38th International Electric Vehicle Symposium and Exhibition (EVS38) Göteborg, Sweden, June 15-18, 2025

Cost Savings and Flexibility in Household Energy Consumption with Electric Vehicles and Heat Pumps

Lars-Henrik Björnsson[1], Markus Lindahl[2], Jan Ekman[3]

[1]*(corresponding author) RISE Research Institutes of Sweden AB, Department of System Transition, Box 857, SE-501 15 Borås, Sweden, lars-henrik.bjornsson@ri.se*

[2]*RISE Research Institutes of Sweden AB, Department of Building and real estate, Borås, Sweden*

[3]*RISE Research Institutes of Sweden AB, Department of Computer Science, Stockholm, Sweden*

Executive Summary

This study evaluates the economic and technical benefits of coordinated control of heat pump operation and electric vehicle charging in Swedish households. The research demonstrates significant potential for reducing household energy costs and peak power demand by analyzing various control strategies. The developed control strategy, which minimizes household electricity costs with respect to electricity prices and power tariffs, can lead to average annual savings of approximately €450, with higher savings in years with elevated and highly volatile spot prices. Coordinated control can substantially decrease average peak power demand, alleviating stress on the local power grid and reducing grid fees. However, the results also showed that average peak power could increase if control focused on moving electricity consumption to hours with low spot price.

Keywords: Electric Vehicles, Consumer behaviour, Smart charging

1 Introduction

The electrification of the car fleet increases the household's electricity demand and the risk of high-power peaks due to the simultaneous use of large power consumers, particularly in homes with electric vehicle (EV) charging and electric heating based on heat pumps (HP). As grid owners introduce power tariffs, households have the option to manage their electricity use to keep costs down.

This paper focuses on the technical potential and possible economic savings related to the coordinated operation of a heat pump and electric vehicle charging for a Swedish household by reducing the power peak loads and shifting electricity usage to periods with lower electricity prices. Through simulations, the total electricity costs (including both consumption and network fees) for a household have been studied to determine how the coordinated control of the heat pump and electric vehicle charging affects these costs compared to a load profile based on no control. The study focuses on a single-family home where heating and domestic hot water are produced using a heat pump, and in addition, the household has an electric car that is charged at home overnight.

1.1 Background

Sweden is undergoing a significant electrification to develop a more sustainable energy system. This shift is expected to increase the need for a more flexible electricity usage [1]. However, the energy transition, urbanization, and an aging power grid have led to capacity issues in parts of the grid [2]. There is thus a risk that the power grid becomes a limiting factor for societal development. To address this, all Swedish grid owners must implement power tariffs by January 1, 2027 [3]. With these tariffs, the cost for the grid fee will partly be based on the power levels of the household's electricity demand. These tariffs are intended to serve as an incentive for end-users to adapt their electricity usage in order to reduce problems with high power peaks in the power system.

Simultaneously, the household's energy consumption and power demand are influenced by the ongoing electrification of the vehicle fleet [4], as electric cars are typically charged at home. The shift to EVs will increase the household's electricity consumption and introduce high power peaks if multiple large electricity consumers are used simultaneously, particularly in homes with EV charging and heat pumps. This is a new aspect for households to consider. Until now, most Swedish households have not had to consider when they use electricity or whether several large power consumers are running simultaneously. However, as power tariffs become more common and electricity prices fluctuate more, households are receiving clear signals that power issues are something they need to consider, which can significantly affect their electricity bills.

In December 2024, there were about 690,000 rechargeable passenger cars in Sweden, representing 14% of the passenger car fleet, and this number is expected to rise to approximately 2.5 million by 2030 [5]. Of the rechargeable vehicles registered in 2020, 76% were purchased by buyers living in single-family houses [6]. Meanwhile, approximately 900,000 of Sweden's over 2 million detached houses are heated with a heat pump connected to a hydronic heating system [7]. Given the high prevalence of heat pumps in Swedish detached houses and the ongoing electrification of the vehicle fleet, the proportion of single-family houses with the combination of these technologies is expected to increase. Another reason to focus on electrical loads related to heating and EV charging is that these loads can, within certain limits, be controlled over time, providing a technical potential for lower peak loads.

1.2 Scope

The study evaluates how coordinated control of heat pump heating and EV charging can reduce peak loads and impact household energy and power costs in a Swedish context.

1.2.1 Delimitations

The project focuses on single-family houses with heat pumps and EV chargers under Swedish conditions, such as outdoor temperature, building standards, electricity prices, and the design of power tariffs. The heat pump is assumed to produce heat for both space heating and domestic hot water and is assumed to be connected to a hydronic system for heat distribution. Households using air-to-air heat pumps are therefore not included in the study.

2 Method

For single-family houses with hourly electricity pricing and a network fee based on the home's power peaks, control strategies that focus solely on electricity prices risk leading to higher network fees due to high power peaks. Similarly, an approach focusing only on minimizing power peaks may result in unnecessarily high electricity consumption during hours with high electricity prices. Therefore, the study has focused on the potential of a control strategy that considers both components. Costs are kept down by maintaining low power peaks while simultaneously shifting the electricity consumption of the heat pump and EV charging to hours with low electricity prices.

The economic potential of a smart control has been evaluated through simulations. The simulation model has been developed in Python 3.8.10 [8], as part of the project " When the electric car moves in!", funded by the Swedish Energy Agency. For further details, see the project's final report [9]. The case study developed was based on a fictional 160m² detached house in Norrköping on the Swedish east coast, 150km south of Stockholm. The building's electricity use for appliances and lighting is based on data developed originally by Psimopoulos [11]. The calculated electricity use is based on a Markov-chain model for occupancy and energy use according to Widén and Wäckelgård [10] and assumes that two adults and two children live in the building. Psimopoulos extended the original model to include domestic hot water (DHW) demand. The electricity use related to the heat pump's production of DHW is based on simulations in Trnsys [12]. Occupancy, domestic electricity, and DHW load profiles cover a complete year. The simulations of electricity usage and costs are conducted with a time step of one hour over the course of a full year.

The house is assumed to have a 25A main fuse, corresponding to a maximum power of 17.3kW. Two years have been evaluated in the simulations 2022 and 2023, and historical data for temperatures and hourly spot prices for electricity from each year have been used. Outdoor temperatures are based on historical data from SMHI for Norrköping [13] and historical electricity prices for SE3 have been used [14]. In the simulations, the grid tariff for Göteborg Energi [15] has been used, see Table 1. The tariff is based on the three highest power peaks (from different days) each month, regardless of when they occur during the day. The heating demand of the building is assumed to depend solely on the outdoor temperature, following the methodology in EN 14825:2018 [16], which is a standard used to calculate heat pump performance for the EU's energy labeling regulation based on laboratory tests of heat pumps. The villa is assumed to have a heating power demand (P_{design}) of 9kW during the coldest hour of the year, which in the base case is met by an 8kW ground source heat pump that also produces the domestic hot water. The heat pump's COP is assumed to vary based only on outdoor temperature. When the heat output from the heat pump's compressor is insufficient, the heat pump's auxiliary heater (electrical heater with COP 1) covers the remaining heating needs.

Table 1: Overview of Göteborg Energi's grid tariff

Year	Fixed fee [€/year]	Transmission fee [€/kWh]	Power tariff [€/kW, mo.]
2022	122.8	0.018	3.16
2023	154.2	0.022	3.16

The household is assumed to have one EV and to investigate the impact of differences in driving needs this study utilizes the driving patterns from 431 privately driven conventional passenger cars measured with GPS over 1-3 months in Sweden [16,17]. We estimate the energy use for hypothetical EVs with the same individual movement patterns as the conventional cars in the database. To single out the effect of these movement patterns we intentionally leave out possible differences due to driving behaviour, road and climate conditions and traffic situation etc., and focus only on trip distances and the time of the first and the last trip of each day. The distance of all trips in between the first and the last trip of a single day is considered the driving need of the household for the day. The time available between the last trip of the day and the first trip of the coming day is considered the time available for charging of the EV. Data for each car movement pattern are then scaled to one year of driving. It is assumed that the car is charged daily after returning home in the afternoon, with the aim of being fully charged the next morning. Each household is assumed to have an electric vehicle with a 50kWh usable battery capacity and an energy consumption of 0.2kWh per km, following one of the 431 measured driving patterns. In the base case, the charging power is assumed to be 11kW, but alternative scenarios with 6.9kW and 5.52kW are also considered.

2.1 Control strategies

The developed control strategy for combined heat pump operation and EV charging starts by scheduling the heat pump's heating of the house, followed by the scheduling of EV charging. Other household electricity consumption and the heat pump's domestic hot water production are not controlled but are considered a base load and included in the house's total power and electricity usage.

An important aspect of the control algorithm is that it deals with the uncertainties of future energy demand. The usage of the EV is not assumed to be known in advance, that is, it is not known in advance when the car is available for charging and the charging needed is not known in advance. Likewise, the future base load and house heating demand are assumed not to be known in advance but will be known immediately after each hour that passes.

The heat pump is controlled to shift the house's heating to hours with low electricity prices, while keeping the household's peak power demand, if possible, below a certain value. This value is the maximum of a monthly initial value and the maximum peak power so far during the month. Since the flexibility related to heating depends on the thermal inertia of the house and varies depending on age and construction, the study has assumed that the simulated house can freely control heating over eight hours based on when it is cheapest to meet the house's heating needs, independent of season or outdoor temperature. The heat pump control is divided into periods, where a new period begins when the heating is equal to what it would have been without any control. The control algorithm determines the period length, for each period, from one to the maximum period length of eight hours. After meeting the house's heating demand, the EV charging is scheduled, and the load from the charging is added to the other electrical loads, again considering power peaks and electricity prices.

The developed strategy for coordinated control is compared with three other, simpler control strategies where the EV charging strategy varies. The developed strategy and the three variants for electric vehicle charging are summarized in .

Table 2. Overview control strategies for electric car charging

Control strategy	Description
A	Charges with focus on low electricity prices and low power peaks (the developed strategy for coordinated control)
B	Charges with focus on low electricity prices only
C	Charges regardless of price signals, but start no earlier than 00:00
D	Charges regardless of price signals and unrestricted, as quickly as possible when the car is plugged in (reference case)

For each EV charging strategy, the simulations can be performed with or without the active control of the heat pump operation described above.

3 Results

Below follows a presentation of the results from the simulations. Starting with the average annual cost-saving potential for the control strategies, followed by variations in results comparing 2022 and 2023, as well as individual variations depending on the driving pattern.

Section 3.2 shows the potential reduction in average peak power for the control strategies, as well as how a limited EV charging power can reduce the average peak power for the house and thereby decrease the costs. Finally, Section 3.3 includes a sensitivity analysis of how the results are influenced if the ground source heat pump is replaced with an exhaust air heat pump with a smaller heating capacity from the compressor, and Section 3.6 shows the impact on the results if the heating demand of the building is changed.

3.1 Cost Savings

Figure 1 illustrates the total electricity cost for a detached house equipped with a ground source heat pump and an EV in 2023, based on the control strategy for charging and heating. The results, which are averaged over 431 individual driving patterns, encompass all electricity costs, including fixed fees, electricity trading, and grid charges.

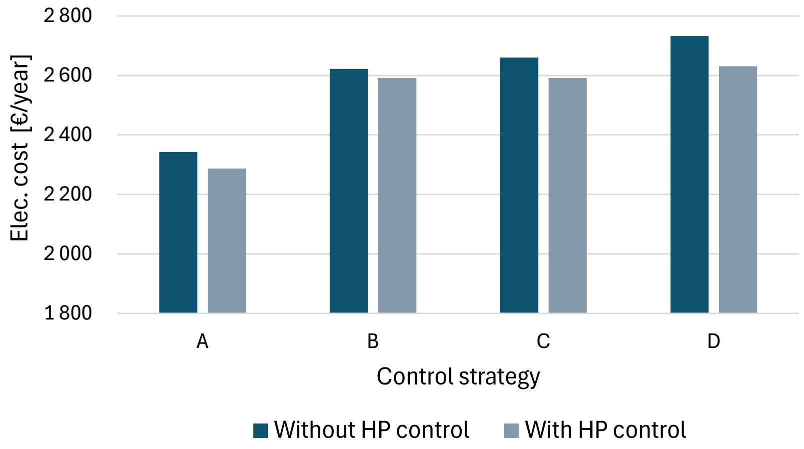

Figure 1. Total electricity cost for 2023, based on the control strategy and with or without optimization of heat pump operation (average based on 431 driving patterns). Note that the y-axis of the graph does not start at zero. Overview of control strategies: **A**: Low spot price and low power peaks (the developed strategy). **B**: Low spot price. **C**: Delayed EV charging (past 00:00). **D**: Charge unrestricted, as fast as possible (reference case).

Optimizing EV charging and heat pump operation to minimize costs associated with power tariffs and electricity prices results in the lowest total cost (Control strategy A, with HP control). Conversely, the reference case with immediate charging (strategy D, without HP control) incurs the highest costs. The annual cost difference is approximately €450, as depicted in Figure 2, which compares the yearly electricity costs of various control strategies with the reference case (strategy D, without HP control). In the reference case, the EV is charged at high power (11kW) immediately upon arriving home in the afternoon, and the heat pump operation is solely regulated by the outdoor temperature.

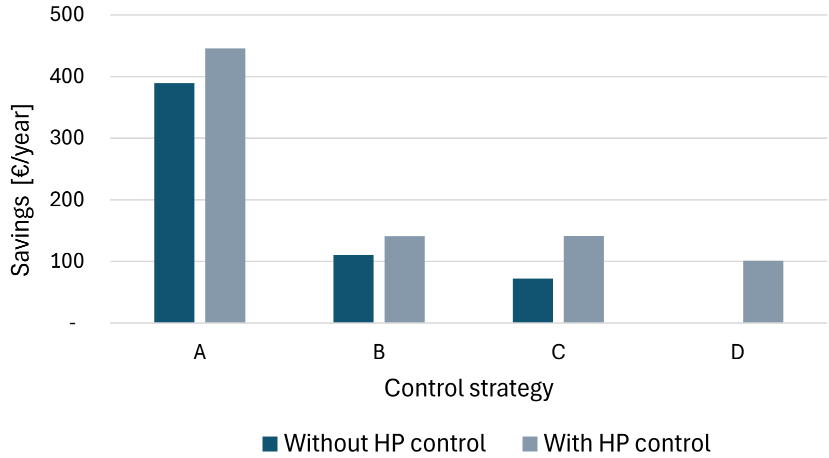

Figure 2: Annual electricity cost savings for 2023, based on the control strategy and with or without optimization of heat pump operation (average based on 431 driving patterns). Overview of control strategies: **A**: Low spot price and low power peaks (the developed strategy). **B**: Low spot price. **C**: Delayed EV charging (past 00:00). **D**: Charge unrestricted, as fast as possible (reference case).

For control strategy B, where EV charging is controlled solely to minimize spot price costs, the savings amount to approximately 30% of those achieved by control strategy A. For control strategy C, where EV charging is delayed until midnight, the cost savings are about 20% without HP control. Adding HP control to strategies A-D increases annual savings by €30 to €70, corresponding to an increase of 15-90%.

In 2022, the yearly electricity costs for the simulated household were 40-50% higher compared to 2023. As shown in Figure 3, this significant difference is primarily due to the higher cost of electricity (spot price), while other price categories remain relatively constant. Figure 3 also indicates that only two cost categories vary depending on the control strategy: the cost of electricity (spot price) and the power tariff. In 2023, subscription and transmission fees and the energy tax accounted for 45-50% of the total electricity cost. Additionally, the potential for annual savings was larger in 2022 than in 2023, with average savings reaching

€770 when both EV charging and HP were controlled.

Fig a) 2022 Fig b) 2023

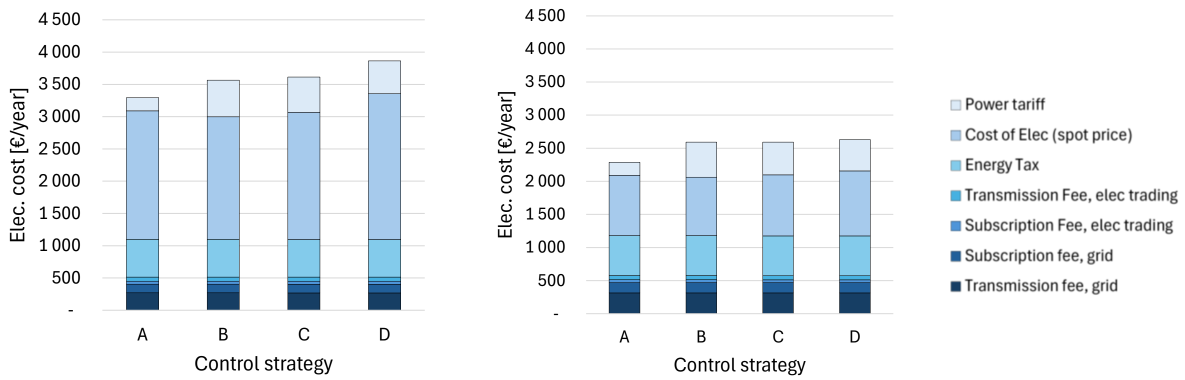

Figure 3: Total electricity cost, divided by cost category for 2022 (a) and 2023 (b) depending on control strategy and with optimization of heat pump operation (average based on 431 driving patterns). Overview of control strategies: A: Low spot price and low power peaks (the developed strategy). B: Low price. C: Delayed EV charging (past 00:00). D: Charge unrestricted, as fast as possible (reference case).

3.2 Individual variations

The annual total costs for electricity for the 431 households in 2023 are shown in Figure 4a, where the costs are presented for control strategy A and the reference case (strategy D), without any active control. The total cost depends, to a large extent, on the annual driving distance since longer distances mean that the need to buy electricity increases. Figure 4b shows the annual savings, calculated as the difference between the two strategies, where the average savings for 2023 amounted to approximately €400. For households with roughly the same annual driving distance, the savings are seen to vary by up to 50%, mainly due to differences in daily driving distances. If driving is spread out over many days, it provides larger flexibility in charging, allowing for higher cost savings compared to fewer days with more intensive driving and charging.

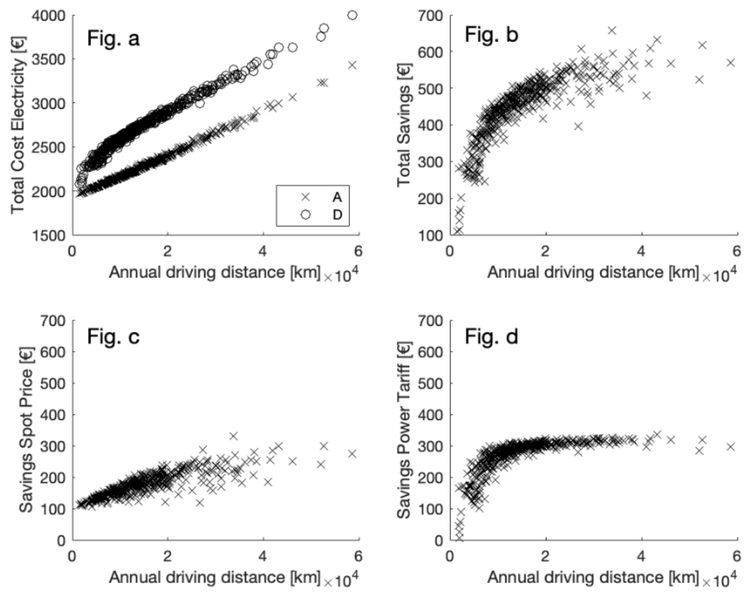

Figure 4: (**a**) Annual total cost per household for electricity, sorted by annual driving distance, for the control strategy with active management (A, with HP control) and without management (D). (**b**) Annual total savings, sorted by annual driving distance. (**c**) Annual savings from shifting consumption to hours with lower electricity prices, sorted by annual driving distance. (**d**) Annual savings from reduced demand tariff costs, sorted by annual driving distance.

Figure 4c shows the portion of the savings achieved by shifting consumption to hours with lower electricity prices, which on average was about €180. Figure 4d shows that the larger portion of the total savings, approximately €270, came from avoiding costs associated with Göteborg Energi's power tariffs. Spot prices were considerably higher during 2022, leading to an average saving due to shifting consumption to hours with lower electricity prices of €475, while the average savings from power tariffs remained roughly the same at about €295. The importance of focusing on low power tariffs versus low electricity spot prices depends on the cost levels of the year. The annual savings from coordinated control increase with driving distance up to approximately 10,000–30,000 kilometers per year, after which they level off. Part of the explanation is that a significant portion of the savings consists of reduced costs for power tariffs, which do not decrease further with increased driving distance; these car movement patterns already contributed to a maximum of 11kW charging in the reference strategy (D). A higher driving distance can make achieving the same savings on power tariffs more challenging, as shown in Figure 4d, where the savings from power tariffs remain relatively constant after 10,000 kilometers and slightly decrease for the longest driving distances. The portion of the savings related to electricity prices, see Figure 4c, shows a larger variation and is more dependent on the driver's driving patterns.

3.3 Average peak power

The peak power for each driving pattern has been calculated as the average of the three highest power peaks (from different days) each month throughout the year. Subsequently, the average of the 431 driving patterns was calculated and presented in Figure 5. Optimizing EV charging to lower powers (strategy A) results in a reduced average peak power of about 7-8 kW compared to the reference case (strategy D). Control strategies B and C, where electric vehicle charging is focused solely on reducing spot price costs or is scheduled after 00:00, do not generally lead to higher peak power compared to control strategy D, despite concentrating EV charging to hours with lower prices. This is because these strategies move electricity consumption away from high demand to other times of household electricity consumption. Adding heat pump control to strategies B and C leads to average power peaks higher than in the uncontrolled strategy D, even for the individual household. Further suggesting that these strategies focusing on buying electricity at a lower spot price or delaying charging until after midnight can result in a higher average peak power for the local grid. The savings from shifting heat production to hours with lower electricity prices outweigh the increased cost due to higher average peak power.

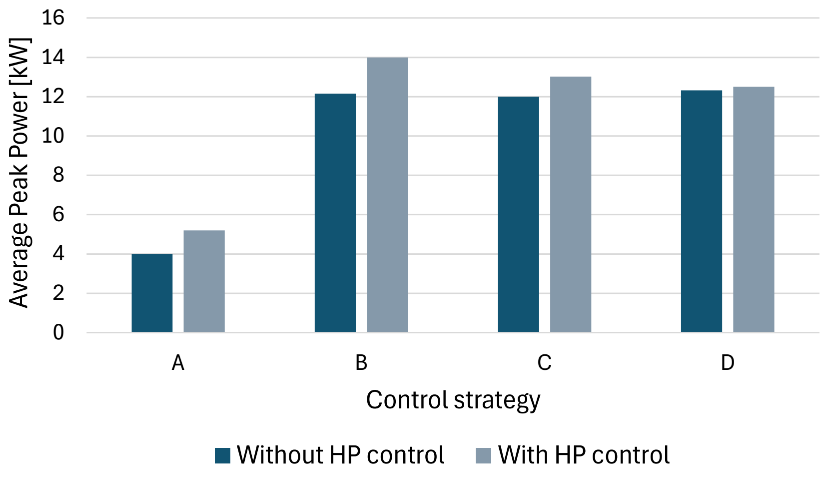

Figure 5: Yearly average peak power 2023 for the 431 driving patterns for control strategy A-D. Calculated as the average of the three hours (from different days) with the highest peak power each month.

3.4 Reduced charging power

Households that optimize EV charging to minimize electricity spot prices (control strategy B) or delay charging to nighttime (control strategy C), without actively reducing peak power, can still achieve significant cost savings on power tariffs by limiting their charging power. Figure 6 shows the resulting change in average power due to the limited charging power. Reducing charging from 11kW to 6.9kW corresponds to a decrease in average peak power of about 3kW. Active optimization to reduce power (strategy A) can further reduce the average peak power by about 4kW.

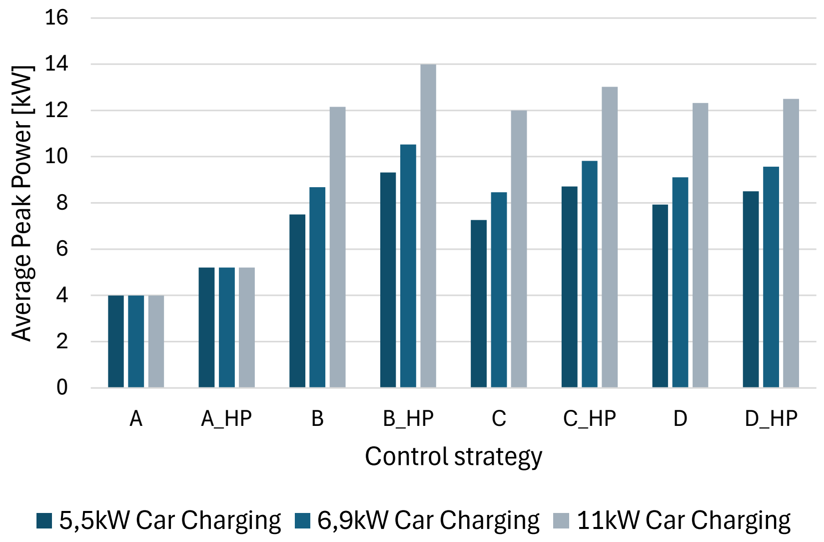

Figure 6: Average peak power for the control strategies, with and without heat pump control, for three EV charging powers. Labelling: Without heat pump control is shown as the letter for the control strategy only, with active heat pump control is shown as the control strategy followed by "_HP"

The resulting change in cost savings from capping the EV charging power is shown in Figure 7, with cost savings approximately doubling when reducing charging from 11 to 6.9 kW for strategies B and C, reaching about 50% of the savings achieved for strategy A. For the reference case (control strategy D), average savings are more than €100 per year when reducing charging from 11 to 6.9kW.

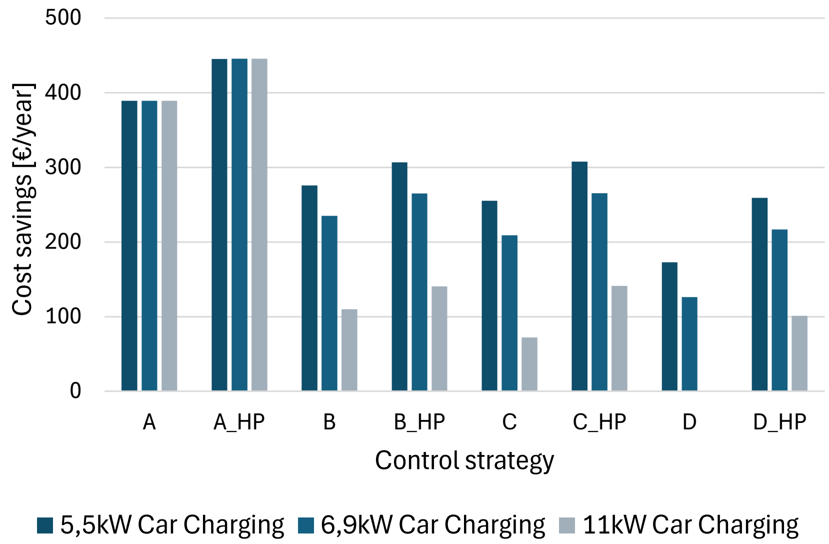

Figure 7: Annual electricity cost savings 2023, with and without heat pump control, for three different EV charging powers. Labelling: Without heat pump control is shown as the letter for the control strategy only, with active heat pump control is shown as the control strategy followed by "_HP"

3.5 Type of Heat pump

Figure 8 compares the total electricity costs for a household based on the type of heat pump used. The heat pump is either a geothermal heat pump with a compressor with 8 kW maximum heat output or an exhaust air heat pump with a 3kW compressor. The significantly smaller compressor of the exhaust air heat pump necessitates more frequent activation of the heat pump's auxiliary heater, which consists of an electric heater with a COP of 1. This results in an average of 16% higher electricity consumption and consequently higher electricity costs of approximately €3200/year compared to around €2700/year for the geothermal heat pump. However, the potential savings are roughly similar: €450/year for the geothermal heat pump and €460/year for the exhaust air heat pump. The exhaust air heat pump also results in somewhat higher average peak power (about 0.7kW and 0.3kW higher than the geothermal pump under control strategies A and D, respectively).

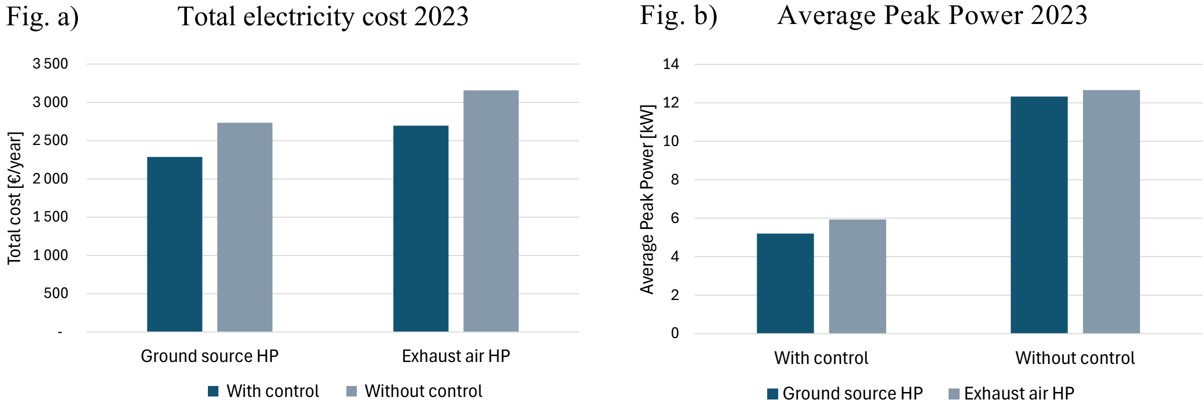

Figure 8: a) Total electricity cost 2023 and b) Average peak power, shown as an average based on 431 driving patterns. Comparing an active control strategy (A) and the reference case without any control strategy (D) for a ground source heat pump (maximum 8 kW heating capacity) and an exhaust air heat pump (maximum 3 kW heating capacity)

3.6 Space heating demand

The heating power demand of the house on the coldest day (P_{design}) was assumed to be 9kW. This demand was adjusted to reflect a 30% decrease or increase in heating requirements, which impacted on the total electricity cost, see Figure 9 (left). The total cost decreased by approximately 10% with lower heating requirements and increased by about 10% with higher heating requirements. Concurrently, potential savings decreased or increased by 4%, resulting in actual cost savings between €430 and €460. Despite a 30% increase or decrease in heating requirements, the potential cost savings remain relatively constant at approximately €450.

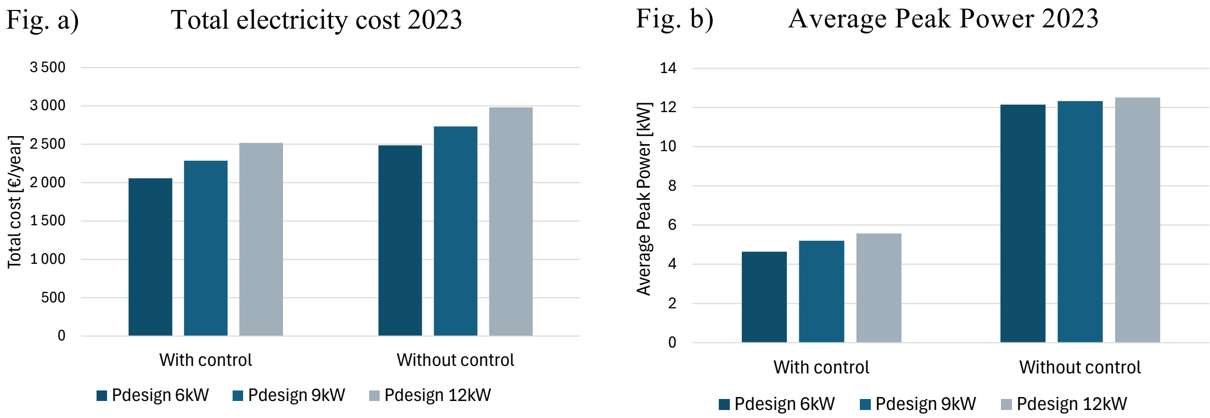

Figure 9: a) Total electricity cost [€/year] 2023 and b) average peak power [kW], shown as an average based on 431 driving patterns. Comparing an active control strategy (A) and the reference case without any control strategy (D) for three different heating demands.

As seen in the right part of Figure 9, adjusting the heating requirement resulted in slightly lower or higher average peak power. Specifically, the average peak power when lowering the heating requirement by 30% was about 0.6 and 0.2kW lower for strategies A and D, respectively, and increasing the heating requirement by 30% led to about 0.4 and 0.2kW higher average peak power under control strategy A and D, respectively.

4 Discussion

The results of this study highlight the significant impact that coordinated control of heat pump operation and EV charging can have on household energy costs and peak power demand. Several key insights and implications for households and energy policy can be drawn by analyzing the studied control strategies.

Economic Benefits of Coordinated Control. The developed strategy (strategy A), which focuses on low electricity prices and low power peaks, demonstrates the most significant cost-savings potential. Households that adopt this strategy can substantially reduce their annual electricity costs compared to the reference case (strategy D), where opportunistic EV charging is done without any control. The results from 2023 indicate that coordinated control can lead to average annual savings of €450, with about two-thirds of these savings stemming from reduced power tariffs and one-third of the savings coming from optimized electricity consumption during low-price periods. During 2022, when spot prices were considerably higher, the potential savings increased to about €770 with the largest savings now coming from optimized electricity consumption during low-price periods, corresponding to approximately two-thirds of the total savings.

Algorithm design. The results are dependent on the algorithm design, which could be improved or altered. For example, the strategy for determining peak usage could be refined. Instead of using the highest peak as the maximum effect, it might be more effective to adjust the strategy based on the distribution of peaks throughout the month. For instance, employing the highest peak at the start, the second highest in the middle, and the third highest towards the end could potentially optimize performance. This nuanced approach acknowledges the variability in peak distributions and aims to enhance the overall efficiency of the optimization process. Future research should investigate how closely the algorithm approximates a case with perfect foresight, which besides simplifying the problem also could work as a benchmark for the maximum achievable savings.

Impact on Peak Power Demand. Coordinated control significantly reduced average peak power demand. Control strategies B and C, combined with a reduction in EV charging power, led to considerably lower average peak power than the reference case, suggesting that part of the potential can be achieved through relatively simple strategies. Control strategy A, prioritizing low power peaks, resulted in an even larger decrease in average peak power by about 7-8kW compared to the reference case. Such a reduction directly translates to lower grid fees for the household but can also alleviate stress on the local power grid, contributing to overall grid stability and reliability. However, adding control of the heat pump often increased the average peak power, sometimes leading to higher peaks than the reference case. Furthermore, when a group of households follows similar strategies to shift electricity consumption to hours with low spot prices, this can increase aggregated power demand among the group, even though the average peak power of individual households is lowered compared to the uncontrolled strategy. The next step for this study would be to consider the accumulated power demand from a group of households to assess further how these different strategies affect the power demand of a local grid.

Flexibility and User Behavior. Variations in the movement patterns of electric vehicles (EVs) lead to different levels of cost-saving potential, even among patterns with similar annual driving distances. This suggests that individual drivers' daily distances and available charging times significantly impact their ability to achieve cost savings. Households with more flexible driving patterns and heating needs can better align their energy consumption with periods of low electricity prices while maintaining a low average peak power, thereby maximizing their savings. Conversely, households with rigid schedules may find it more challenging to optimize their energy use, highlighting the need for adaptable and user-friendly control systems.

In this study, we assumed that EVs are charged daily. However, in reality, EVs may be charged only when needed, which would increase the average amount of energy required per charge. This would reduce the opportunities to shift electricity usage to low-cost hours and increase the average power needed to charge the car before morning. Future studies should further investigate charging behavior and groups of users with similar characteristics to better understand their potential for achieving cost and peak power savings through controlled EV charging and heat pump use.

Sensitivity to Electricity price. The results reveal that external factors, such as the electricity price, significantly influence the cost saving potential of the control strategies. For instance, the exceptionally high electricity prices in 2022 led to higher overall costs and increased potential savings from coordinated control. This variability emphasizes the need for dynamic control strategies that can adapt to changing external conditions to maintain optimal performance.

Heating of the building. The sizing of the heat pump significantly influences the amount of auxiliary heat required to meet the building's heating needs. In the simulations, this is evaluated through two types of heat pumps, a geothermal heat pump, whose compressor can cover almost the entire heating demand, and an exhaust air heat pump with relatively low compressor capacity. A low compressor capacity necessitates more auxiliary heating, which is produced using an electric heater with a COP of 1, thereby increasing electricity consumption. However, the savings potential with a smart control strategy is approximately the same for the two heat pump types. This is because electric vehicle charging is scheduled after the heat pump's operation, thus largely avoiding the aggregation of power peaks.

Policy Implications. Encouraging households to adopt coordinated control strategies can lower costs and reduce peak power demand, at the same time, the results show that average peak power can increase if control is focused on moving electricity consumption to hours with low spot price. Policymakers should consider implementing educational campaigns to promote the adoption of smart control systems that take both power tariffs and electric prices into account, particularly in regions with high penetration of EVs and heat pumps.

5 Conclusion

In conclusion, coordinating heat pump operation and EV charging offers a promising approach to managing household energy costs and peak power demand. The results of this study demonstrate the substantial economic and technical benefits of such strategies. The results from the simulations show that the annual cost savings based on data from 2023 were about €450 on average, corresponding to a reduction of 16% in total electricity cost. For 2022, a year with very high electricity prices, the savings were about €770 or 19%. A simpler control strategy, combining a reduction of the EV charging power from 11 to 6.9kW and starting the charging at midnight yielded about half the cost savings compared to the more complex strategy. By implementing a control strategy focusing on low power peaks, it was possible to lower the yearly average power peak by 7-8kW compared to a reference case without any active control. Reducing the EV charging power from 11 to 6.9kW reduced the households power peaks by approximately 3kW. However, the results also showed that average peak power could increase if control focused on moving electricity consumption to hours with low spot price.

Acknowledgments

This analysis was possible through support from the Swedish Energy Agency, project "When the electric car moves in! - The social and technical potential with coordinated control of heat pumps and electric car charging in single-family homes" [project number P2022-00921] and project "Households' motivations and potential to begin contributing to frequency regulation through Vehicle-to-Grid" [project number P2024-01077].

References

[1] Regeringskansliet, *Nationell strategi för elektrifiering*, available from: www.regeringen.se, accessed on 2022-06-09

[2] Energimarknadsinspektionen, Ei. *Kapacitetsutmaningen i elnäten* (Ei R2020:06). available from: https://ei.se/, 2020

[3] Energimarknadsinspektionen, Ei,. *Effektavgift*, 2022, available from: https://ei.se/konsument/el/elnatsavgiften-och-elnatsreglering/effektavgift-effekttariff, accessed on 2025-03-18

[4] Bunsen, T., Cazzola P., Gorner M., Paoli L., Scheffer S., Schuitmaker R., Tattini J. and Teter J., *Global EV Outlook 2018. Towards cross-modal electrification*, Paris: International Energy Agency, Available from: www.iea.org, 2018

[5] Trafikanalys, *Fordon i län och kommuner 2024*, available from: https://www.trafa.se/vagtrafik/fordon/, 2025

[6] Trafikanalys, *Vem väljer en elbil? De svenska hushållens val av elbilar och laddhybrider,* (Rapport 2023:2). available from: www.trafa.se, 2023

[7] Energimyndigheten, *Energistatistik för småhus*, available from: https://www.energimyndigheten.se/statistik/officiell-energistatistik/tillforsel-och-anvandning/energistatistik-for-smahus/, 2024

[8] Python, *Python 3.8.10*, available from: https://www.python.org/downloads/release/python-3810/, accessed on 2025-03-28, 2021

[9] Hiller C. Lindahl M., Björnsson L. Björner Brauer H. Ekman J., *När elbilen flyttar in! Den sociala och tekniska potentialen med samordnad styrning av värmepumpar och elbilsladdning i småhus*, 2025

[10] Widen J, Wäckelgård E (2010). A high-resolution stochastic model of domestic activity patterns and

electricity demand. Applied Energy 2010;87:1880–92. https://doi.org/10.1016/j.apenergy.2009.11.006

[11] Psimopoulos, E., Bee E., Widén J., Bales C. (2019). Techno-economic analysis of control algorithms for an exhaust air heat pump system for detached houses coupled to a photovoltaic system. Applied Energy 219;249:355-367, https://doi.org/10.1016/j.apenergy.2019.04.080

[12] Haglund Stignor C. et al. (2021). Svenskt bidrag till Comfort&Climate Box Annex – ett samarbete mellan IEAs TCPer och Mission Innovation, https://termoinnovation.se/wp-content/uploads/2022/07/48287-1-comfort-and-climate-box-pdf.pdf

[13] SMHI, *Ladda ner meteorologiska observationer*, available from: https://www.smhi.se/data/meteorologi/ladda-ner-meteorologiska-observationer/airtemperatureInstant/85050, accessed 2024-10-22.

[14] ENTSO (u.å). *ENTSO Transparency platform* [Online]. Available from: https://transparency.entsoe.eu/

[15] Göteborg Energi, *Elnätsavgiften*, available from: https://www.goteborgenergi.se/privat/elnat/elnatsavgiften, 2024

[16] SIS, *Svensk Standard SS-EN 14825:2018, Luftkonditioneringsaggregat, vätskekylare och värmepumpar, med elektriskt drivna kompressorer, för rumsuppvärmning och kylning - Provning och prestanda vid dellastförhållanden, samt beräkning av säsongsprestanda*, Edition 4, 2018

[17] Karlsson S., *The Swedish car movement data project: final report*, PRT report 2013:1, Chalmers University of Technology, Gothenburg. Available from: http://publications.lib.chalmers.se/records/fulltext/187380/local_187380.pdf, 2013.

[18] Karlsson S., Kullingsjö L-H. *GPS measurement of Swedish car movements for assessment of possible electrification*, In: Proceedings of EVS27 symposium, Barcelona, Spain. Available from: http://publications.lib.chalmers.se/records/fulltext/184575/local_184575.pdf; 2013.

Presenter Biography

Lars-Henrik Björnsson holds a PhD from the Division of Physical Resource Theory at the Department of Energy and Environment at Chalmers University of Technology. He is currently working as a senior researcher in electromobility within the Local Energy Systems unit at the Department for System Transition at RISE (Research Institutes of Sweden).