

Evaluating Allocation Methods for Collective Self-Consumption in Nordic Multi-Dwelling Buildings

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Abstract— This study evaluates four energy allocation methods for collective self-consumption (CSC) in Finnish multi-dwelling buildings (MDB) using photovoltaic (PV) systems. The methods are compared to the ideal Neighboring Credit (NC) system, which prioritizes surplus energy distribution to apartments with unmet needs. Two PV dimensioning scenarios—optimal and practical—are analyzed using consumption and simulated production data from two case properties. Under optimal PV dimensioning, the NC system achieved a self-consumption ratio (SCR) of 86.9%–88.3%, while fixed allocation methods resulted in reductions of 6–17 percentage points. Economically, the decrease in total electricity cost savings compared to the ideal NC system ranged from 2.3 to 9.1 €/kWp. Under practical PV dimensioning, the NC system achieved a near 100% SCR, reflecting efficient energy utilization. The results indicate that allocation methods significantly influence SCR and financial outcomes in the utilization of PV systems in MDBs.

Index Terms— Collective self-consumption, multi-dwelling buildings, sharing coefficient, photovoltaic systems, economic feasibility.

I. INTRODUCTION

The European Union's Clean Energy for All Europeans package, adopted in 2019, set ambitious goals for renewable energy integration by promoting frameworks like Renewable Energy Communities and Citizen Energy Communities [1]. These initiatives enable collective renewable energy production, consumption, and management, forming the foundation for concepts such as collective self-consumption (CSC). CSC allows residents of multi-dwelling buildings (MDB) to share locally generated energy, such as solar photovoltaic (PV) electricity [2]. With nearly 47.5% of the EU population living in apartments [3], MDBs offer a significant opportunity to enhance renewable energy utilization. Finland has tailored this CSC framework to suit its unique housing and energy systems.

In 2021, Finland introduced the credit calculation model (CCM), enabling CSC in MDBs with virtual net-metering under Distribution System Operator (DSO) management [4]. This framework facilitates the allocation of surplus PV energy among residents and enhancing the financial viability of PV

investments [5]. The CCM aligns with Finnish Limited Liability Housing Company (LLHC) structures [6], where shares typically dictate the distribution of financial responsibilities and resources [7]. However, the current CCM allocates energy using a fixed allocation ratio, which does not support neighboring credit (NC) allocation. This means that surplus energy cannot be dynamically shared with neighboring apartments that have unmet energy needs, limiting the potential benefits of self-production.

Building on prior research, findings from Finland [8] and Norway [9] reveal that allocation methods based on floor area or annual consumption influence self-consumption ratio (SCR). While these studies provide valuable insights, further research is required to refine allocation methods for Finnish contexts.

This study evaluates four allocation methods for surplus energy distribution under the CCM: apartment floor area, ownership shares of LLHC, equal allocation, and shareholders' annual consumption. In this study those four allocation methods are compared to the ideal neighboring credit (NC) system, which prioritizes surplus energy allocation to apartments with unmet energy needs during production, aiming to maximize self-consumption efficiency. From the energy allocation point of view, NC system is identical to back-metered CSC systems [8] or behind-the-meter energy communities [10] presented in previous studies. In Finland, CCM calculations are carried out in the centralized data management system, "Datahub", maintained by the national transmission system operator, Fingrid Oyj [4], [11]. Although the NC system has not been implemented in Finland, it could be integrated into the Datahub by reallocating surplus energy remaining after the initial credit calculation to shareholders with remaining consumption needs.

By addressing optimal and practical PV dimensioning scenarios to two case properties, this study seeks to answer three key questions: How do different surplus energy allocation methods affect the SCR in Finnish MDBs? What are the financial implications of various sharing methods under practical and optimized PV dimensioning scenarios? Are there financial or operational benefits to adopting the NC system?

II. METHODOLOGY

The methodology of this study is designed to evaluate the efficiency and economic viability of various sharing methods in CCM systems within MDBs. This chapter presents the key input data and calculation methods relevant to this study. More detailed information about the case properties, data collection, and simulations can be found in the earlier study conducted by Kortetmäki et al. [8]

A. Case overview

The research is based on actual consumption data from the case properties and simulated production data from PV systems. Two MDBs located in Tampere, Finland are used as case properties. These properties represent typical Finnish housing structures with varying layouts and sizes, offering a practical basis for evaluating CSC methods. Table I summarizes the key characteristics of the properties.

TABLE I. DESCRIPTION OF THE CASE PROPERTIES

| Info | Case Property | |
|---|------------------|--|
| | A | B |
| Year of construction | 1958 | 1960 |
| Number of apartments | 190 | 114 |
| Number of commercial premises | 11 | 0 |
| Floors | 7 | 6 |
| Heating method | District heating | Hybrid heating: District heating and heat pump |
| Total electricity consumption 2020 (MWh) | 454.3 | 358.7 |
| Common electricity consumption 2020 (MWh) ^a | 221.5 | 215.5 |

a. Property's common electrical consumption as corridor lighting, public sauna, centralized air ventilation system, etc.

Property A comprises three seven-story buildings with 190 apartments and ground-floor commercial spaces. Property B includes two six-story buildings and a row house with 114 apartments. Detailed descriptions and further context of the case properties is presented in the previous study [8].

B. Data collection and simulations

The study relies on hourly electricity consumption data from 2020 for apartments and common energy consumption in shared facilities for both properties. Data were anonymized and proportionally distributed by the anonymization process ensured that individual shareholders could not be directly identified.

Two PV dimensioning scenarios were simulated to analyze CSC performance. In the optimal PV dimensioning scenario, system sizes were maximized for profitability without considering physical constraints, providing a benchmark for energy utilization and financial outcomes. Optimal PV system sizes were determined using a method from Koskela et al. [12], which assumes a linear annual cost function (€/kWp) near the optimal size. Optimal sizes were identified by comparing annual electricity cost savings across different PV capacities.

This study maximized production by assuming panels oriented south at a 45-degree angle [13].

In the practical PV dimensioning scenario, system sizes were constrained by rooftop space availability, reflecting real-world limitations in PV system capacities, azimuths, and slopes. All simulations were conducted using the PVGIS¹ tool, with key parameters such as orientation, slope, and system losses standardized for comparability.

Table II presents the technical parameters used in the PV simulations for both properties. These parameters include PV power capacity, azimuth, slope, and system losses, ensuring consistent conditions across scenarios.

TABLE II. PV SYSTEMS TECHNICAL INFORMATION

| Info | Case Property | | | |
|-------------------|---------------|-----------|---------|-----------|
| | A | | B | |
| PV dimensioning | Optimal | Practical | Optimal | Practical |
| PV power (kWp) | 105 | 59 | 60 | 34 |
| Azimuth (°) | 0 | -71 | 0 | -71 |
| Slope (°) | 45 | 18 | 45 | 18 |
| System losses (%) | 10 | | | |
| Datasource | PVGIS | | | |
| Year | 2020 | | | |

These simulations provided insights into the energy generation potential of PV systems under both scenarios. The results were further analyzed to evaluate the impact of different allocation methods on SCR and financial outcomes. To calculate the impacts of allocation methods, the floor areas of apartments and the shareholders' share counts were used. These parameters allowed for proportional distribution of generated energy and financial outcomes under various allocation methods.

C. Calculations

The analysis focused on evaluating SCR and electricity cost savings due to different sharing methods under both PV dimensioning scenarios. Table III summarizes the sharing methods applied in the study, including their allocation principles.

In the calculations, a denotes the total number of hours in a year, and t represents the ordinal time step (hourly basis). Each shareholder is indexed as n , with N being the total number of shareholders. Consumption is denoted as C , while PV system production is E_{PV} .

First, surplus energy S remaining after meeting the common energy consumption (CC) was calculated using (1), serving as the baseline for further distribution among shareholders. The total surplus energy in CCM, considering different allocation shares k under allocation method x and NC, was then evaluated using (2) and (3). Finally, SCR was determined for CCM and NC using (4), comparing the energy consumed within the property to the total energy generated by the PV system.

¹ PVGIS (Photovoltaic Geographical Information System) is a publicly available tool developed by the European Commission's Joint Research Centre

TABLE III. ALLOCATION METHODS AND PRINCIPLES

| Allocation method | Abbreviation | Description |
|-------------------------|--------------|---|
| Neighboring credit (NC) | NC | Hypothetical allocation method in which surplus energy is dynamically redistributed to apartments with unmet consumption needs during each settlement period, ensuring maximum self-consumption efficiency. |
| Apartment floor area | area | Allocation proportional to apartment size. |
| Ownership shares | shares | Based on housing company shares, aligning with Finnish Limited Liability Housing Companies (LLHC) |
| Equal allocation | equal | Surplus energy divided equally among residents. This method does not consider apartment size or energy consumption, treating all participants equally regardless of their specific energy needs or living conditions. |
| Annual consumption | consumption | Proportional allocation based on shareholder's (apartment's) annual energy consumptions |

$$S_{CC} = \sum_{t=1}^a \sum_{E_{PV}(t) > C_{CC}(t)} E_{PV}(t) - C_{CC}(t) \quad (1)$$

$$S_{CCM} = \sum_{t=1}^a \sum_{n=1}^N S_n(t, n) \quad (2)$$

$$\Leftrightarrow \sum_{t=1}^a \sum_{k(n) \cdot S_{CC}(t) > C_n(n, t)}^N k_x(n) \cdot S_{CC}(t) - C_n(n, t)$$

$$S_{NC} = \sum_{t=1}^a \sum_{E_{PV}(t) > C_{total}(t)} E_{PV}(t) - C_{total}(t) \quad (3)$$

$$\Leftrightarrow \sum_{t=1}^a \sum_{E_{PV}(t) > C_{total}(t)} \{E_{PV}(t) - (C_{CC}(t) + \sum_{n=1}^N C_n(n, t))\}$$

$$SCR = \sum_{t=1}^a \frac{E_{PV}(t) - S(t)}{E_{PV}(t)} \cdot 100\% \quad (4)$$

Financial outcomes were evaluated using day-ahead prices and relevant taxes. The financial calculations utilized electricity price data from local DSO's service charges, the Nordic electricity exchange (Nord Pool) day-ahead prices, and Finnish state electricity and value-added taxes. (Table IV)

TABLE IV. ELECTRICITY PRICE PARAMETERS USED IN FINANCIAL CALCULATIONS.

| Price Description | Abbreviation | Value |
|---------------------------------------|--------------|-------------|
| Energy price ^a | V_{DA} | Day ahead |
| Volumetric price DSO ^b | V_{SV} | 2.93 c/kWh |
| Electricity tax ^b | T_E | 2.253 c/kWh |
| Retail margin ^b | M_{retail} | 0.363 c/kWh |
| Export volumetric margin ^b | M_{export} | 0.363 c/kWh |
| Value added tax | T_{VAT} | 24% |

Note: All values are presented without VAT (0% VAT)
a. Time-dependent spot price from Nord Pool day-ahead market
b. Fixed price component (does not vary with time)

Equation (5) calculated electricity cost savings from self-consumed energy (i_{self}), while savings from surplus energy fed back to the grid ($i_{surplus}$) are determined using (6). The total electricity cost savings (i_{total}) are then obtained in (7) and normalized by PV system capacity (P_{PV}) to compute relative savings (i_{rel}) in (8), allowing for a comparison between different scenarios.

$$i_{self} = \sum_{t=1}^a (S(t) \cdot V_{DA}(t) + M_{retail} + V_{SV} + T_E) \cdot T_{VAT} \quad (5)$$

$$i_{surplus} = \sum_{t=1}^a (E_{PV}(t) - S(t)) \cdot (V_{DA}(t) - M_{export}) \quad (6)$$

$$i_{total} = i_{self} + i_{surplus} \quad (7)$$

$$i_{rel} = i_{total} / P_{PV} \quad (8)$$

These calculations provided insights into the energy utilization and financial performance of CSC systems under varying dimensioning scenarios and allocation method.

III. RESULTS

The results illustrate the impact of different allocation methods on the SCR in MDBs utilizing PV systems with CSC. Two scenarios were analyzed: optimal PV dimensioning and practical PV dimensioning. This chapter summarizes the results by comparing changes in SCR and electricity cost savings.

Figure 1 shows the differences in SCR across allocation methods under optimal dimensioning. In CSC with NC, the SCR was 86.9% for Property A and 88.3% for Property B. Allocation methods significantly reduced the SCR for both properties. For Property A, reductions ranged from -8.4 pp with the consumption-based method to -17.6 pp with the equal-based method. For Property B, reductions were slightly smaller, ranging from -6.0 pp (consumption-based) to -8.1 pp (equal-based).

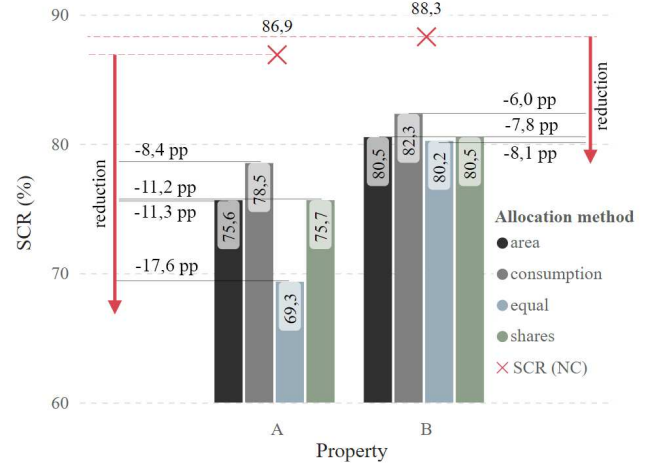


Figure 1. Difference on SCR in different sharing method in caseproperties A and B with optimal PV dimensioning.

Under practical dimensioning (Figure 2), the baseline SCR values with NC were higher, with 100% for Property A and 99.5% for Property B. Reductions due to allocation methods were smaller compared to the optimal scenario. For Property A, reductions ranged from -3.1 pp with the consumption-based method to -6.7 pp with the equal-based method. For Property B, the reductions ranged from -4.2 pp (consumption-based) to -5.6 pp (equal-based). Among the four methods (area, consumption, equal, shares), the consumption-based method consistently resulted in the least reduction in SCR and equal-based method most reduction in every cases.

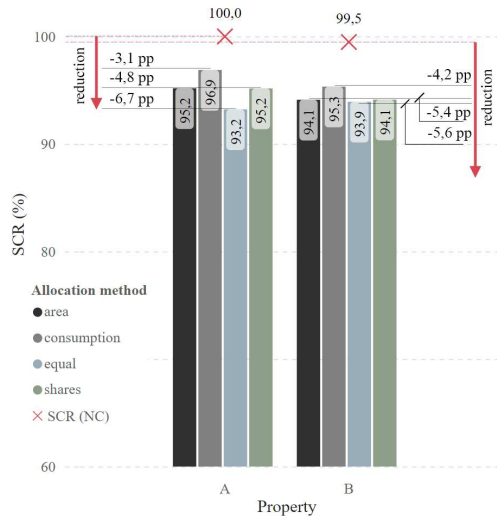


Figure 2. Difference on SCRs in different sharing method in caseproperties A and B with practical PV dimensioning.

Table V provides a detailed comparison of the electricity cost savings per shareholder and their changes across the four sharing methods for properties A and B under both optimal and practical PV dimensioning scenarios. It highlights the financial impact of these allocation methods relative to the NC system baseline. The trends observed in electricity cost savings closely mirror the SCR reductions, with the consumption-based method causing the smallest decrease in savings compared to the NC system, while the equal-based method resulted in the largest decline.

TABLE V. ELECTRICITY COST SAVINGS FOR LLHC SHAREHOLDERS UNDER DIFFERENT ALLOCATION METHODS AND PV DIMENSIONING, COMPARED TO NC SYSTEM.

| Property | Sharing method | PV dim. | Annual savings per shareholder | | |
|----------|----------------|-----------|--------------------------------|---------------------|---------------------|
| | | | Total | Change ^a | Change ^a |
| A | area | optimal | 45.80 € | -4.41 € | -8.8% |
| A | consumption | optimal | 46.93 € | -3.28 € | -6.5% |
| A | equal | optimal | 43.31 € | -6.90 € | -13.7% |
| A | shares | optimal | 45.80 € | -4.41 € | -8.8% |
| B | area | optimal | 45.39 € | -2.90 € | -6.0% |
| B | consumption | optimal | 46.06 € | -2.23 € | -4.6% |
| B | equal | optimal | 45.28 € | -3.01 € | -6.2% |
| B | shares | optimal | 45.39 € | -2.90 € | -6.0% |
| A | area | practical | 25.89 € | -5.23 € | -16.8% |
| A | consumption | practical | 26.22 € | -4.90 € | -15.8% |
| A | equal | practical | 25.51 € | -5.61 € | -18.0% |
| A | shares | practical | 25.88 € | -5.24 € | -16.8% |
| B | area | practical | 24.49 € | -5.17 € | -17.4% |
| B | consumption | practical | 24.72 € | -4.95 € | -16.7% |
| B | equal | practical | 24.46 € | -5.21 € | -17.6% |
| B | shares | practical | 24.49 € | -5.17 € | -17.4% |

^a. Change in savings compared to the NC system

The average changes in SCR and total electricity cost savings relative to the dimensioned PV capacity, compared to the NC system, are presented in Figure 3. Under optimal dimensioning, the consumption-based method resulted in the

smallest average decrease in SCR and the smallest decrease in total electricity cost savings relative to NC, whereas the equal-based method led to the largest decrease in SCR and the largest decrease in savings. The area-based and shares-based methods showed similar decreases in both SCR and savings. Under practical dimensioning, the decreases in SCR and savings were generally smaller across all methods. Similar to the optimal case, the consumption-based method had the smallest decrease in SCR and savings, while the equal-based method had the largest decrease. The area- and share-based methods again exhibited similar decreases in both SCR and savings.

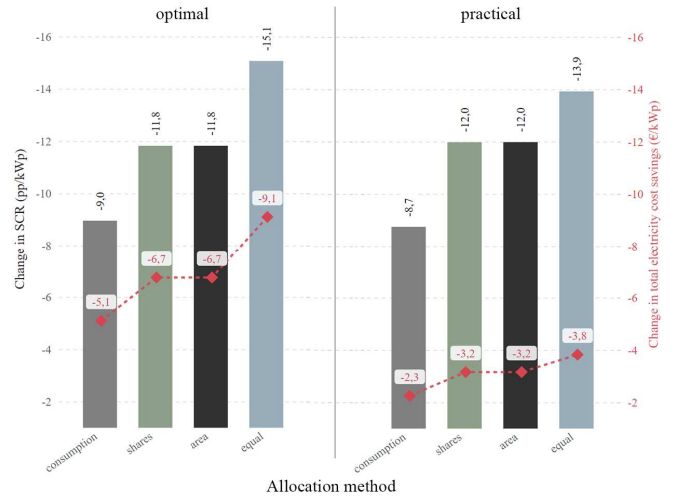


Figure 3. Average changes in SCR (pp/kWp) and total electricity cost savings (€/kWp) compared to NC system relative to PV capacity across different allocation methods. On the left, optimal dimensioning. On the right, practical dimensioning.

Across both optimal and practical dimensioning scenarios, the consumption-based method consistently resulted in the smallest average decrease in SCR and the smallest decrease in total electricity cost savings, reflecting its alignment with actual energy usage patterns. In contrast, the equal-based method led to the largest decrease in both SCR and total savings. The area-based and shares-based methods exhibited similar performance in both scenarios, with moderate decreases in SCR and total savings.

IV. DISCUSSION

This study investigated the effects of different allocation methods on SCR and financial outcomes in CSC systems compared to ideal NC system. On average, the consumption-based method consistently resulted in the smallest decreases in SCR, reflecting its alignment with energy usage patterns. For both properties, average reductions ranged from -6.0 to -17.6 pp under optimal dimensioning and to -3.1 to -6.7 pp under practical dimensioning. In contrast, the equal-based method caused the largest reductions, averaging -12.9 pp under optimal and -6.2 pp under practical dimensioning. These findings emphasize the importance of choosing allocation methods that balance efficiency and equity, particularly in maximizing local energy utilization.

The economic impacts of allocation methods closely mirrored the trends observed in SCR reductions. The financial performance of PV systems, measured as the change in total electricity cost savings relative to PV capacity compared to the ideal NC system, ranged from -2.3 to -9.1 €/kWp across all scenarios. In the worst-case scenario (Property A, practical dimensioning, equal-based allocation), electricity cost savings per shareholder were 5.61 € lower, representing an 18% decrease compared to the NC system. While these absolute changes in savings are modest, their relative significance becomes clear when distributed among shareholders, particularly in lower-savings scenarios. These results emphasize the importance of financial adjustments. Even small decreases in electricity cost savings can affect shareholder perceptions of fairness and the feasibility of CSC systems. The observed SCR reductions, which ranged from 3.1 to 17.6 pp across all allocation methods, further highlight the need for allocation methods that align with consumption patterns to optimize both SCR and financial outcomes.

From a system design perspective, these findings support the feasibility of using building-level net consumption data for PV system sizing. While the drop in SCR without NC system results in some financial losses, the impact from individual shareholder's point of view is minimal. This validates the practicality of using aggregated data for CSC system planning in MDBs, especially when individual apartment-level data is unavailable due to privacy concerns. The observed financial stability across allocation methods suggests that system sizing can reasonably rely on aggregate consumption data without compromising economic viability.

This study acknowledges several uncertainties that may affect the interpretation of the results. The first uncertainty relates to the anonymized consumption data of apartments. Consumption data were anonymized by distributing it according to apartment floor areas. If there were fewer than three apartments of a specific floor area, they were grouped into a larger "floor area group" to maintain anonymity. This also impacted the use of share as allocation method, as the share count could not be accurately assigned to individual apartment consumption. However, the results do not indicate that this had a significant effect on the conclusions. The second uncertainty concerns the number of apartments in the studied MDBs. The two case properties used in this research were relatively large apartment complexes. The results may not be generalizable to smaller buildings, where the effects of allocation methods could differ significantly. Lastly, the findings of this study are specific to the two Finnish case properties analyzed. Generalizing these results to other properties or international contexts would require further research to account for potential differences in building design, energy consumption patterns, and regulatory frameworks.

V. CONCLUSION

This study analyzed the impact of different fixed allocation methods on the self-consumption ratio (SCR) and electricity cost savings from photovoltaic (PV) systems in multi-dwelling buildings (MDB) with collective self-consumption (CSC) systems. The analysis compared these fixed allocation methods within the credit calculation model (CCM) to the ideal

neighboring credit (NC) system, using both optimal and practical PV system dimensioning.

The consumption-based method resulted in the smallest decreases in SCR and electricity cost savings compared to the ideal NC system, whereas the equal-based method led to the largest decreases in both SCR and total savings. The area- and share-based methods showed moderate decreases in both SCR and savings. Under practical dimensioning, decreases were smaller due to nearly complete energy utilization under the ideal NC system.

Economically, shareholder losses were minimal, even in the least favorable conditions. The worst-case scenario resulted in a 5.61 €/shareholder/year decrease (18% reduction) in electricity cost savings, indicating that allocation methods and neighborhood crediting do not significantly affect the financial viability of PV systems.

From a system design perspective, privacy concerns limit access to detailed consumption data for PV sizing. However, building-level net consumption data proved sufficient. While NC systems improve SCR compared to CSC systems with fixed allocation, their financial impact on shareholders remains negligible, supporting the use of aggregated data for PV sizing in MDBs.

This study underscores the need to balance efficiency and fairness in allocation methods. The findings offer insights for housing companies and stakeholders aiming to maximize CSC benefits in MDBs. Further testing with varying building sizes and locations is needed to confirm broader applicability.

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work the authors used ChatGPT-4 to improve readability and language. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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