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When the Electric Car Moves In - Coordinated Control of Heat Pumps and Electric Car Charging

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There is an ongoing electrification of the Swedish society, bringing new challenges and opportunities for electricity use in our homes. One of the most exciting developments is the integration of electric cars into the household energy systems. Results from ongoing research by RISE show that homeowners in Sweden with heat pumps and electric cars can save significant costs per year through coordinated and optimized control of their heat pumps and car charging. This coordinated control can help reduce the strain on the power grid, while households avoid high peak tariffs and reduce their electricity costs.

Electrification of the energy system

Sweden is undergoing a significant electrification process aimed at creating a more sustainable energy system. This shift is expected to increase the need for a more flexible electricity usage. However, the energy transition, urbanization, and an aging power grid have led to capacity issues in parts of the power grid. To address this, more and more Swedish grid operators are introducing "peak tariffs". These tariffs, which will become mandatory in Sweden by 2027, base part of the grid fee on the household's highest power peaks during the month and aim to incentivise the user to spread out their electricity usage to avoid peak loads that can lead to problems in the power system.

Simultaneously, household energy consumption and power demand are influenced by the ongoing electrification of the vehicle fleet, as the electric cars are typically charged at home. This shift will increase the household electricity consumption and risk of high power peaks if multiple large electricity consumers are used simultaneously, particularly in homes with both electric vehicle charging and heat pumps. This is a new aspect for households to consider, and they may not necessarily have the knowledge or awareness of coordinated control and its potential impact on their daily habits. Until now, most Swedish households have not had to consider when they use electricity or whether several large power consumers are running simultaneously. But as peak tariffs become more common and the electricity prices fluctuate more, households are receiving clear signals that power issues are something they need to consider, which can significantly impact their electricity bills.

To reduce power peaks and keep costs down, the homeowners' need for a flexible electricity usage is increasing, especially for those with both electric heating and an electric vehicle. These households are becoming more common. As of September 2024, there were 630,000 rechargeable cars in Sweden, and it is expected that there will be about 2.5 million rechargeable vehicles by 2030. At the same time, 800,000 of Sweden's approximately 2 million single-family homes are heated with a heat pump connected to a hydronic heating system. One advantage of electric loads related to heating and electric vehicle charging is that they can be shifted in time within certain limits, offering the potential for lower power peaks.

Coordinating heat pumps and EV charging

For single-family homes 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, a strategy that focuses 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 car charging to hours with low electricity prices.

The economic potential of a smart control has been evaluated through simulations. The case study developed was based on a fictional 160m^2 single-family building located in Norrköping on the Swedish east coast, 150 km south of Stockholm. The villa is assumed to have a heating demand of 9 kW 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. When the heat output from the compressor is insufficient, the heat pump’s auxiliary heater kicks in to cover the remaining heating needs. In each scenario, we modelled households with electric cars that follow their unique driving patterns and are charged at home every night using an 11kW charger. The car usage is based on real-world data collected with GPS for 1-3 months from about 400 passenger cars representative for Swedish driving.

The developed control strategy for combined heat pump operation and electric car charging starts by scheduling the heat pump's heating of the house, followed by scheduling the car charging. The heat pump is controlled so that the house's heating is shifted to hours with low electricity prices, while the total electrical power remains below previous maximum values for the current month. Since heating flexibility depends on the house's thermal inertia and varies from house to house, the study assumes a house that can choose the cheapest hours to meet its heating needs within an eight-hour window. The fact that the house can handle periods of up to eight hours does not mean that these periods are always eight hours. The control algorithm determines the period length, from one to eight hours, for each period. The study also assumes that the electric car is plugged in in the evening and fully charged every night. Other household electricity and the heat pump's production of domestic hot water are not controlled and are considered as a base load.

Potential for cost savings

The left part of Figure 1 shows the total electricity costs for the simulated 400 households, presented for two scenarios: one with active control (red) and one without active control (blue). The results are based on data from 2021 and a grid fee from Göteborg Energi. As expected, a longer annual driving distance leads to higher costs due to increased electricity consumption. The figure on the right illustrates the annual savings, calculated as the difference between the two scenarios, with the average savings potential amounting to approximately $470 per year, which correspond to 20% of the total annual electricity costs for the villa. Note that for households with the same annual driving distance, savings can vary by up to 40%, primarily due to daily driving patterns. Spreading driving over many days provides greater flexibility in charging, enabling higher cost savings compared to fewer days with more intensive driving and charging. About 70% of the savings, or $330, relate to avoiding costs associated with peak tariffs, while 30% relate to savings achieved by shifting consumption to hours with lower electricity prices, which averaged around $140 per year. The savings potential is shown as the difference between two extremes, either no control strategy at all or a fairly advanced strategy. In the case without any control, the electric car is charged at high power (11kW) as soon as the driver get home in the afternoon. Part of the savings can be achieved through simpler control strategies, such as reducing the power of the electric car charger or starting the charging after midnight.

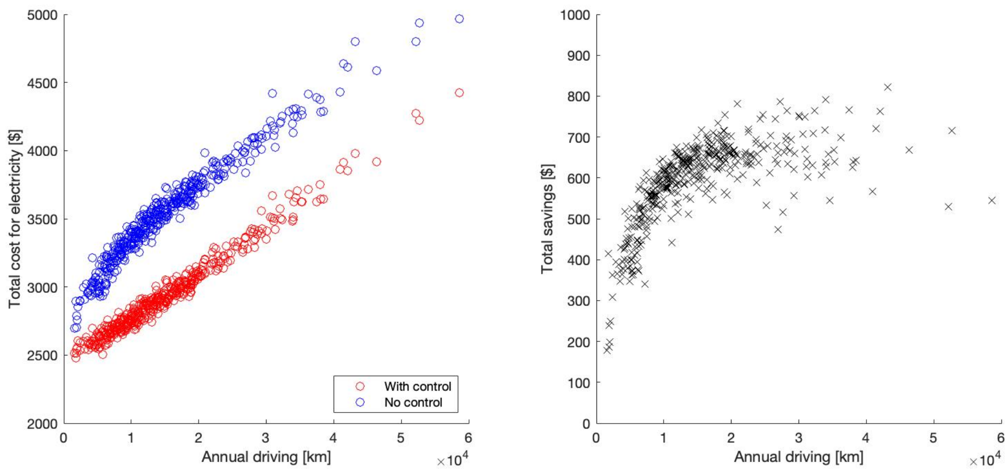

Figure 1. Left: Total annual cost per household for electricity price and power tariff, sorted by annual mileage, for the scenario with active control (red) and without control (blue). Right: Annual total cost savings, sorted by annual mileage.

The annual savings from coordinated control increase with the driving distance up to about 10,000 km per year, after which they level off. Part of the explanation is that a significant portion of the savings consists of reduced peak tariff costs, which do not decrease further with additional mileage. Variations in electricity prices between different years also play a significant role in the results. For example, 2022 had higher electricity prices compared to 2021 and 2023, leading to savings from coordinated control being about 40% higher in 2022 compared to the other years.

To simulate a villa with an exhaust air heat pump, the maximum compressor output of the heat pump was reduced to 3 kW, resulting in an increase in total electricity costs, mainly due to higher energy consumption associated with increased use of the auxiliary heater. However, the smaller heat pump also offered fewer opportunities for savings through active control. This is because longer operating hours at higher outputs reduce the flexibility to shift electricity consumption to periods with lower prices and make it harder to keep the power peaks down. The same trend of reduced savings potential was observed when the house's P-design (i.e. heating demand in the coldest hour of the year) was increased by 30% to represent a house with higher heating demand but with the same heat pump. Reducing the house's P-design by 30%, however, only provided a small additional savings potential, which can be interpreted as the heat pump in the base case already having significant flexibility to schedule heating.

Social aspects affect the saving potential

Behavior related to heating and electric car charging significantly affects the potential for savings from coordinated control. For households, coordinated control introduces new aspects to consider in daily life. Previously, most people did not have to think about when they use electricity, but with power tariffs and varying electricity prices, this is becoming increasingly important to keep the costs low.

We have seen a clear technical potential for coordinated control in the study, but it must be understood in its social context. Households' practices, norms, and expectations play a crucial role in how the technology can be implemented and used effectively. Expectations for an available, fully charged electric car and norms around indoor temperature can challenge the possibilities for flexibility.

Coordinated control of heat pumps and electric car charging offers a promising solution for managing peak electricity demand and reducing energy costs in single-family homes. However, realizing this potential requires increased awareness and knowledge among households, as well as technical solutions that are user-friendly and adapted to their needs and daily practices.

In the future, we can expect more households to prioritize and plan their electricity use to reduce peak demand and electricity costs. With the right support and information, coordinated control can become an important part of a sustainable and efficient energy system.

About the project

This article is based on findings from the ongoing Swedish research 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" which has been funded by the Swedish Energy Agency, and is being carried out in collaboration with researchers from RISE Research Institutes of Sweden and Dalarna University along with industry partners.

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