

ENERGY FINDINGS

Price Signals and Load Flexibility in Public Transport: A Cost Analysis of Electric Bus Charging

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Findings

This paper examines how electricity pricing structures influence the cost of flexible electricity demand in Sweden. Using an electric bus fleet operating within the Skövde municipal area as a case study, three charging scenarios are evaluated across the tariff structures of seven distribution system operators (DSOs). Wholesale electricity prices generally contribute more to electricity costs than grid fees; within grid tariffs, peak-related components dominate. Modest temporal load adjustments can yield measurable end-user cost savings, while grid-optimized charging may be penalized. Significant differences in tariff structures across adjacent DSO areas suggest the potential for spatial, as well as temporal, load flexibility.

1. Questions

This study investigates how spatial and temporal flexibility in electric vehicle (EV) charging affects user costs under Sweden's electricity tariff system. Most end-users pay separately for electric energy and grid connectivity. While consumers choose among energy providers, whose tariffs reflect wholesale market prices in Sweden's four bidding areas (SE1–SE4), grid fees are charged by the local distribution system operator (DSO), which holds a natural monopoly over electricity distribution in one or more of the 311 non-overlapping network concession areas (as of 2024). Though set by the local DSO, network tariffs also capture costs from the national transmission system and regional distribution grids, where applicable. Wholesale energy prices are uniform within a bidding area but vary hourly (and may be settled over 15-minute increments, effective 30 September 2025); by contrast, most grid tariffs show relatively little time-of-use variation, while the 125 unique DSO tariffs in Sweden (as of 2024) provide significant spatial variation.

Electric vehicles can exploit both temporal and spatial tariff differences. To explore this potential, we analyze the charging costs of Skövde's municipal bus fleet, assuming a transition from diesel to electric buses. Fleet charging is assumed to be cost-driven, constrained by route schedules. Building on prior grid-optimized load profiles (Najafi, Gao, Parishwad, Tsaousoglou, et al. 2025; Najafi, Gao, Parishwad, Pourakbari-Kasmaei, et al. 2025; Najafi, Gao, Wang, et al. 2025), we examine whether current tariffs incentivize such charging behavior.

We address three questions:

1. How do wholesale and local tariffs contribute to charging costs?
2. Do current price signals align with grid-optimal charging behavior?
3. Could revised grid tariffs strengthen incentives for spatio-temporal load flexibility?

The third question concerns whether improved tariff structures are possible, rather than the design of a tariff that achieves fully grid-optimal behavior, which would require assumptions about operations and scheduling beyond the scope of this study; we note this as a direction for future research.

2. Methods

The analysis focuses on variations in electricity costs across network concession areas operated by multiple DSOs in the Skövde municipal area (SE3 bidding zone, Västra Götaland). Hourly wholesale prices for 2024 were obtained from Vattenfall (2024); grid tariff data were sourced from the Swedish Energy Markets Inspectorate (2025).

For each DSO, annual grid cost C^{grid} is computed as:

$$C^{\text{grid}} = C^{\text{fixed}} + C^{\text{power}} \sum_m P_m + C^{\text{power,hl}} \sum_{m \in \mathcal{H}^{\text{hl}}} P_m^{\text{hl}} + \sum_h C^{\text{energy}}(h) E_h,$$

$$C^{\text{energy}}(h) = \begin{cases} C^{\text{energy,hl}}, & \text{if } h \in \mathcal{H}^{\text{hl}}, \\ C^{\text{energy,ll}}, & \text{if } h \notin \mathcal{H}^{\text{hl}}. \end{cases}$$

where:

- C^{fixed} : Fixed charge, including regulatory charges and subscription fee (SEK),
- C^{power} : Subscribed power capacity charge (SEK/kW),
- P_m : Subscribed power capacity (kW) in month m ,
- $\mathcal{H}^{\text{hl}}$: High load time period,
- $C^{\text{power,hl}}$: High load power charge (SEK/kW),
- P_m^{hl} : High load power (kW) during months m in $\mathcal{H}^{\text{hl}}$,

Table 1. Overview of DSOs included in the study, including short identifiers and each operator's definition of high-load hours.

DSO (long)	DSO (short)	$\mathcal{H}^{\text{hl}}$
Skövde Energi Elnät	DSO A	Nov–Mar, 06–22
Ellevio	DSO B	Nov–Mar, 06–22
Falbygdens Energi Nät	DSO C	Nov–Mar, 07–19
Götene Elförening	DSO D	None
Sjogerstads Elektriska Distributionsförening	DSO E	Nov–Mar, 06–22
Tibro Elnät	DSO F	Nov–Mar
Vattenfall Eldistribution	DSO G	Nov–Mar, 06–22

Table 2. DSO tariff parameters (2024). Values exclude VAT.

DSO (short)	C^{fixed} (SEK)	C^{power} (SEK/kw)	$C^{\text{power,hl}}$ (SEK/kw)	$C^{\text{energy,hl}}$ (öre/kWh)	$C^{\text{energy,ll}}$ (öre/kWh)
DSO A	13 785	124	74	15,00	2,50
DSO B	18 000	346	475	5,00	5,00
DSO C	56 193	0	36	9,59	9,59
DSO D	25 830	404	0	9,20	9,20
DSO E	40 894	398	446	15,70	9,70
DSO F	34 244	130	396	19,40	10,30
DSO G	32 400	360	310	21,20	7,40

- $C^{\text{energy}}(h)$: Energy transmission charge function (SEK/kWh) for hour h , where $C^{\text{energy,hl}}$ is the charge for energy during high load period $\mathcal{H}^{\text{HL}}$ and $C^{\text{energy,ll}}$ is the charge for energy outside high load period.
- E_h : Energy (kWh) consumed in hour h .

These numbers are assumed to exclude VAT. High-load definitions vary by DSO ([Table 1](#)); tariff components are summarized in [Table 2](#).

Hourly e-bus charging load profiles for the Skövde fleet are based on a representative day optimized to minimize local grid congestion (Najafi, Gao, Parishwad, Tsousoglou, et al. 2025; Najafi, Gao, Parishwad, Pourakbari-Kasmaei, et al. 2025; Najafi, Gao, Wang, et al. 2025). Assuming static route schedules and charging behavior, the representative day is replicated across the year to approximate annual charging demand.

We consider three scenarios ([Figure 1](#)):

1. *Baseline scenario*: Uses the load profile from Najafi et al., which adjusts charging to optimize circuit-level distribution network operation without regard to end-use electricity costs. The pronounced drop at midnight occurs because buses are in transit returning to the depot during this hour, during which neither in-route nor depot charging is available.

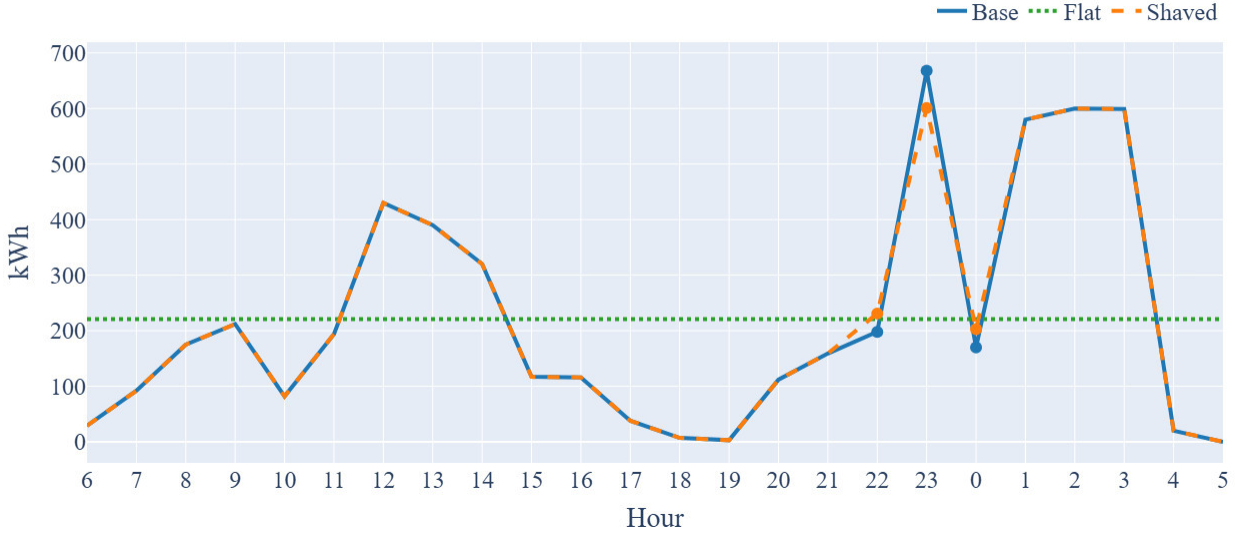


Figure 1. The hourly load profile for the baseline, flat and peak shaving scenarios over the course of a representative day, starting at 06:00. The peak hour (23:00) and its two adjacent hours differs for the baseline and peak shaving scenarios; all other hours are identical in these cases.

2. *Flat scenario*: Redistributes total daily energy evenly across all hours, producing a flat load curve. This limiting case is illustrative of the minimal peak power load for a given energy consumption, although it is presumably operationally unrealistic.
3. *Peak shaving scenario*: Reduces the daily peak load from the base scenario by 10%, redistributing the shaved energy evenly to the two adjacent hours to maintain the same total energy consumption. This is presented as a more realistic, incrementally reduced-cost variant of the Baseline scenario. We use only the two adjacent hours to the peak to illustrate a minimal operational adjustment, as shifting load over longer periods (e.g., 4–6 hours) would require schedule changes beyond what is deemed as operationally feasible for the Skövde bus system.

3. Findings

[Figure 2](#) provides background on seasonal variation under Skövde Energi Elnät's tariffs (2024). Wholesale prices show pronounced seasonality, driving large month-to-month differences in total cost, while network charges vary less across months. While this underscores that energy prices contribute substantially to total cost, public transport services with daily/weekly operating patterns cannot meaningfully shift charging across seasons; therefore, seasonal variation is informative context rather than a strategy for cost reduction in this application.

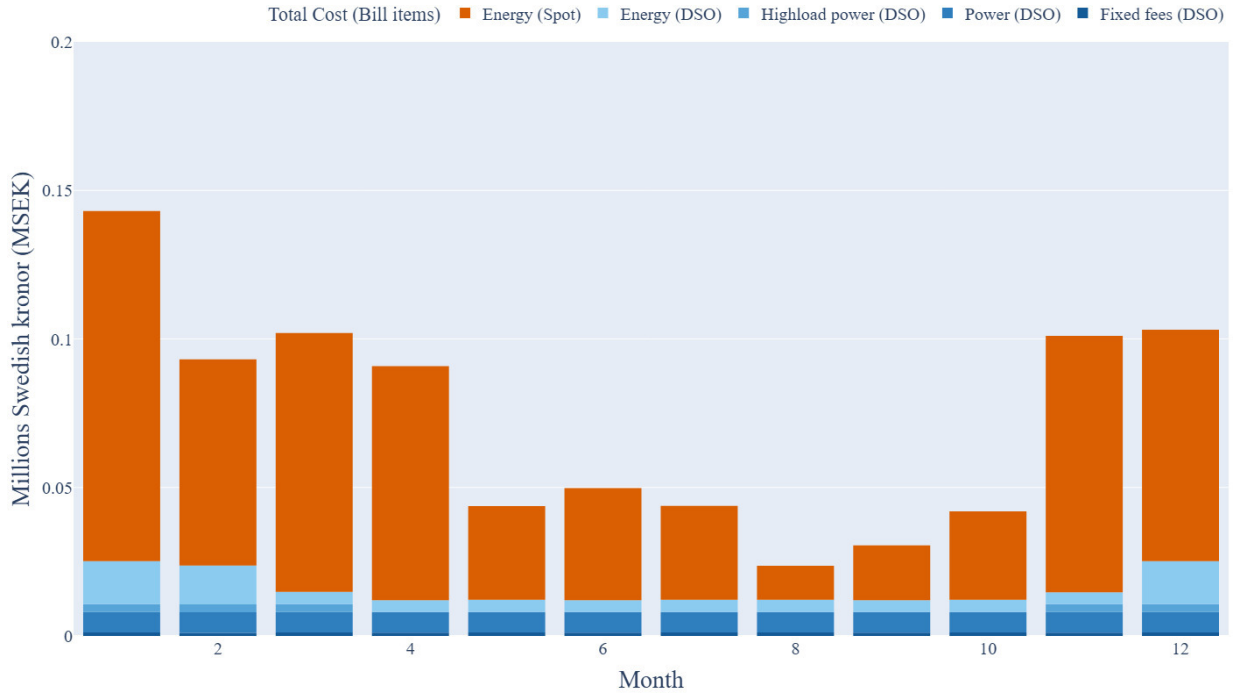


Figure 2. Monthly breakdown of total charging costs under Skövde Energi Elnät tariffs (2024). Fixed charges are distributed proportionally by month length (days). Wholesale prices drive pronounced seasonality; total monthly costs vary by a factor of 5 between the least- and most-expensive months.

[Figure 3a](#) presents the implied end-use electricity costs of the three charging scenarios under Skövde Energi Elnät’s 2024 tariffs. The flat scenario has the highest total cost; while it eliminates demand peaks and minimizes subscribed power capacity charges, its evenly distributed profile shifts a substantial portion of charging to hours with higher wholesale prices. Because wholesale energy constitute the largest component of total cost, the Flat scenario performs poorly despite its low network-tariff charges.

The Peak-shaving scenario lowers subscribed-capacity charges via a 10% peak reduction, while slightly increasing energy costs due to load redistribution. The net effect is a lower total cost than Baseline, showing that modest intra-day load adjustments can reduce costs without major operational changes (see also [Table 3](#)). The analysis does not identify the cost-minimizing profile, but Peak-shaving illustrates how tariff structures can create economic incentives for temporal load shifting.

[Figure 3b](#) compares Baseline costs across DSO concession areas within the Skövde municipal area. This illustrates the user cost implications of relocating the bus charging in Skövde (i.e., relocating the bus depot) to an adjacent service area. Despite common wholesale prices across these areas, total electricity costs differ substantially among DSOs due to tariff structure differences. The lowest-cost DSO (Skövde Energi Elnät) is 46% below the highest-cost DSO (Sjogerstads Elektriska Distributionsförening). These differences illustrate the potential for spatial load shifting, if charging opportunities were available in neighboring concession areas even within

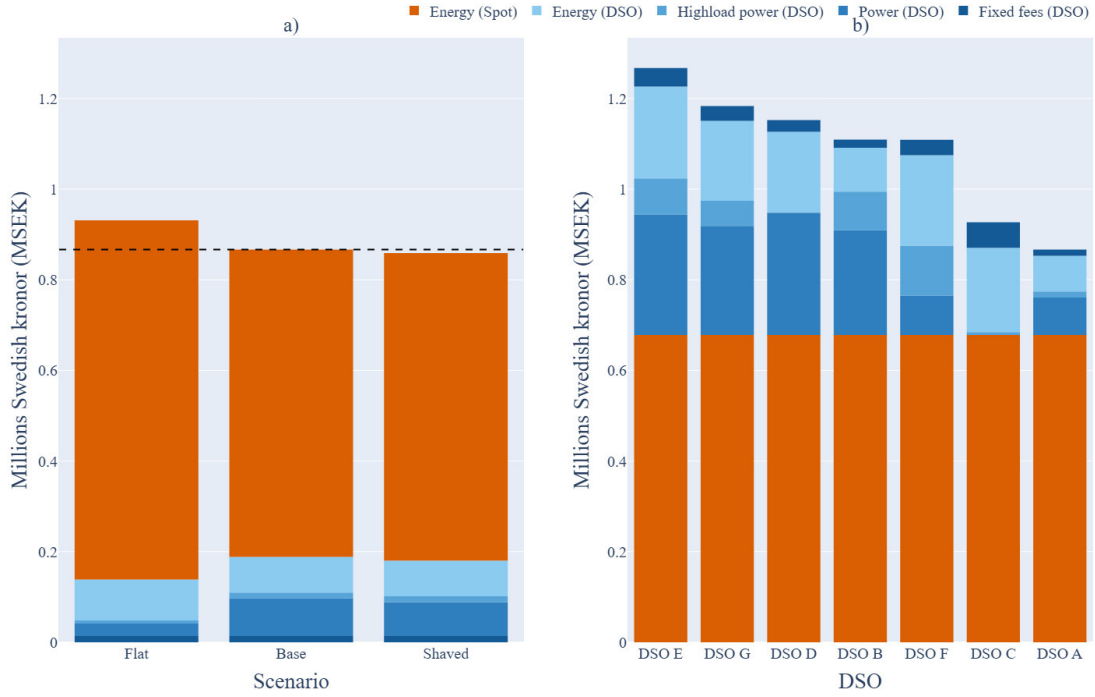


Figure 3. (a) Scenario cost comparison for Skövde Energi Elnät tariffs (2024): the Flat scenario has the highest total cost due to increased consumption during high-price hours, while Peak-shaving achieves the lowest total cost via reduced subscribed power capacity charges. (b) Spatial cost comparison for the Baseline scenario across DSOs in the Skövde municipal area: Skövde Energi Elnät exhibits the lowest cost; Sjögerstads Elektriska Distributionsförening the highest (difference 46%). Differences reflect DSO-specific tariff structures; wholesale prices are uniform across SE3.

Table 3. Resulting annual cost for DSO grid tariffs as well as wholesale energy prices, for the charging scenarios for Skövde Energi Elnät (DSO A) as well as the different DSOs for the Base scenario. Costs in SEK; energy prices from SE3 (2024). Mapping between short name and true DSO name is found in [Table 1](#).

Scen.	DSO	DSO tariffs			Energy	Total	Wholesale Energy	All Total
		Fixed fees	Sub. power capacity	High load power				
Flat	DSO A	13 785	27 404	6 814	90 665	138 668	792 627	931 296
Shaved	DSO A	13 785	74 524	13 258	78 908	180 475	678 614	859 089
Base	DSO A	13 785	82 832	13 258	78 545	188 421	678 206	866 627
Base	DSO B	18 000	231 128	85 104	96 926	431 158	678 206	1 109 364
Base	DSO C	56 193	0	6 450	185 904	248 547	678 206	926 752
Base	DSO D	25 830	269 872	0	178 343	474 045	678 206	1 152 251
Base	DSO E	40 894	265 864	79 908	202 476	589 142	678 206	1 267 348
Base	DSO F	34 244	86 840	110 220	199 667	430 971	678 206	1 109 177
Base	DSO G	32 400	240 480	55 542	176 661	505 083	678 206	1 183 289

a single municipal area. Wholesale energy costs could be minimized by temporal load shifting, but the effect would be identical in any of these network areas; by contrast, the tariff structures of different DSOs play a bigger role in encouraging spatial load shifting.

Overall, tariff design significantly affects charging costs and incentives for flexibility. Wholesale price variation dominates total costs and creates incentives for temporal load shifting, while network-tariff structures

(particularly subscribed power capacity charges) influence the economic value of peak-shaving measures, and encourage spatial load-shifting, where possible. More targeted tariff designs could improve alignment between user economic incentives and distribution-grid conditions.

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