# Smart-charging of EVs:
## Coordinated energy consumption through Tibber's digital platform

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October 22nd, 2020

# Energimarked 2.0


- Tibber customers offer flexibility

- Flexible devices are controlled by Tibber
  - EVs and domestic appliances

- Potential value of flexibility
  - Price-optimization (day-ahead market)
  - Fast frequency reserves (TSO)
  - Local grid (DSO)

# Related works

Norwegian School of Economics
Bergen, Spring 2019

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## Market Evaluation for the Business Model of an Electric Vehicle Aggregator

*An Analysis of the Value of Flexibility in the German Power Markets*

**Marius Zipf**

**Supervisor: Mette Helene Bjørndal, Endre Bjørndal**

Master Thesis in the MSc. in Economics and Business Administration, Major in Energy, Natural Resources and the Environment

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MASTER'S THESIS

## Giving Way: Electric Vehicles and Automated Load Shifting

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## End-User Flexibility in the Local Electricity Grid – Blurring the Vertical Separation of Market and Monopoly?

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**Abstract**

*In the Norwegian electricity system, new consumption patterns and changing load profiles increase an already apparent need for reinvestment in the aging network infrastructure. This is very costly, and network operators consider alternative ways of increasing capacity, which are less costly and more flexible. One such option is end-user flexibility. In the paper, we give an overview of the Norwegian electricity market and regulation and the potential of end-user flexibility. We present an investment case provided by a network company, which illustrates that the choice of compensation method to customers have a large impact on the cost and/or revenue cap in the regulatory model. By issuing direct payments for flexibility services, end-user flexibility results in a lower efficiency, although the revenue cap may be higher, while redistribution of network tariffs have a marginal effect on efficiency and the revenue cap. Through redistribution of network tariffs, the network operator can defer investments without a notable change in the revenue cap or change in efficiency. This highlights some of the future challenges that the regulator faces in setting a regulatory framework for end-user flexibility and it challenges the vertical separation that has been a corner stone in the deregulated electricity market.*

### 1. Introduction

The unique physical properties of electricity define how electricity systems are designed. Since supply and demand must be perfectly balanced at all times, changes in demand must be matched by a similar change in supply. Furthermore, the electricity system is built to be a redundant network. To ensure a reliable electricity supply and a sufficient safeguard against loss of power, network operators determine investments based on the hours of peak load in a year. This often results in significant investments in network capacity to ensure that reliability and safety standards are met. Thus, optimizing investment decisions through smarter electricity system solutions is highly prioritized by Norwegian network operators.

The global trends of electrification, decentralization and digitalization increase the focus on finding innovative ways of planning and upgrading the electricity system infrastructure. The trends introduce a plethora of new solutions to the network operator. To ensure a secure and stable supply of electricity, exploiting flexible resources and capabilities in the electricity system is highlighted as a promising way forward. However, utilizing flexible capacities in the electricity system is not a new concept. With a tight relationship between supply and demand, flexible generation and production has been implemented by large generators and producers at the transmission level of the Norwegian electricity systems for several years. Since technological advances mainly occur at the distribution level of the electricity system, there is a large, untapped potential in utilizing flexibility at the end-user level. This type of end-user flexibility can be used to shift consumption in periods of peak-load, mitigating the need for costly investments in network infrastructure.

With an increasing share of decentralized energy production, Europe's highest EV penetration rate and an aging and mature infrastructure, new and cost-efficient ways of securing sufficient capacity is a priority. On the other hand, the Norwegian electricity system is well equipped for the challenges of the

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## Smart Charging of Electrical Vehicles: Coordinated Energy Consumption Through a Digital Platform

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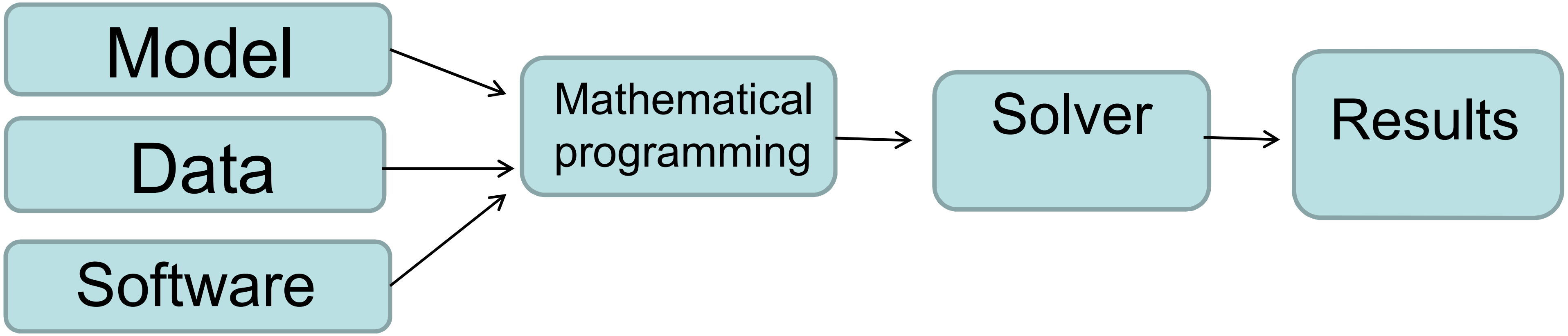
**Abstract:** With the penetration of electric vehicles (EVs) growing considerably, it is important to understand the implications of different charging mechanisms in the grid operation and in the budget of users. The progress on smart meters and digital platforms provides great opportunities not only to better analyze the behaviour of energy consumers, but also to coordinate the efforts of different stakeholders towards a more efficient pattern of energy consumption.

In collaboration with Tibber, an energy aggregator which has created the first fully digital energy platform in the world, we conduct an empirical study analyzing data on 438 EVs over a period of 3,687 consecutive hours (five months). Our study is based in Norway, the country with the largest fleet of plug-in electric vehicles per capita and with the largest plug-in car segment market share in the world. We first develop an optimization model to compute an ideal scheduling plan to address the charging requirements of all EVs in the dataset at minimum cost, under some idealistic but mild assumptions. Then, we compare the realized plans against this ideal solution, distinguishing users who use a *smart-charging* functionality of the digital platform with those who do not use it. Our findings indicate that the smart-charging behaviour conduces to considerably better results than the *non-smart* charging behaviour, and close to the idealistic optimal solution. More specifically, the smart-charging solution lies within 3% gap from the ideal solution, while the non-smart solution is around 10% more expensive. We also conduct simulations to back-up our empirical results and to estimate the effect of different shares of non-smart behaviour in the overall cost of the solution. The non-smart behaviour is characterized by the majority of users starting to charge as soon as they plug-in their EVs. This often occurs at peak consumption times, negatively affecting the grid in terms of congestion and also the consumers' budget, since the energy consumption is more expensive at these peak times. In contrast, the smart-charging strategy usually shifts the charging schedules towards times where the consumption is cheaper and the grid is less congested. We illustrate this effect by incorporating into the analysis data from the distribution system operator and computing standard metrics on efficiency. The results indicate that smart-charging positively contributes to efficiency, illustrated in a load factor of 87.5%, which is very close to the 88.2% achieved by the ideal solution. In contrast, the non-smart behaviour conduces to a load factor of 85.1%, which is far by about 3.5% from the load factor achieved by the ideal solution. The non-smart solution also implies higher power losses than the smart-charging behaviour.

In conclusion, our article contributes with a pioneer piece of evidence on the economic impact of the charging behaviour of EV owners and their implications in the congestion of distribution grids. Also, our article contributes to highlight the positive role of energy aggregators and digital platforms in coordinating users to lower the cost and enhance efficiency of energy consumption.




Objective function: Minimization of total charging cost

$$\min z = \sum_{k \in K} \sum_{a \in A} \sum_{t \in T} p_{t,a} \cdot b_{k,a} \cdot x_{k,t}$$

Constraints

$$s_{k,i}^{start} + \sum_{t \in \{i,\ldots,f\}} x_{k,t} = s_{k,f}^{end} \quad \forall (k,i,f) \in U$$

$$x_{k,t} \leq m_k \quad \forall k \in K, t \in T$$

$$\sum_{k \in K} x_{k,t} \leq c_t \quad \forall k \in K, t \in T$$

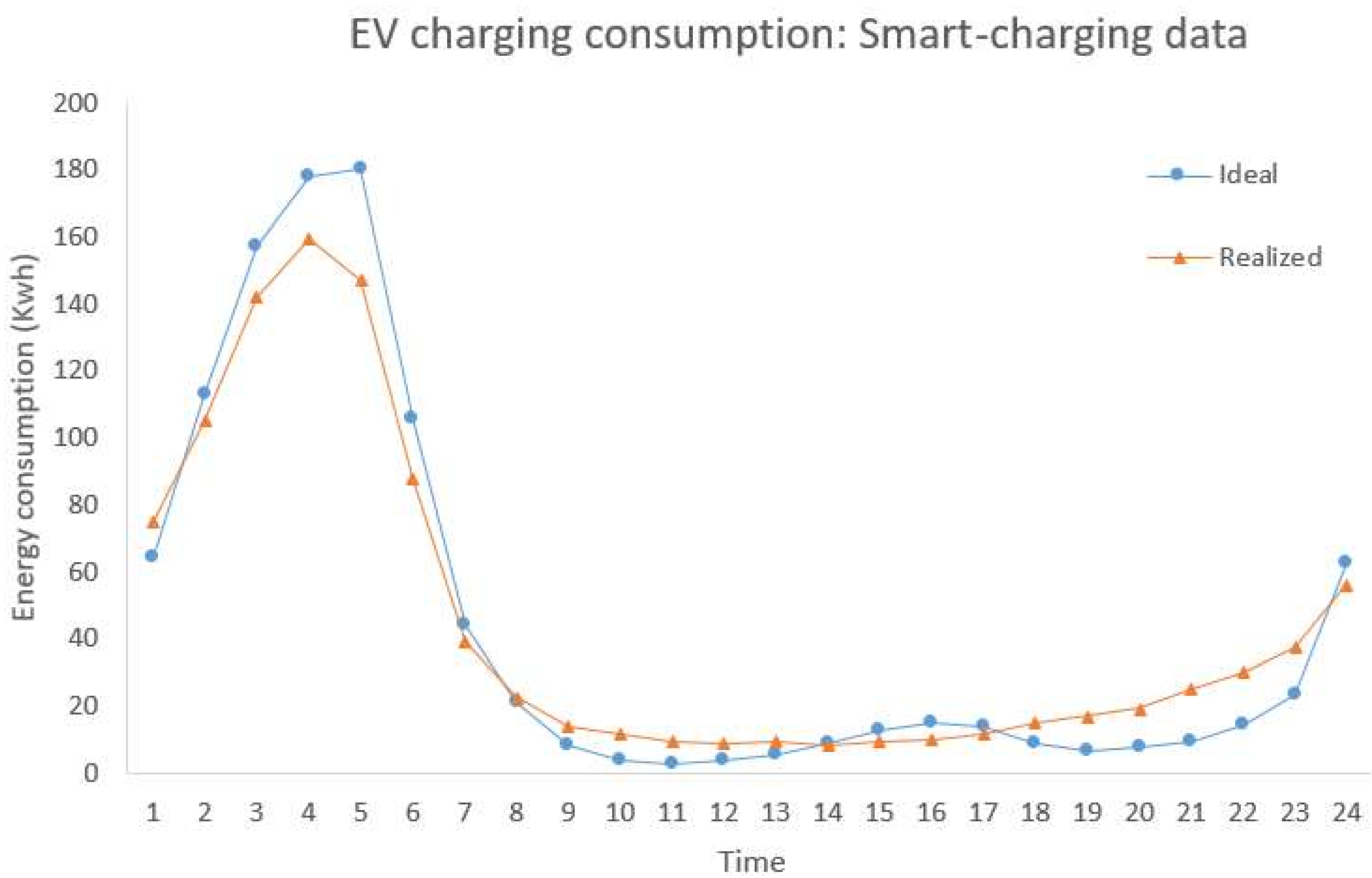
$$x_{k,t} \geq 0 \quad \forall k \in K, t \in T$$

- 438 EVs
- 3,687 consecutive hours (5 months)
- Smart-charging

  &

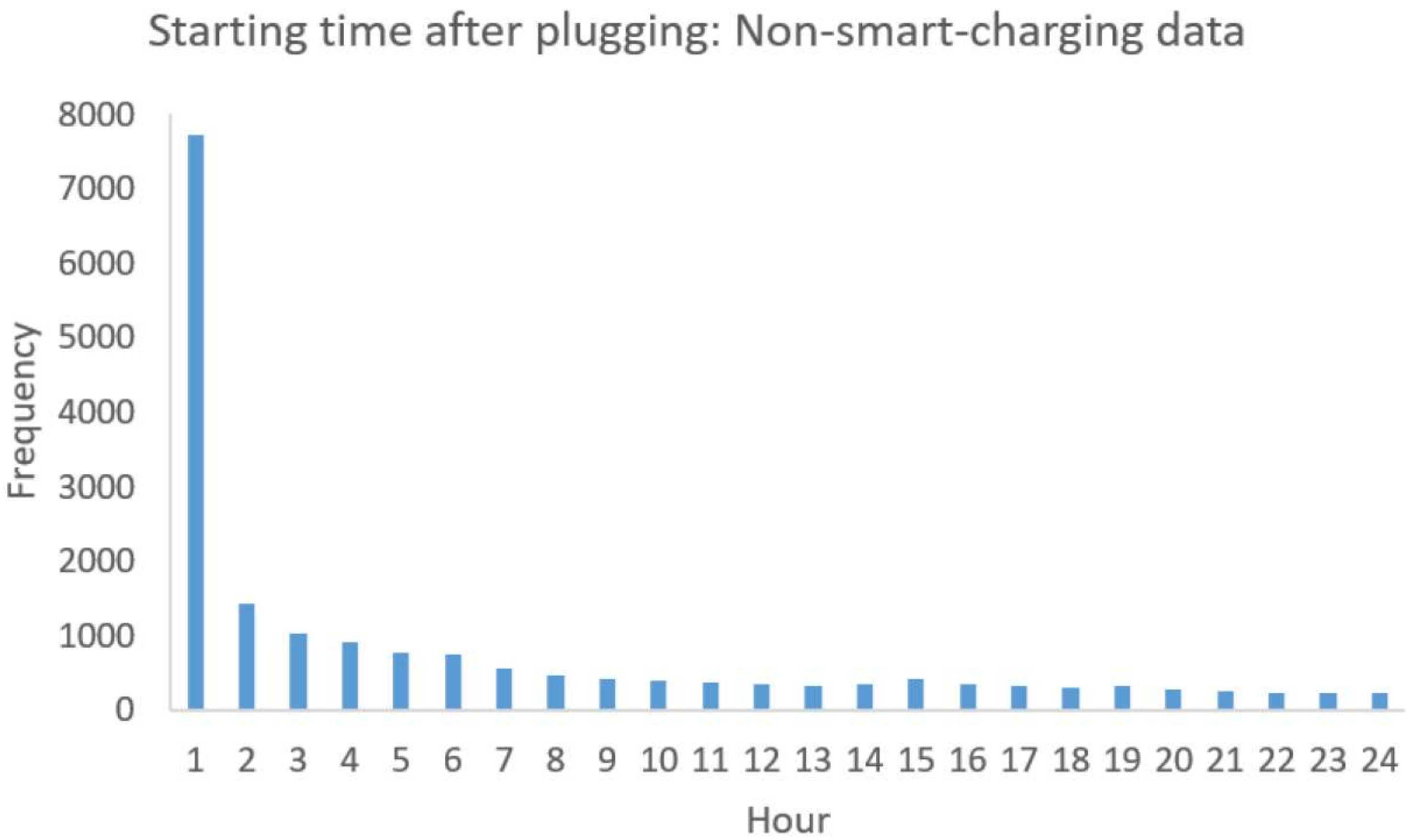
  Non-smart-charging

# Summary of Results: Smart-charging data Ideal vs Realized

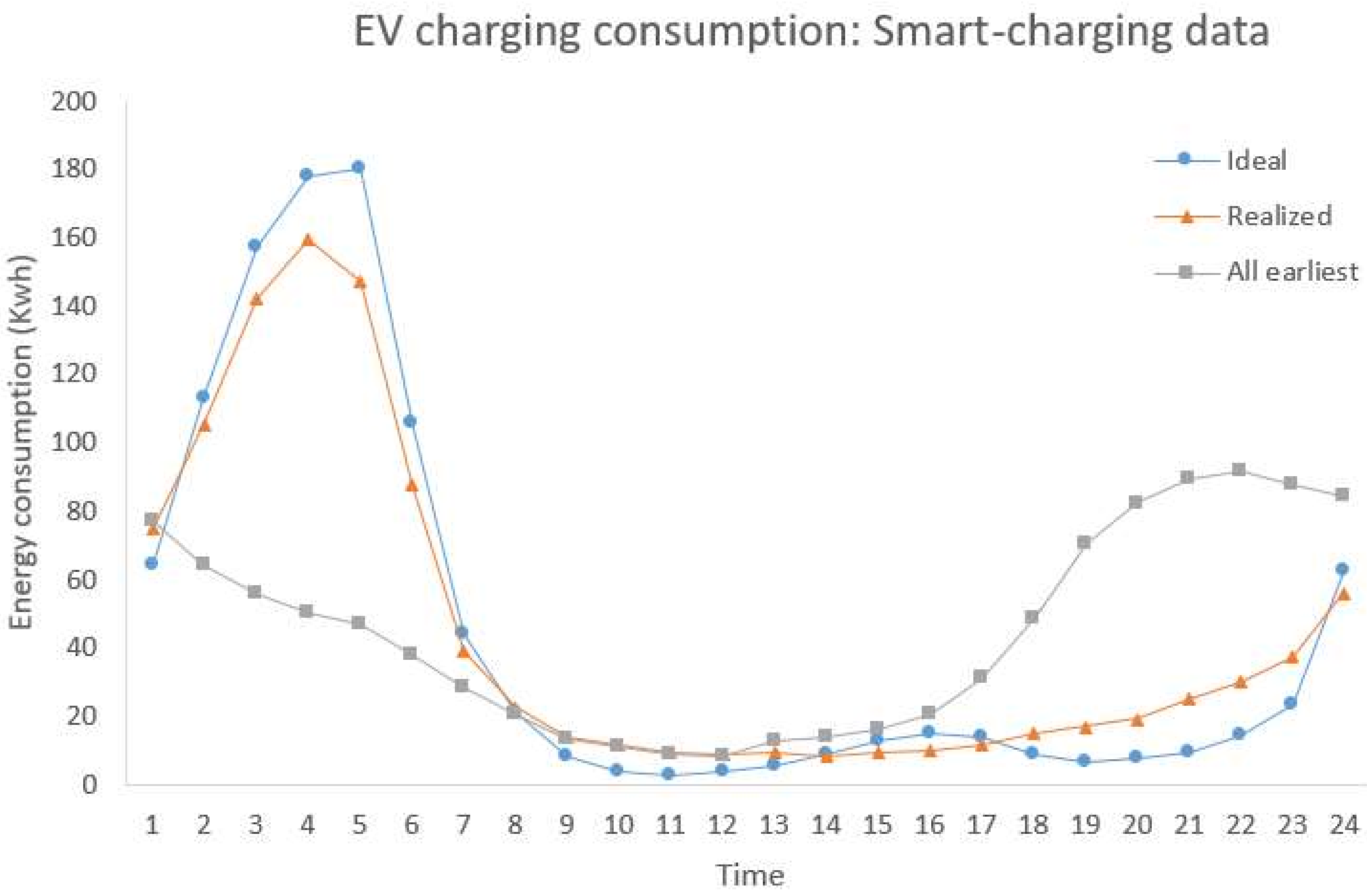



- Possible explanation: max charging power per time period, time horizon, the model allows for flexible ON-OFF-ON sequences…

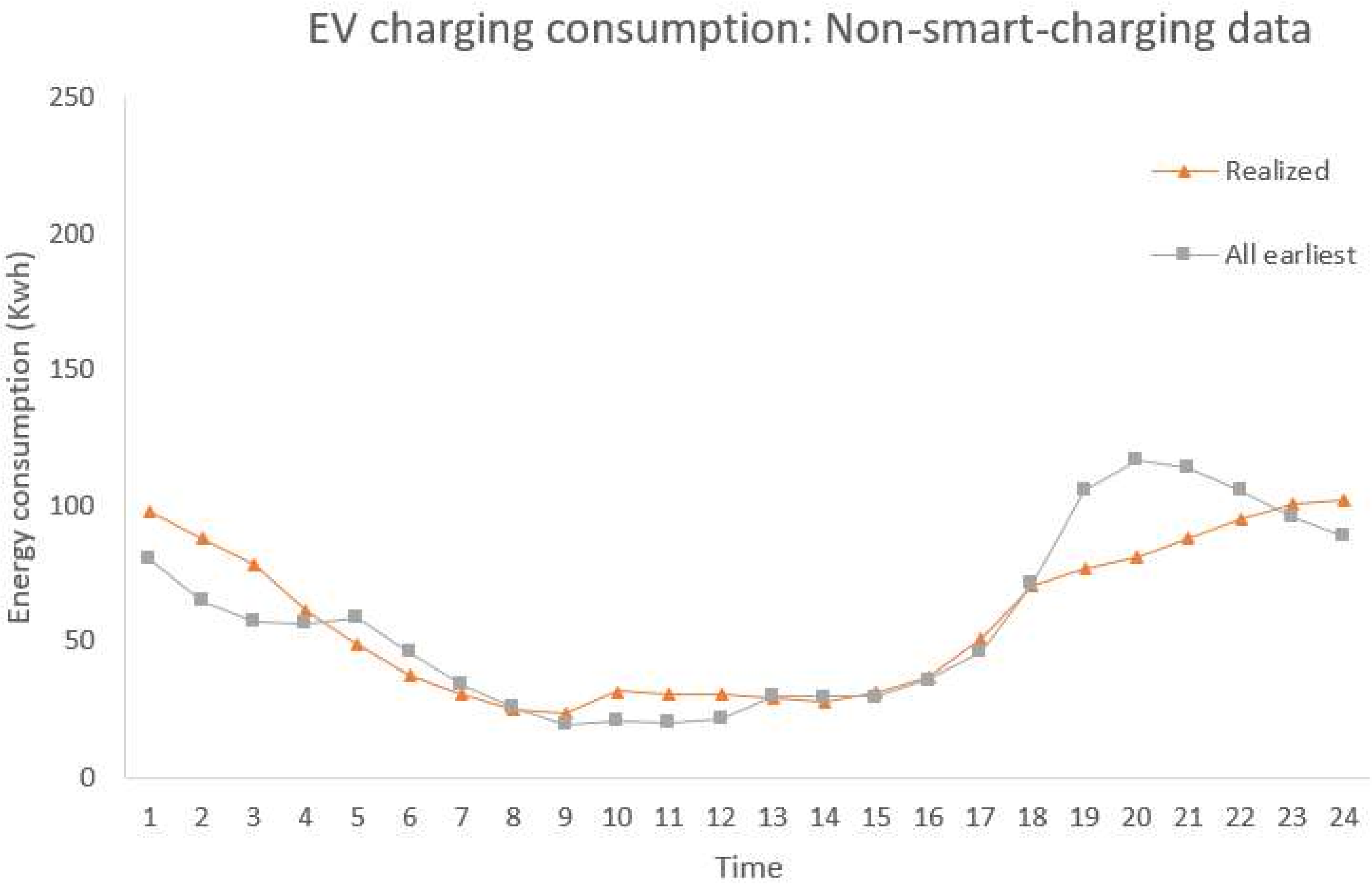
# Summary of Results: Non-smart-charging data "All-earliest" strategy



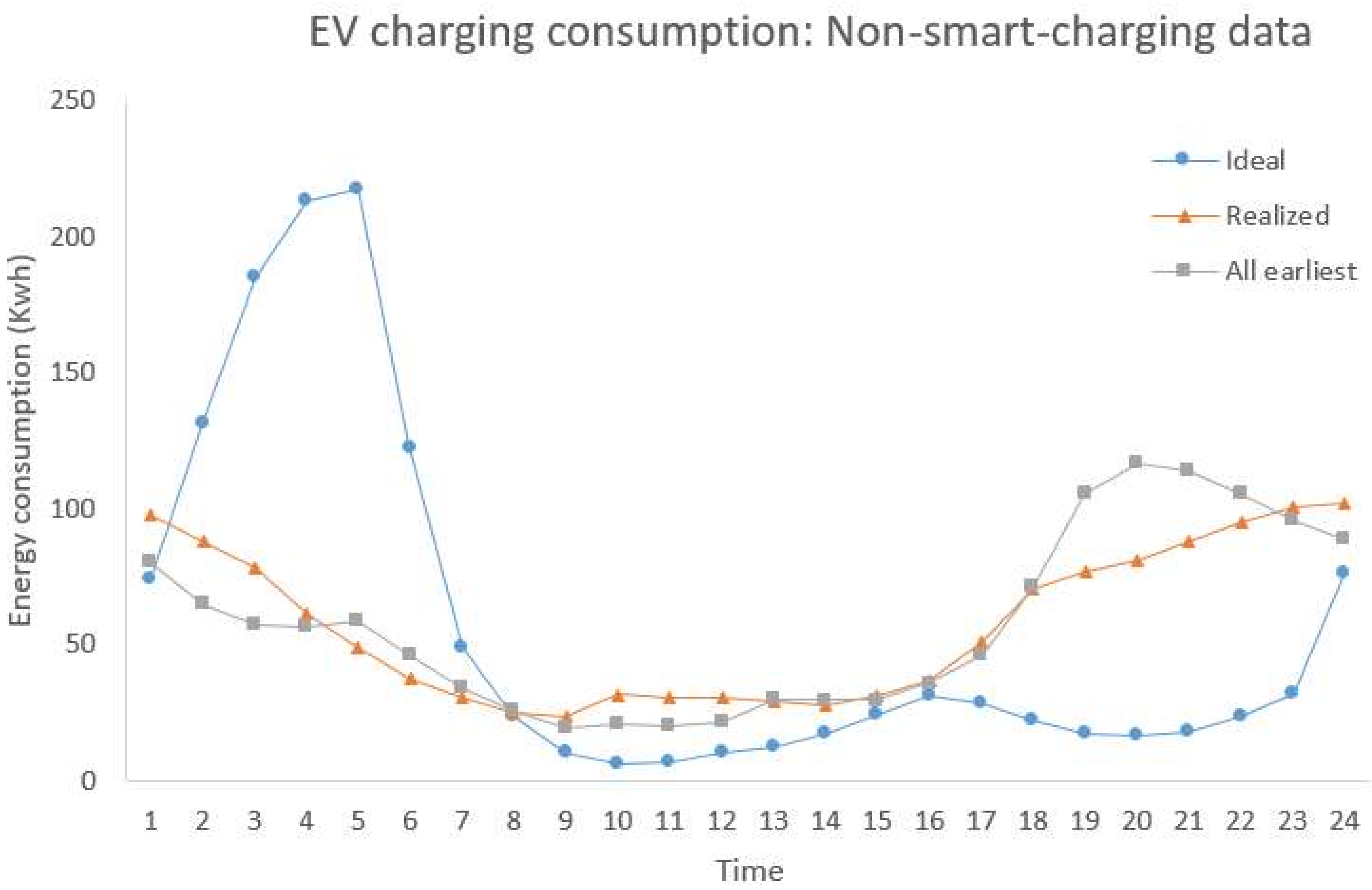
# Summary of Results: Smart-charging data Ideal vs Realized vs All-earliest



# Summary of Results: Non-smart-charging data Realized vs All-earliest



# Summary of Results: Non-smart-charging data Ideal vs Realized vs All-earliest

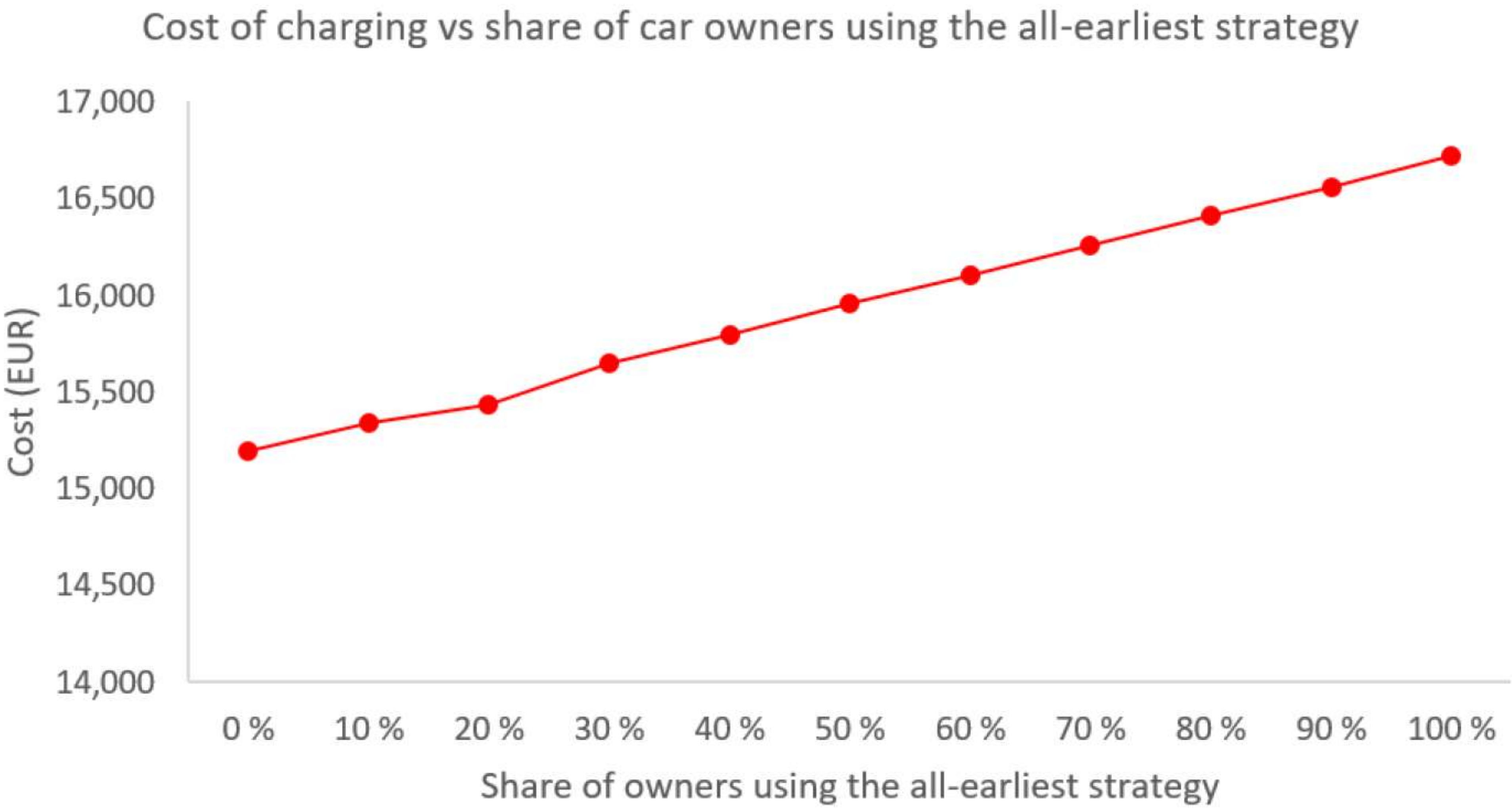


# Summary of Results: Cost analysis

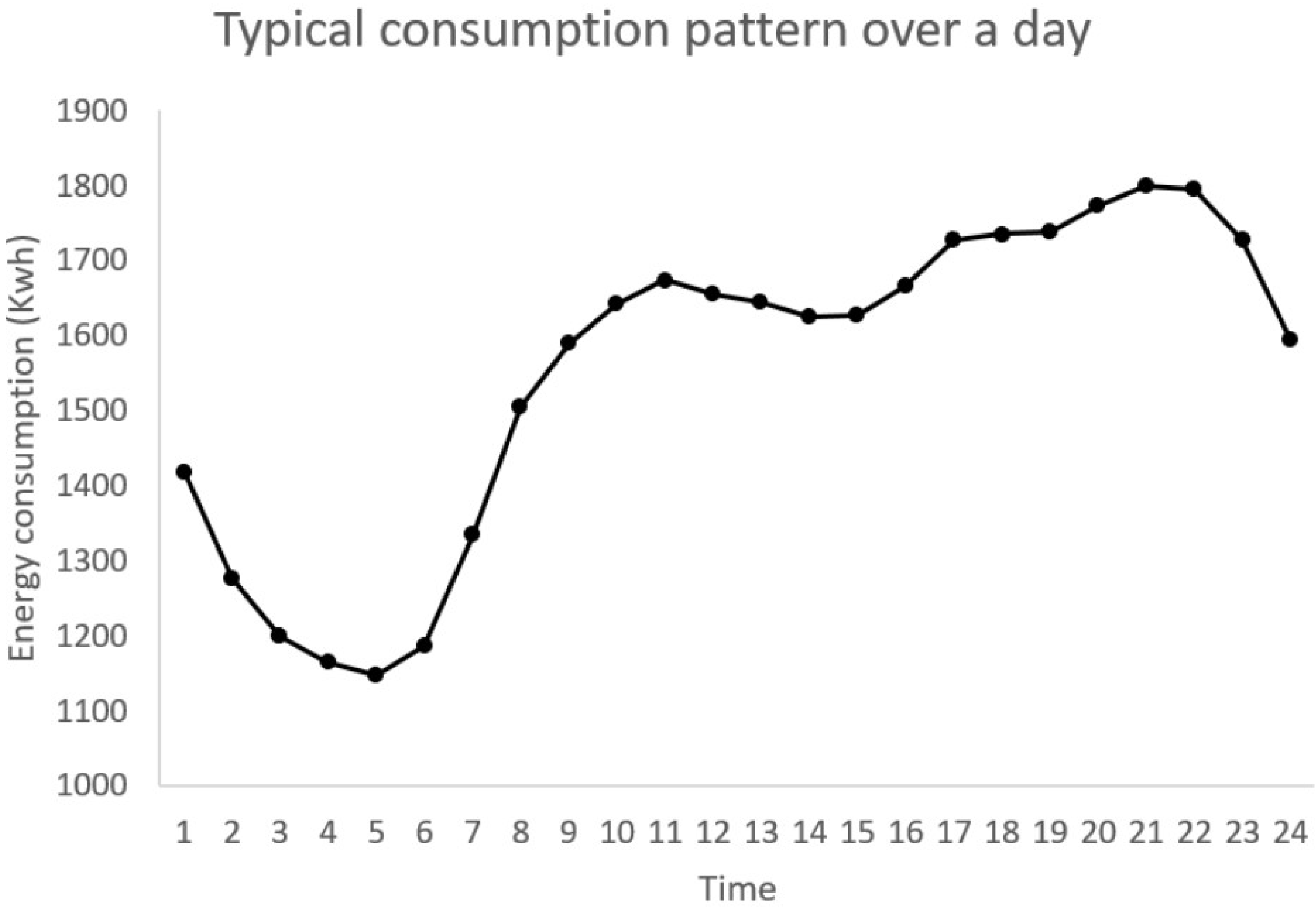
| | | Cost (EUR) |
|---|---|---|
| Smart-charging data | | |
| | Ideal | 6,435 |
| | Realized | 6,626 |
| | All earliest | 7,144 |
| Non-smart charging data | | |
| | Ideal | 8,773 |
| | Realized | 9,553 |
| | All earliest | 9,587 |
| All data | | |
| | Ideal | 15,192 |
| | Realized | 16,179 |
| | All earliest | 16,718 |

- **Smart-charging** solution is very close to the ideal solution computed by our model: gap **3%**.
- In contrast, the **non-smart** and all-earliest solutions are about **10%** more costly than the ideal solution.
- **Worst-case** scenario (max cost): **17.8%** far from the ideal solution.

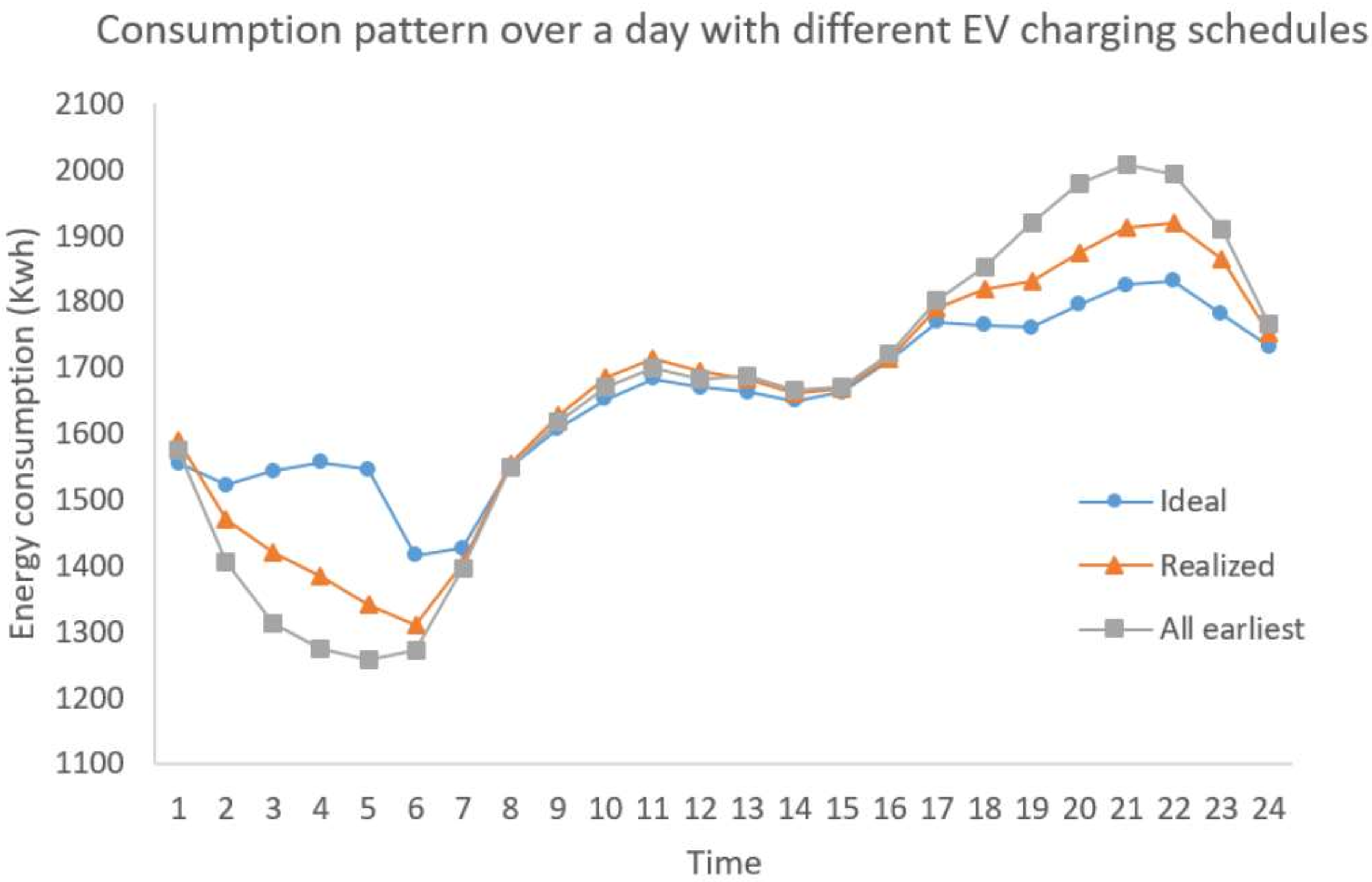
# Summary of Results: Simulations
# Two shares of users: ideal and all-earliest



# Summary of Results: Peak-shaving
# Illustrating the effect on the grid



# Summary of Results: Peak-shaving
# Illustrating the effect on the grid



# Summary of Results: Load factor, Power losses Illustrating the effect on the grid

| | | Load factor (%) | Power loss (Kwh) |
|---|---|---|---|
| Smart-charging data | | | |
| | Ideal | 88.2 % | 510 |
| | Realized | 87.5 % | 511 |
| | All earliest | 84.5 % | 515 |
| Non-smart charging data | | | |
| | Ideal | 88.5 % | 518 |
| | Realized | 85.1 % | 522 |
| | All earliest | 84.1 % | 523 |
| All data | | | |
| | Ideal | 90.2 % | 545 |
| | Realized | 86.1 % | 548 |
| | All earliest | 82.4 % | 553 |

# Concluding remarks

- Through optimization techniques and an empirical study, we are able to conclude that smart-charging performs considerably better than the non-smart-charging strategy.

- Evidence on the important effect of an energy aggregator to coordinate energy consumption: less cost for the users, more efficient grid operation.

- Important findings foreseeing higher penetration of EVs.

- Future research ideas: cost/revenue sharing, incentives, newsvendor model, storage & sell-out capacity.