Tampere University of Applied Sciences

Please note! This is a self-archived version of the original article.

Huom! Tämä on rinnakkaistallenne.

To cite this Article / Käytä viittauksessa alkuperäistä lähdettä:

Kortetmäki, A., Koskela, J., Ylipaino, J., Kallioharju, K. & Järventausta, P. (2024) From Hourly to Quarter-Hourly : Effects of Metering Intervals on Self-Consumption Ratios and Economic Viability of Solar Photovoltaic Systems in Finnish Residential Buildings. Teoksessa 2024 IEEE PES Innovative Smart Grid Technologies Europe, ISGT EUROPE 2024. IEEE Institute of Electrical and Electronics Engineers, s. 1-5.

URL: https://doi.org/10.1109/ISGTEUROPE62998.2024.10863766

TAMPEREEN AMMATTIKORKEAKOULU
Kuntokatu 3, 33520 Tampere www.tuni.fi/tamk | p. 0294 5222

From Hourly to Quarter-Hourly: Effects of Metering Intervals on Self-Consumption Ratios and Economic Viability of Solar Photovoltaic Systems in Finnish Residential Buildings

Aki Kortetmäki
School of Built Environment and Bioeconomy
Tampere University of Applied Sciences
Tampere, Finland
aki.kortetmaki@tuni.fi

Juha Koskela
Faculty of Information Technology and Communication Sciences
Tampere University
Tampere, Finland
juha.j.koskela@tuni.fi

Juho Ylipaino
School of Built Environment and Bioeconomy
Tampere University of Applied Sciences
Tampere, Finland
juho.ylipaino@tuni.fi

Kari Kalliohariu
School of Built Environment and Bioeconomy
Tampere University of Applied Sciences
Tampere, Finland
kari.kalliohariu@tuni.fi

Pertti Järventausta
Faculty of Information Technology and Communication Sciences
Tampere University
Tampere, Finland
pertti.jarventausta@tuni.fi

***Abstract*—The adoption of solar photovoltaic (PV) systems in Finnish residential buildings has significantly increased, reflecting broader global trends. A crucial element in the investment evaluation of these systems is the self-consumption ratio (SCR). Self-consumed energy reduces costs on energy purchases, taxes, and distribution system operator (DSO) fees, thus linking the SCR with profitability. This study explores the effects of transitioning from hourly to 15-minute metering intervals on SCR and the consequent financial outcomes. This research utilizes actual consumption data from 10 detached and 10 multi-dwelling buildings (MDB) in Finland and simulated production in 15-minute intervals to evaluate SCR impacts across various system sizes. Detached buildings (DB) were analyzed with system sizes of 3 kWp, 5 kWp, and 7 kWp, and MDBs with 10 kWp, 20 kWp, and 30 kWp. Results reveal SCR decreases from -0.60% to -4.52% across all DB's PV system sizes, with corresponding financial benefits decreasing by -1.02% to -3.67%. In MDBs, SCR decreases ranged from -0.01% to -4.61%, with financial impacts decreasing by -0.01% to -3.41%. These findings underscore the variability of SCR influenced by metering intervals and site-specific factors such as production and consumption patterns, providing substantial data to the discourse on sustainable energy practices in residential settings.**

Keywords—Photovoltaic Systems, Self-Consumption, Multi-Dwelling Buildings, Energy Metering Intervals, Smart Metering

I. Introduction

In recent years, the adoption of solar photovoltaic (PV) systems in Finnish residential buildings has surged [1], reflecting broader global trends [2], [3]. This increase has been driven by declining costs [4], [5] and direct financial incentives such as tax credit for household expenses [6], and subsidies from the Housing Finance and Development Centre of Finland (ARA) for residential buildings [7].

A critical factor in investment calculations for PV systems is the self-consumption ratio (SCR), which represents the proportion of energy consumed on-site. Accurate calculation of SCR is essential for determining the amount of energy sold to energy companies and the amount used by consumers. Self-consumed energy reduces costs on energy purchases, taxes, and distribution system operator (DSO) fees, thus generally linking the higher SCR to more profitable investments.

Significant changes to SCR calculations have been achieved through Finland's advancements in metering technologies, together with Government Decree (767/2021) [8] and centralized data exchange unit Datahub [9]. The shift from instantaneous per-phase netting to hourly summation netting was recognized as the first significant enhancement. Concurrently, the implementation of virtual net metering for multi-dwelling buildings allowed excess energy produced beyond common consumption to be proportionally credited to the residents' individual electricity bills [8].

Previously, consumption and production allocations were netted against each other over an hour interval. A substantial regulatory change reduced this balancing period to 15 minutes [8], aligning with European Commission guidelines that mandated EU member states to adopt a 15-minute balancing period by the end of 2020 [10]. After Nordic transmission system operators delayed its implementation, Finland introduced the 15-minute balancing period on May 22, 2023 [11]. This transition is expected to decrease SCR, potentially reducing the profitability of solar PV systems.

This study investigates the impact of the new 15-minute metering interval on SCR and the consequent annual financial outcomes for typical system sizes. Our research utilizes actual consumption data from 10 detached buildings (DB) and 10 multi-dwelling buildings (MDB), with production simulated across various system sizes that mirror typical configurations in the Finnish PV market. Both consumption and production are measured and simulated at 15-minute intervals. This is further supported by calculations based on current hourly electricity prices.

979-8-3503-9042-1/24/$31.00 ©2024 IEEE

Building on prior research, Koskela et al. reported a decrease in SCR of 2.32 – 5.98% when transitioning from 60-minute to 15-minute intervals, using consumption data from three DBs in Finland with simulated production for 2 kWp and 3 kWp system sizes [12]. On the other hand, Ayala-Gilardón et al. observed changes in SCR ranging from 69% to 73% with a 1.15 kWp system and from 28% to 29% with a 4.6 kWp system in DB in Spain, when transitioning from quarter-hour to hour intervals. [13]. This publication expands on these findings with a more extensive and diverse dataset, incorporating simulations of various system sizes that represent typical installations in the Finnish PV market. Additionally, this study considers the ongoing fluctuations in spot market prices. Our dataset, collected from April 2023 to the end of May 2024, captures these fluctuations, providing a detailed view of the financial dynamics in Finland's PV market amidst the geopolitical shifts of recent events.

II. Data Collection and Calculation Methods

A. Data Collection

For this simulation, electricity consumption data was collected from the DSO for one year, covering the initial period when quarter-hourly metering was fully implemented. The dataset encompasses 10 DBs with connection sizes of 3x25 A and 10 MDBs with connection sizes of 3x160 A, all located in the Pirkanmaa region of Finland. The consumption data spans from April 2023 to April 2024. It's important to note that PV systems were not installed in the buildings used for this study, so there was no load shifting to optimize self-consumption.

B. Simulation of PV Production

PV production was simulated using a methodology previously outlined e.g., in [12], which includes components of beam (Gb), diffuse (Gd), and reflected (Gr) irradiances measured by the FMI [14]. Data from the nearest weather station was utilized, and the Reindl model [15] was applied to calculate irradiances for a tilted surface from measurements taken from a horizontal surface. The total PV production was then calculated using the equation:

$$P_{PV} = P_{STC} G_i \big(1 - \beta_P (T_c - T_{STC})\big), \quad (1)$$

where β_p, T_c, and P_{STC} represent the solar power temperature coefficient (0.006), solar cell temperature, and the nominal power of a PV system under standard test conditions (STC) and temperature T_{STC} (25 °C), respectively. The solar cell temperature is calculated based on the measured ambient temperature and the calculated total radiation, using FMI data [14].

The primary aim of this study is to examine the impact of transitioning to quarter-hourly balancing on the profitability of typical residential PV systems. The simulated PV system sizes for DBs were 3 kWp, 5 kWp, and 7 kWp, and for larger MDBs, system sizes of 10 kWp, 20 kWp, and 30 kWp were selected. All systems were modeled with a typical roof angle of 18 degrees and south orientation.

C. Calculation of SCR

To determine financial savings and SCR for each interval, the self-consumed part of the produced energy was calculated using the following expression:

$$SC_{PV,INT} = \begin{cases} C_{INT} & if\ C_{INT} < E_{PV,INT}\ (kWh) \\ E_{PV,INT} & otherwise\ (kWh), \end{cases} \quad (2)$$

where $SC_{PV,INT}$ is the self-consumed energy during the interval, C_{INT} is the building's consumption during the interval, and $E_{PV,INT}$ is the energy produced during the interval. If the production exceeds consumed energy, self-consumed energy equals consumption. Otherwise, $SC_{PV,INT}$ is equal to PV production.

After determining the self-consumed energy for each interval, SCRs were calculated for individual intervals and for the entire year as follows:

$$SCR_{INT} = \frac{SC_{PV,INT}}{E_{PV,INT}} \cdot 100\%, \quad (3)$$

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

where SCR_{INT} presents the SCR for one interval, and the annual SCR is calculated by summing over all intervals (t) throughout the year (a).

D. Calculation of Financial Savings

Used energy retailer's price based on Finland area price in electricity market [16]. During the period under consideration, electricity prices ranged from -50.0 to 189.6 c/kWh, with an average of 5.5 c/kWh and a median of 4.1 c/kWh. During the most significant production months (May to September), prices varied from -6.0 to 55.0 c/kWh, with an average of 4.0 c/kWh and a median of 2.4 c/kWh. In purchase price is added retailer's margin 0.45 c/kWh, which include VAT (24%) and surplus compensation is same without VAT (0.36 c/kWh).

Local DSO prices were used in this study. In the case of MDBs, DSO costs were considered as one energy community with a joint electricity subscription for each building. The DSO's tariffs are presented in Table 1. Additionally, calculations accounted for electricity taxes (22.53 €/MWh at 0% VAT) and value-added taxes (24%) when considering the total energy purchase price. This study did not consider basic charges (€/month), as PV has no impact on these costs.

TABLE I. DSO'S TARIFFS (0% VAT)

Connection	Tariff components	
	Volumetric price (€/MWh)	***Demand charge (€/kW)***
3x25A (DB)	45.30	-
3x160A (MDB)	30.92	2.87[a]

[a] Average of the two highest monthly powers in last 12 months, but at least 40 kW

III. Results

A. Analysis of Consumption Patterns in Buildings

The yearly consumption and SCR for various PV system sizes in DBs and MDBs are depicted in Figure 1.

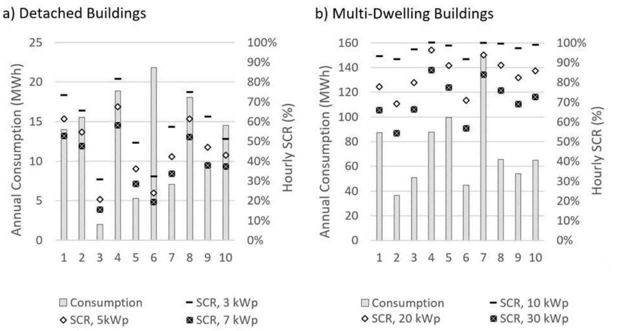

Fig. 1. Yearly consumption and hourly SCRs (60-minute intervals) for detached and multi-dwelling buildings.

Analysis of Figure 1 reveals that yearly consumption varies from 2,011 kWh to 21,849 kWh for DBs, offering a broad perspective across different building types. SCR with hourly intervals ranges from 30.7% to 81.5% for the smallest 3 kWp system size and 15.6% to 58.1% for the largest 7 kWp system. In MDBs, yearly consumption ranges significantly from 36 MWh to 149 MWh, with SCR ranging from 91.6% to 100% for the smallest 10 kWp system size and from 54.3% to 86.2% for the largest 30 kWp system.

A notable observation from DBs number 4 and 6 shows that high yearly consumption does not necessarily correlate with high SCR. Building 4 consistently exhibits the highest SCR across all setups, while Building 6, despite having the highest yearly consumption, shows one of the lowest SCRs. Figure 2 illustrates the daily consumption profiles of these buildings during winter (October-March) and summer (April-September) periods, which helps explain these discrepancies.

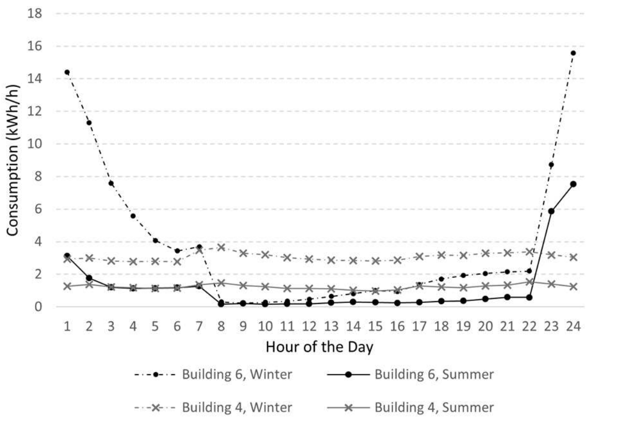

Fig. 2. Average daily consumption profiles of detached buildings 4 and 6 during summer and winter.

Building 4 exhibits a stable consumption pattern throughout the day, whereas Building 6 experiences elevated nighttime consumption, often attributed to the use of electricity for heating purposes. This pattern is typical in Finnish buildings that utilize electric heaters in conjunction with heat storage systems, such as water tanks or massive constructions with heat storage capabilities. These systems often take advantage of lower nighttime prices offered by Time-of-Use tariffs, leading to discernible consumption patterns. However, buildings like 6 may possess significant potential for load shifting if a PV installation were implemented.

B. Transition to Quarter-Hourly Balancing

The transition from hourly to quarter-hourly intervals impacts SCR, as illustrated in Figures 3 and 4, which presents the percentage changes in SCR for DBs and MDBs.

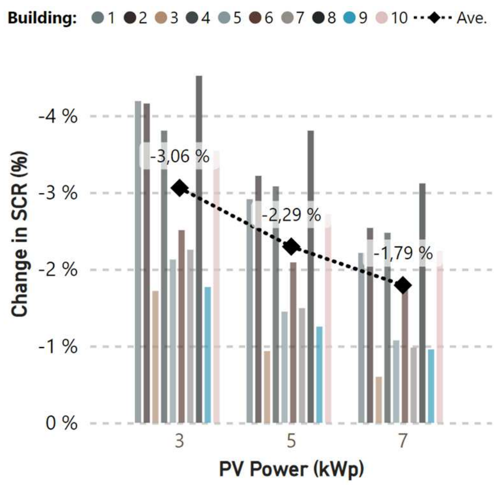

Fig. 3. Changes in SCR in detached buildings with the transition from hourly to quarter-hourly intervals.

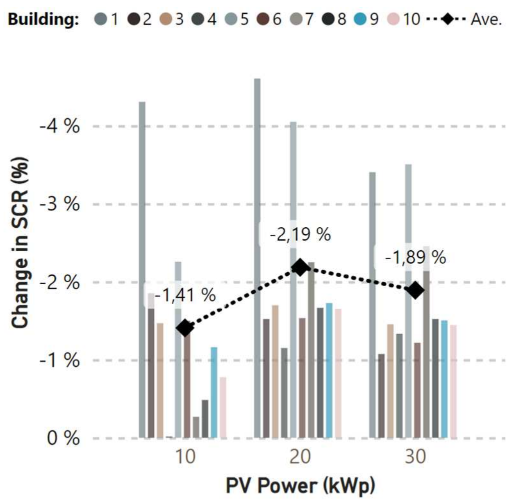

Fig. 4. Changes in SCR in multi-dwelling buildings with the transition from hourly to quarter-hourly intervals.

The SCR with 15-minute intervals decreased by -1.72% to -4.52% for 3 kWp, -0.93% to -3.8% for 5 kWp, and -0.6% to -3.12% for 7 kWp systems in DBs. In MDBs, the decreases ranged from -0.01% to -4.31% for 10 kWp, -1.15% to -4.61% for 20 kWp, and -1.1% to -3.51% for 30 kWp systems.

C. Financial Implications

Figures 5 and 6 present the change in annual financial savings calculated based on PV system production and self-consumption, considering current market prices, sales margins, and DSO's tariffs, expressed in €/kWp. Figures 7 and 8 depict the same savings as relative values for total yearly savings.

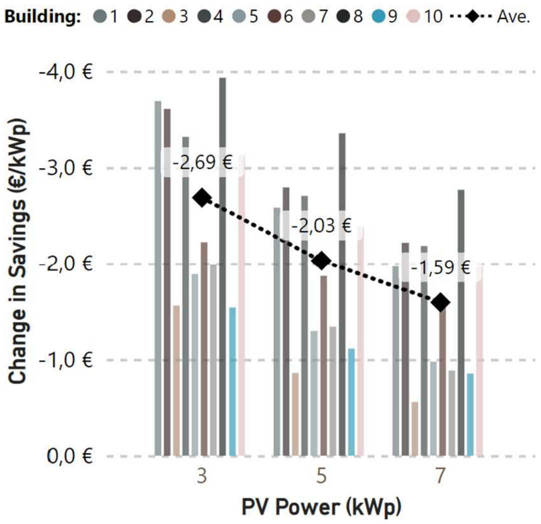

Fig. 5. Changes in yearly PV savings, expressed as €/kWp in detached buildings with the transition from hourly to quarter-hourly intervals.

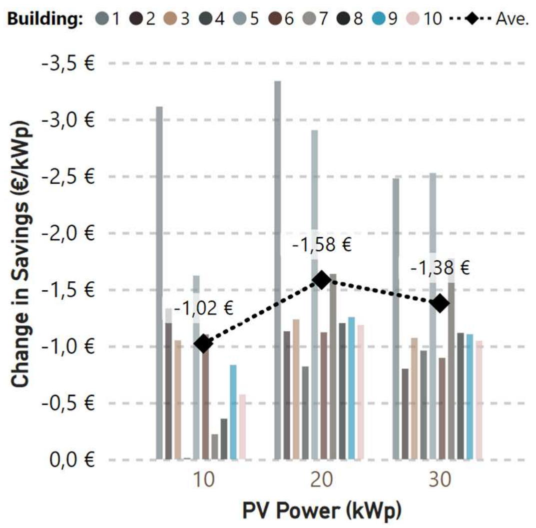

Fig. 6. Changes in yearly PV savings, expressed as €/kWp in multi-dwelling buildings with the transition from hourly to quarter-hourly intervals.

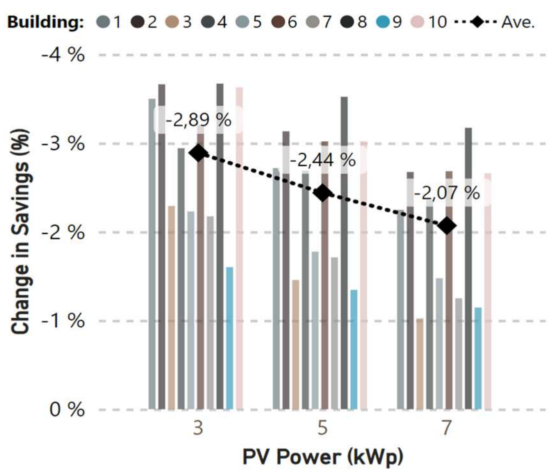

Fig. 7. Relative PV savings changes in detached buildings.

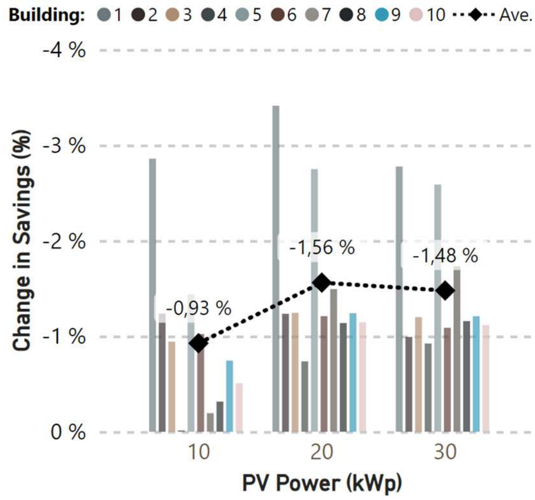

Fig. 8. Relative PV savings changes in multi-dwelling buildings.

In DBs, savings ranged from -€1.54 to -€3.93 per kWp (or -1.6% to -3.67%) for 3 kWp systems, from -€0.86 to -€3.36 per kWp (or -1.35% to -3.52%) for 5 kWp systems, and from -€0.56 to -€2.77 per kWp (or -1.02% to -3.17%) for 7 kWp systems.

In MDBs, savings ranged from -€0.01 to -€3.11 per kWp (or -0.01% to -2.86%) for 10 kWp systems, from -€0.82 to -€3.34 per kWp (or -0.74% to -3.41%) for 20 kWp systems, and from -€0.80 to -€2.53 per kWp (or -0.92% to -2.78%) for 30 kWp systems.

IV. Discussion

Our findings contribute significant insights to the existing literature by examining the impact of different metering intervals on PV investment and SCRs. By shedding light on these changes, we offer valuable perspectives on the economic viability of solar investments in Nordic countries, particularly following the transition from hourly to quarter-hour intervals. While our focus is on the Nordic region, our results also provide an initial estimate of SCR impacts that could have relevance internationally, albeit acknowledging potential variations in consumption and production patterns.

The calculations for MDBs are based on aggregated data for entire connections, simulating a scenario where electricity is collectively purchased although in reality, many buildings might have individual contracts for each apartment. However, virtual net-metering is commonly utilized in typical Finnish MDBs structured as Limited Liability Housing Companies. This system allows surplus production to exceed common consumption distributed among residents with a fixed sharing ratio, effectively reducing their individual electricity purchases. While this approach may not entirely align with typical virtual net-metering practices, it reasonably assesses the impacts of the transition to shorter balancing intervals. Notably, Kortetmäki et al. present novel results on the differences in SCR and financial benefits between virtual net-metering and collective purchase scenarios, further enriching the context of our findings [17].

Importantly, it should be noted that our study relied on simulations rather than real-world solar panel installations. Additionally, the consumption data used in our analysis was sourced from buildings without PV production, precluding any load shifting. Furthermore, while we presented a common setup for roof angle and orientation, individual optimization was not performed for each building, allowing us to focus on the differences between metering intervals.

Given that our study was based on one year of data from April 2023, it is crucial to recognize that long-term economic calculations may evolve. Future trends in market prices, the impending transition to 15-minute pricing intervals in the electricity market, and potential developments in demand charges by DSO tariffs all represent factors that could significantly impact our conclusions.

These considerations underscore the necessity for continuous research to monitor how these changes influence the economic landscape of PV investments. Ongoing studies will be essential for policymakers, investors, and stakeholders to maintain an up-to-date understanding of PV system design and economic calculations in a rapidly evolving market and regulatory environment.

V. Summary

This study has significantly advanced our understanding of the effects of shortened metering intervals on the self-consumption and economic viability of PV systems across different residential setups. It has also addressed a key issue in the national discourse, providing precise numerical assessments of a topic that has generated considerable debate.

A. Findings

In DBs, SCR decreases ranged from -0.60% to -4.52% across all simulated system sizes, with average decreases of -3.06%, -2.29%, and -1.79% for 3 kWp, 5 kWp, and 7 kWp south-oriented setups, respectively. The annual financial benefits decreased by -1.02% to -3.67%, averaging -2.47%. This translates to an annual financial impact of €4.6-11.8 for the smallest systems and €3.9-19.4 for the largest.

In MDBs, SCR decreases ranged from -0.01% to -4.61% for all simulated sizes, with average decreases of -1.41%, -2.19%, and -1.89% for 10 kWp, 20 kWp, and 30 kWp setups, respectively. The financial benefits decreased by -0.01% to -3.41%, averaging -1.32%. This results in an annual financial impact of €0.1-31.1 for the smallest systems and €24.0-87.2 for the largest.

B. Implications

The findings offer robust numerical support for ongoing discussions and debates in the energy sector. However, it's essential to acknowledge the nuanced impact of unique factors on each property and solar production setup, including roof angle, orientation, annual production variability, consumption patterns, and fluctuating electricity prices. Therefore, interpreting these findings should consider the specific characteristics of each property to provide accurate insights.

C. Future Research

The forthcoming transition to 15-minute pricing intervals in the electricity market introduces new dynamics warranting extensive study. For example, future research should address gaps in our understanding of the effects on power tariff costs associated with these shorter intervals. Additionally, examining the impacts at the apartment level with virtual net-metering in MDBs at quarter-hour intervals could yield valuable insights into the aspects of collective self-consumption. Moreover, considering the profitability of Electrical Energy Storages together with PV systems after quarter-hour intervals would provide further depth to our understanding of the evolving energy landscape and the potential synergies between renewable energy technologies.

Acknowledgment

We thank the DSO company Elenia for providing the valuable consumption data essential for this research.

References

[1] Energiavirasto, "Aurinkosähkön pientuotanto kasvoi voimakkaasti vuonna 2022," Jun. 2023. [Online]. Available: https://energiavirasto.fi/-/aurinkosahkon-pientuotanto-kasvoi-voimakkaasti-vuonna-2022

[2] IEA, "Snapshot of Global PV Markets - 2023," 2024. [Online]. Available: https://iea-pvps.org/snapshot-reports/snapshot-2024/

[3] IRENA, "Renewable energy statistics 2023," Jul. 2023, [Online]. Available: https://www.irena.org/Publications/2023/Jul/Renewable-energy-statistics-2023

[4] IRENA, "Renewable power generation costs in 2022," Aug. 2023, [Online]. Available: https://www.irena.org/Publications/2023/Aug/Renewable-Power-Generation-Costs-in-2022

[5] Motiva, "Aurinkosähköjärjestelmien hinta." [Online]. Available: https://www.motiva.fi/ratkaisut/uusiutuva_energia/aurinkosahko/jarjestelman_valinta/aurinkosahkojarjestelmien_hinta

[6] Verohallinto, "Tax credit for household expenses." [Online]. Available: https://www.vero.fi/en/individuals/tax-cards-and-tax-returns/deductions/Tax-credit-for-household-expenses/

[7] Asumisen rahoitus- ja kehittämiskeskus (Ara), "Energia-avustukset." [Online]. Available: https://www.ara.fi/fi-FI/Lainat_ja_avustukset/Energiaavustus

[8] *Valtioneuvoston asetussähköntoimitusten selvityksestä ja mittauksesta 767/2021*. Oikeusministeriö. Accessed: Nov. 15, 2023. [Online]. Available: https://finlex.fi/fi/laki/alkup/2021/20210767

[9] Fingrid, "Datahub." [Online]. Available: https://www.fingrid.fi/en/electricity-market/datahub/

[10] European Comission, "Comission Regulation (EU) 2017/2195 - of 23 November 2017 - establishing a guideline on electricity balancing", [Online]. Available: https://eur-lex.europa.eu/eli/reg/2017/2195/oj

[11] Fingrid, "Varttitase eli 15 minuutin taseselvitysjakso." [Online]. Available: https://www.fingrid.fi/sahkomarkkinat/markkinoiden-yhtenaisyys/pohjoismainen-tasehallinta/varttitase/#selvitykset

[12] J. Koskela, A. Rautiainen, K. Kallioharju, P. Harsia, and P. Järventausta, "Effect of the Electricity Metering Interval on the Profitability of Domestic Grid-Connected PV Systems and BESSs," *IREE*, vol. 15, no. 2, p. 164, Apr. 2020, doi: 10.15866/iree.v15i2.18357.

[13] A. Ayala-Gilardón, M. Sidrach-de-Cardona, and L. Mora-López, "Influence of time resolution in the estimation of self-consumption and self-sufficiency of photovoltaic facilities," *Applied Energy*, vol. 229, pp. 990–997, Nov. 2018, doi: 10.1016/j.apenergy.2018.08.072.

[14] Finnish Meteorological Institute, "Open Data." Apr. 17, 2024. [Online]. Available: https://en.ilmatieteenlaitos.fi/open-data

[15] D.T. Reindl, W.A. Beckman, and J.A. Duffie, "Diffuse fraction correlations," *Solar Energy*, vol. 45, no. 1, pp. 1–7, 1990, doi: https://doi.org/10.1016/0038-092X(90)90060-P.

[16] ENTSO-E, "Day-ahead Prices." [Online]. Available: https://transparency.entsoe.eu/transmission-domain/r2/dayAheadPrices/show

[17] A. Kortetmäki, J. Ylipaino, J. Koskela, K. Kallioharju, and P. Järventausta, "The Impact of Metering Methods on Collective Self-Consumption: Insights from Multi-Dwelling Buildings in Finland," 2024. doi: 10.2139/ssrn.4782201.