Business Models for Energy Community with Vulnerable Consumers

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***Abstract*—Renewable energy communities (REC) can involve final consumers into the energy system incentivizing investments in decentralized renewable energy sources and shaping their energy behaviour to improve the local balance of consumption and generation. However, RECs can also help alleviate energy poverty, which occurs when low incomes and inefficient buildings and appliances result in disproportionately high energy costs for households, by lowering energy expenses through the sharing of surplus electricity at reduced prices with vulnerable members. This work explores REC business models with the specific focus on incorporating and empowering vulnerable consumers. Based on the literature review, we propose indexes to assess the vulnerability and non-vulnerability of REC members. From these indexes, we propose two business models based on two different strategies for the operation and settlement of a REC with flexible assets and vulnerable members.**

***Index Terms*— energy communities, collective self-consumption, local energy markets, allocation rules, settlement**

I. Introduction

The decarbonization of the energy system strongly relies on the partial decentralization of energy production, making use of renewable sources for collective self-consumption. This allows consumers to privately own their resources, self-consume the locally produced energy and even share this energy with other nearby consumers. This was introduced by the EU legislation in [1] and [2], with a last update of the Portuguese transposition in 2022 in [3]. Present works tackles energy decentralization through renewable energy communities (REC) with the focus on energy poverty, by designing mechanisms to include vulnerable consumers as REC members. We will call these RECs, inclusive RECs.

The Directive 2023/1791 from the European Parliament and the Council [4] defines energy poverty as "*a household's lack of access to essential energy services, where such services provide basic levels and decent standards of living and health, including adequate heating, hot water, cooling, lighting, and energy to power appliances, in the relevant national context, existing national social policy and other relevant national policies, caused by a combination of factors, including at least non-affordability, insufficient disposable income, high energy expenditure and poor energy efficiency of homes*" and the EU site [5] deals with the EU approach on energy poverty and relevant documents and links, with specific recommendations in [6], being collective self-consumption and energy communities one of the potential tools, with the emphasis on the role of municipalities to develop them. Indeed, there are several approaches and principles to follow to alleviate energy poverty, mostly based on financial mechanisms including social rates and subsidies, energy efficiency, rehabilitation and retrofit of old equipment and infrastructure, and more recently focused on developing renewable energies. In the context of the Portuguese regulation, the Portuguese government developed some measures and efforts such as the '*Tarifa Social de Energia*', which applies a 33.8% discount over the electricity and natural gas grid access tariffs [7] for any end consumer assumed to be in a state of economic vulnerability.

A key aspect is therefore the assessment of consumers' vulnerability. Document [8] identifies and quantifies vulnerabilities in the energy sector by working with a Low Income High Cost (LIHC) coefficient, which takes into account the household's annual energy expenditures (se_i), relating it to the median value of the reference sample ($P50(se_i)$), as well as the household's annual income (y_i) per resident who benefits or is in a position to benefit from a salary ($Nind_{income}$), comparing it to a set threshold ($y^{\cdot}$):

$$LIHC = [se_i > P50(se_i)] \cup \left[\frac{y_i - se_i}{Nind_{income}} < y^{\cdot}\right]$$

The work in [9] analyzes indicators to assess energy poverty considering a set of potential advantages and disadvantages.

When focusing on business models (BM) for inclusive REC, [10] proposes a Pareto front showcasing the trade-offs between the two conflicting objectives of minimizing costs and discomfort. An individual goal-oriented approach is presented where each consumer is characterized as either cost-driven, comfort-driven or balanced. Vulnerable consumers are assumed as cost-driven users and energy transactions towards these end consumers are always prioritized. Reference [11] proposes and discusses three energy allocation models through the use of allocation coefficients (AC): an equal AC model, where all vulnerable consumers are assigned the same energy

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share at any given time step; an equal savings model, where the AC are such that all vulnerable consumer have equal monthly savings; and lastly, an equal energy model, where the AC are such that they all receive the same energy amount yearly. Document [8] presents a bi-level algorithm, where 2% of the REC economic benefits are allocated to each vulnerable consumer, up to a threshold of 50%, while the remaining benefits are distributed among non-vulnerable consumers, either according to their ownership share of REC renewable sources or according to their consumption.

Regarding the key aspect of fairness, [12] reports its view on several sharing methods under an EC context, thoroughly discussing its fairness and stability, as well as simplicity and intellectual accessibility. Reference [13] introduces three distinct dimensions regarding energy justice: a Procedural Justice dimension, aiming to ensure an equitable, non-discriminatory engagement procedure for all stakeholders, a Distributional Justice perspective, granting access to both consumption and production related activities/services, and lastly a Recognitional Justice facet, acknowledging misrepresented and overlooked social groups.

This work contributes by developing innovative business models aimed at the fair and inclusive integration of vulnerable and overlooked groups into the energy transition process, ensuring it is equitable and non-intrusive. To achieve this goal, both vulnerability and non-vulnerability indexes (VI and NVI respectively) are developed to efficiently evaluate the socio-economic setting of any REC member. Based on such indexes, two business models are proposed, one aiming to achieve lower prices when allocating local energy to vulnerable consumers within the REC, and another aiming to share the REC's economic benefits with its vulnerable groups.

II. Proposed Buisness Models

A. *Vulnerability Indexes*

To assess the vulnerability of potential REC members, two indexes were developed: one is a Boolean index, and the other one is a continuous variable, which measures the degree of vulnerability of a consumer in accordance with the REC socio-economic characteristics. When conducting this assessment, it's advisable a fair degree of consciousness as to not only avoid an invasive approach, but to also minimize any required time/effort on the consumer side.

To identify vulnerabilities in a setting of potential REC members, we propose the Boolean VI_n in (1), which assumes the value 1 if both conditions are True, and 0 in any other case. This *VI* is based on the LIHC index presented in [8], being that it also evaluates each household's energy expenditures and income per resident, but modified to fit the vulnerability scope intended for this model.

$$VI_n = \left\{\left[\frac{exp_n}{inc_n} > ref_1\right] \cap \left[\frac{inc_n}{N_n^{inc}} - N_n^{dep} * ref_3 < ref_2\right]\right\} \quad (1)$$

The first condition compares the annual energy expenses of household n, exp_n [€], to its annual income inc_n [€], and evaluates whether it exceeds a reference threshold ref_1. The second condition evaluates the total household's annual income inc_n per resident in the household that benefits or could benefit from a salary, N_n^{inc}, subtracts a conservative annual expenditure estimation ref_3 for those household members N_n^{dep} not able to benefit from a salary (such as children, elderly, people with disabilities, etc) and compares it with a reference income threshold ref_2. As proposed in [8], N_n^{inc} also accounts for unemployed residents. These residents might benefit from an unemployment allowance and could eventually benefit from a salary. Thus, they're placed inside this variable to distinguish residents who can generate income and residents that are fully dependent on those same incomes. For simulation purposes in the Portuguese context, ref_1 was set at 10%, ref_3 at 3800€ and ref_2 at 7000€.

Once vulnerable consumers are identified with (1), the objective is to assess the degree of vulnerability, easing the way into a fairer and more adaptable BM. To achieve this, three non-binary indicators were defined. The first is:

$$ind_{1,n} = \begin{cases} \left(\frac{exp_n}{inc_n}\right) * 2, \; if \; 0.12 < \frac{exp_n}{inc_n} < 0.14 \\ \left(\frac{exp_n}{inc_n}\right) * 3, \; if \; \frac{exp_n}{inc_n} > 0.14 \\ \frac{exp_n}{inc_n}, \; otherwise \end{cases} \quad (2)$$

Indicator in (2) relates the household's annual energy expenses to its annual income, in a way that a higher value reflects a higher vulnerability. This indicator is designed to double in value if the user's energy expenses exceed 12% of their income and triple in value if they surpass 14% of their income. Note that [14] shows that for the lowest income level, energy expenses typically represent more than 14% of household income, while for the second income level, expenses represent about 10%. However, since this second level should include slightly higher incomes than those considered as 'vulnerable', we used 12% instead of 10%. The second indicator is:

$$ind_{2,n} = ref_2 - \frac{inc_n}{N_n^{inc}} \quad (3)$$

Indicator in (3) evaluates a household's annual income per source of income (active or not), in a way that a higher value relates to a higher vulnerability. The third indicator is:

$$ind_{3,n} \begin{cases} \left(\frac{N_n^{dep}}{N_n^{inc}}\right) * 2, \; if \; N_n^{inc} = 1 \cap N_n^{dep} \neq 0 \\ \frac{N_n^{dep}}{N_n^{inc}}, \; otherwise \end{cases} \quad (4)$$

Indicator in (4) relates the number of sources of income with the number of residents dependent on those sources, in a way that a higher value assumes a higher vulnerability. This indicator doubles in value when a household includes one or more dependent residents and relies on a single source of income (such as single-parent households) to ensure that this scenario has the appropriate impact on the final index value.

Once computed, all three indicators are normalized in accordance with the REC context, returning, for each member, three values between 0 (least vulnerable) and 1 (most vulnerable) to help place the consumer in a vulnerability spectrum. This normalization is performed as follows:

$$ind_{i,n}^{norm} = \frac{ind_{i,n}}{\sum_{n \in N} ind_{i,n}}, \; for \; i = 1, 2, 3 \quad (5)$$

Finally, a weighted average combines all three indicators, returning the final continuous VI VI_n^{cont} proposed in this work:

$$VI_n^{cont} = 0.20 * ind_{1,n}^{norm} + 0.60 * ind_{2,n}^{norm} + 0.20 * ind_{3,n}^{norm}$$

This index places additional emphasis on the income indicator (weighted with 0.6), as it plays a pivotal role in assessing an energy poverty scenario. With a lower weight, indicators 1 and 3 serve more as "tie breakers" rather than primary determinants, ensuring that vulnerabilities affecting individuals (such as living alone or compromising comfort to reduce energy costs) are not overlooked.

B. *Non-Vulnerability Index*

The integration of members unable to make an equal and fair contribution to the community due to their vulnerability will necessarily have an economic impact on the non-vulnerable members of the REC. For this reason, a non-vulnerability index, NVI_n^{cont}, was created to understand how the non-vulnerable members could better support this additional cost due to vulnerable members. Similarly to VI_n^{cont}, NVI_n^{cont} is also based on the following three non-binary indicators:

$$ind_{1,n} = \begin{cases} \left(1 - \frac{exp_n}{inc_n}\right) * 1.5, \ if \ \frac{exp_n}{inc_n} < 0.04 \\ 1 - \frac{exp_n}{inc_n}, \ otherwise \end{cases} \quad (6)$$

Indicator (4) is such that, a higher value corresponds to a higher non- vulnerability when looking at the incomes compared with the energy expenses. The indicator increases by 50% if the member's energy expenses account for less than 4% of their income. The next indicator is:

$$ind_{2,n} = \begin{cases} \left(\frac{inc_n}{N_n^{inc}}\right) * 1.15, \ if \ St_n = 1 \\ \left(\frac{inc_n}{N_n^{inc}}\right) * 1.35, \ if \ RES_n = 1 \\ \frac{inc_n}{N_n^{inc}}, \ otherwise \end{cases} \quad (7)$$

Indicator (5) focus on the incomes compared to the household residents, and a higher value also indicates a higher non-vulnerability. This indicator increases by 15% if a REC member owns storage assets and by 35% if they own generation assets, resulting in a total increase of 50% for members owning both types of assets. The last indicator is:

$$ind_{3,n} = \begin{cases} \left(\frac{N_n^{inc}}{N_n^{dep}}\right) * 0.5, \ if \ N_n^{inc} = 1 \cap N_n^{dep} \neq 0 \\ N_n^{inc}, \ if \ N_n^{dep} = 0 \\ \frac{N_n^{inc}}{N_n^{dep}}, \ otherwise \end{cases} \quad (8)$$

Indicator (6) focuses on the relationship between economically independent and dependent households' members. It decreases by 50% if a household includes one or more dependent residents and relies on a single source of income.

Once computed, all three indicators are then normalized:

$$ind_{i,n}^{norm} = \frac{ind_{i,n}}{\sum_{n \epsilon N} ind_{i,n}}, \ for \ i = 1, 2, 3 \quad (9)$$

Lastly, the weighted average is calculated, returning NVI_n^{cont}, a value between 0 and 1, where a higher value represents a higher non-vulnerability:

$$NVI_n^{cont} = 0.10 * ind_{1,n}^{norm} + 0.80 * ind_{2,n}^{norm} + 0.10 * ind_{3,n}^{norm} \quad (10)$$

Once again, a higher relevance is given to the income indicator (5).

C. *Optimization Model*

The proposed business models were implemented in the OSTEC tool, the energy management system (EMS) of RECreation, INESC TEC's digital platform for managing energy communities, as described in [15]. OSTEC can apply a two-stage optimization model [16] where the first stage minimizes each member's individual energy bill by scheduling their flexible assets considering their energy buying and selling prices with their supplier and aggregator. The resulting individual cost C_n^{ind1} is used in the second stage in (13) to ensure that REC members do not incur any financial loss because of their participation in the REC. The stage 1 objective function is thus written as:

$$min \sum_{t \epsilon T} \left(E_{n,t}^{SUP} . \lambda_{n,t}^{buy} - E_{n,t}^{SUR} . \lambda_{n,t}^{sell} + E_{n,s,t}^{BD} . \lambda_{n,s}^{deg}\right) \quad (11)$$

where $E_{n,t}^{SUP}$ is the energy supplied to member *n* by its retailer at time *t*, $E_{n,t}^{SUR}$ is the energy sold to its aggregator at time *t*, $\lambda_{n,t}^{buy}$ is the energy buying price, $\lambda_{n,t}^{sell}$ the energy selling price, and $E_{n,s,t}^{BD}$ and $\lambda_{n,s}^{deg}$ are the energy charged in the batteries and cost $\lambda_{n,s}^{deg}$ to account for the batterie degradation.

The second stage considers local energy sharing among the REC members and minimizes the total REC cost with the following objective function:

$$min \sum_{t \epsilon T} \left(\sum_{n \epsilon N} \left(E_{n,t}^{SUP} . \lambda_{n,t}^{buy} - E_{n,t}^{SUR} . \lambda_{n,t}^{sell} + E_{n,t}^{SC} . \lambda_{t}^{grid} + \sum_{s \epsilon S} E_{n,s,t}^{BD} . \lambda_{n,s}^{deg}\right)\right) \quad (12)$$

where $E_{n,t}^{SC}$ is the energy self-consumed by meter *n* at time *t* and λ_t^{grid} the grid access tariff for the use of the public grid. In addition, constraint (13) is added to guarantee that the collective operation benefits all REC members:

$$\sum_{t \epsilon T} \left(E_{n,t}^{SUP} . \lambda_{n,t}^{buy} - E_{n,t}^{SUR} . \lambda_{n,t}^{sell} + E_{n,t}^{SC} . \lambda_{t}^{grid} + \left(E_{n,t}^{PUR} - E_{n,t}^{SALE}\right) . \lambda_{t}^{p2p} + \sum_{s \epsilon S} E_{n,s,t}^{BD} . \lambda_{n,s}^{deg}\right) \leq C_n^{ind1} \quad (13)$$

where $E_{n,t}^{PUR}$ and $E_{n,t}^{SALE}$ are the locally purchased and sold energies at the local uniform price λ_t^{p2p}.

D. *BM1: price discounts for vulnerable consumers*

The first proposed BM consists in applying a discount d_n to the energy shared with vulnerable consumers, so that constraint (13) becomes:

$$\sum_{t \epsilon T} \left(E_{n,t}^{SUP} . \lambda_{n,t}^{buy} - E_{n,t}^{SUR} . \lambda_{n,t}^{sell} + E_{n,t}^{SC} . \lambda_{t}^{grid} + \left(E_{n,t}^{PUR} - E_{n,t}^{SALE}\right) . \lambda_{t}^{p2p} . (1 - d_n) + \sum_{s \epsilon S} E_{n,s,t}^{BD} . \lambda_{n,s}^{deg}\right) \leq C_n^{ind1} \quad (14)$$

where d_n is the discount applied to each vulnerable member, set to 0 for those non-vulnerable. It is also assumed that a vulnerable member has no generation assets, so the discount can be applied to the entire parcel $\left(E_{n,t}^{PUR} - E_{n,t}^{SALE}\right)$. Finally, the discount is computed according to the degree of vulnerability of the member as follows:

$$d_n = \begin{cases} 0.20 \ if \ VI_n^{cont} > \overline{VI^{cont}} + 15\% \\ 0.10 \ if \ VI_n^{cont} < \overline{VI^{cont}} - 15\% \\ 0.15 \ otherwise \end{cases} \quad (15)$$

Therefore, a discount of 20% is applied to the local energy price to any vulnerable consumer with VI_n^{cont} index above 15% of its average value $\overline{VI^{cont}}$, 10% discount to for those with VI_n^{cont} index 15% below its average value, and 15% discount in any other case.

As mentioned in Section I, energy consumers classified as vulnerable may benefit from a social energy tariff, which provides a 33.8% discount on their grid access tariffs when purchasing energy from their retailers. Since this discount is only for highly vulnerable consumers, it is possible that when one of these beneficiaries joins a REC, the lower local price may not result in a more advantageous situation compared to purchasing energy from a retailer. To avoid this scenario, a same discount d_n^{social}=33.8% can be implemented in (14) applied to the energy self-consumed of any vulnerable member profiting from the Social Energy Tariff. Then, (12) and (14) become:

$$min \sum_{t\epsilon T}\Big(\sum_{n\epsilon N}\big(E_{n,t}^{SUP}.\lambda_{n,t}^{buy} - E_{n,t}^{SUR}.\lambda_{n,t}^{sell} + E_{n,t}^{SC}.\lambda_t^{grid}.(1-d_n^{social}) + \sum_{s\epsilon S} E_{n,s,t}^{BD}.\lambda_{n,s}^{deg}\big)\Big) \quad (16)$$

$$\sum_{t\epsilon T}\Big(E_{n,t}^{SUP}.\lambda_{n,t}^{buy} - E_{n,t}^{SUR}.\lambda_{n,t}^{sell} + E_{n,t}^{SC}.\lambda_t^{grid}.(1-d_n^{social}) + \big(E_{n,t}^{PUR} - E_{n,t}^{SALE}\big).\lambda_t^{p2p}.(1-d_n) + \sum_{s\epsilon S} E_{n,s,t}^{BD}.\lambda_{n,s}^{deg}\Big) \leq C_n^{ind1} \quad (17)$$

Finally, it should be noted that the discounts in (14) or (16) are applied to the buying price of the vulnerable members, but not to the selling price of non-vulnerable members. This means that there is a cost due to the mismatch between what the vulnerable members pay and what the sellers would expect. This cost (*total penalty*) is recovered from the individual benefits of non-vulnerable consumers through a post-optimization process. This cost allocation is based, not on the amount of energy they sell to vulnerable members, but rather on their non-vulnerability index value NVI_n^{cont}. Thus the cost penalty pen each non-vulnerable consumer must support is:

$$pen_n = total\, penalty \cdot NVI_n^{cont} \quad (18)$$

E. *BM2: post-optimization benefit allocation*

The second BM proposed allocates part of the REC collective benefits to the vulnerable members, instead of applying a discount to the local price they pay. However, a fair and balanced approach for non-vulnerable members is equally important to ensure they feel valued and respected within the community they have built and supported. Therefore, allocating economic benefits to the vulnerable members based on the REC overall revenues seems impractical. To ease this financial burden, it seems reasonable to analyze the revenues streams that can be identified for each REC member:

- Revenues from selling the energy surplus to the retailer:

$$\sum_{t\epsilon T}\Big(\sum_{n\epsilon N}\big(E_{n,t}^{SUR}.\lambda_{n,t}^{sell}\big)\Big) \quad (19)$$

- Revenues from selling energy locally to other REC members:

$$\sum_{t\epsilon T}\Big(\sum_{n\epsilon N}\big(E_{n,t}^{SALE}.\lambda_t^{p2p}\big)\Big) \quad (20)$$

- Avoided cost due to self-consumption, derived from the energy self-consumption of personally owned local generation assets, as opposed to buying from a retailer

The revenues from selling energy back to the aggregators and from the avoided costs from self-consumption mainly depend on monetary investments in the community, such as acquiring new generation or storage assets. Since these investments are made by non-vulnerable members, sharing these benefits with vulnerable consumers may not be considered fair. In contrast, revenues from energy sharing, while also influenced by monetary investments, can increase with the addition of new members with different consumption and generation profiles, creating more opportunities for buying and selling in the local energy market.

Thus, it was decided to allocate only the REC benefit generated from energy sharing revenues among the non-vulnerable members. This helps to build a more easily scalable model, where a larger revenue allocation to vulnerable members typically comes along with a larger community, and hence more members to support the associated cost.

In this BM it was proposed that 4% of the energy sharing revenues could be allocated among the vulnerable consumers, up to a threshold of 33.3% of the total revenue:

$$min\Big(\sum_{n\epsilon N}\big(E_{n,t}^{SALE}.\lambda_t^{p2p}\big)\cdot 0.04 \cdot NVI_n,\ \sum_{n\epsilon N}\big(E_{n,t}^{SALE}.\lambda_t^{p2p}\big)\cdot 0.333\Big) \quad (21)$$

Finally, this 4% is shared among the vulnerable members according to VI_n^{cont}, and the associated extra cost supported by the non-vulnerable members according to NVI_n^{cont}.

F. *Individual Cost Constraint*

In the post-optimization cost distribution process, constraint (13) or alike is no longer active. To avoid the individual cost of non-vulnerable consumers rising above their individual cost in stage 1, the algorithm in Figure 1 was implemented.

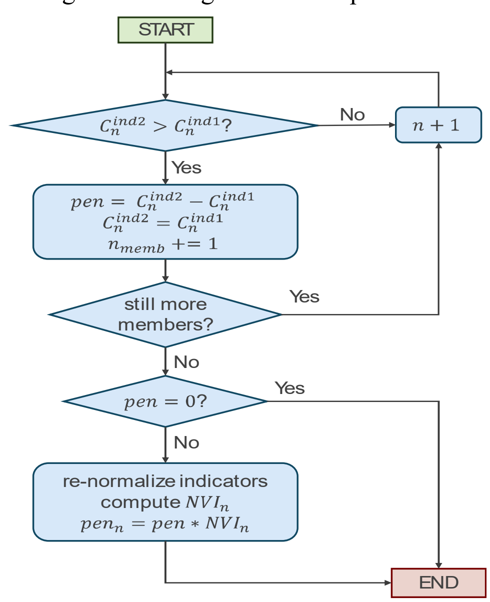

Figure 1. *Redistribution of the costs to support vulnerable members*

The algorithm checks if the cost C_n^{ind2} of any REC member n surpasses C_n^{ind1} after allocating the costs due to the vulnerable members or after sharing the collective benefits from energy sharing with them. In case it does, the final cost is set to C_n^{ind1} and the difference allocated among the remaining non-vulnerable members. To do so, VI_n^{cont} is re-normalized accounting only for the members whose individual cost did not surpass the set threshold, to calculate the extra cost penalty assigned to each remaining non-vulnerable member.

III. Case Study

A REC operation was simulated to assess the proposed BM, with 10 members (and respective meters): 6 non-vulnerable (meters #0 to #5) and 4 vulnerable (meters #6 to #9), with meter #6 benefiting from the Social Energy Tariff [7]. Meters #0 to #3 have PV generation and only meter #0 has storage. TABLE I describes them, including their annual income and energy expenses, and the number of incomes and dependent residents to compute their respective VI and NVI. Prices were set to $\lambda_{n,t}^{buy} = 1.0\ €/kWh$, $\lambda_{n,t}^{sell} = 0.01\ €/kWh$ and $\lambda_{t}^{p2p} = 0.14 €/kWh$.

TABLE I: EC MEMBERS

consumers	vulnerable?	annual income	energy expenses	Ninc	Ndep	PV?	Storage?	Social Tariff?
Meter#0	no	75 000.00 €	3 420.00 €	2	0	yes	yes	no
Meter#1	no	110 000.00 €	4 060.00 €	2	3	yes	no	no
Meter#2	no	69 000.00 €	2 800.00 €	2	1	yes	no	no
Meter#3	no	42 000.00 €	1 900.00 €	1	2	yes	no	no
Meter#4	no	66 500.00 €	3 125.00 €	2	0	no	no	no
Meter#5	no	38 000.00 €	1 860.00 €	1	0	no	no	no
Meter#6	yes	5 530.00 €	775.00 €	1	0	no	no	yes
Meter#7	yes	13 600.00 €	1 700.00 €	2	1	no	no	no
Meter#8	yes	6 510.00 €	845.00 €	1	2	no	no	no
Meter#9	yes	6 200.00 €	730.00 €	1	1	no	no	no

Figure 2 shows the normalized non-vulnerability indexes of the non-vulnerable members of the REC.

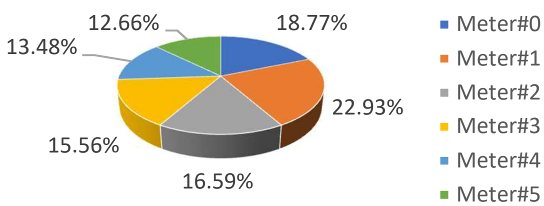

Figure 2. Relative non-vulnerability of the non-vulnerable members

Figure 3 shows the normalized vulnerability index of the vulnerable members.

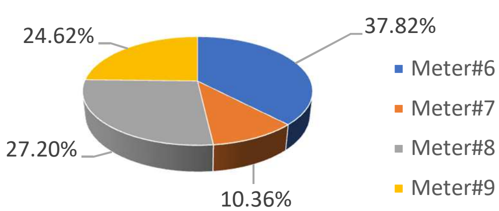

Figure 3. Relative vulnerability of the vulnerable members

When BM 1 is used, a discount is applied to the local energy price of the vulnerable members. In this case, meter #6 benefits from a 20% discount, meter #7 from a 10% discount and meters #8 and #9 from a 15% discount both. When BM 2 is used, the percentages in Figure 3 are used to share the allocated economic benefits with each vulnerable consumer.

Figure 4 compares the energy costs for each member for the scenarios: 'Ind' (acting individually, with energy transactions solely involving retailers and aggregators), 'Collective' (participating in a collective REC optimization, without distinguishing between vulnerable and non-vulnerable members), 'BM1' (using BM1) and 'BM2' (using BM2). As can be seen, almost every consumer benefits from integrating the REC. Regarding meter #3, it was verified that in all collective scenarios it has negligible energy exchanges with other meters, so its individual cost remains the same in all collective scenarios, confirming that the post-optimization individual cost constraints work as intended. Meter #4, with a slight profit in the 'Collective' scenario, increases its cost up to the individual value once the inclusive models BM1 and BM2 are used, hence never shifting into an unprofitable scenario.

Compared to their individual behaviours, it is possible to see how the cost of the non-vulnerable members increases, contrasting with the decreasing cost of the vulnerable members. Indeed, lowering the local energy prices for the vulnerable members implies an extra cost supported by the non-vulnerable ones. However, BM2 has a more significant impact over most members' individual cost, suggesting the need to fine tune the percentage of allocated benefits (set at 4%). It is also relevant to remark how both BM1 and BM2 impact on meter #6, the most vulnerable member, with a cost drop of 0.10 € with BM1 and 0.45 € with BM2.

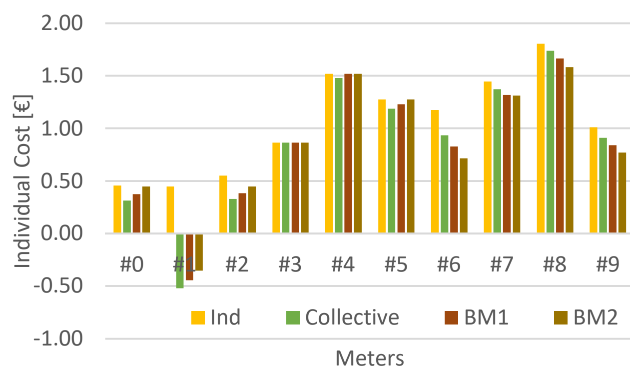

Figure 4. REC members energy costs for to the simulated scenarios

IV. Conclusions

This paper reviews the literature about vulnerable member in renewable energy communities and proposes two indexes to assess the vulnerability and non-vulnerabilities of the potential members of a community. Based on these indexes, two different business models are proposed, with two different ways to support the vulnerable members by lowering the cost of the local energy shared with them and assigning this extra cost among the non-vulnerable members. A main constraint is the guarantee that no member loses by being inside the community compared to their individual behaviour. However, many limitations can be foreseen. For example, these BMs need sensitive information about the economic and social situation of the members, that many may not be willing to provide. In addition, non-vulnerable members need to agree on a common mechanism to support non-vulnerable consumers, and such agreements may be hard to reach.

Aknowlegements

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