Benefits of Dynamic Electricity Tariffs for Industrial Companies in Germany

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***Abstract*—In view of the increasing volatility and uncertainty in the German electricity system, new ways of providing flexibility must be found. In particular, industrial companies could potentially play a significant role in demand-side flexibility as they are the largest consumers of electricity in Germany. This paper investigates the potential benefits of using battery energy storage (BESS), photovoltaic (PV) and dynamic electricity tariffs in industrial companies to reduce costs and how this affects electricity consumption. Realistic load profiles of small and medium-sized German companies are used as input data. The results show that the implementation of BESS, PV and the use of dynamic electricity tariffs can significantly reduce the total annual costs of industrial companies. One of the main reasons for this is a reduction in grid charges. The results indicate that by taking advantage of atypical grid usage, the total grid fee revenues received by the grid operator could be significantly reduced. Therefore, an adjustment of existing mechanisms is most likely required to avoid an unfair distribution of grid-related costs among different stakeholders.**

***Index Terms*—Battery Energy Storage Systems, Industrial Companies, Grid Fees, Optimization**

I. INTRODUCTION

With the increasing penetration of intermittent renewable energy sources (RES), the need for flexibility in the German electricity grid increases. Although in the past flexibility was mainly provided on the supply side, the amount that can be provided in this way will decrease in the next decades. Therefore, the German grid could benefit from demand flexibility. With more than 40% of the total German electricity consumption coming from industrial companies [1], these companies represent a significant potential for flexibility [2].

As early as 1990, the concept of atypical grid usage was introduced in Germany to reduce load during peak demand periods. Grid operators define periods of peak demand and provide incentives for companies to shift their load to periods of low demand. As a reward for being grid-friendly, these companies can benefit from reduced grid charges [3]. To further incentivize industrial flexibility, dynamic electricity tariffs are now mandatory to offer as an electricity provider. In combination with battery energy storage systems (BESS) and photovoltaic (PV), this offers significant savings potential for industrial companies. The use of BESS by industrial customers has been extensively studied, while only a few studies have analyzed the benefits of atypical grid usage. In [4], the impact of incentives on the profitability of BESS is analyzed for two industrial customers in the US. They find that, depending on the state, current incentives may not be sufficient to encourage investment in storage. [5] examine different revenue streams of BESS in 50 different German small and medium enterprises. These revenue streams are peak shaving, primary control reserve (PCR) provision, and energy arbitrage trading through the intraday and day-ahead markets. According to their study, all revenue streams are necessary to achieve the most profitable business model. [6] analyze the profitability of intensive grid usage, atypical grid usage, and peak shaving for more than 5,300 German companies. Their study shows that intensive grid usage is the most profitable option, followed by atypical grid usage. [7] investigate the use of BESS in a bus depot to benefit from atypical grid usage for different scenarios. The objective of the following study is to analyze how BESS, PV and dynamic electricity tariffs can be used by industrial customers for cost minimization, considering the impact on grid charges and grid operators.

The paper is structured as follows. Section II introduces the model developed, as well as the data. Section III discusses the results and findings of the study. Lastly, concluding remarks and a critical reflection are given in section IV.

II. DATA AND METHODOLOGY

This study covers the load profiles of 25 real companies from three different sectors: Hotels, Car Dealerships, and Logistics Companies. It is ensured that none of the analyzed companies has installed BESS or PV yet. Due to computational time, quarter-hourly values are aggregated to hourly

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load profiles. For PV system sizing, the roof area of each company is assumed to be fully suitable for PV installation. A PV load profile was then generated using the PV*SOL simulation software, depending on the roof area and location of the company. It was assumed that all analyzed companies are located in the network area of the network operator Netze BW and are connected to the medium voltage network. Therefore, the data for high demand periods (HDPs) was assumed to be the information provided by Netze BW. Furthermore, day-ahead market prices from 2023 were used as the basis for a dynamic electricity tariff. They were topped up with the current fees and taxes, including the concession fee and the electricity tax, which total 1.49 ct/kWh [8]. Table I shows the assumptions made for the PV and BESS parameters.

TABLE I
PV AND BESS PARAMETERS

Technology	Invest	Maintenance cost	lifetime
PV	1200 €/kWp	8 €/kWp	20 a
BESS	300 €/kWh	5 €/kWh	10 a

These data were then used for the optimization model, which has the objective of minimizing costs, as can be seen in Eqs. (1–5).

A. Model

Model The optimization model chooses how much of the available roof area to use for the PV system. The model also decides how many BESS modules to install, with each module having a capacity of 100 kWh. The objective function minimizes the total annual cost of the PV system, BESS, and electricity.

$$\min(c^{PV} + c^{BT} + c^{elec} + \rho) - R \tag{1}$$

where

$$c^{PV} = \left(\frac{I^{PV} \cdot A^{PV} \cdot P^{PV}}{L^{PV}}\right) + (M^{PV} \cdot A^{PV} \cdot P^{PV}) \tag{2}$$

$$c^{BT} = \left(\frac{I^{BT} \cdot N^{BT} \cdot C^{max}}{L^{BT}}\right) + (M^{BT} \cdot N^{BT} \cdot C^{max}) \tag{3}$$

$$c^{elec} = \sum_{t=1}^{T} (\delta_t^{BT} + \delta_t^{load}) \cdot (p_t^{spot} + fees) \tag{4}$$

$$R = \sum_{t=1}^{T} PV_t^{grid} \cdot p^{spot} + \sum_{t=1}^{T} bd_t^{grid} \cdot p^{spot} + R^{atyp} \tag{5}$$

To calculate the annual PV costs, I^{PV} being the investment cost per kWp, A^{PV} being the roof area used, P^{PV} being the maximum power output are divided by the total expected lifetime of the PV system L^{PV}, which is assumed to be 20 years. The annual maintenance costs for the installed area are added with M^{PV} being the maintenance cost per kWp per year.

The annual battery costs are calculated accordingly with I^{BT} being the investment cost per kWh, N^{BT} being the number of installed battery modules and C^{max} being the maximum capacity of each module, with the lifetime L^{BT} assumed to be 10 years.

The electricity costs result from the sum of the grid consumption for battery charging δ_t^{BT} and load coverage δ_t^{load}, multiplied by the corresponding variable price elements in hour t. Finally, the grid fees ρ are added.

The revenues are coming from PV production PV_t^{grid} and battery discharge bd_t^{grid} that is fed into the grid. Since the grid fees are calculated as if the company does not apply atypical grid usage, the revenue coming from atypical grid usage R^{atyp} is the difference between the original capacity payments without atypical grid usage and the actual capacity payments coming from atypical grid usage.

B. Atypical Grid Usage

Atypical grid usage is a policy instrument designed to incentivize grid-friendly electricity consumption by businesses. The main objective is to encourage a shift of load from high demand periods, as defined by the grid operator, to low demand periods. This policy applies only if a company can reduce its peak load during peak hours by at least 100 kW compared to its peak load during off-peak hours. The company will then only have to pay the capacity price for the maximum peak load during the HDPs, making the peak load outside the HDPs financially irrelevant for the company. Since this could encourage a large increase in peak load outside of HDPs in order to achieve the minimum difference of 100 kW, the peak load must be capped as shown in Eq. (6).

$$P^{max} \leq P_o^{max} + P^{BT} \tag{6}$$

Eq. (6) limits the maximum peak load P^{max} to the sum of the maximum peak load of the original load profile P_o^{max} and the power of the installed battery system P^{BT}.

III. RESULTS

The following section presents two exemplary companies from each sector: one that cannot use atypical grid usage due to low load and one that can. Figure 1 shows the annual load profiles of these companies before and after optimization. Companies with insufficient load to meet the 100 kW minimum reduction required for atypical usage typically adopt a clear peak shaving strategy. This behavior is driven by the incentive of lower energy prices when the company exceeds 2,500 full load hours. However, when a company qualifies for atypical usage, the behavior of the model changes significantly. Not only does the maximum load increase significantly, but this increase is sustained throughout the entire time frame.

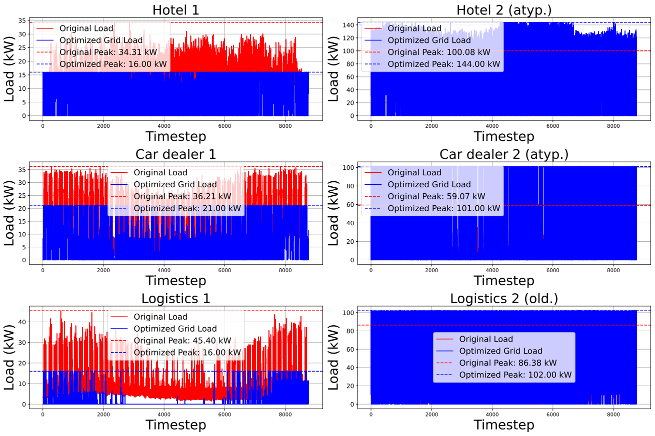

Fig. 1. Yearly load profiles of the original and optimized load

An analysis of the average daily load further highlights this behavior. As illustrated in Figure 2, organizations with atypical grid usage exhibit a distinct load pattern with two pronounced peaks: one occurring during the night and early morning, and another around noon. In contrast, organizations that do not use atypical grid usage experience an overall reduction in load.

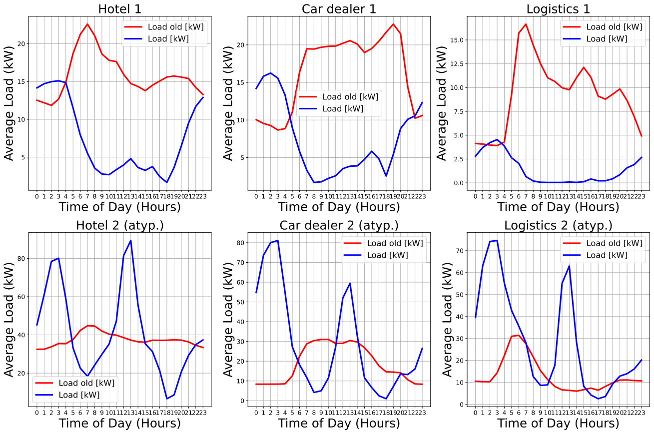

Fig. 2. Average daily load

Figure 3 presents the average load profile during HDPs, with the HDP window (7:15 AM – 5:15 PM [9]) highlighted in orange. During HDPs, companies utilizing atypical grid usage retain only the night and early morning load peak. However, as soon as the HDP window begins at 7:15 AM, all companies significantly reduce their load, with some reaching zero consumption. This phenomenon is primarily driven by the charging and discharging behavior of the installed BESS, as depicted in Figure 4.

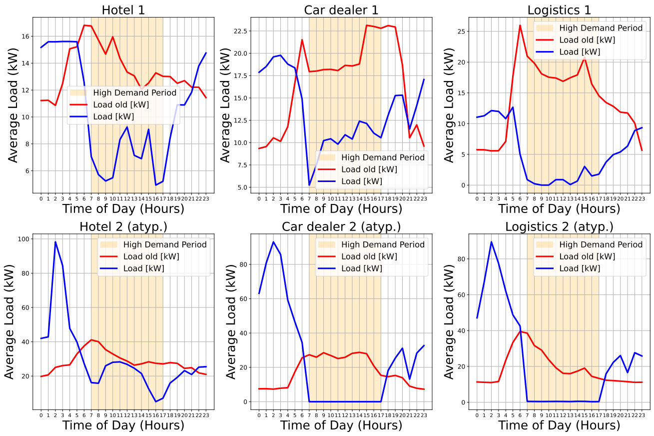

Fig. 3. Average daily load during HDP

Companies that cannot take advantage of atypical grid usage charge their BESS primarily during the day, coinciding with peak PV production and lower spot market prices. In contrast, companies that benefit from atypical grid usage maximize BESS charging during the night to ensure sufficient state of charge (SoC) at the beginning of the HDP window. This strategy allows them to reduce their load in the morning and late afternoon when PV production is insufficient to fully meet demand.

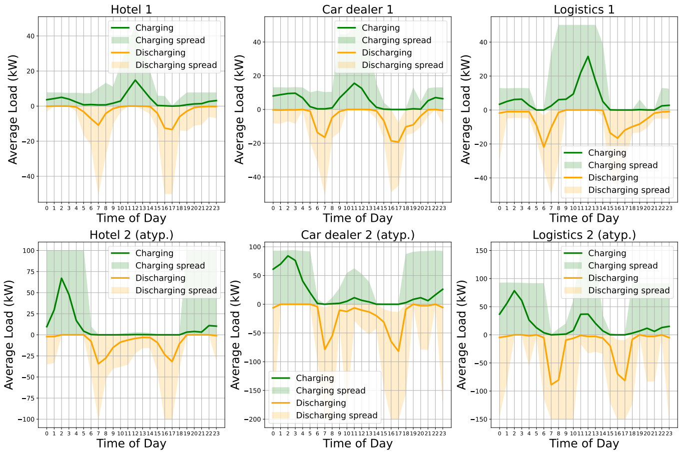

Fig. 4. Daily average charging and discharging behavior of the BESS

In Figure 4, the solid line represents the average charging and discharging pattern of the BESS, while the shaded regions denote the confidence interval.

The resulting impact on companies' total costs after optimization is illustrated in Figure 5. To assure a correct implication of dynamic electricity tariffs, the original electricity cost were calculated based on the mean Day-Ahead price of 2023.

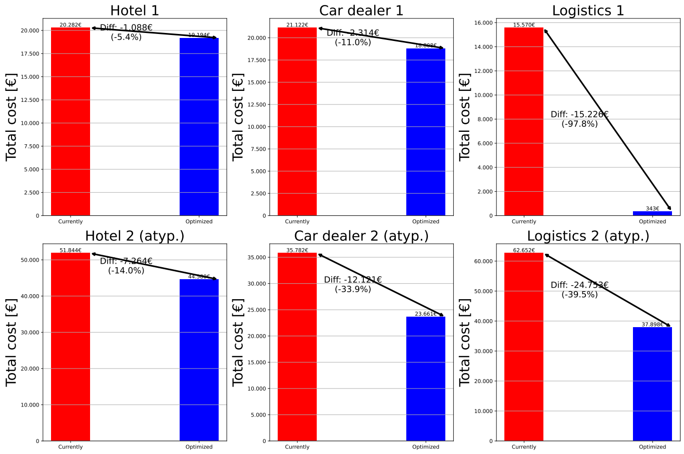

Fig. 5. Development of the companies total cost after optimization

It is evident that all companies can achieve a reduction in their annual costs; however, the magnitude of this reduction is highly dependent on the specific characteristics of each company. While smaller companies, such as Hotel 1 and Car Dealer 1, experience only marginal cost savings, larger companies benefit from double-digit cost reductions. Logistics 1 stands out in this regard. Despite being a relatively small company with a non-optimized peak load of 45.4 kW, its large rooftop area allows for optimal deployment of PV systems. Table II presents the total annual costs and the profits generated by Logistics 1 through electricity trading.

TABLE II
ANNUAL COSTS AND PROFITS OF LOGISTICS 1

Cost Components	**Value [€]**	**Profit Components**	**Value [€]**
PV System Cost	65,378.8	Battery Discharge Grid	1,433.46
Battery System Cost	3,500	PV Production Grid	69,604.67
Electricity Cost	1,120.35		
Grid Fees	1,383.06		
Total cost	**71,382.21**	**Total profit**	**71,038.13**

Although the initial investment in the PV system leads to a significant increase in costs, the company's relatively low energy consumption allows it to sell a substantial proportion of its electricity generation on the spot market. This trading activity offsets a considerable portion of the costs.

The reduction shows not only in total cost but also in the grid fees, as shown in Figure 6.

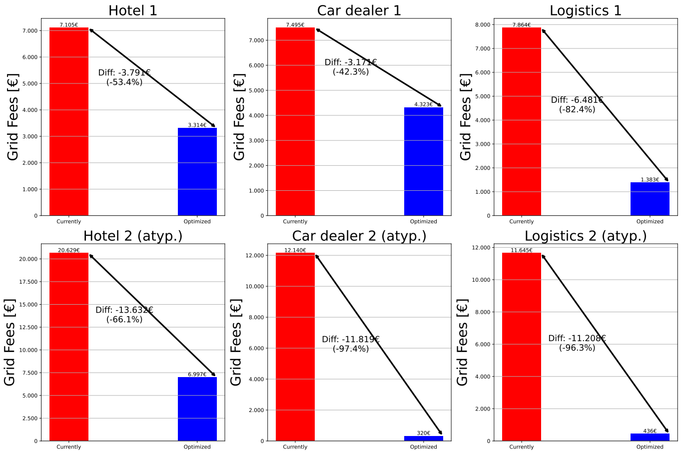

Fig. 6. Development of the companies grid fees after optimization

As observed, and under the assumption that the current methodology for calculating grid costs will not change due to the widespread adoption of PV and BESS systems by companies, all companies experience a significant reduction in grid fees. This effect is particularly pronounced for logistics companies, which have significant potential for cost savings due to their large PV capacity. Extensive PV deployment reduces their reliance on the grid, which in turn has a direct impact on grid fees. Large-scale deployment of PV, BESS and dynamic electricity tariffs could therefore lead to a potential need for grid operators to change their approaches to calculating grid fees.

IV. CONCLUSION

This study uses unique empirical data and proposes a novel methodology to evaluate the benefits of BESS, PV and dynamic electricity tariffs for industrial companies. Our results indicate that while all companies benefit from cost reductions, the magnitude of these savings varies depending on company-specific characteristics. Companies that do not meet the threshold for atypical grid usage focus primarily on peak shaving strategies to optimize their electricity costs. In contrast, companies that qualify for atypical use adopt a strong load-shifting strategy, significantly reducing their demand during high-demand periods (HDPs) while increasing their peak load outside of HDPs, thereby reducing their grid charges. The most pronounced cost reductions are observed in logistics companies due to their high PV potential, which reduces their dependence on grid-supplied electricity and increases their ability to generate revenue from electricity trading. Although the deployment of PV and BESS systems initially increases capital expenditures, our analysis confirms that the ability to sell excess electricity on the spot market and optimize grid fees offsets these costs in the long run. In addition, the widespread adoption of these technologies has broader implications for grid operators, as the reduction in grid fees could impact their revenue models. Future research should investigate the potential regulatory and economic consequences of large-scale industrial adoption of these flexibility measures. Furthermore, the model should be extended by implementing battery degradation and operational constraints, as well as simulating different price paths for future electricity prices. In conclusion, the integration of PV, BESS, and dynamic electricity tariffs offers a viable path for industrial companies to optimize their electricity costs while supporting grid stability. However, careful assessment of the regulatory framework and long-term grid impacts is necessary to ensure that these developments contribute to a sustainable and balanced electricity market.

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