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Impact of 15-Minute Peak-Shaving on Aggregated Demand in Residential Customer Groups

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Abstract— This study investigates the transition from 60-minute to 15-minute metering resolutions and its impact on residential peak demand management. Using smart meter data from 60 Finnish detached houses, the research analyzes peak-shaving effectiveness at both the individual and aggregated levels. Monte Carlo simulations for group sizes of 1 to 10 households reveal significant impact decay, where individual reductions are heavily diluted when aggregated. This study identifies a critical “resolution gap”: an individual 30% monthly peak reduction based on hourly average data translates to a 9.5% reduction in the coincident annual hourly peak for ten households. In contrast, a 30% strategy based on quarter-hourly data achieves only a 5.9% reduction in the same annual hourly peak. These findings demonstrate that 15-minute clipping is less effective at the grid level than hourly-based shaving, providing empirical support for the regulatory decision to utilize 60-minute averages for harmonized power-based tariffs.

Index Terms— Peak shaving, power-based tariffs, smart meter data, metering intervals, 15-minute metering.

I. INTRODUCTION

Traditionally, the design of electrical distribution grids, grid connection sizing for customers, and the structure of distribution grid tariffs have relied on hourly consumption data. This resolution has served as the industry standard for assessing peak demand and determining long-term capacity requirements. The transition to a 15-minute imbalance settlement period in Europe has necessitated a rapid shift in metering infrastructure; in Finland, this is reflected by the deployment of next-generation smart meters—required for all consumption sites by the end of 2028—and the transition of the Day-Ahead market to 15-minute trading intervals in autumn 2025 [1].

The vast majority of distribution system operator (DSO) expenditures are associated with fixed costs for maintaining, operating, and expanding a grid sized specifically for instantaneous peak loads [2]. Despite this, residential tariffs in Finland have historically been dominated by fixed monthly fees and

volumetric energy-based charges. As electrification—driven by the adoption of heat pumps, electric vehicles (EVs), and rooftop photovoltaics (PV)—fundamentally changes the relationship between energy consumption and peak demand, there is significant pressure to adopt power-based tariffs (€/kW) to reflect true capacity costs [3], [4], [5]. This transition aims to provide customers with better opportunities to influence their distribution grid service fees by managing their peak power demands.

The regulatory framework for this transition was solidified by the July 2025 amendment to the Finnish Electricity Market Act, which clarified allowable tariff components and empowered the Energy Authority to issue harmonizing mandates [6]. A central point of scientific and regulatory debate during this process was the selection of the measurement interval for the billing peak. While a 15-minute resolution offers higher accuracy regarding physical grid stress, it also introduces higher volatility for the consumer. Consequently, while initial regulatory drafts proposed a power charge based on the highest monthly 15-minute peak with a 5 kW billing threshold (i.e., charges apply only to the portion exceeding 5 kW), the final mandate issued in February 2026 (entering into force in 2029) shifted the basis to a 60-minute rolling average calculated from four consecutive 15-minute periods, applying an 8 kW threshold [7].

Previous research investigated the critical relationship between annual peak demand calculated from hourly averages versus 15-minute intervals [8]. By comparing the highest measured annual hourly and quarter-hourly peak demands across various building types and connection sizes, the study found that shifting to a 15-minute resolution revealed peaks that were, on average, 7.4% to 27.5% higher than those recorded via hourly data. For detached houses, this range spanned from 0.2% to 65.9%, with an average increase of 24.4% for 3x25A customers and 15% for 3x35A customers. This measurement gap suggests that traditional hourly models may significantly underestimate the actual short-term peak demands of individual

customers. However, the resulting effect on the aggregated distribution level remains largely unstudied.

This paper extends the analysis by comparing the effectiveness and relationship of 15-minute versus 60-minute peak-shaving strategies using the same dataset as in the previous study. Specifically, this study examines how individual peak clipping—based on monthly peak demand thresholds of 90%, 80%, and 70%—affects the frequency of peak-shaving "activations" and how these individual actions translate into reduced peak consumption at both the customer and aggregated distribution levels. Since coincidental peak demand is the primary driver for DSO infrastructure investment, quantifying the aggregation effect of individual peak shaving on the coincidental group peak is essential for assessing the grid-level benefits of current tariff-based regulatory signals.

II. DATA & METHODS

A. Consumption data

The primary data used in this study consist of 15-minute resolution consumption measurements collected by a Finnish DSO. The dataset spans a one-year period from November 1, 2023, to October 31, 2024. The sample comprises 60 detached houses from three geographically distinct regions—Pirkanmaa, Keski-Suomi, and Pohjois-Pohjanmaa—provided by a single DSO. While these areas represent a moderate climatic gradient rather than extreme variations, they provide distinct samples from different parts of Finland. Selection was based on a convenience sampling of the first customers equipped with next-generation smart meters providing 15-minute resolution data. To ensure a balanced dataset, 10 houses per fuse size (3x25 A and 3x35 A) were selected from each region, resulting in six uniform clusters of 10 households each. The original energy values, recorded in kWh per 15-minute interval, were converted to average quarter-hourly power by multiplying the values by four to achieve the kilowatt equivalent. For comparison, a secondary hourly dataset was generated by summing the four 15-minute energy values within each hour, representing hourly average demand.

B. Peak-Shaving Strategy

Various peak-shaving strategies were investigated to evaluate the impact of individual household load limiting on both individual and aggregated consumption. For each customer, the monthly maximum peak demand was identified to establish individual reduction thresholds at 90%, 80%, and 70% of the recorded peak, corresponding to 10%, 20%, and 30% clipping levels. New consumption profiles were generated by clipping any measurement interval exceeding these thresholds to the specified limit. This methodology simulates a specific control environment where customers limit demand to mitigate power-based tariff fees through a "hard cut" approach, which removes the load exceeding the limit rather than shifting it to a later period.

These peak-shaving methods were implemented identically across both hourly and quarter-hourly datasets to ensure a direct comparison of resolution effects. To assess the operational impact, the total number of clipped intervals—defined as "activations"—per year was recorded for each strategy. This metric

quantifies the frequency of intervention required by a control system to achieve the desired reduction targets, providing a measure of the technical intensity required to maintain the set thresholds at different metering resolutions.

C. Monte Carlo Simulation for Aggregated Groups

The impact of individual clipping was analyzed across varying group sizes using a Monte Carlo simulation. Customers were categorized by fuse size (3x25A and 3x35A), and randomized groups ranging from 1 to 10 households were formed from the total sample of 60 customers ($n=30$ per fuse size). For each group size, 1,000 iterations were performed. In every iteration, the coincident annual peak demand of aggregated quarter-hourly and hourly data was recorded for the original baseline and for the 10%, 20%, and 30% individual reduction scenarios.

The final results represent both the average coincident peak across the 1,000 iterations and the absolute maximum peak identified for each group size. By comparing the average group peaks of clipped data to the original baseline, the study quantifies the extent to which individual peak shaving is neutralized by the inherent diversity of residential demand and the non-coincidence of individual peaks. This approach provides a robust statistical foundation for evaluating how individual power-limiting actions scale to the distribution grid level.

D. Comparison between quarter-hourly and Hourly Resolution

To bridge the gap between quarter-hourly load behavior and hourly metering, the final phase of the methodology examines the cross-effects of 15-minute and 60-minute resolutions. Building on the previous group-level analysis, this stage utilizes six distinct clusters of 10 detached houses—segmented by region and fuse size—to provide a more localized assessment of aggregated consumption peaks.

The comparison follows a multi-stage process to isolate the impact of the metering interval. First, individual consumption profiles modified by 15-minute clipping were averaged into hourly values based on fixed clock hours. This step illustrates how individual 15-minute shaving is perceived when measured at an hourly resolution. Second, these households were spatially aggregated into their respective 10-customer groups to determine the annual group peak demand under the 15-minute clipping scenarios. In the third phase, these aggregated 15-minute group profiles were averaged into hourly data to identify the maximum annual hourly consumption resulting from 15-minute control.

Finally, a comparative baseline was established by performing clipping directly on monthly hourly peak consumption. Following this hourly-based intervention, the 10-household groups were aggregated once more. By comparing these results to the 15-minute outcomes from the previous step, the study quantifies the difference in effectiveness between managing demand based on 15-minute peaks versus hourly loads.

III. RESULTS

A. Number of Activations

The frequency of peak-shaving activations is a critical metric for assessing the operational demand placed on peak shaving and the potential impact on consumer convenience. Fig. 1 presents how the number of activations changes on average every month across different threshold levels. The left side of the figure displays monthly results for 15-minute based peak shaving, while the right side shows results based on 60-minute interval thresholds. It is important to note that the 15-minute resolution inherently includes four times the number of measurement moments compared to the hourly resolution.

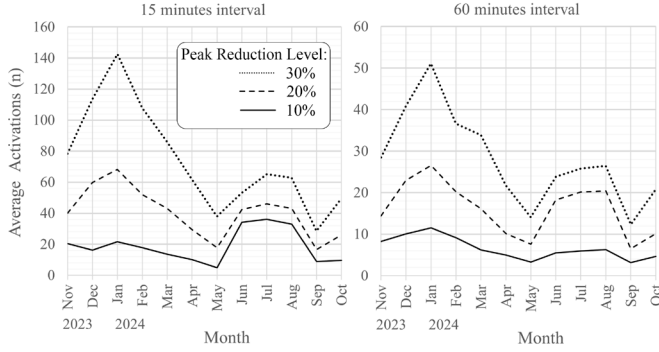


Figure 1. Average monthly peak-shaving events for 15-minute vs. 60-minute metering intervals.

Analysis of Fig. 1 reveals that January 2024, characterized by extreme cold in Finland, recorded the highest number of clipping events. Under the most intensive 30% peak reduction scenario, January saw an average of 143 activations per month at the 15-minute resolution and 51 activations at the 60-minute resolution.

A secondary trend of high clipping frequency was initially observed during summer months. Detailed investigation confirms this was primarily driven by a single outlier customer with near-zero base consumption during the summer; under the relative clipping logic, even minor load fluctuations in this near-zero profile triggered disproportionately high activation counts. Sensitivity analysis shows that excluding this outlier reduces the average January activations under the 30% reduction to 125 (15-min) and 47 (hourly). Most notably, the average July activations for the 10% reduction scenario drop to only 9 (15-min) and 3 (hourly) with the filtered data, confirming that the initial summer spike was not representative of the broader residential group.

B. Individual and aggregated peak demands

Fig. 2 illustrates the maximum annual coincidental peak demand per customer, segmented by two fuse sizes (3x25A and 3x35A) and two measurement resolutions (15-min and 60-min). The data points represent the average of the maximum annual peaks identified across 1,000 Monte Carlo iterations for each group size.

Although all subjects in the dataset are classified as detached houses, significant variation exists in individual peak demands. Detailed analysis of the underlying data reveals that the

lowest recorded annual peak for an individual household was 2.7 kW with 15-minute metering and 1.4 kW with hourly metering. Conversely, the highest peaks reached 30.5 kW with 15-minute metering and 27.7 kW with hourly averages. A critical observation from Fig. 2 is that peak demands are registered as clearly higher at the 15-minute resolution compared to the 60-minute resolution when examining individual customers. However, as the customer group size increases, this discrepancy becomes relatively smaller. This suggests that the "peak-smoothing" effect of hourly averaging is most pronounced at the individual level, whereas the inherent diversity of consumption across larger groups naturally moderates the impact of high-resolution peaks on the coincidental total.

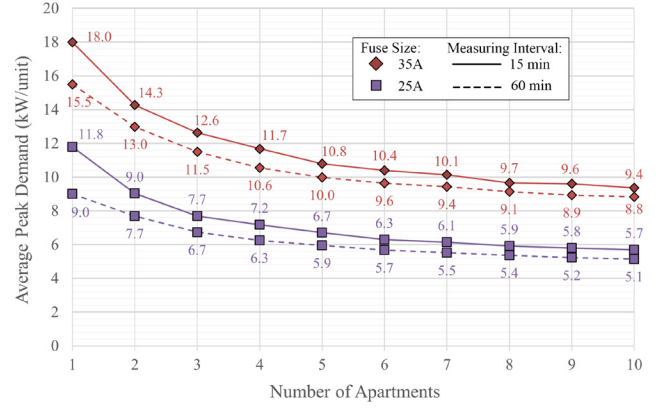


Figure 2. Average annual coincidental peak demand per customer across varying group sizes and measurement resolutions.

C. Comparative Effectiveness of 15-min vs. 60-min Peak Shaving

Fig. 3 illustrates the relative change in coincidental annual peaks across varying group sizes under 90%, 80%, and 70% monthly clipping thresholds, synthesizing three distinct perspectives to evaluate how measurement resolutions influence grid-level results. The visualization is structured into three panels: the left panel displays the reduction in the annual maximum 15-minute peak based on individual monthly 15-minute clipping, the middle panel shows the reduction in the annual maximum 60-minute peak based on monthly hourly clipping, and the right panel illustrates the impact of 15-minute-based clipping when observed through 60-minute resolution.

Analysis of the results indicates that both the 15-minute and 60-minute clipping strategies follow remarkably similar decay curves as the group size increases. Depending on the specific cluster and clipping level, the effectiveness of the peak reduction drops to approximately half of the single-customer level when the group size reaches 2 to 4 households. For a group size of 10, the reduction in the coincidental peak is less than one-third of the individual household's reduction across almost all simulated scenarios.

A critical resolution impact is identified when examining the effect of 15-minute based clipping on hourly measurements. The most significant discrepancy is observed at the individual household level. For several groups, the average reduction in the hourly annual peak was less than half of the reduction

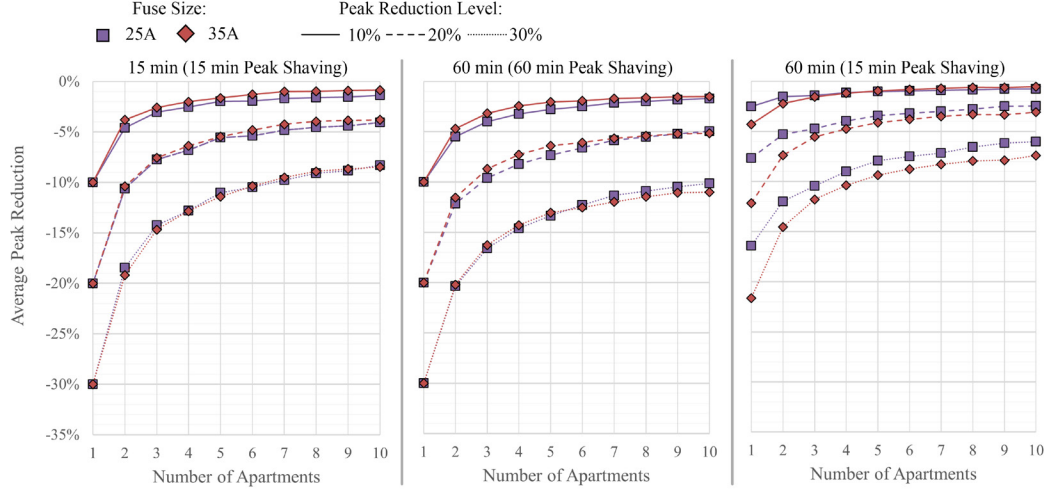


Figure 3. Average annual coincidental peak reduction relative to baseline demand for varying clipping strategies and group sizes.

observed at the 15-minute resolution. This suggests that a substantial portion of the high-resolution shaving achieved at the household level is essentially invisible to hourly metering.

The final stage of the study involved a geographically segmented analysis to account for potential variations between the three study regions: Pirkanmaa, Keski-Suomi, and Pohjois-Pohjanmaa. The 60 households were divided into six distinct clusters of 10 households each, categorized by both region and fuse size (25 A and 35 A). By applying the previously defined peak-shaving methodologies to these localized groups, the study quantified the consistency of demand reduction across different environments. Fig. 4 synthesizes these results, contrasting individual impacts against aggregated group performance across varying measurement resolutions.

The four panels in Fig. 4 provide a comprehensive overview of the relationship between different peak-shaving strategies and metering intervals. The top-left panel highlights the smoothing effect of hourly metering, showing how individual 15-minute clipping only partially reduces an individual's annual maximum hourly peak. The top-right panel represents the impact of 15-minute clipping on the annual 15-minute coincidental peak for the 10-household clusters, where diamonds denote regional clusters and the red line shows the average. The bottom-left panel reveals the extent to which 15-minute control at the individual level translates into reductions when measured via hourly resolution. Finally, the bottom-right panel demonstrates how hourly-based shaving affects coincidental annual hourly peaks.

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The analysis of regional clusters further quantifies these cross-effects through key performance metrics. When 10%, 20%, and 30% 15-minute monthly peak reduction strategies are applied at the household level, they convert to annual peak reductions of only 3.4%, 9.8%, and 18.8%, respectively, when observed via hourly metering. At the aggregate level, these same 15-minute reductions lead to a 1.0%, 4.3%, and 8.9% annual peak reduction within the clusters of 10-households with a 15-minute metering. When measured at the distribution level

using hourly resolution, the impact of 15-minute shaving is further diluted to 0.4%, 2.3%, and 5.9%. In contrast, when peak shaving is based directly on monthly hourly average peaks, the 10%, 20%, and 30% targets achieve more effective coincidental results, leading to 1.3%, 4.4%, and 9.5% reductions in the hourly annual peaks of the aggregated groups. These results demonstrate that while 15-minute clipping is more granular, its impact on coincidental group peaks is significantly lower than that of hourly-based clipping when observed at the hourly resolution.

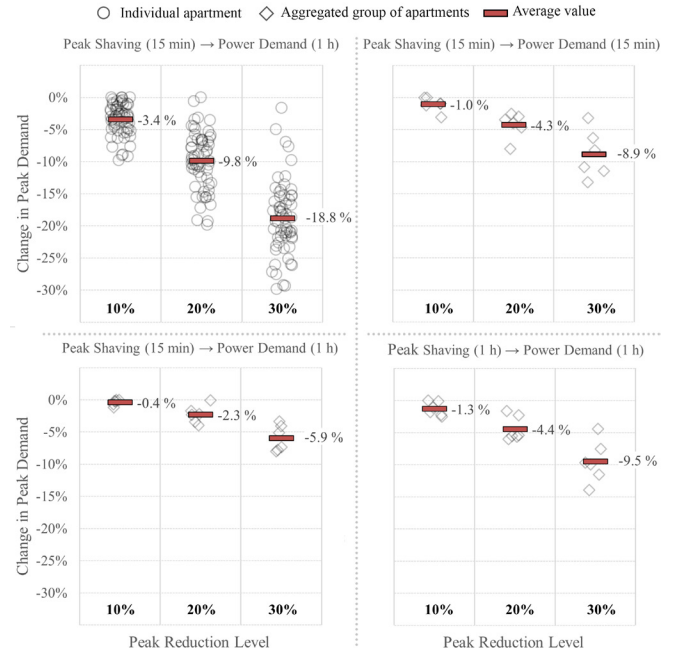


Figure 4. Cross-impact of 15-minute vs. 60-minute clipping and metering resolutions on individual and aggregated annual peaks across regional groups.

IV. DISCUSSION

This research addresses the disparity between 15-minute and hourly metering power dynamics, expanding upon earlier studies regarding resolution-driven peak estimation with a focus on peak-shaving analytics. The findings confirm that the relative effectiveness of individual peak shaving stabilizes at only a small fraction of the reduction achieved at the household level as the size of the aggregated customer group increases.

The observed attenuation in peak-shaving effectiveness is congruent with earlier Finnish research by Supponen et al., whose simulations indicated that while power-based tariffs can mitigate spot-price-driven demand spikes, their cumulative impact on the distribution baseline remains marginal [9]. This disconnect between individual peak demand and grid-level load is documented globally as well. In Sydney, Passey et al. identified a weak correlation (0.56) between individual peak charges and actual network peak responsibility, while research from Central Sweden by El Gohary et al. similarly found such charges unsuitable for deferring grid investments due to high diversity factors [10], [11]. Regarding the US market, Lebel et al. also argue that conventional individual demand charges are often inefficient for addressing system-level capacity needs [12].

A critical observation is the significant discrepancy in clipping effectiveness across different metering resolutions. Although 15-minute clipping directly addresses short-duration power spikes, an hourly-based strategy yielded a greater reduction from a grid management perspective. These results indicate that targeting hourly averages may be a more effective strategy for reducing the aggregated peaks that necessitate distribution grid investments. Consequently, this evidence provides robust empirical support for the Finnish Energy Authority's February 2026 mandate to utilize 60-minute averages as the basis for harmonized power-based tariffs.

Furthermore, while this study calculated hourly averages based on fixed clock hours, the harmonized mandate defines the hourly peak using four consecutive 15-minute intervals. This methodological nuance represents a separate research element to study the discrepancy between fixed-hour and rolling-hour peak detection. Investigating this difference would provide further clarity on how accurately fixed-hour models represent the actual peak under the new regulatory framework.

Beyond the primary results, extreme cold spells—such as the January 2024 period with temperatures below -30°C —triggered synchronized maximum peaks during nighttime hours. During these intervals, residential loads were dominated by thermostatic demand from heating, making winter grid stress largely independent of active daytime consumer routines. However, as residential buildings adopt flexible, energy-intensive loads with 15-minute price-responsive control, the risk of synchronization increases. In such a future, power-based tariffs will serve as essential counter-signals to maintain local grid stability during these price-optimized consumption periods.

While this study utilized a static "clipping" strategy that effectively curtailed demand during peak hours, it did not account for the rescheduling of excess consumption to other periods. In real-world scenarios where consumption is shifted rather than curtailed—such as delayed EV charging or price-responsive

heating—the net benefit to the grid may be significantly limited by the emergence of secondary "rebound" peaks. If deferred consumption is synchronized, these rebound peaks could even exceed the original peaks. Future research should therefore investigate these rebound effects more deeply to determine if load-shifting behaviors, combined with price-responsive control, inadvertently create new distribution-level constraints.

V. CONCLUSION

This study provides a comprehensive understanding of the dynamics between 15-minute and 60-minute metering resolutions on coincidental peaks in Finnish residential clusters. Consistent with previous research, the findings confirm that individual peak shaving based on historical data has a limited impact on aggregated distribution-level consumption due to natural demand diversity.

Quantitatively, individual 15-minute monthly peak reduction targets of 30% were found to translate into annual hourly peak reductions of only 18.8%. When aggregated into groups of 10 detached houses, the average impact of the same 15-minute monthly threshold dropped significantly, yielding only an 8.9% reduction in the annual 15-minute peak and just a 5.9% reduction in the highest annual hourly consumption. Notably, peak reduction strategies based directly on hourly average consumption proved relatively more effective at the distribution level, achieving coincidental peak reductions of 9.5% with the same respective thresholds.

As the industry transitions to 15-minute market resolutions and harmonized power tariffs, these results provide vital guidelines for maintaining grid stability. Future research should shift from historical datasets to forward-looking scenarios involving the growing synchronization of flexible loads driven by 15-minute spot-price volatility. Such insights are essential to support DSOs in establishing fair and effective power tariffs that prevent unnecessary distribution grid overinvestment triggered by synchronized consumption during extreme low-price events.

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