provide a regulatory framework to enable the existence of energy communities. Another rule is that all members of the community should keep their rights and obligations as final consumers and should not be subject to discriminatory conditions that could prevent them to participate in a community.

Concerning the pricing of exchanges within the community, no precise rules are proposed. The directive only specifies that the regulatory framework of Member States should ensure that *rules to secure the equal and non-discriminatory treatment of consumers that participate in the renewable energy community are in place* (Art. 22, 4(i)).

Through this directive, we see that the development of energy communities is perceived as crucial for the expansion of renewable energies. This new regulatory framework should help the development of energy communities, by encouraging Member States to develop a framework for them in the coming years. Note that some countries, such as Germany and France, did not wait for this directive to provide a framework for energy communities. we will analyze their legal framework in the next section.

2.2 Main projects and regulations in Europe

In Europe only France and Germany have defined so far a legislation for energy communities (according to the decree project (2019) of the Walloon Government). For this reason we will have a quick overview of their regulations and of some existing projects in both countries.

2.2.1 Germany

In Germany, the self-consumption is authorized since 2012 (Ducros et al., 2018). The country fostered even more self-consumption with a new law, voted in July 2017. This new law allows owners or tenants in collective buildings to self-consume locally produced electricity without using the public network (Build Up, 2017). This law is named *Gesetz zur Förderung von Mieterstrom* which means "Law for the promotion of tenant electricity".

The law provides advantages both for landlords and tenants. The landlords will be paid a premium for providing electricity to their tenants and the tenants will have access to electricity at reduced cost. This should spur landlords to install solar panels and their rooftops (German Federal Ministry for Economic Affairs and Energy, 2017). Note that tenants can choose to take part to the project or not.

We mention here the Heidelberg Energy Cooperative that existed before the law presented hereabove. In particular there is the solar project "Neue Heimat Nussloch" that began in 2013 and that concerns 7 multi-story buildings and 116 tenants. Instead of landlords, the solar panels are managed by the cooperative and each tenant may invest in the solar panels via a crowdfunding campaign. The cooperative produces up to 370,000 kWh per year (Heidelberger Energiegenossenschaft, n.d.), for which the percentage of solar power directly consumed is 31% (Schäfer, 2014). A picture of the project can be seen in Figure 2.1.

Note that in Germany, smart meters are not mandatory and it is therefore not straightforward that the individual consumption of each member of the community is known at every moment. Therefore finding fair sharing rules that satisfy all the members of the community is quite difficult. It is the context of energy communities studied in the paper written by Abada, Ehrenmann, and Lambin (2017). In this paper, the authors describe several sharing rules in case there is no smart meter.

Figure 2.1: The "Neue Heimat" project in Heidelberg[1].

2.2.2 France

Energy communities, under the term collective self-consumption, was legalized in France on the 28th of April 2017 in the *Articles L315-1 to 8 of the French Energy Code* (2017). It authorizes collective self-consumption between members of a legal entity and within a building, or a neighbourhood downstream of the same distribution substation, if the production installations have a capacity smaller than 100kW.

The production of the community decreases the bill of each member, with a sharing rule freely decided by them. If no rule is defined by the community manager, the sharing is based on coefficients proportional to the consumption of each member (*Article D315-6 of the French Energy Code*, 2017).

Contrary to Germany, smart meters are mandatory (*Article D315-3 of the French Energy Code*, 2017). The flux are measured every 30 min (Enedis, n.d.). It allows to base the sharing policy on the true consumption of the members of the community.

We mention Enercoop in the Midi-Pyrénées as an example of collective self-consumption. Enercoop is a citizen cooperative that provides support to build energy communities. The first energy community they helped to create was inaugurated in September 2018, in Aveyron. They

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[1] Source: `https://www.heidelberger-energiegenossenschaft.de/projekte/solarprojekte/neue-heimat-nussloch`

are currently three members in the community: a shop named Biocoop Lou Cussou, a veterinary clinic and Enercoop that rents the rooftop of the shop to produce electricity via solar panels. Other members are expected to join soon the community. The eligible area for the community is represented in Figure 2.2. The cooperative is also the manager of the community and deals directly with the DSO Enedis (Enercoop Midi-Pyrénées, 2018).

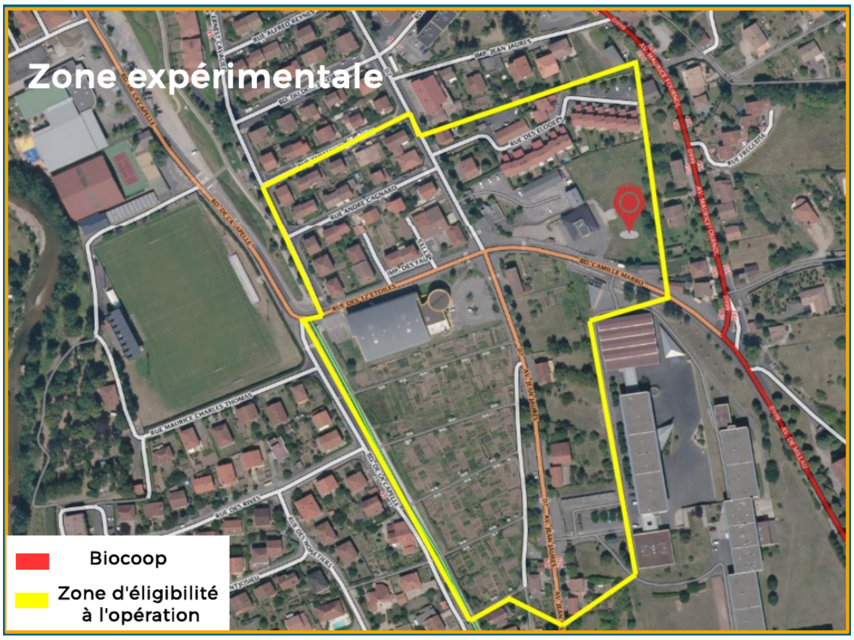

Figure 2.2: Aerial view[2] of the eligible area for the Aveyron energy community.

On the website of the company Enercoop, there is no information about how the PV production is shared between participants. They only indicate that the electricity surplus will supply the Enercoop network, at a preferential rate.

2.3 Conclusion

Energy communities are at their early stages in Europe but EU and countries are willing to facilitate their development through regulatory frameworks and pilot-projects.

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[2] Source: `https://midipyrenees.enercoop.fr/actualites/enercoop-midi-pyrenees-experimente-lautoconsommation-collective`

Chapter 3

Energy Communities in Belgium: regulation and projects

This chapter describes the evolution of the regulation in the three Regions of Belgium. It also presents some main energy communities existing in Belgium as well as some future projects.

3.1 Regulation in Belgium

In Belgium, the energy competence is regional, meaning that it can be different in the Flemish Region, the Brussels-Capital Region and the Walloon Region. We will therefore analyze how the regulation evolved in the three regions separately. Each Region is at a different stage of the process but all are working to include energy communities in the legislation.

3.1.1 Regulation in the Walloon Region

The regulation in Wallonia is currently evolving to conform to the change of energy landscape due to the energy transition. The Walloon Government recently voted a project for a new legislative framework (2019) fostering the development of renewable energy communities. This framework allows the collective self-consumption of electricity, which is defined as the consumption by the members of the community of the electricity produced by the community during the same 15-minute period.

In the current legislative framework, energy communities are not allowed and thus this modification is necessary for new microgrid projects to emerge. Some pilot projects, described in the next section, received exemption to evaluate the impact of these new systems on the main grid.

The new legislation follows the *Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources* (2018), introduced in the previous chapter.

But what does the new Walloon legislation say? The decree project (2019) defines a renewable energy community as a legal entity, comprised of several participants, created to share via the public distribution or local transport network electricity produced exclusively by production (or storage) units owned by the community. The production units are either renewable sources or quality cogeneration. The members of a renewable energy community can be small or medium enterprises, local authorities or natural persons. They are free to join the community but the Government can modify the participants list following some criteria. The perimeter of the community depends on geographical or technical areas and is defined by the Government. However, each member is still free to choose his energy producer.

Furthermore, to create a new renewable energy community, a permission from the Walloon regulator (CWaPE[1]) is required, in conjunction with the involved distribution system operator (DSO).

The legislative framework also introduces a new actor in the energy landscape, the community operator. He may be external to the community. It is considered in that case as commercial activity linked to the energy. The community operator cannot be a DSO, pursuant to Article 8, §2 of the *Décret relatif à l'organisation du marché régional de l'électricité* (2001).

To summarize, the future legislation framework is quite open about the definition or the organization of the renewable energy communities. There can be many types of communities such as residential buildings, economic activity zones, rural areas, social housings.

About the organization within the community, the participants can decide themselves the rules about exchange pricing within the community. The decree project anticipates that to simplify the administrative work (especially for natural persons) the Government has the right to define some default standard rules.

As in France, it is expected that each member of a community has a smart meter that will

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[1] *Commission wallonne pour l'Energie*

measure its real-time consumption every 15 minutes (instead of 30 minutes in France).

3.1.2 Regulation in the Flamish Region

In Flanders, there is currently no legislation about energy communities. However, the ROLECS project, described in Section 3.2.3, aims to roll out local energy communities in Flanders. The legislator is waiting for the conclusions of this project to modify the decree and write new executive decisions. One can expect a new legislation for 2021.

3.1.3 Regulation in the Brussels-Capital Region

Energy communities appeared recently in the Brussels-Capital Region regulation, being referred to as collective self-consumption. This term is defined in Art 89 of the order of July 2018 modifying the order of July 19 2001 concerning the electricity market organisation in the Brussels Region (2018). They consider the self-consumption as collective if the electricity supply is performed between several producers and consumers grouped together into a legal entity. They must be situated downstream of the same station of the low and medium-voltage grid. This definition is similar to the French one. Energy communities are still at the project stage in this Region. Indeed, Brugel, the energy market regulator for the Brussels-Capital Region, can modify for a limited period of time tariff and market rules for pilot-projects, pursuant Art. 90 of the same order.

3.2 Main energy community projects in Belgium

In Belgium, many community energy projects are launched. However all these projects are pilot-projects, the energy communities in Belgium are still at their early stages.

3.2.1 MeryGrid: the first community microgrid in Wallonia

MeryGrid is an energy community based in Méry, near Liège. The community is composed of three enterprises: Merybois, Merytherm and CBV.

This project started in 2016. Before the creation of the community, Merybois already had a photovoltoic installation and Merytherm a hydroelectric powerplant. The objective of the project is to create an energy community with these three companies in such a way that it is considered that the cluster of companies has one connection to the public grid. From the DSO side, the community acts like one microgrid. The objective also includes the development of an energy management system (EMS) to manage the community microgrid in real-time and the design and installation of an energy storage system.

Many partners were involved in this project such as Nethys, the coordinator of the project, the SPI, which is the local economic development agency, the company CE+T, the research center Sirris, the three SMEs involved and the University of Liège (Cornélusse, Ernst, Warichet, & Legros, 2017).

MeryGrid was built before it was authorized in the legislation. This pilot project needed and received an exemption to the market rules.

The exchange pricing policy that will be put in place is the one proposed by Cornélusse, Savelli, Paoletti, Giannitrapani, and Vicino (2018). The energy community and the model are described and analyzed via simulations in Part II of this work.

3.2.2 E-CLOUD: for an open-microgrid solution

The E-Cloud project is funded by the Walloon Region and coordinated by the DSO Ores. As the MeryGrid project, it started in 2016.

The principle of the project is to build community microgrids in industrial areas already fully integrated in the public network. The objective is to maximize the consumption of energy produced locally (Vangulick, Cornélusse, Vanherck, Devolder, & Lachi, 2017). To achieve this, they compute the best combination of renewable generation units (with their capacity) given the demand profiles of the members of the cloud and other practical constraints. They also propose different ways to share the local renewable generation between members, *e.g.,* proportionally to the demand or based on the benefits of each member. They expect at least a 10% decrease in the electricity bills of the participants. From the DSO point of view, this project fosters development of renewable energy and may reduce investment on the DSO network.

The industrial areas considered in the project are Tournai-Ouest and Sart-Tilman (Ores, 2017).

3.2.3 The ROLECS project

In Flanders, the ROLECS[2] project (Roll out of Local Energy Communities) is a consortium of 40 counterparties (Q. Ramon, personal communication, April 29, 2019). The project is subsidised by the Flanders Region and the operational part will last two years. It is divided in six work packages, described hereafter:

- WP 1: Management and coordination of the ROLECS project
- WP 2: Legislative aspect
- WP 3: Network tariff
- WP 4: Societal acceptance
- WP 5: Pilot-projects
- WP 6: Conclusions and recommendations

Concerning the pilot-projects, there are ten of them. The objective is to have real examples to structure the discussion for the other work packages. Each of them corresponds to a different context. For the sake of example, we present shortly two of them.

The first one is similar to the MeryGrid project in Wallonia but at a larger scale. It takes place in an industrial area in Malines.

The other one is a community composed of natural persons from the same street that at first wanted to be disconnected from the main grid. They have some solar panels, electric cars and batteries. They accepted to be part of the ROLECS project and will still be connected to the public grid.

All the pilot-projects should be realized in one year, in order to have time to analyze them and draw pertinent conclusions before December 2020, the end of the ROLECS project. The conclusions will then be communicated to the Flemish Government, in order to create a regulatory framework for local energy communities.

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[2] Note that due to a strong similarity with the name of a famous brand, the name of the project will be modified soon.

3.2.4 *Free Power for You*, Crisnée

The project *Free Power for You* in Crisnée, a locality near Liège, is still in its early stages. The objective of this project is to build a wind turbine that will produce electricity for the inhabitants and enterprises of the locality. The wind turbine and the solar panels already installed on the roofs of some public buildings should produce more electricity than the consumption of the locality, according to the forecast of the experts working on this project (Crisnée commune, 2019).

It seems that the pricing policy for inhabitants is simple: the energy will be free for the participants, they will only pay the network fees and the taxes existing in every electricity bill. The inhabitants can leave the community freely.

In the future, they consider adding more solar panels and a storage system to the energy community.

3.2.5 Hauts-Sarts zoning - Liège

In the Hauts-Sarts industrial zoning (the biggest in Wallonia), a community microgrid is expected to emerge soon (L'Echo, 2019). The objective of this project is to reproduce what was done in MeryGrid but at a larger scale. It should involve the building of new renewable energy generators (mainly solar panels) as well as storage systems. The EMS system will be developed by the University of Liège. The actors of the project expect at least 10 to 20MW of renewable production capacity.

As in Crisnée, the project is waiting for the Walloon decree presented in Section 3.1.1 to be sanctioned by the next Government and should take shape in the course of 2020.

3.3 Conclusion

Despite the fact that Belgium is not as advanced as France and Germany concerning energy communities legislation, we saw in this chapter that Belgium is eager to catch up and follow this path for the fostering of renewable energy. Indeed regulatory frameworks are being written and many pilot-projects are initiated.

Chapter 4

Energy communities in the literature

In this chapter, we review the main papers on energy communities that deal with the internal organisations on these virtual networks.

Energy communities (with collective self-consumption) is quite a recent concept and therefore, the literature on that specific subject is small but growing.

Several approaches are proposed to manage exchanges within communities and share gains and they depend mainly on the type of energy community studied. We notice notably cooperative game theory and local energy market, where participants trade locally generated energy within their community.

4.1 Cooperative game theory

Abada et al. (2017) use the framework of cooperative game theory to share the gains between the members of the community. They take the example of a building of tenants with a rooftop covered by solar panels. In the paper, they focus on the viability of these communities and they study in particular the case where a subset of participants could find more profitable to leave the community and create a new one. They compare their approach to usual sharing rules (per capita, per capacity, per energy) and show that these approaches may not satisfy the participants. They also propose a way to optimally split the community. One of their conclusions is that the community would be more stable if it is possible to measure the consumption of each household and provide personal bills. Dynamic pricing is also mentioned.

Abada, Ehrenmann, and Lambin (2018) wrote another paper about energy communities where they study again how to share the gains of the community between the participants with cooperative game theory but this time they consider also the interaction with the DSO. They fear the *snowball effect* that inadequate grid tariffs could endeavour and therefore try to estimate the impact.

4.2 Local energy market

As part of the EMPOWER project, Bremdal, Olivella-Rosell, Rajasekharan, and Ilieva (2017) propose a local energy market concept for neighbourhood of prosumers, small-scale suppliers and consumers. The local energy market integrates trade in energy, end-user flexibility and energy-related services and products. The participation to the local market is voluntary and the market is managed by a *smart energy service provider*. It places emphasis on a value-oriented approach and not energy price alone.

Olivier, Marulli, Ernst, and Fonteneau (2017) develop a mathematical framework for modelling energy exchanges between prosumers[1] in an energy community (named Electricity Prosumer Community in the paper). They consider several objectives, such as maximizing renewable energy production or optimizing cost and revenue, as well as centralized and distributed control schemes.

Stephant, Hassam-Ouari, Abbes, Labrunie, and Robyns (2018) wrote a survey of the main energy management methods that are applicable for demand-side management in the case of collective self-consumption, with an emphasis on methods based on block-chains. In particular, they list some applications of block-chain for energy communities.

Finally, Cornélusse et al. (2018) propose a bi-level optimization model to manage the exchanges within the community and compute dynamically the prices of these exchanges. This model maximizes the social-welfare of the community. They consider a community manager to handle these exchanges and each participant is free to choose his contract with the public grid. This is the market model we analyse in the second part of this work.

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[1] A prosumer is a consumer that both consumes and produces electricity.

Part II

Application to the MeryGrid case

Chapter 5

Description of the case study

In this chapter, we describe the case study of this master thesis. In the first section we present more in detail the MeryGrid project and the data we have concerning this community. In the second section, we extend the description of the pricing model studied.

5.1 The MeryGrid project as a test case

MeryGrid is an energy community, and more specifically a commmunity microgrid based in Méry, near Liège. A community microgrid is a community composed of several single microgrids. The community is composed of three enterprises: Merybois, Merytherm and CBV. An aerial view of the three companies can be seen in Figure 5.1.

The three companies have complementary electricity demand and therefore all three could benefit from the creation of a community microgrid to share the renewable resources and especially avoid the large peak cost due to large energy peaks.

Before the beginning of the community project, Merybois had already a photovoltaic installation with 60kWp of installed power and Merytherm a hydroelectric powerplant with a capacity of 200kVA[1]. No new generation unit was built for the project but they designed and built an energy storage system with a capacity of 270kWh.

There are therefore four entities in the community microgrid: the three companies and the battery system. The first entity is CBV and is a pure consumer with non-flexible load. The

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[1] Note that MeryGrid is not a community microgrid representative of possible Belgian communities because hydropower is uncommon there.

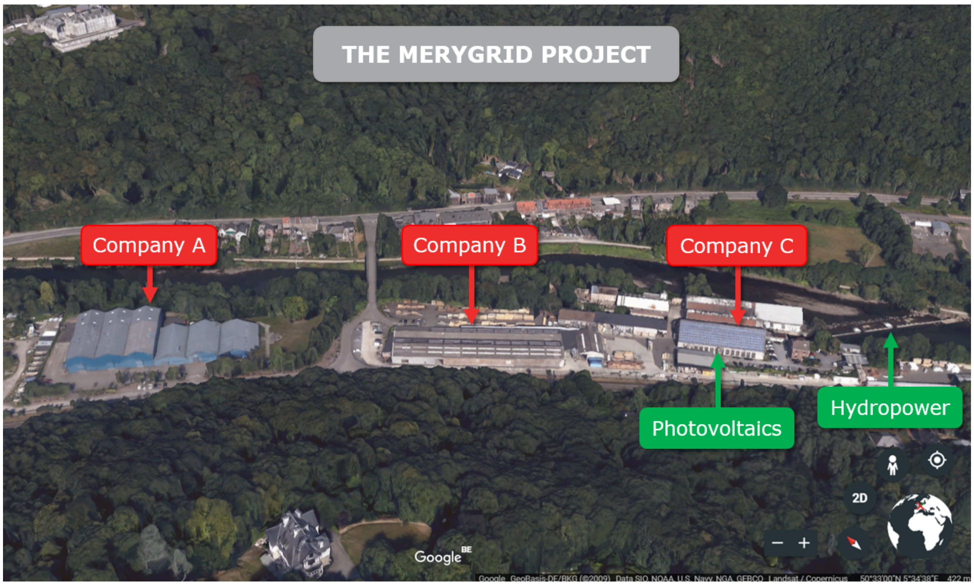

Figure 5.1: Aerial view[2] of the MeryGrid community. Companies A, B and C are respectively CBV, Merybois and Merytherm.

second is Merybois with non-flexible load and PV panels, the third Merytherm, also with non-flexible load, and a hydroelectric powerplant and the last entity is the battery.

We have access to the demand and renewable generation data that were measured with time steps of 15 minutes during the year 2017 and we therefore use these data as demand and supply orders in our simulations.

5.2 Description of the sharing policy

The sharing policy used in our simulations is a local market model managing the exchanges within the community and with the main grid and sharing the profits among the members. It was developed by Cornélusse et al. (2018) and was briefly presented in Chapter 4.

The proposed architecture consists of an internal local market based on the marginal pricing scheme. The objective is to maximize the social welfare of the community by sharing efficiently the resources. They consider as actors in the community the entities forming the community and a community operator that acts as a benevolent planner. Collectively, the entities decide both the quantity to trade among themselves within the community, and the quantity to trade outside of the community directly with the main grid. This is illustrated in Fig. 5.2.

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[2] Source: `https://les-smartgrids.fr/merygrid-premier-micro-grid-belgique/`

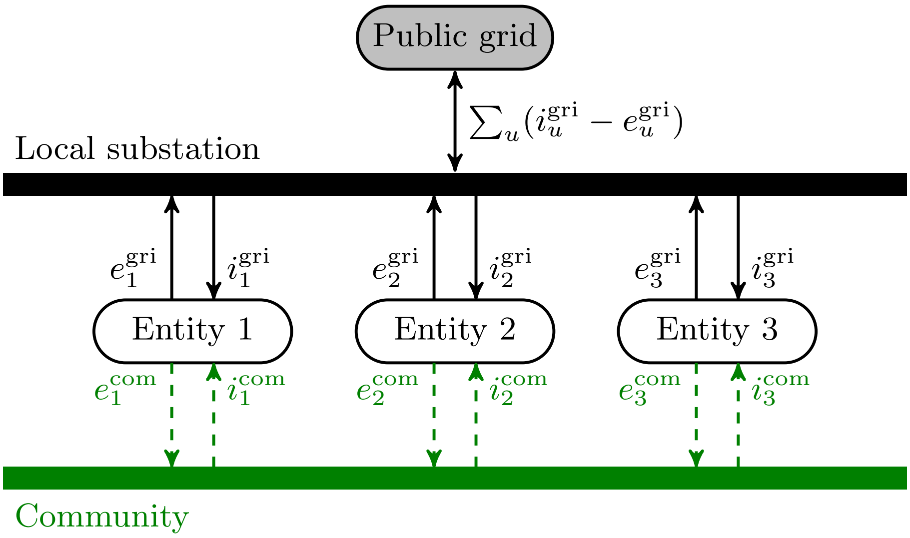

Figure 5.2: Schematic community model[3]. The flow e_i^{com} (resp. i_i^{com}) represents the export (resp. import) of entity i to the community. Flows tagged by "gri" denote traditional exchanges with the public grid.

A bi-level model has been implemented in order to model this architecture. It consists of two nested optimization problems, termed upper and lower level problems (Bard, 1998). This structure can be sketched as follows:

$$\begin{aligned} \max_{u \in \mathscr{U}} \quad & F(u, x^*) \\ \text{s.t.} \quad & x^* \in \arg\max_{x \in \mathscr{X}} f(x; u)\,, \end{aligned}$$

where F is the objective function of the upper level, and f is the objective function of the lower level.

The lower level solves the market clearing problem among the community. It determines the flows, prices, reserves and peak power maximizing the social welfare of the community. The upper level allocates the resources among the entities in such a way that it satisfies the Pareto superior condition for each entity, meaning that each entity has a profit larger or equal to its profit received when acting alone, without being in the community. This Pareto superior condition ensures the participation of the members on a voluntary basis. The overall process is sketched in Fig. 5.3.

By using the community, the entities can achieve a more efficient allocation of the resources, and therefore a reduction of the energy costs. Furthermore, from the public grid the community

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[3] Figure reprinted from Duchesne et al. (2019).

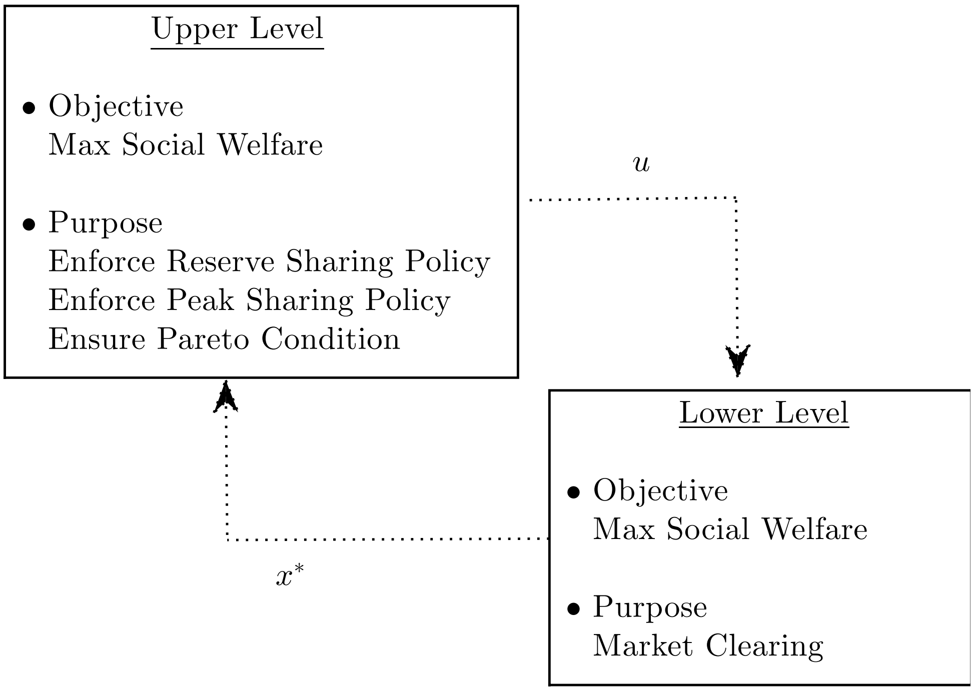

Figure 5.3: The bi-level model structure[4]. The lower level problem determines both the market equilibrium within the community, and the exchanges with the main grid. The upper level problem represents the community operator.

is seen as a single entity. Therefore, the entities could also benefit from a reduction of the peak cost due to the import/export netting effect at an aggregated level, since the energy peak considered is the one of the community. The entities could also provide energy reserve to the public grid as a group. The upper level splits these costs/revenues resulting from a collective effort based on a predetermined sharing policy. It is why a community operator is introduced, to guarantee the efficient sharing within the entities. An operator fee γ^{com} is considered to remunerate the activity of the community operator[5]. This operator fee is collected each time there is an internal exchange in the community. Furthermore, in case there is a storage system in the community, a storage fee γ^{sto} is collected by the storage system owner each time its device is used.

Monetary compensations within the community are allowed to ensure the Pareto superior condition is met.

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[4] Figure reprinted from Duchesne et al. (2019).

[5] Note that in this model, it is assumed that the physical flows go through the public grid. Therefore the DSO should also be remunerated for the internal exchanges within the community. We consider that the community operator has a contract with the public grid and thus the operator fee is used not only to remunerate the operator but also the DSO.

Chapter 6

Sensitivity analysis of a community microgrid local market model on MeryGrid

In this chapter, we perform a sensitivity analysis of the bi-level model presented in the previous chapter on the following parameters: the community operator fee, the storage owner fee, and the capacity of the storage system. The purpose is two-fold: first to assess how different values of the parameters can affect the community and each participant; second to find a good value for each of these parameters. The content of this chapter led to a publication (Duchesne et al., 2019).

6.1 Description of the data

For the sensitivity analysis, we focus on two months, January and August, chosen to evaluate the impact of some parameters under different weather conditions. Table 6.1 summarizes the consumption and generation data for these two months. On average, the consumption is larger in January than in August, but it is the contrary for the generation.

We consider as fixed the parameters depending on the contract with the main grid: the peak cost and the prices at which each entity can buy from and sell to the grid. Their values are respectively 0.15 € per kW, 0.15 € per kWh and 0.035 € per kWh. One instance of the problem lasts one day with time steps of 15 minutes. We do not consider reserves in our test

		January			August		
Entity	Type	μ	σ	Max	μ	σ	Max
1	Load	27	30	237	23	29	164
2	Load	39	22	91	7	10	47
2	PV gen.	0	1	26	5	11	67
3	Load	21	37	183	17	36	193
3	Hydro gen.	45	37	116	54	51	183
Total	Load	87	61	417	47	58	320
	Generation	45	37	123	59	54	224

Table 6.1: Mean (μ), standard deviation (σ), and maximum values of the consumption and renewable generation of each entity and the community respectively in January and in August, in kW.

case.

About the storage system, we consider that the battery has charging and discharging efficiencies of 0.95. Furthermore, the initial and final states of charge of the battery are equal to half its capacity.

6.2 Impact of the community operator fee

The operator fee γ^{com} is collected by the community operator each time an entity buys from or sells to another entity in the community. In this study, the value of γ^{com} varies from 0.005 to 0.10 €/kWh with steps of 0.005. All the other parameters stay constant, in particular the storage owner fee is equal to 0.04 €/kWh.

Figure 6.1 shows the total fees collected by the community operator during January 2017 as a function of the operator fee per kWh. The operator revenue increases almost linearly and reaches the maximum with a tariff of 0.055 €/kWh. With a larger γ^{com}, no fee is collected, meaning that there are no exchanges within the community. This analysis shows that from the community operator's point of view, the operator fee should be 0.055 €/kWh to maximize his revenue.

To check if the value of 0.055 €/kWh is meaningful, note that it is interesting for an entity to

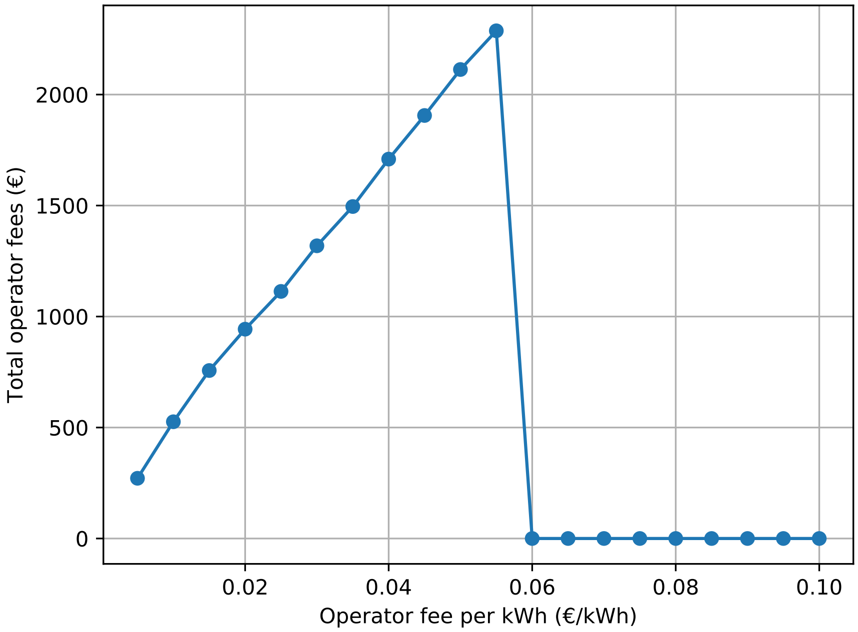

Figure 6.1: Total fees paid to the operator during January 2017 as a function of γ^{com}.

sell to the community instead of the grid only if the community market price is equal to or larger than the grid purchase price. Thus, the minimum selling price to the community for an entity is 0.035 €/kWh. In that case, the buying entity has to pay this price and remunerate the community operator. The selling entity must also remunerate the community operator. However, in the proposed framework, the selling entity charges this cost to the buying entity. Therefore, the latter pays a minimum of $0.035 + 2 \times \gamma^{com}$ €/kWh. If this quantity is greater than 0.15 €/kWh (the grid selling price), that is if γ^{com} is greater than 0.05825 €/kWh, no entity is willing to buy from the community, and therefore the selling entity sells to the grid. This explains the zero revenue for the community operator for $\gamma^{com} \geq 0.06$ €/kWh. Even though there is no exchange between entities, Figure 6.2 shows that it is still profitable for each entity to stay in the community, since joining the community decreases the peak penalty for the members. In particular, each entity improves its condition, and the Pareto condition is thus met. However, adopting a peak penalty scheme at the community level will likely force the DSO to increase the peak penalty tariff, which should incentivize community members to decrease and desynchronize their peak consumptions.

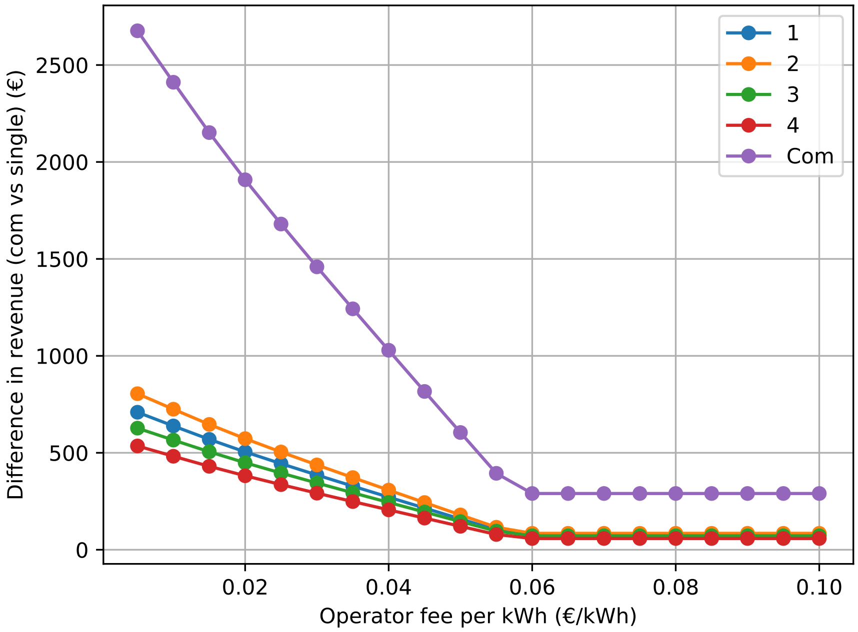

Figure 6.2: Difference in revenue for being in the community compared to being a single entity during January 2017 as a function of γ^{com}.

6.3 Impact of the storage fee

A storage fee per kWh γ^{sto} is collected by the battery owner each time the battery is charged or discharged. In this work γ^{sto} varies from 0 to 0.32 €/kWh with steps of 0.02. Furthermore, the community operator fee is equal to 0.01 €/kWh.

Figure 6.3 shows how the total fees collected by the storage owner in January evolves with the storage fee per kWh. A first interesting observation is that it reaches the maximum value with $\gamma^{sto} = 0.04$ €/kWh. It is therefore a good choice for the battery owner to pick this value as storage fee, for the nominal capacity of the storage system.

After reaching the maximum, the fees collected by the storage owner do not decrease monotonically. We can explain this by looking at the use of the battery (the sum of charge and discharge actions). Figure 6.4 shows that it decreases exponentially as a function of the storage fee per kWh. Therefore, for large values of γ^{sto}, the decrease in the use of the battery does not compensate the increase of γ^{sto}, explaining why the total storage fees collected by the storage owner increase with γ^{sto}.

We notice that the storage system is not exploited anymore if $\gamma^{sto} \geq 0.32$ €/kWh. In fact, it

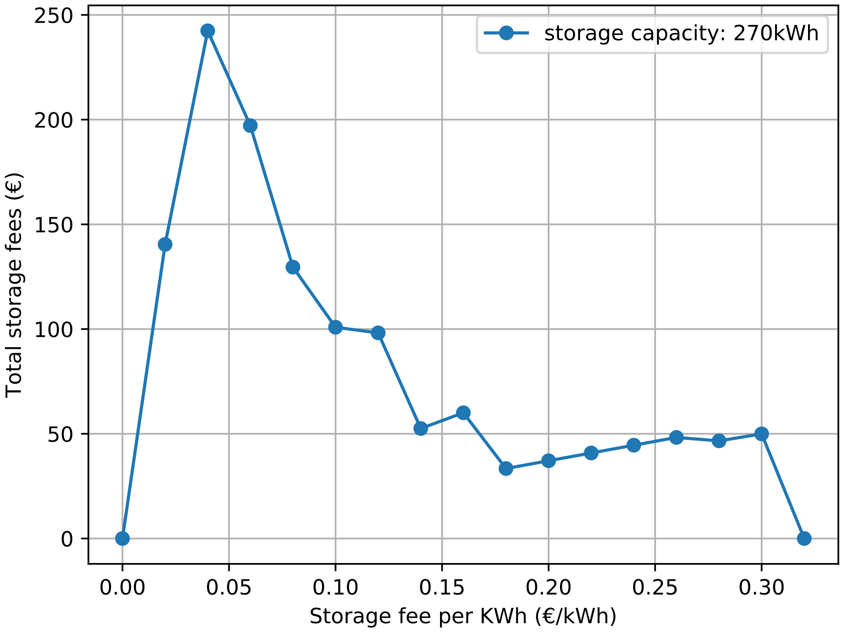

Figure 6.3: Total storage fees during January 2017 as a function of γ^{sto} for a storage capacity of 270kWh.

is shown in (Cornélusse et al., 2018, eq. (39)) that the community market price $\pi_{4,t+n}^{com}$ for entity 4 at discharging time $t+n$, is defined as

$$\pi_{4,t+n}^{com} = \frac{\pi_{4,t}^{com}}{\eta^{cha}\eta^{dis}} + \frac{2\gamma^{sto}}{\eta^{dis}}, \tag{6.1}$$

where η^{cha} and η^{dis} are the charging and discharging efficiencies of the battery, and $\pi_{4,t}^{com}$ is the market price paid by entity 4 at time t to charge the battery. This market price is such that it compensates for the price paid by the battery owner to charge the battery, and for the losses due to the charging and discharging efficiencies. It also considers the storage fee. Notice that, the maximum market price an entity d is willing to pay, in order to buy electricity within the community, is capped by the price paid to buy directly from the grid. In this setting, this value is equal to 0.75 €/kWh[1], and it is given by the following relation (Cornélusse et al., 2018, eq. (38)):

$$\pi_d^{igr} + \frac{\pi_{peak}}{\Delta_T} = 0.75 \text{ €/kWh}, \tag{6.2}$$

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[1] Note that this situation occurs only when all entities need to import from the grid and therefore the battery is used to reduce the maximum peak value by spreading the import over several time steps.

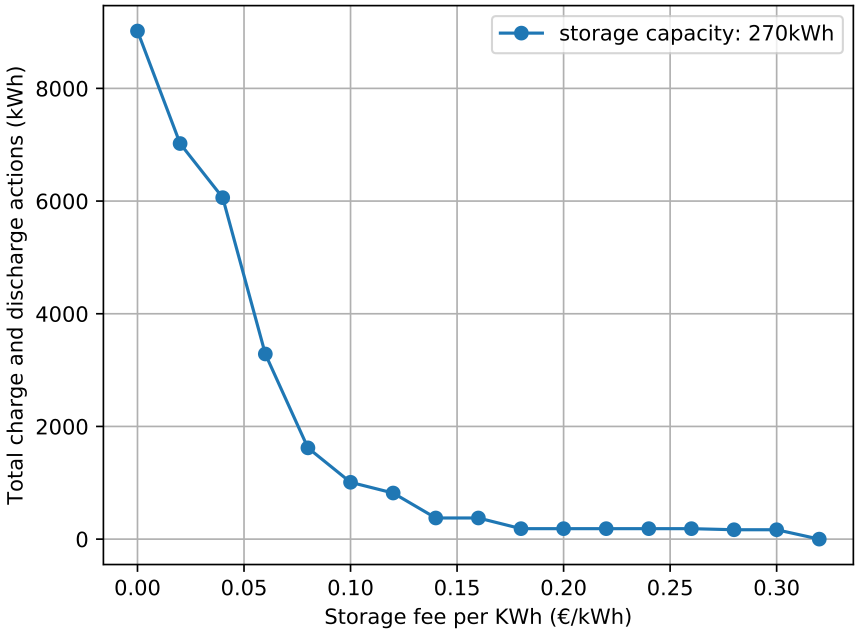


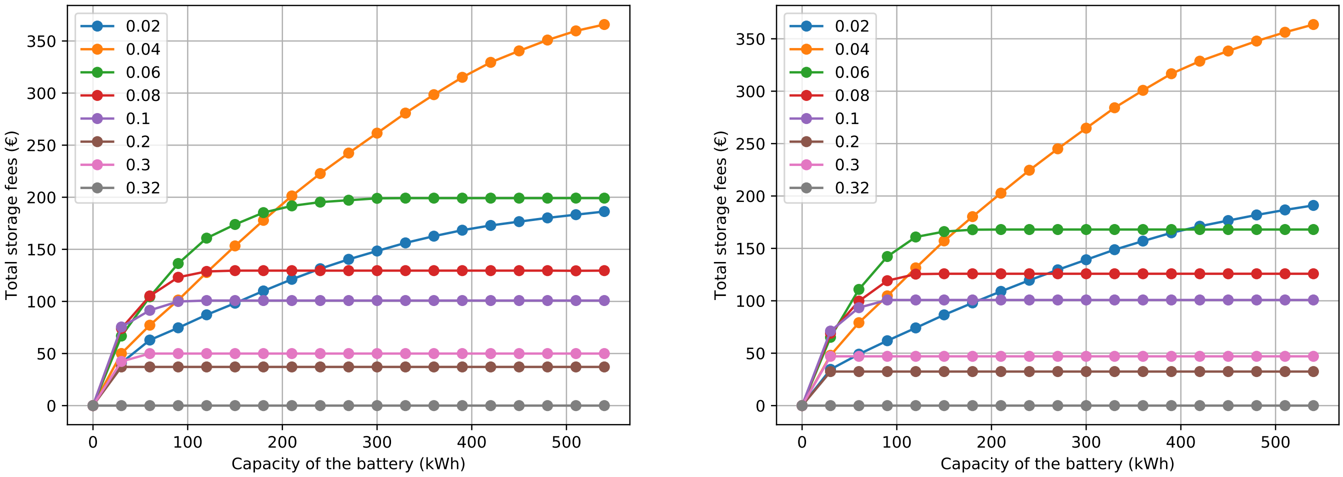
Figure 6.4: Total charge and discharge actions during January 2017 as a function of γ^{sto} for a storage capacity of 270kWh.

with the grid selling price $\pi_d^{igr} = 0.15$ €/kWh, the peak price $\pi_{peak} = 0.15$ €/kW and $\Delta_T = 0.25$ hours. It is therefore necessary for the market price of entity 4 at discharging time, i.e. $\pi_{4,t+n}^{com}$ in (6.1), to be smaller than 0.75 €/kWh to be attractive. Assuming a charging price $\pi_{4,t}^{com}$ equal to its minimum value, 0.035 €/kWh, this condition is fulfilled only if $\gamma^{sto} < 0.3378$, which explains the values observed both in Figures 6.3 and 6.4.

6.4 Impact of the storage fee and the capacity of the storage system

We now study simultaneously the impact of the storage fee per kWh and the capacity of the storage system. For this analysis, the storage fee per kWh varies as in Section 6.3 and the storage capacity varies from 0 to 540 kWh with steps of 30kWh.

Figure 6.5 shows the total fees collected by the battery owner in January and in August as a function of the capacity of the battery, for different values of γ^{sto}. The capacity of the battery maximizing the owner revenue is very sensitive to the value γ^{sto}. For a large γ^{sto}, the current capacity of the community (270kWh) is too large. This graph corroborates the observation made in the previous subsection: with $\gamma^{sto} = 0.32$, the battery is not used, independently of its capacity.



(a) January

(b) August

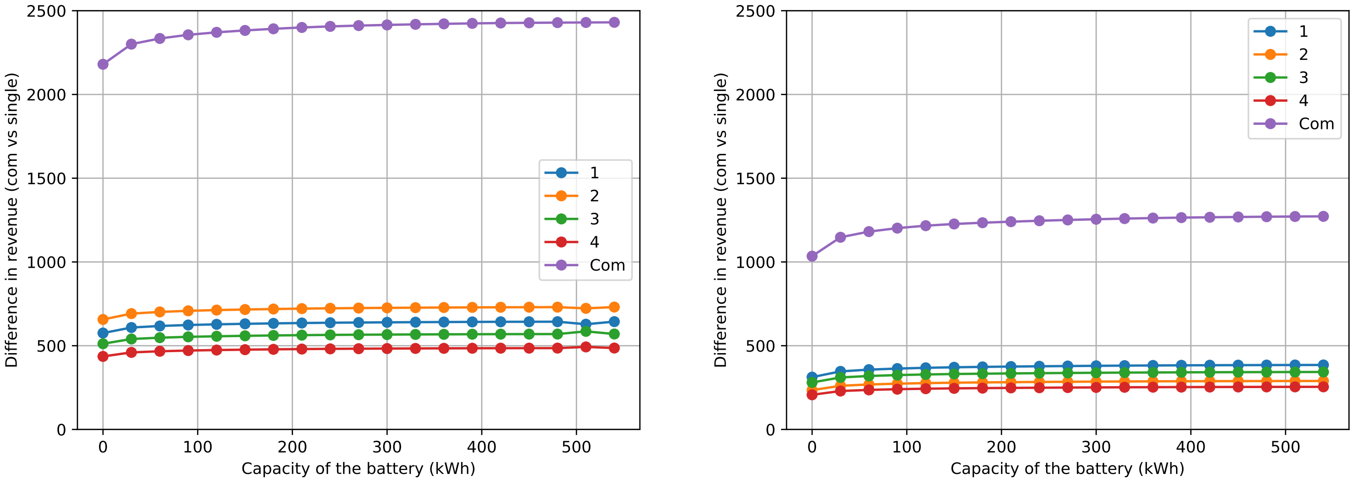
Figure 6.5: Total storage fees as a function of the storage capacity for various γ^{sto}, respectively in January and in August.

For both January and August, despite the difference in consumption and generation profiles, the value of 0.04 for the storage fee per kWh leads to the maximum revenue for the storage owner, if the storage capacity is large enough. Otherwise, there is a clear dependency between the capacity of the storage unit and the γ^{sto} maximizing the owner fees.

Figure 6.6 shows the difference in revenue for being in the community compared to being a single entity as a function of the storage capacity, for $\gamma^{sto} = 0.04$ €/kWh. The difference is positive for all entities, due to the Pareto condition. The difference in revenue for being in the community increases similarly for all entities when the capacity increases. Therefore the battery allows to increase the gain for being in the community for the two months studied.

The opposite behavior can be observed in Figure 6.7 which also shows the difference in revenue for being in the community, but this time as a function of γ^{sto}. The situation maximizing the welfare of the community corresponds to the case $\gamma^{sto} = 0$. In that case, the battery owner is only remunerated via wealth transfer (monetary compensations).

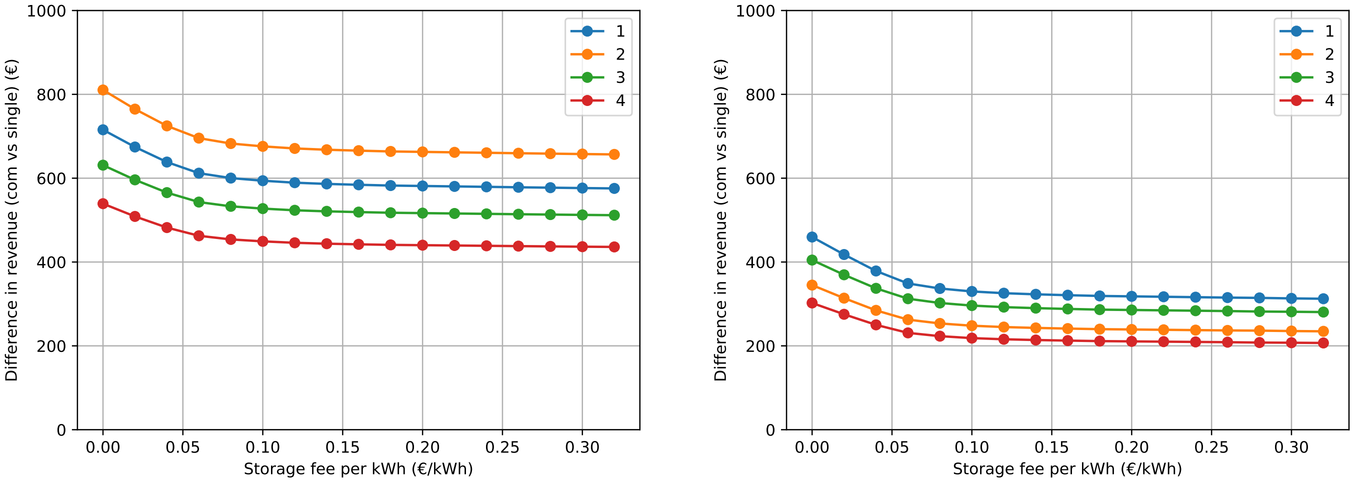
In both figures, we notice a clear difference between January and August. It seems that it is more interesting to be in the community in January, when the consumption is higher than the production in average.



(a) January

(b) August

Figure 6.6: Difference in revenue for being in the community compared to being a single entity as a function of the storage capacity for γ^{sto}= 0.04€/kWh, respectively in January and in August.



(a) January

(b) August

Figure 6.7: Difference in revenue for being in the community compared to being a single entity as a function of γ^{sto}, and for the nominal storage capacity (270kWh), respectively in January and in August.

The entities that make the most of the community are entity 2 in January and entity 1 in August. They are the largest consumers in average for the given month and they seem to exploit well the production surplus of the other entities.

6.5 Conclusions

The proposed sensitivity analysis helps to shed light on how different parameter settings can affect revenues, costs and welfare of both the participants and the community as a whole. The fee collected by the community operator on each trade has a significant impact on the community. In particular, the operator fee can be increased up to the point where no exchange is worthwhile within the community. Notice that the community can be regarded as a hedging tool, where entities can trade among themselves as long as the internal community prices are more favourable than the grid prices. We also notice that the storage device has a considerable impact on the welfare of the community, in particular concerning the storage fee. We study this impact in more detail in the next Chapter.

Assessing a good value for a parameter is not an easy task. Most of the time, the value of a parameter maximizing the revenue of one member of the community is not the one maximizing the revenue of the other members. To pick a good value, one should probably consider a value maximizing the welfare of the community as a whole.

Chapter 7

Analysis of the storage system in MeryGrid

In the MeryGrid project, the largest investment for the community was the storage system. In this chapter, we therefore focus on the storage system. In particular we attempt to answer several questions: does the storage energy system brings value to the community? How to maximize this value? Considering that a private investor decides to invest in this storage energy system for the community, is this investment profitable for a given period, *e.g.,* twenty years?

7.1 Value of the storage unit in the community

In order to evaluate the value of the storage unit for the community, we consider three cases and we simulate the operation of the community during the year 2017 for these three cases. The two first cases consider that there is a storage system and the third case that there is not. We use the default parameters presented in (Cornélusse et al., 2018). We define the community operator fee γ^{com} as 0.01€/kWh. In the first case, we consider a storage fee γ^{sto} equal to 0.04 €/kWh since we saw previously (in Figure 6.3) that this value maximizes the revenue of the storage owner. In the second case, we consider that there is no storage fee and the battery owner is remunerated with monetary transfer. Indeed, this corresponds to the situation where the difference of revenue for being in the community is maximum in January and August (Figure 6.7). The installed storage system has a capacity of 270kWh.

We define the value of the community as the difference between the amount each entity would pay if there were in the community and the amount they would pay if there were still single entities.

Figure 7.1 presents the cumulative value of the community as a whole with and without storage, with different values of γ^{sto}.

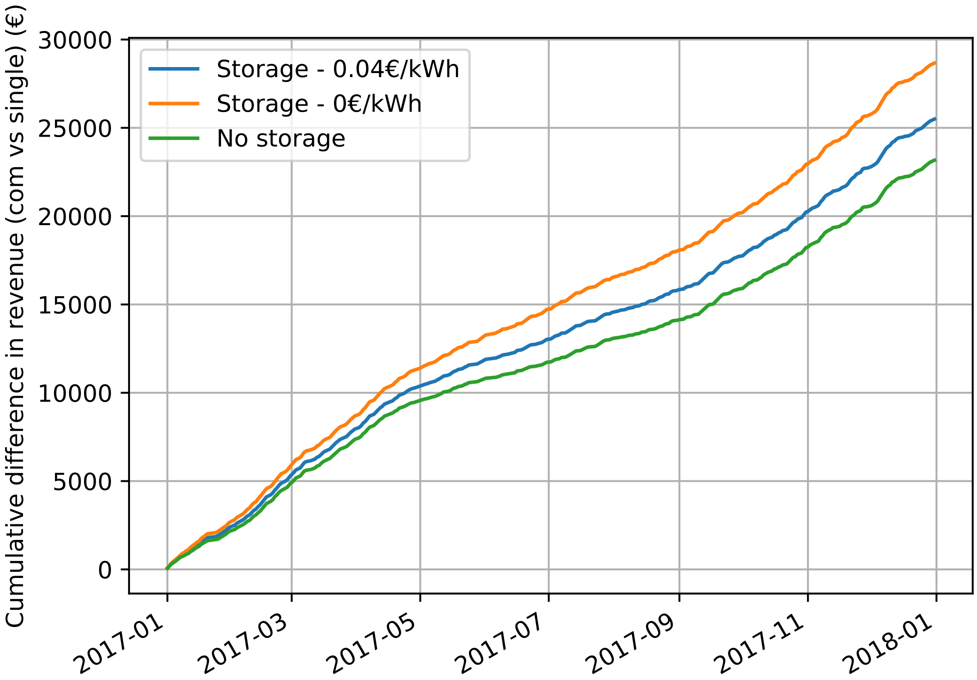


Figure 7.1: Cumulative value of the community along the year when there is a storage entity and when there is not.

We can see that with a storage system, the value of the community is larger. We can also notice that, as already observed in the previous chapter during January and August, the value of the community is larger when γ^{sto} is equal to 0. This zero value allows the community to optimize the use of the storage system. The increase in value in this case compared to the case without storage amounts to 5496.78€.

Let now look at the value of the community for the three companies with and without storage. Since the value of the community is larger with a storage fee $\gamma^{sto} = 0$, we will only look at it for the following analysis when storage is considered. The results are presented in Figure 7.2.

In that case, the value of the community for each entity is similar with and without the storage system. For more precise results, the cumulative value of the community for each entity

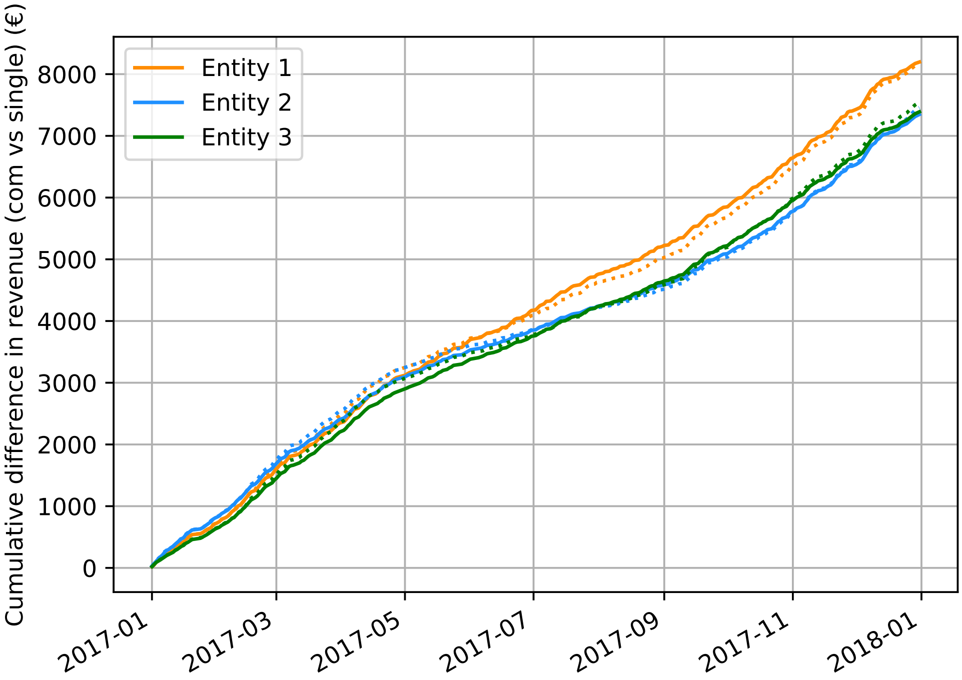


Figure 7.2: Cumulative value along the year when there is a storage entity (solid lines) and when there is not (dotted lines) for the three first entities. When storage is considered, $\gamma^{sto} = 0$.

at the end of year 2017 can be found in Table 7.1.

Case	Entity 1	Entity 2	Entity 3	Total for the three entities
w storage	8,195.90	7,346.08	7,389.23	22,931.21
w/o storage	8,168.41	7,457.60	7,540.72	23,166.73

Table 7.1: Cumulative value at the end of the year for the three entities, with and without storage, and total cumulative value for the three entities (which is different from the value of the community when there is a storage unit). When storage is considered, $\gamma^{sto} = 0$.

We see that for entity 1, the situation is slightly better at the end of the year when there is a storage system but it is not the case for the two other entities. When we compute the sum of cumulative values for the three entities, the total is slightly better without a storage system. Therefore, the extra-value brought by the battery does not compensate the diminution of value for the other entities due to wealth transfer. However, the fact that the value of the community is slightly smaller for entities 2 and 3 depends on the rules for wealth transfer and could be modified if necessary.

Even if the value decreases for the three entities, the storage system is still interesting for the community, in particular when there is no storage fee. Indeed, it increases the value of the community as a whole. Moreover, from the point of view of the DSO, the storage system could help reduce congestion and, if reserves were considered in this problem, the reserves the battery could offer should increase even more the value of the community.

Note also that there is a hydrothermal powerplant in Merygrid that reduces the usefulness of the battery. In practice in Belgium, few energy communities will have this kind of generation unit and therefore we could expect the value brought by the battery to be larger in other energy communities.

In that particular case, we have a participation constraint that is met, meaning that every member of the community is at least as well as if they were out of the community. But we neglected the amount of money invested to build the battery, that could modify this conclusion. This is considered in the next section.

7.2 Return of investment of the storage unit

Now that we analysed the value of the storage unit in the community, we can estimate if the storage investment is profitable in a horizon of 20 years.

In order to evaluate if the storage system investment was profitable in a duration of $n = 20$ years, we compute the net present value (NPV) (Kwasinski, Weaver, & Balog, 2016). The net present value computes the difference between inflows and outflows at different time periods by considering the present value of future inflows and outflows via a discount factor $(1+i)^t$. It can be computed with the following formula:

$$NPV = \sum_{t=1}^{n} \frac{P_t}{(1+i)^t} - C,$$

where C is the invested amount at time $t = 0$, P_t is the cash flow of the battery system in period t and i is the discount rate.

In this section, we will compute the NPV for different cases.

First, we consider two pricing mechanisms: a case where there is a storage fee equal to 0.04€/kWh each time the battery is used and a case where there is no storage fees and the battery owner is only remunerated with monetary transfer.

We have data from 2017, we thus estimate the inflows from this year. With $\gamma^{sto} = 0.04$€/kWh, the battery owner earns 3,017.04€ during the year 2017 for the use of the battery and 5,098.80€ via wealth transfer. Thus, the total income of 2017 amounts for 8,115.84€ in that case. In the second case, when $\gamma^{sto} = 0$€/kWh, the total income of 2017 amounts for 5,732.30€. Normally the capacity of the battery will decrease over the cycles (i.e. charge and discharge) leading to a decreasing amount of income. In this work, for the sake of simplicity, we assume that the inflow of the storage unit is the same each year. We also neglect maintenance and reparation costs along the life of the storage system. We thus have as constant inflows 8,115.84€ or 5,732.30€.

Since the MeryGrid project is a pilot-project, the real costs of this project are not representative for future project. We will therefore consider market prices. The energy storage prices are decreasing rapidly for the moment, we will therefore consider two different costs. In one of its reports (IRENA, 2017), IRENA (International Renewable Energy Agency) predicts prices below 200€/kWh for stationary installations by 2030, which corresponds to a reduction of at least 50% of the cost in 2016. We therefore consider as storage installation cost two costs which seem plausible: 400€/kWh and 200€/kWh. The usable capacity of the battery is 270kWh but the actual size of the battery is 300kWh. We thus consider this size to estimate the cost of the storage system, which gives respectively $120,000$€ and $60,000$€ of investment.

We now need to fix the discount rate. In this work, we assume a discount rate of 3%.

In addition, we evaluate two funding methods, one based on the cash flow and another based on debt.

Funding with cash flow

We consider that the investor pays directly the cost of the storage system at time period 0, that is $C = 120,000$€ or $C = 60,000$€ . Table 7.2 shows the NPV in the cases studied, for different γ^{sto} and different energy storage costs, in a horizon of 20 years. We see that with a cost of 400€/kWh for the storage system, the net present value is small or negative, thus the project would not be profitable for the investor. However, with a reduced cost of 200€/kWh, the investment is profitable with both tariff methods. It is however more advantageous when there is a storage fee.

Therefore, with the current storage installation cost (400€/kWh), the investment is not really profitable but it will be in a few years when the cost of the storage installation will decrease.

Battery cost (€/kWh)	γ_{sto} (€/kWh)	C (€)	P_t (€)	NPV (€)
400	0.04	120,000	8,115.84	743,20
400	0	120,000	5,732.30	-34.717,85
200	0.04	60,000	8,115.84	60,743.21
200	0	60,000	5,732.30	25,282.14

Table 7.2: Net present value of the storage system investment for different battery costs per kWh and different storage fees for a period of 20 years, in case the investment is funded with the cash flow.

Funding with a loan

Let us now consider another case, where the storage system is not funded anymore by the cash flow but with a loan. We consider an interest rate i_L of 2% which corresponds to the rounded mean interest rate of loan for Belgian non-financial companies according the the report of the Belgian National Bank (BNB, 2019). Let us consider also a reimbursement with constant annuity for which the reimbursement and interest payment begin at the end of the first year. To repay the loan over 20 years, an investor will have for a loan L_1 of 120,000€ an annuity of

$$\begin{aligned} A &= L_1 \frac{i_L}{1-(1+i_L)^{-n}} \\ &= 120000 \frac{0.02}{1-(1+0.02)^{-20}} \\ &= 7338.81€. \end{aligned}$$

For a loan L_2 of 60,000€, he will have an annuity of

$$\begin{aligned} A &= L_2 \frac{i_L}{1-(1+i_L)^{-n}} \\ &= 60000 \frac{0.02}{1-(1+0.02)^{-20}} \\ &= 3669.40€. \end{aligned}$$

The NPV for the different cases studied are presented in Table 7.3. Compared to Table 7.2, the NPV are larger. It is thus more profitable to invest in a storage system with a loan than with the cash flow. The best situation for the battery owner is clearly when the members of the community pay a storage fee. In that case, the investment is profitable even with the current storage system cost of 400€/ kWh.

Battery cost (€/kWh)	γ_{sto} (€/kWh)	Annuity (€)	Constant inflows (€)	P_t (€)	NPV (€)
400	0.04	7,338.81	8,115.84		11,560.24
400	0	7,338.81	5,732.30		-23,900.81
200	0.04	3,669.40	8,115.84		66,151.80
200	0	3,669.40	5,732.30		30,690.74

Table 7.3: Net present value of the storage system investment for different battery costs per kWh and different storage fees for a period of 20 years, in case the investment is funded by loan.

Conclusion

The evaluation of the net present value shows that even if the storage system increases the value of the community, the investment is not always profitable in a period of 20 years for the investor. It depends on the battery cost and the pricing method. Henceforth the participation constraint is not met in all cases. It is a possible improvement for the local market model studied. Investment cost for participants could be introduced in the model to guarantee an efficient allocation of the resources.

Part III

Conclusions and perspectives

Chapter 8

Conclusions and future work

Throughout this thesis, we studied exchange pricing within energy communities. While we were studying energy communities in Europe, we noticed that regulatory frameworks are currently emerging. In particular, regulations facilitating the development of these communities should be passed in the EU Member States to follow the EU directive RED II in a near future. We also looked at different energy communities projects, some involving natural persons, others industrials or public authorities, most of them being pilot-projects. In Belgium we noticed that people are working actively to develop energy communities, either by writing decree projects or by developing many different pilot-projects. We can say that energy communities are still at the beginning of their developments but we expect there will be many more in a near future.

From the sensitivity study of a local energy market on the MeryGrid case, we noticed the substantial impact of the operator fee on the value of the community as well as the capacity of the battery. We also studied different pricing methods concerning the storage system. We saw that for the storage system investor, receiving a storage fee each time the battery is charged or discharged is more profitable and increase the net present value of the project. However, in order to maximize the value of the community as a whole, it is better to remunerate directly the storage system owner with wealth transfer rather than with a remuneration proportional to the use of the battery. This allows to better exploit the storage system. The disadvantage is the decrease net present value of the investment, that could have a chilling effect on potential investors. However, we also saw that when the storage installation price per kWh will decrease as it is expected, this will not be a problem anymore.

Our opinion

We believe that energy communities are part of the solution to increase the penetration of renewable energy. Indeed they present several advantages. For instance, they allow natural persons with low investment budget to invest in renewable energy, become prosumers and therefore participate in the energy transition. They may also increase the societal acceptance of renewable energy production units and they favour local economy.

However, for the success of their integration in the energy landscape, a fair exchange pricing is critical. Throughout this report, we saw different exchange pricing methods. Each participant must find value in the community, this is essential for the viability of the community. Simple pricing methods and smart meters can help participants of a community to better understand gain sharing and the benefits they get. Concerning local energy market, a benevolent planner, as proposed in the literature, can help managing it and guaranteeing the fairness of the market.

Future works

Since energy communities are quite recent market models, there are many possible future works. First of all, concerning the pricing model studied in this work, one could include investment in the local market model, in order to share the benefits of the community in a way that guarantees the return of investment for all members. The proposed model could also be tested on another energy communities, more representative of Belgium where hydroelectric powerplants are not common. Furthermore, we could include possible modifications of distribution tariffs into the model to verify that it is still valuable for the members of a community.

Another possibility is to study if this local internal market encourage wanted behaviours such as maximizing local energy consumption, alleviating distribution network congestion or providing reserves.

Finally, as another future work, distribution tariff should be studied. In particular, it should meet the principle of equality of the network tariff, meaning that no user should be discriminated, participating in a community or not. Participants of a community should still contribute to taxes and subsidies. However, since they can help the DSO by reducing congestion, offering ancillary services (such as reserves) and reducing network losses due to the proximity between production and consumption, they should receive a monetary compensation. This compensation could be used to favour wanted behaviours. Several possibilities exist, such as keeping the current tariff and adding a constant monetary compensation, or adapting the current distribution tariff. If these questions are not correctly studied and solved, these could lead to the failure of energy community model in the energy landscape.

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