Upper-layer Post-processing Local Energy Bids and Offers from Neighbouring Energy Communities

1st Juan J. Cuenca
School of Engineering and Architecture
University College Cork
Cork, Ireland
j.cuenca@umail.ucc.ie

2nd Vahid Hosseinnezhad
School of Engineering and Architecture
University College Cork
Cork, Ireland
vahid.hosseinnezhad@ucc.ie

3rd Barry Hayes
School of Engineering and Architecture
University College Cork
Cork, Ireland
barry.hayes@ucc.ie

***Abstract*—Future local energy trading schemes represent an important economic incentive for inclusion of distributed energy resources (DER) and flexibility in local energy communities. Nonetheless, trading schemes at the low voltage level are envisioned to result in unattended bids and offers of energy. In the absence of an alternative, these leftovers are expected to be captured by the supplier at a low price (in case of excess energy) and at a high price (in the case of energy requirements), which can represent significant economic benefits. This paper proposes a decentralised offline trading method to transfer this benefit from the supplier to the local energy communities using a minimum electrical distance criterion. Validation is made by running a year-long quasi-static time-series (QSTS) simulation with a resolution of one minute, using PV generation profiles, and four state-of-the-art DER allocation methods in the IEEE 33-bus distribution test network. Results suggest that transferring these benefits can increase incomes up to 227% and decrease expenses up to 6.1% for local energy communities. Additionally, the sensitivity of the method to energy prices and market time step is studied.**

***Index Terms*—Communities, resource management, power generation economics, electricity supply industry deregulation.**

NOMENCLATURE

L	Set of lines.
N	Set of participants (i.e., LV energy communities or LV/MV transformers).
i, j, l, m	Indexes for participants.
t, t_x	Indexes for time.
$A_i(t)$	Energy leftover surplus (positive sign) or requirement (negative sign) for participant i during time step t.
$\vec{A(t)}$	Vector containing leftovers from all participants during time step t.
$P_{sell}^{supplier}$	Selling price offered by the supplier. It can depend on time of the day.
$P_{buy}^{supplier}$	Buying price offered by the supplier. It can depend on time of the day.
P_{agreed}	Price at which LV energy communities agree to trade the leftover resource.
FiT	Feed in Tariff, particular price scheme for the supplier to buy energy.
P_{flat}	Flat Tariff, particular price scheme for the supplier to sell energy.
ToU	Time of Use tariff, particular dynamic price scheme for the supplier to sell energy at different prices throughout the day.
$\boldsymbol{Z_m}$	Impedance matrix.
$\boldsymbol{Y_m}$	Admittance matrix.
D_{ij}	Electrical distance between participants i and j.
$\boldsymbol{D_m}$	Electrical distance matrix.
Z_{ij}^{th}	Thevenin complex impedance between participants i and j.
Z_{ij}	Complex impedance between participants i and j taken from the impedance matrix.
$\boldsymbol{D'_m}$	Modified electrical distance matrix.
H_{lm}	Energy to be transacted between participants l and m.
T_i	Stored transaction for participant i.

This work has been funded by the Department of Business, Enterprise and Innovation, under the Government of Ireland's Project 2040 Plan ("CENTS" project, contract DT 2018 0040-D).

I. INTRODUCTION

Increased interest in local energy trading, energy communities and distributed energy resources (DER) has drawn attention to market-clearing algorithms that allow participants of the electricity grid to make bids and offers for energy. Regardless of the mechanism used [1], local energy communities in the low-voltage level perform a pre-event round of market clearing with proposed/expected energy bids and offers from its participants. These come from load, generation, and flexibility projections for the time step, as well as market and technical constraints. Due to the stochastic nature of the variables, the offers and bids initially accepted during the pre-event round are often not fulfilled exactly, this creates the need for a post-event round of market clearing to settle the actual energy transfers and turn them into a flow of revenue (i.e., two stage market [2]). Especially because of the stochastic and non-dispatchable nature of certain DER technologies, and lack of flexibility resources to effectively balance generated, consumed and stored energy, local trading may result in leftover bids and offers not assigned to any participant.

There is research on economic interactions between entities that aggregate individual users as trading in multi-microgrids [3], using priority indexes (PI) to define potential trades [4], including the potential to aggregate resources and participate in the wholesale market [5]. However, these solutions are conceived for a pre-event market environment where participants are still able to make decisions on their capabilities. Surveying the literature, the authors did not find a method to deal with leftover bids and offers resulting from a local trading environment. Given this gap, leftovers are expected to be individually sold and bought at the prices of the supplier. This in turn benefits the latter by purchasing electricity at a low price and selling at a high price, capturing revenue without the need to use the transmission infrastructure.

This paper offers an alternative: instead of accepting the prices of the supplier, leftover bids and offers can be aggregated and matched using a topological criterion. This way, after local energy balancing, LV energy communities with electricity excess and requirements can trade offline at a mutually beneficial price. The selected matching criterion was the minimum electrical distance, similar applications can be found in [6]–[10]. The main contributions of this paper are as follows.

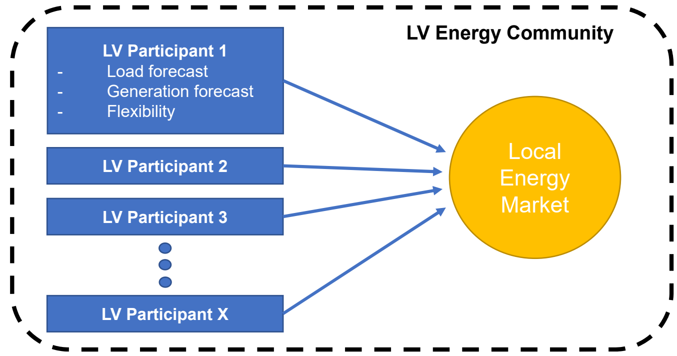
- Presenting and validating a low-computational-cost, scalable decentralised method for the offline post-processing of leftover energy bids and offers in an new trading layer.
- Demonstrating the potential economic benefits for local energy communities of dealing with them, transferring the benefits from the supplier to the users, improving fairness [11].

II. Methodology

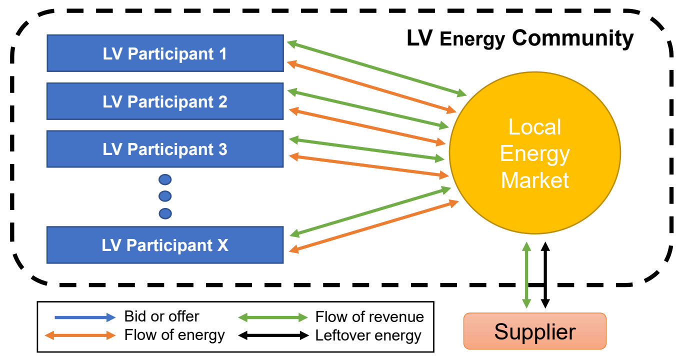
Consider an electricity distribution feeder with a set N of distribution transformers that can be hypothesised as low voltage (LV) local energy communities. Individual LV participants, can be hypothesised as being part of the community that they are physically connected to. In the future, these participants are envisioned to constantly trade electricity in this enclosed topology (i.e., local energy trading occurs between LV participants in a two-stage process as in Fig. 1). This is expected to often result in unmatched excess and requirements of resource which normally are traded directly with the supplier. This paper offers an alternative way to deal with these unmatched bids and offers, a new trading layer is proposed: through the implementation of a minimum electrical distance criterion, participants' leftovers from the local trading layer are aggregated and matched with those of other energy communities. The mathematical formulation is presented below.

A. Bids and Offers

As previously discussed, following local trading, each time step results in aggregated unattended bids and offers taken from or injected into the MV grid by each LV energy community for energy balancing. The variable set of leftover bids and offers that result from internal local trading in the LV level



(a)



(b)

Fig. 1: Two-stage local energy market for a LV energy community. a) LV participants submit preliminary bids and offers in the first stage, b) actual bids and offers are matched according to trading rules of the market in the second stage and leftovers are settled with the supplier.

can be represented by a vector with size n. In it, every potential participant i is giving its energy surplus or requirement, the sign of this value defines if this participant is offering or asking for energy (e.g., positive sign is energy surplus, and negative sign is energy requirement).

$$\vec{A(t)} = [A_1(t), A_2(t), A_3(t), ..., A_n(t)] \tag{1}$$

As this paper offers a post-processing tool, these leftover bids and offers do not need to be cleared in real time, and they can be stored for tardier offline settling. The clearing or post-process can even be done by blocks of transactions after a significant amount of time (e.g., after one month, all the leftover bids and offers in each time step can be post-processed).

B. Agreed Price for Transaction Post-processing

The idea behind the proposed methodology is to complement the traditional real-time market-clearing mechanisms (i.e., local trading) applied by each LV energy community, not to replace them. In line with this, prices in this method must be simultaneously less attractive than those in local trading, and more attractive than those offered by the supplier. Therefore, it is proposed that the participating LV energy communities agree on a price beforehand, as follows.

At any given moment, the price agreed for transacting leftovers must be higher than the supplier's selling price $P_{sell}^{supplier}$ - this is the minimum possible price for a transaction, guaranteed by the supplier (i.e., there is no interest in selling electricity at a lower price, if it is possible to sell it to the supplier at this value). Likewise, the agreed price must be lower than the supplier's buying price $P_{buy}^{supplier}$ - as this is the maximum possible price for a transaction, guaranteed by the supplier (i.e., there is no interest in buying electricity at a higher price, if it is possible to buy it from the supplier at this value). It is foreseen that any early negotiation process to result in an agreed price scheme (either static as in (2) or dynamic as in (3)) representing values between the supplier's buy and sale price for the time step. This is expected to benefit both leftover buyers and sellers, as confirmed ahead in this paper.

$$P_{sell}^{supplier} \leq P_{agreed} \leq P_{buy}^{supplier} \tag{2}$$

$$P_{sell}^{supplier}(t) \leq P_{agreed}(t) \leq P_{buy}^{supplier}(t), \forall\, t \tag{3}$$

It is important for transparency purposes that the price at which the post-processing of leftover bids and offers occurs is agreed upon beforehand by the LV energy communities. Per unit transacted, this model is expected to generate less revenue than the regular market-clearing mechanisms for real-time local energy balancing and more revenue than trading leftovers with the supplier.

C. Price Schemes

As the agreed price is negotiated using the supplier's buy and sale price as caps, it is useful for validation to study the common practices. Two energy price schemes for the supplier will be considered for this work:

1) The supplier sells to participants at a Flat tariff P_{flat},
2) The supplier sells to participants following a Time-of-Use ToU tariff, particular to the time of the day.

The supplier offers to buy energy from participants at a Feed-in Tariff FiT for both price schemes, which is modelled as a constant value in time.

To validate this work, it will be hypothesised that the agreed price P_{agreed} was negotiated as in (4) and (5): a set proportion between the supplier's buy and sell price, represented by b. Note in (5) that given the time-dependence nature of the ToU tariff, P_{agreed} is a parameter that for price scheme 2) depends on time.

$$P_{agreed} = FiT + (P_{flat} - FiT) \times b \text{ ; for scheme 1)} \tag{4}$$

$$P_{agreed}(t) = FiT + (ToU(t) - FiT) \times b \text{ ; for scheme 2)} \tag{5}$$

$$0 \leq b \leq 1 \tag{6}$$

While it is possible to visualise an infinite number of agreed pricing schemes for LV energy communities (e.g., a dynamic proportion where b varies with time), the problem was hedged using only the fixed proportion defined above.

D. Electrical Distance Matrix

As differential pricing is not offered (i.e., the transaction price was agreed before any leftover bid or offer existed), leftover buyers and sellers are matched using an impartial mechanism: the minimum electrical distance. For this matching, the first step is to build an electrical distance matrix $\boldsymbol{D_m}$ containing all potential physical paths for the flow of electricity.

Since the purpose of this study is to cover the distribution network level normally operated in a radial way, the Thevenin impedance is preferred [6] (for meshed transmission network applications refer to [12]). Given the studied distribution grid with the set N of LV energy communities and a set of L lines connecting them, it is possible to obtain the admittance matrix particular to its topology. The impedance matrix $\boldsymbol{Z_m}$ of the grid is given by the inverse of the admittance matrix $\boldsymbol{Y_m}$ with size $n \times n$ as seen in (7).

$$\boldsymbol{Z_m} = [\boldsymbol{Y_m}]^{-1} \tag{7}$$

The electrical distance D_{ij} between two communities i and j of set N, is given by the magnitude of the Thevenin impedance as seen in (8). By performing this calculation for every combination of communities it is possible to build the electrical distance matrix $\boldsymbol{D_m}$ in which columns and rows represent participant LV energy communities, and the value assigned to the respective position is the magnitude of the Thevenin electrical distance between them.

$$D_{ij} = |Z_{ij}^{th}| = |Z_{ii} + Z_{jj} - 2 \times Z_{ij}| \tag{8}$$

E. Market Clearing

Leftover bids and offers are not expected to follow any operational or economic rule. They are solely the result of the stochastic technical-economic interactions between participants of LV energy communities in different stages. Under normal circumstances, all LV participants within an enclosed energy community interact according to their load and generation capabilities. They submit their proposed bids and offers according to scheduled/forecasted resource, and local energy balancing occurs following the market rules of the community, as seen above in Fig. 1. It is not relevant for the application of the methodology proposed in this paper to know the details of these interactions between participants. In simple terms, LV energy balancing and local trading appear as a "black box" that has an output of leftover energy bids and offers; these last ones are relevant for this study. Any concerns related to the local energy trading (e.g., voltage problems, congestion, etc.) are part of this "black box", and are out of the scope of this study.

These unattended bids and offers that occur subsequently must then be aggregated as one leftover bid/offer from the LV energy community for the time step and traded with neighbouring LV energy communities as seen in Fig. 2. The matching process is decentralised and occurs offline through iterations, finding the leftover buyer and seller LV energy communities with the lowest electrical distance between them and matching

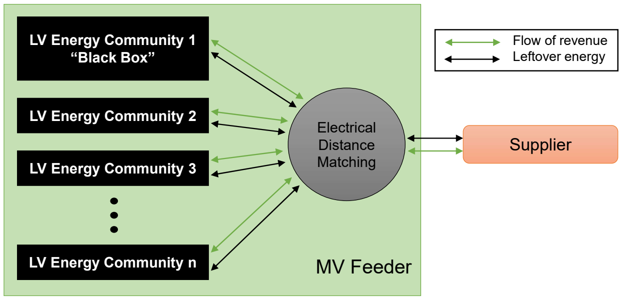


Fig. 2: Proposed scheme for leftovers market clearing, internal local trading in LV energy communities is considered a black box, and leftover bids and offers are traded.

their resource until there are no more bids or offers. As it is coordinated by all the LV energy communities, the model represents a fair and transparent settling environment that solely follows topological reasons.

Given that a particular time step t_x presents one possible leftover bid or offer for each LV energy community - registered in $\vec{A(t)}$ -, the next step is to identify which LV energy communities are part of the subsets B of buyers and S sellers. If the vector $\vec{A(t)}$ is composed exclusively of bids or offers, these should be settled directly with the supplier at the buy or sell price respectively, this avoids unnecessary iterations. Non-valid interactions can be blocked by creating a modified version of $\boldsymbol{D_m}$ corresponding to the time step. Transactions between the same participant, between buying participants and between selling participants can be blocked using (9) and (10).

$$\boldsymbol{D'_m}(t_x) = \boldsymbol{D_m} \tag{9}$$

$$D'_{ij}(t_x) = MAX\{\boldsymbol{D_m}\}/i,j \in B \vee i,j \in S \vee i = j \tag{10}$$

Once the non-valid transactions are blocked, the best possible transaction between a buyer and a seller can be obtained simply searching for the minimum value in $\boldsymbol{D'_m}(t_x)$, the row l and column m identify the participants that will perform this initial trade, corresponding to the minimum value H_{lm} of their offer/bid in (11), at the agreed price using (12) to (14). The transaction must be recorded for both participants in a vector $\vec{T}$ for the time step t_x,

$$H_{lm}(t_x) = MIN\{|A_l(t_x)|, |A_m(t_x)|\} \tag{11}$$

$$T_l(t_x) = H_{lm}(t_x) \times P_{agreed}(t_x)/l \in B \tag{12}$$

$$T_l(t_x) = -H_{lm}(t_x) \times P_{agreed}(t_x)/l \in S \tag{13}$$

$$T_m(t_x) = -T_l(t_x) \tag{14}$$

Ultimately the settled bid and offer must be subtracted from $\vec{A}(t_x)$ using (15) and (16), and the modified electrical distance matrix must block this transaction for the time step as it was already performed, this is done using (17).

$$A_{l,new}(t_x) = A_l(t_x) \pm H_{lm}(t_x) \tag{15}$$

$$A_{m,new}(t_x) = A_m(t_x) \mp H_{lm}(t_x) \tag{16}$$

$$D'_{lm}(t_x) = D'_{ml}(t_x) = MAX\{\boldsymbol{D_m}\} \tag{17}$$

This process is repeated iteratively, finding the new minimum value in $\boldsymbol{D'_m}(t_x)$ and performing calculations from (11) to (17) until there are no further bids or offers in $\vec{A}(t_x)$. Remaining bids or offers are settled at the supplier's price, all the transactions are then stored for the time step t_x and the algorithm ends, restarting all the variables.

III. Simulations and Results

A year-long quasi-static time-series (QSTS) power flow simulation was performed. Demand, PV generation and flexibility scenarios derived from local trading were modelled using [13] to obtain leftover bids and offers after a hypothetical local trading environment inside each LV energy community's "black box". The IEEE 33-Bus modified radial distribution network was used, branch and base loading data for this test network can be found in [14]. Four state-of-the-art allocation methods from the literature were selected to study if the location and size of DER impact the proposed methodology as follows.

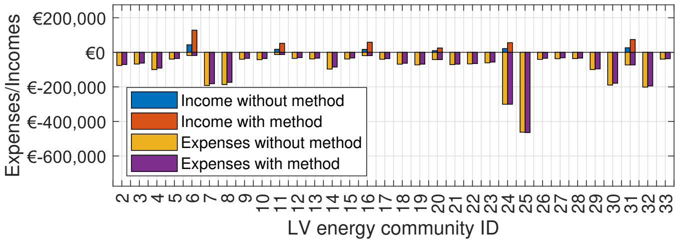
- Ref. [15] offers a total PV installed capacity of 3,500 kW distributed amongst a total of 6 locations (i.e., LV energy communities),
- Ref. [16] considers 3 locations for PV installations adding up to a total amount of 3,427 kW,
- Ref. [17] offers an allocation of 3,000 kW of PV distributed amongst 5 communities, and
- Ref. [18] presents an even distribution resource in which all potential 32 communities have an equal share of the total 3,390 kW of installed PV.

Reference prices for ToU, FiT and Flat tariffs can be found in [19]. A summary of the resulting changes in income, expenses and transferred benefits when using the proposed methodology for each allocation method and price scheme considered can be found in Table I.

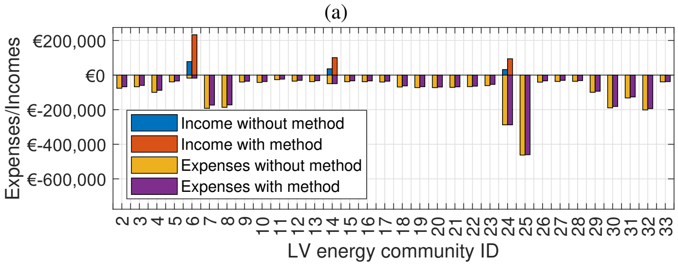
TABLE I
Changes due to Post-processing - Year QSTS Simulation

Resource Distribution	Price Scheme	Increase in Income	Expenses Reduction	Transferred Benefit
Ref. [15]	Fix Tariffs	158 %	3.7 %	€ 113,184
	ToU & FiT	189 %	4.9 %	€ 114,371
Ref. [16]	Fix Tariffs	163 %	4.7 %	€ 102,184
	ToU & FiT	194 %	**6.1 %**	€ 101,331
Ref. [17]	Fix Tariffs	190 %	4.2 %	€ 99,636
	ToU & FiT	**227 %**	5.5 %	€ 97,798
Ref. [18]	Fix Tariffs	128 %	-2.3 %	€ 134,659
	ToU & FiT	156 %	-2.0 %	€ 145,673

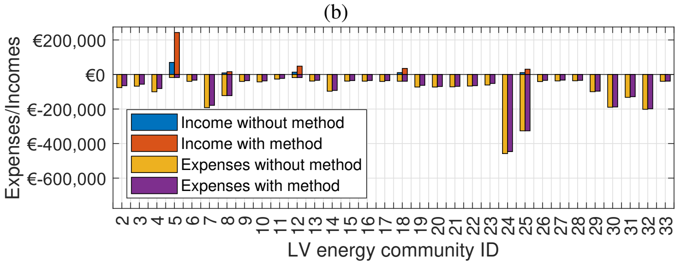
While each time step was cleared on an average time of 3.7 ms, the algorithm represents an increase of between 163 % and 227 % of income and a change in expenses between 2.3 % increase and 6.1 % reduction. This translates into additional revenue received by the local energy communities of between € 97.798 and € 145.673 for the studied year. The supplier



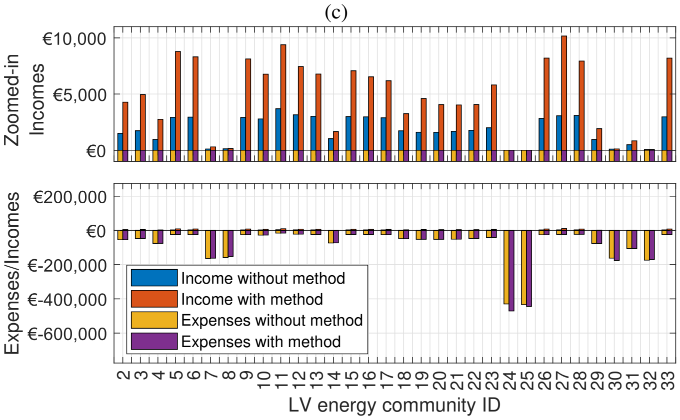
(a)



(b)

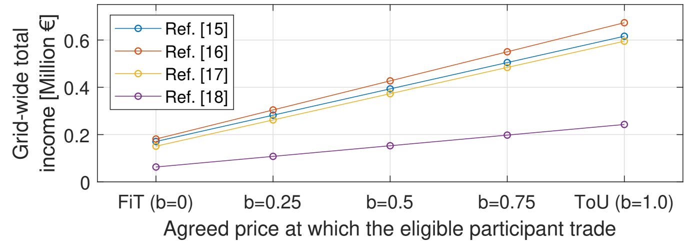


(c)

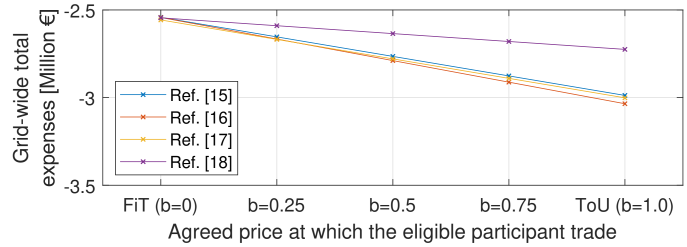


(d)

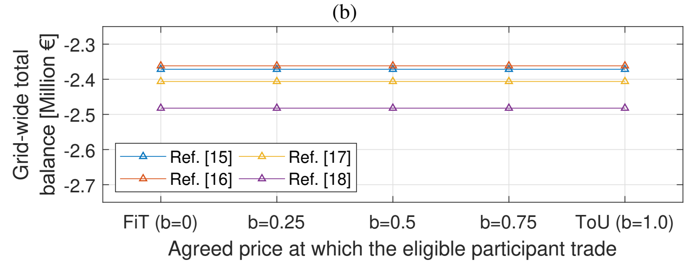
Fig. 3: Comparison of yearly incomes and expenses derived from leftovers for each participant with and without the proposed method considering ToU and FiT tariffs for a) Ref. [15], b) Ref. [16], c) Ref. [17], and d) Ref. [18].



(a)



(b)



(c)

Fig. 4: Sensitivity of the method to agreed price proportion b using ToU and FiT tariffs. Yearly a) income, b) expenses, and c) balance.

would receive these benefits without the application of the proposed method.

Yearly incomes and expenses received by each LV energy community due to leftover trading can be found in Fig. 3, given each DER allocation proposed in [15]–[18] and the use of ToU and FiT prices. In all cases, a significant increase in incomes (i.e., more than double the amount is perceived when compared to settling directly with the supplier) and a relatively small variation in expenses is visible, which supports the results shown in Table I.

It is notable how the allocation of PV resources plays an important role on how leftovers generate incomes and expenses for LV energy communities. In allocation methods [15]–[17], only 6, 3 and 4 communities respectively have generation capabilities out of the possible 32 different locations. Opposed to that, [18] has smaller amounts of DER assigned to all communities. Results suggest that when using the proposed methodology, allocation methods with a more inclusive distribution of resources benefit more participants with income due to leftover trading. Furthermore, Table I suggests that the largest overall transferred benefits occur in methods with higher participation rates, not necessarily those with the largest amount of installed PV.

To better understand the performance of the method, sensitivity studies were carried out. First, Fig. 4 presents the sensitivity of the income, expenses and balance to changes in the agreed price (i.e., the proportion between buy and sell price determined by the value of b). Results suggest that the income and expenses are directly proportional to b with the same gradient but opposite sign, these variations are cancelled in the balance, and this means that the agreed price potentially benefits more buyers or sellers, but has no impact on the supplier.

In parallel, Fig. 5 presents the sensitivity of the grid-wide balance to the time step for different DER distributions. Considering that the energy transfer and prices do not vary, this change in balance is only product of the selected time step, a longer time step appears to benefit more the local participants

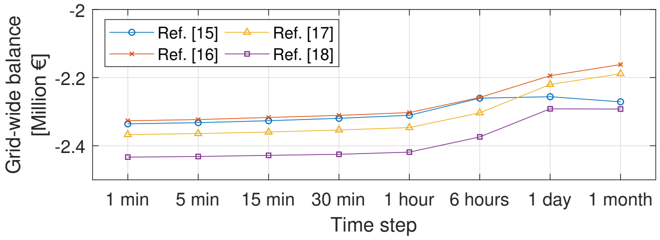


Fig. 5: Sensitivity to time step. Yearly balance comparison for variations in time step using different DER distributions and Fixed tariffs.

to the detriment of the supplier. This result highlights the necessity for appropriate granularity in metering systems to properly capture energy and revenue flows. The results presented graphically for sensitivity studies are consistent with those obtained using the other allocation methods and price schemes studied.

IV. Conclusion

A decentralised offline method to match leftover bids and offers for LV local energy communities is presented, studied and validated. The results show economic benefits for local energy communities after creating mechanisms for trading leftovers rather than allowing the supplier to act as an intermediary. While similar results are expected for the use of generation technologies other than PV, these require further study.

It was discovered that the way PV installed capacity is distributed amongst participants had an important role in how leftover bids and offers became revenue. For allocation methods with higher participation (i.e., methods that assign PV to more participants instead of focusing in big localised installations), larger overall revenue is obtained, and more participants receive it - regardless of the overall installed capacity not being the largest.

As this matching process is not ruled by the supplier or grid operator (i.e., it is impartially governed by participants), being a post-processing tool, it responds to a fair settling that follows topological reasons (i.e., the minimum electrical distance).

Potential limitations for the application of this work include the existence of more than one supplier with different price schemes for participants, the necessity of smart metering roll out at the distribution level, and the composition and governance of future local energy communities. Ultimately, future work needs to address the allocation of use of network charges for the distribution infrastructure.

Acknowledgment

The authors would like to give special thanks to the CENTS project industry and research partners, IERC, NUI Galway, TU Dublin, mSemicon Teoranta, MPOWER, and Community Power for their support and inputs into finalising this article.

References

[1] A. Shrestha, R. Bishwokarma, A. Chapagain, S. Banjara, S. Aryal, B. Mali, R. Thapa, D. Bista, B. P. Hayes, A. Papadakis, and P. Korba, “Peer-to-peer energy trading in micro/mini-grids for local energy communities: A review and case study of nepal,” *IEEE Access*, vol. 7, pp. 131 911–131 928, 2019.

[2] J. Kim, Y. Heo, G. H. Lee, J. Lee, H. Oh, and J. Choi, “Two stage market model in microgrid using cooperative game theory,” in *2018 IEEE 7th Global Conference on Consumer Electronics (GCCE)*, 2018, pp. 138–140.

[3] W.-Y. Chiu, H. Sun, and H. Vincent Poor, “A multiobjective approach to multimicrogrid system design,” *IEEE Transactions on Smart Grid*, vol. 6, no. 5, pp. 2263–2272, 2015.

[4] A. M. Jadhav and N. R. Patne, “Priority-based energy scheduling in a smart distributed network with multiple microgrids,” *IEEE Transactions on Industrial Informatics*, vol. 13, no. 6, pp. 3134–3143, 2017.

[5] K. Dehghanpour and H. Nehrir, “An agent-based hierarchical bargaining framework for power management of multiple cooperative microgrids,” *IEEE Transactions on Smart Grid*, vol. 10, no. 1, pp. 514–522, 2019.

[6] T. Baroche, P. Pinson, R. L. G. Latimier, and H. B. Ahmed, “Exogenous cost allocation in peer-to-peer electricity markets,” *IEEE Transactions on Power Systems*, vol. 34, no. 4, pp. 2553–2564, 2019.

[7] J. Guerrero, B. Sok, A. C. Chapman, and G. Verbič, “Electrical-distance driven peer-to-peer energy trading in a low-voltage network,” *Applied Energy*, vol. 287, p. 116598, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0306261921001380

[8] P. Lagonotte, J. Sabonnadiere, J.-Y. Leost, and J.-P. Paul, “Structural analysis of the electrical system: application to secondary voltage control in france,” *IEEE Transactions on Power Systems*, vol. 4, no. 2, pp. 479–486, 1989.

[9] H. Liu, A. Bose, and V. Venkatasubramanian, “A fast voltage security assessment method using adaptive bounding,” *IEEE Transactions on Power Systems*, vol. 15, no. 3, pp. 1137–1141, 2000.

[10] J. Zhong, E. Nobile, A. Bose, and K. Bhattacharya, “Localized reactive power markets using the concept of voltage control areas,” *IEEE Transactions on Power Systems*, vol. 19, no. 3, pp. 1555–1561, 2004.

[11] J. J. Cuenca, E. Jamil, and B. Hayes, “State of the art in energy communities and sharing economy concepts in the electricity sector,” *IEEE Transactions on Industry Applications*, vol. 57, no. 6, pp. 5737–5746, 2021.

[12] A. Paudel, L. P. M. I. Sampath, J. Yang, and H. B. Gooi, “Peer-to-peer energy trading in smart grid considering power losses and network fees,” *IEEE Transactions on Smart Grid*, vol. 11, no. 6, pp. 4727–4737, 2020.

[13] E. McKenna, M. Thomson, and J. Barton, “Crest demand model,” Loughborough University, Sep 2015.

[14] V. Vita, “Development of a decision-making algorithm for the optimum size and placement of distributed generation units in distribution networks,” *Energies*, vol. 10, no. 9, 2017.

[15] M. Kefayat, A. Lashkar Ara, and S. Nabavi Niaki, “A hybrid of ant colony optimization and artificial bee colony algorithm for probabilistic optimal placement and sizing of distributed energy resources,” *Energy Conversion and Management*, vol. 92, pp. 149–161, 2015.

[16] R. Viral and D. Khatod, “An analytical approach for sizing and siting of DGs in balanced radial distribution networks for loss minimization,” *International Journal of Electrical Power Energy Systems*, vol. 67, pp. 191–201, 2015.

[17] M. F. Shaaban, Y. M. Atwa, and E. F. El-Saadany, “DG allocation for benefit maximization in distribution networks,” *IEEE Transactions on Power Systems*, vol. 28, no. 2, pp. 639–649, 2013.

[18] J. J. Cuenca and B. P. Hayes, “Non-bias allocation of export capacity for distribution network planning with high distributed energy resource integration,” *IEEE Transactions on Power Systems*, pp. 1–1, 2021.

[19] J. Guerrero, A. C. Chapman, and G. Verbič, “Decentralized p2p energy trading under network constraints in a low-voltage network,” *IEEE Transactions on Smart Grid*, vol. 10, no. 5, pp. 5163–5173, 2019.