SIMULATION BASED ASSESSMENT OF A VEHICLE-TO-BUILDING USE CASE FOR AN INDUSTRIAL SITE

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Abstract: The increasing number of battery electric vehicles and the related charging infrastructure is a big challenge for the energy system. At the same time this increase also brings up opportunities as the vehicle batteries can be used as energy storage. In the present paper a vehicle-to building (V2B) concept for an industrial site is investigated and compared with a stationary battery as alternative energy storage. Therefore, energy production and consumption data of this industrial site are evaluated and future scenarios with additional renewable energy sources considered. The energy surplus is evaluated for these different scenarios and based on that the dimensioning of the vehicle-to-building concept and battery storages is done. Finally, the net present value is calculated for these options.

Keywords: Vehicle-to-building, battery storage, industrial site, net present value

1 Introduction

The number of battery electric vehicles (BEVs) is strongly increasing and expected to reach 42% market share until 2030 in the EU [1]. This strong increase is a big challenge for the energy system but offers at the same time opportunities due to the usage of advanced charging concepts with different grid level integrations [2] as smart charging (V1G), vehicle-to-home (V2H), vehicle-to building (V2B) and vehicle-to-grid (V2G). Within the EU-project "XL-Connect" these possibilities are investigated and compared for different use cases. One example is a so-called virtual demonstration action for the company Neuman Aluminium in Austria. At this industrial site renewable energy production in combination with different storage and charging technologies are investigated.

In general, the company Neuman Aluminium, located in Lower Austria, produces aluminum parts and has an overall yearly energy demand of ~110,000 MWh. The energy demand in 2022/23 of the use case can be divided in ~36% electricity demand and ~64% natural gas demand. Neuman Aluminium employed two hydroelectric power plants with an overall size of 0.95 MWp and a photovoltaic (PV) system of size 1.1 MWp. Currently, these power plants produce 4,100 MWh/year. As the production covers only ~10% of the needed electricity, Neuman wants to increase their renewable energy production by employing additional PV systems (up to 4 MWp). In addition, the virtual demonstration action considers an additional scenario where two wind turbines (4.5 MWp each) are assumed. Therefore, three future scenarios for the virtual use case are elaborated (see **Table 1**).

	Scenario 0 (Status quo)	Scenario 1	Scenario 2	Scenario 3
Hydroelectric power plant	0.95 MWp	0.95 MWp	0.95 MWp	0.95 MWp
Photovoltaic system	1.1 MWp	1.3 MWp	4 MWp	4 MWp
Wind power station	-	-	-	9 MWp

Table 1: Neuman Aluminium Scenario Overview

In addition to the expansion of the renewable energy production of Neuman Aluminium, smart energy management systems will be analysed and discussed. Therefore, a V2B concept, where BEVs on the company parking lot are used as energy storage is explored. Further, the V2B is compared with a battery storage as alternative solution.

2 Methodology

In order to analyse the potential economic benefits of a battery storage and a V2B concept the four-step approach shown in **Figure 1** has been chosen. In a first step the energy production and consumption data of the industrial site are assessed. Based on that, the energy surplus is calculated and analysed for the whole year in the second step. In the third step the potential economic benefits of a V2B concept are investigated. Therefore, financial KPIs as the payback period, the return of investment and the net present value are calculated. Finally, in step 4 a stationary battery storage is investigated as alternative solution.

Figure 1: Work steps for the analysis of the Neuman Aluminium use case

3 Assessment of energy production and consumption data

The energy consumption data from Neuman Aluminium were assessed based on a 15 min interval for a whole year. For the energy production data models for the PV system and the wind power station have been established for the Neuman Aluminium location. The models provide the energy production based on the same 15 min interval as the consumption data. For the hydroelectric power plant, the sum of the monthly energy production was available and was evenly spread to the 15 min intervals of each month. All the production and consumption values were averaged for a week, but it was distinguished between “summer” (March to August) and “winter” (September to February) as there are significant differences in the renewable energy production.

Figure 2 shows the energy demand vs. supply for an average week in summer and winter for scenario 1. It can be seen that the energy demand is significantly higher than the energy supply, which leads to very few phases of energy surplus.[1] The status quo is very similar to scenario 1 with a lower peak power of the PV system. **Figure 3** depicts the cumulated energy

[1] Note that only the electricity demand is presented.

surplus for one year per weekday for scenario 0 & 1, which confirms that the major part of the energy surplus occurs on the weekend - especially on Sundays – as here the energy demand is much lower than during working days. Also Saturdays and Mondays show some energy surplus as here the production is ramped down and up and thus the energy demand is also lower.

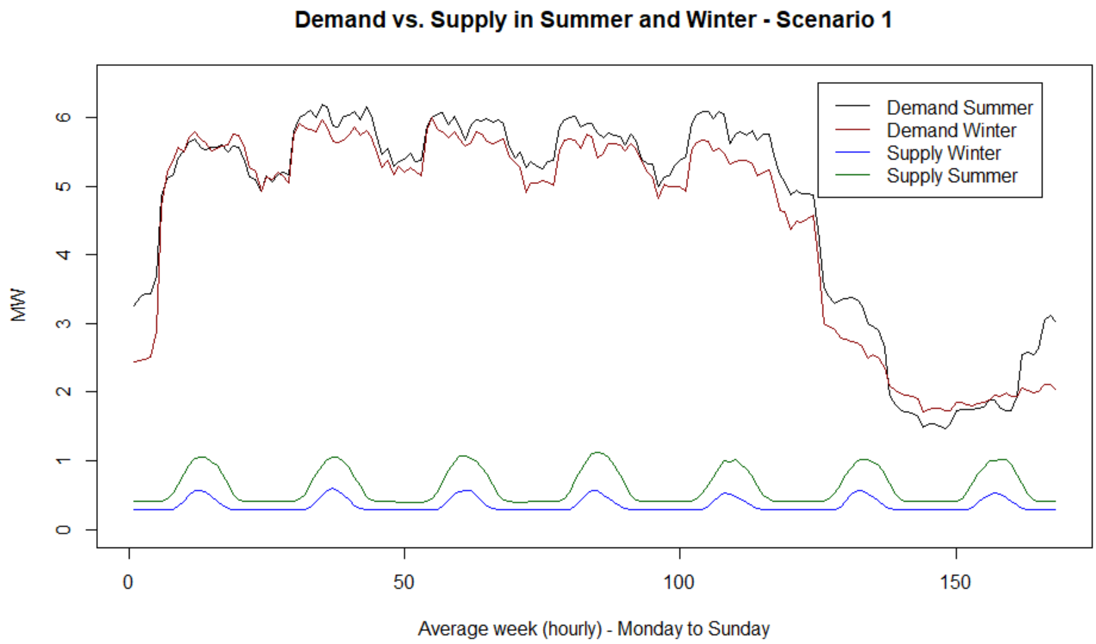

Figure 2: Energy demand vs. supply for an average week in summer and winter for scenario 1

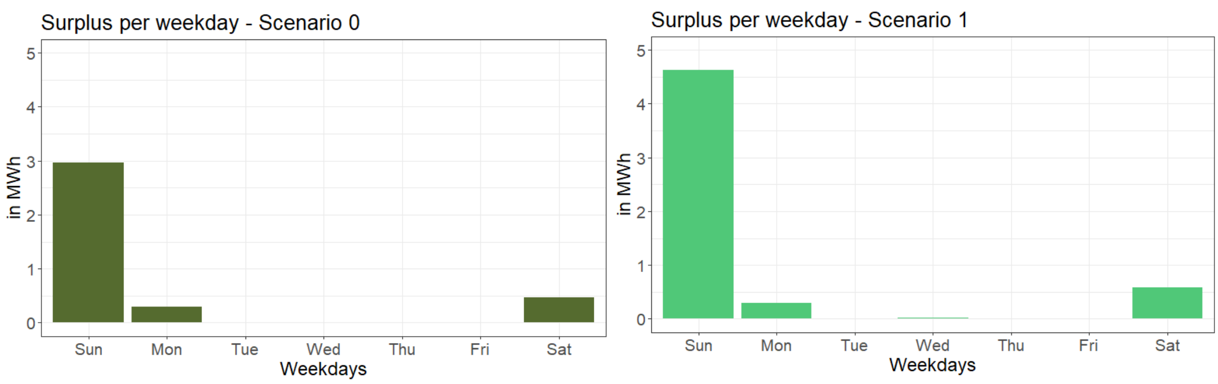

Figure 3: *Cumulated energy surplus for one year per weekday for scenario 0 & 1*

Having a look at the average week in summer and winter for scenario 2 (**Figure 4**), it can be seen that in the summer case the average week has a surplus on Sundays, where the PV production is higher than the energy consumption. For scenario 3, including the wind power stations with 9 MWp, the surplus on Saturdays and Sundays gets significantly higher for the average week in the summer and winter case (**Figure 5**).

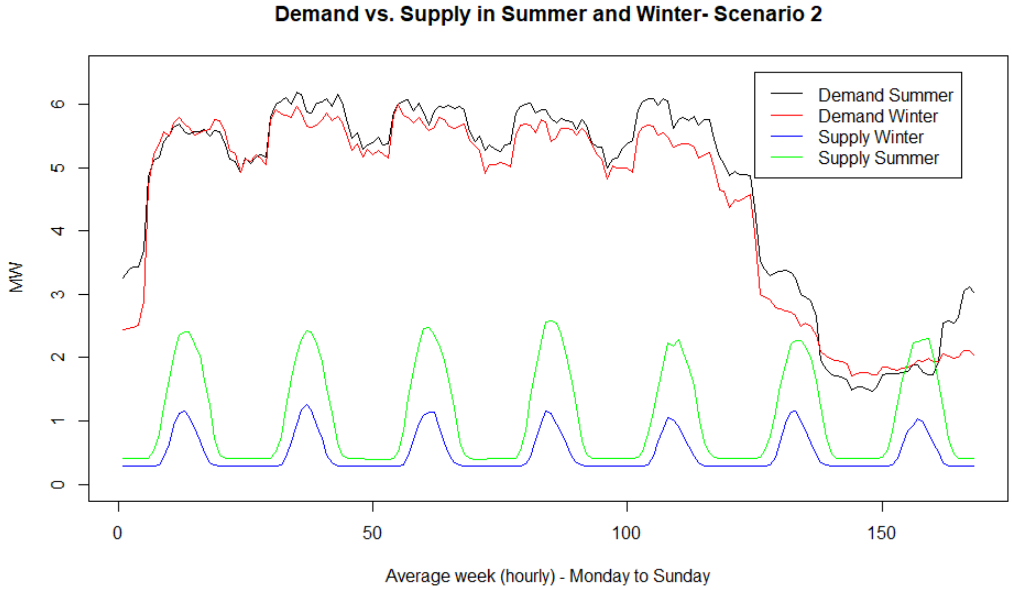

Figure 4: *Energy demand vs. supply for an average week in summer and winter for scenario 2*

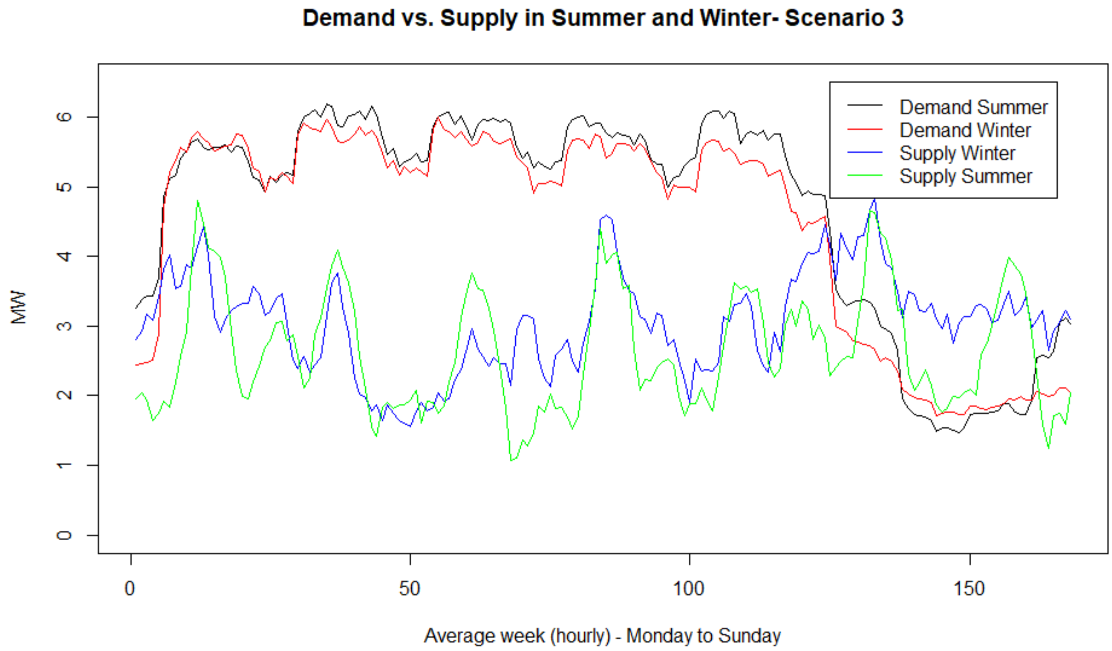

Figure 5: Energy demand vs. supply for an average week in summer and winter for scenario 3

The surplus on Saturdays and Sundays for the average week results in high energy surpluses in one year for scenario 2 and 3 (**Figure 6**). The high peak power of the wind power station also creates a significant amount of surplus from Monday to Friday in scenario 3.

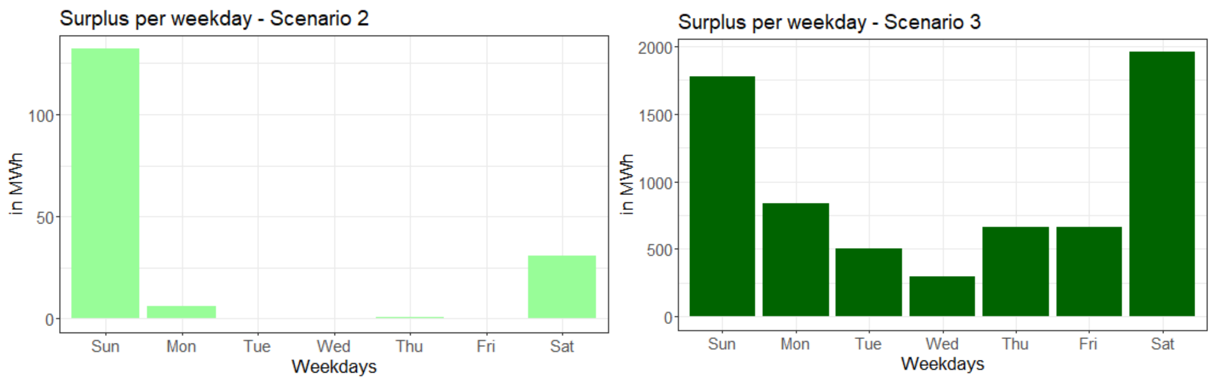

Figure 6: Cumulated energy surplus for one year per weekday for scenario 2 & 3

In order to evaluate the typical range of the energy surplus boxplots for the energy surplus per weekday have been created for all scenarios (**Figure 7** and **Figure 8**). It can be seen that for scenario 0 & 1 there is no energy surplus during working days. On Saturdays the upper quartile value of the surplus is around 0.3 MWh and on Sundays at 1.3 MWh.

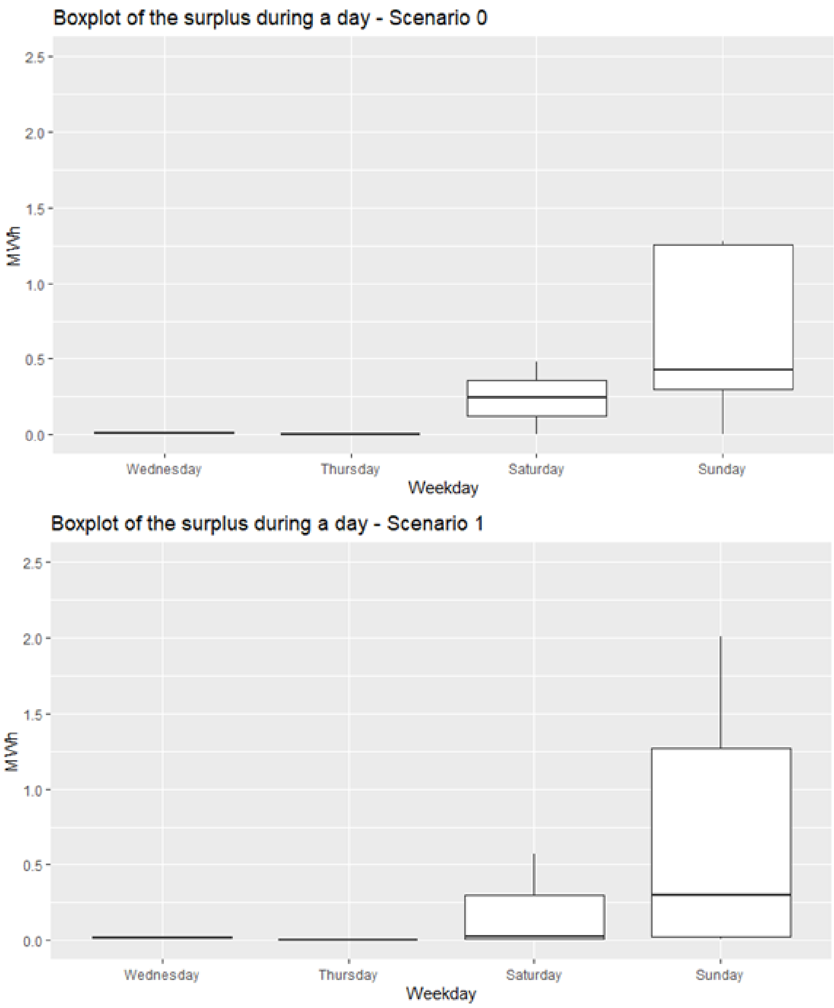

Figure 7: Boxplot for the energy surplus per weekday for scenario 0 & 1

In scenario 2 there is also a surplus on Mondays and in scenario 3 the surplus values get significantly higher with upper quartile values of 25 MWh during the week and more than 50 MWh on Saturdays.

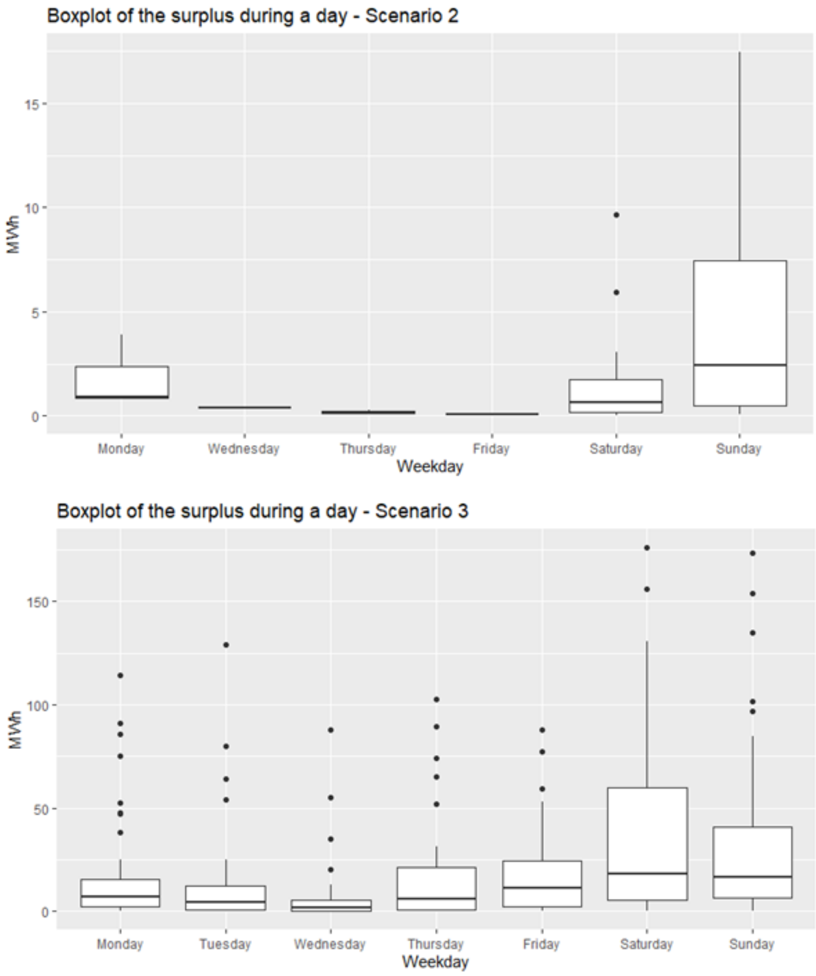

Figure 8: Boxplot for the energy surplus per weekday for scenario 2 & 3

Table 2 summarizes the median values per weekday for all scenarios. It can be seen that all scenarios except scenario 3 have very low median values during working days.

Median	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Scenario 0	-	-	0.012	0.003	-	0.244	0.426
Scenario 1	-	-	0.022	0.007	-	0.024	0.302
Scenario 2	0.887	-	0.397	0.187	0.076	0.673	2.411
Scenario 3	6.862	4.362	1.504	5.996	11.412	18.290	16.709

Table 2: Median values per weekday for all scenarios in MWh

4 Investigation of a V2B concept and stationary battery storage

In this chapter a V2B concept is investigated using several assumptions linked to the parking situation at Neuman Aluminium as well as estimated costs and energy prices for the calculation of financial KPIs. Further, a stationary battery storage with the same capacity is compared to the V2B concept.

For the renewable energy production, the following investment costs were assumed (**Table 3**):

Investment costs	**EUR**
PV	4.00 Mio
Wind turbine	11.83 Mio
Installation costs	**EUR**
PV	2.74 Mio
Wind turbine	1.57 Mio
Yearly O&M costs	**3% of the overall costs**

Energy prices	**EUR/MWh**
Grid price	231.76[2]
Feed in tariff	86.97[3]

Table 3: Assumptions on the investment in renewable energy production and energy prices[4]

4.1 V2B concept

Neuman Aluminium has a parking lot for employees with a capacity of roughly 500 vehicles. In order to assess the max. potential of a future V2B scenario the following assumptions summarized in **Table 4** were made.

Number of vehicles on parking space	500
Number of electric vehicles (80 % share)	400
Usable amount of battery capacity per vehicle	20 kWh
Number of bidirectional charging stations	400
Max. power of bidirectional charging station	22 kW
Price for hardware for bidirectional charging stations (7.000 € per charging station)	2.80 Mio €
Price for software for bidirectional charging stations (150 € per charging station)	60.000 €
Price for hardware for energy management platform and local controllers for 400 charging stations	40.000 €
Price for energy management software for 400 charging stations	30.000 €
Total Investment costs	**2.93 Mio €**

Table 4: Assumptions for V2B use case

For the user behavior for the parking lot, a very simple model has been used, which is directly related to the working shifts of the company. Neuman Aluminium operates with 3 shifts, that ensures a continuous operation of the production plant and therefore continuous occupation of the parking spaces between Monday 5 a.m. and Saturday 5 a.m. The 20 kWh usable amount of battery capacity per vehicle, the total number of 400 electric vehicles and the working shifts, result in a function for the available battery capacity depending on time depicted in **Figure 9**.

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[2] Average of the monthly energy costs of Neuman Aluminium in 2022/23

[3] Source: For the calculations we assumed a feed in tariff that is the average of the feed in tariffs of PV, Wind and Hydro according to the following tariffs: https://www.e-control.at/documents/1785851/1811582/BGBLA_2017_II_408.pdf/077e79d8-a345-858b-5e78-96905bff9b95?t=1515404329487

[4] Source: Nousdilis, A. I., Kryonidis, G. C., Kontis, E. O., Papagiannis, G. K., Christoforidis, G. C., & Panapakidis, I. P. (2018, June). Economic viability of residential PV systems with battery energy storage under different incentive schemes. In 2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe) (pp. 1-6). IEEE.
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The maximum capacity of 8 MWh is constant throughout the working days but decreases to zero at the weekend. Effects due to the exchange of vehicles between the shifts are neglected.[5]

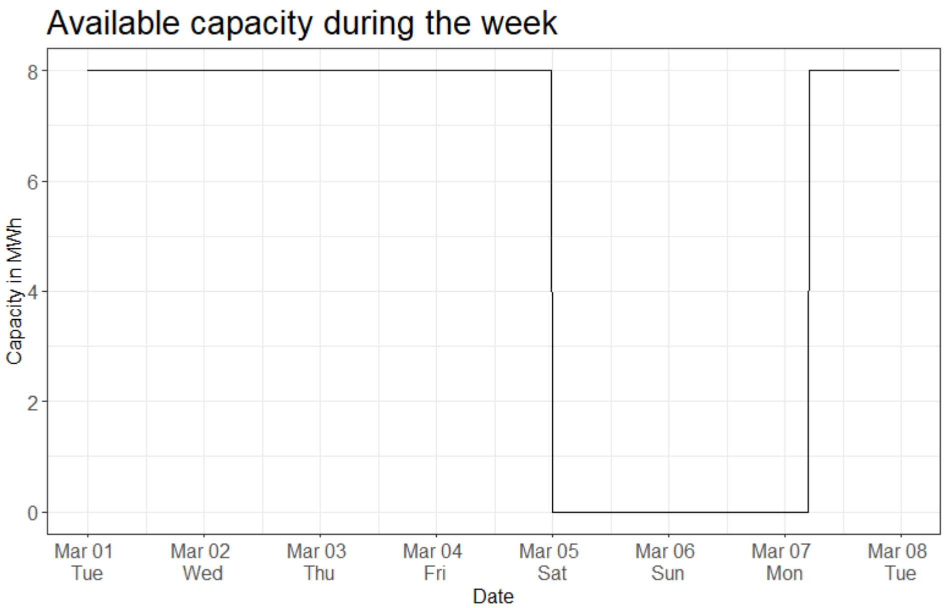

Figure 9: Function of the available battery capacity for the vehicle-to-building use case

Due to the lack of available battery capacity on the weekend, the vehicle-to-building concept only seems to be reasonable for scenario 3. With a max. capacity of 8 MWh the median values of energy surplus during working days ranging from 1.5 MWh (Wednesdays) to 11.4 MWh (Fridays) can be covered to a large extent. The results in **Table 5** show that the investment in renewable energy production in combination with a V2B concept has a positive NPV, a ROI of over 400% and has a payback period of under 5 years.

	NPV	ROI[6]	PBP	SSR	SCR
Renewables with battery storage	29.0 Mio	204.4%	4.7	47.6%	76.7%

	Value	Unit
Total investment costs of the scenario	23.16 Mio	EUR
Total renewable energy consumed	19,123	MWh
Total renewable energy sold	5,788	MWh
Average SoC of the battery	32.8%	%
Savings per year[7]	4.9 Mio	€/a

Table 5: Results of the V2B concept

[5] The work shifts at Neuman are from 05:00 to 13:00, 13:00 to 21:00 and 21:00 to 05:00.

[6] Note: ROI is calculated over a period of 25 years and is defined as $\frac{net\ utility}{total\ costs} \times 100\%$, where the net utility is defined as the expected saving over 25 years minus the total costs during this period.

[7] The savings are defined as the difference in energy costs of the scenario in comparison to the reference scenario where the entire energy is bought from the grid. The yearly costs of the reference scenario are 9,313,752 EUR.

In addition, Neuman Aluminium reaches a self-sufficiency rate (SSR) of 47.5% and a self-consumption rate (SCR) of 76.7%. In this setup, the total investment costs are 23.16 Mio. EUR from which 2.93 Mio. EUR are used to build the charging stations that allow bidirectional charging. With the V2B concept over 19,000 MWh of the produced energy are consumed while around 5,800 MWh are sold to the grid. In total, Neuman Aluminium generated 4.9 Mio. EUR savings over one year when integrating V2B concept to their energy usage. **Figure 10** shows the net present value of the investment in renewables in combination with the V2B concept.

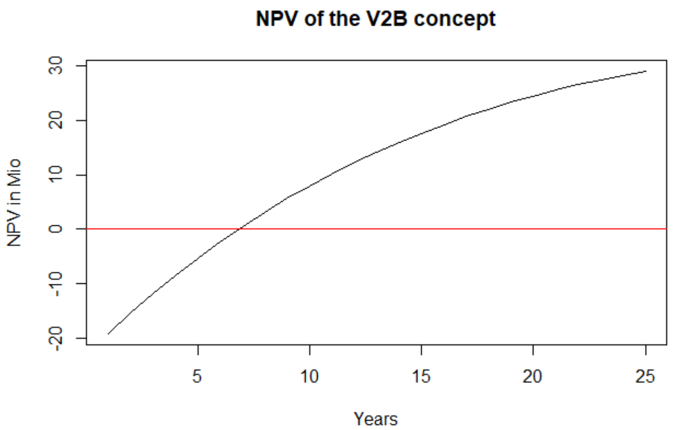

Figure 10: Net present value of the investment in renewables in combination with the V2B concept

4.2 Stationary battery storage

For the alternative battery storage, it is assumed that Neuman Aluminium uses four Tesla Megapacks where each pack has a capacity of 2.6 MWh with costs of 1.13 Mio. EUR per Megapack. This implies an overall capacity of 10.4 MWh as well as a usable capacity of 8.3 MWh when assuming, that the SoC always lies between 10 and 90%. The assumed investment costs are presented in **Table 6** and the results for the battery storage are show in **Table 7.**

Investment costs	in EUR
Costs per Megapack á 2.6 MWh Capacity	1,13 Mio.
Total costs for 10.4 MWh	4,51 Mio.
Installation costs (3% of investment)	135.000
Yearly O&M costs	3% of the overall costs

Table 6: Assumptions for stationary battery storage use case

	NPV	ROI	PBP	SSR	SCR
Renewables with battery	27.4 Mio. €	189.4%	4.9	49.0%	79.0%

	Value	Unit
Total investment costs of the scenario	24.8 Mio	EUR
Total renewable energy consumed	19,699	MWh
Total renewable energy sold	5,240	MWh
Average SoC of the battery	29.7	%
Savings per year	5,0 Mio.	€/a

Table 7: Results for the battery storage

On the one hand, the results show again a positive NPV as well as a ROI over 400% and a payback period of under 5 years. The results of the economic KPIs are slightly worse than for the V2B concept. On the other hand, the battery storage scenario has a higher SSR and SCR, which implies that the produced energy is used more efficiently by Neuman when using a battery storge. This can also be seen when comparing the yearly saving. While the annual savings are slightly below 5 Mio. EUR with a V2B concept, they are slightly above 5 Mio. EUR in the battery storage scenario. **Figure 11** shows the net present value of the investment in renewables in combination with a battery storage.

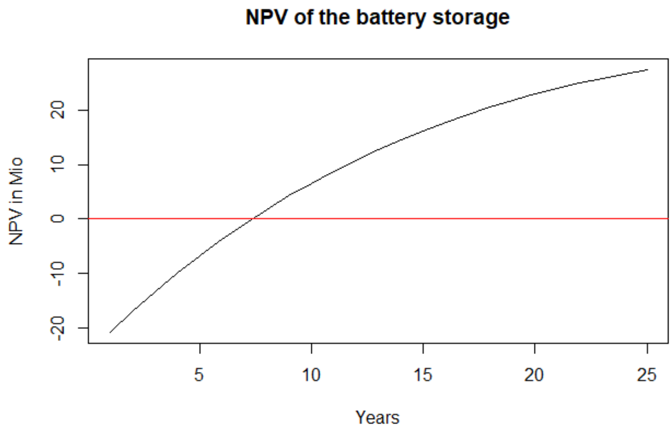

Figure 11: Net present value of the investment in renewables in combination with a battery storage

5 Conclusions at outlook

It can be concluded that a V2B use case could be an interesting alternative to a stationary battery storage but is strongly dependent on the user behavior of the EV fleet. For the Neuman Aluminium use case energy surpluses occurs mostly at the weekend due to the lower power consumption of the production facilities. However, the occupancy of the parking lot is exactly the opposite, as the employees and their EVs are only present during working days. Thus, the V2B use case was only interesting for scenario 3 including the wind power station, where relevant energy surpluses also occur during working days.

In terms of financial KPIs the V2B concept shows slightly better results than the battery storage, which is mainly due to the fact, that this setup has lower investment costs (around 1 Mio. €). The analysis shows that the usage of the renewable energy is more efficient when a battery storage is applied, as the energy can be used more efficiently when the storage possibility is constantly available.

Further steps are to optimize the size of the battery storage in terms of NPV as well as to include a sophisticated model for the user behavior of EV drivers for the parking lot. The latter shall also consider the reaction on different incentives to motivate users to share their battery capacity for the V2B use case.

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Abbreviations

BEV	Battery Electric Vehicle
EV	Electric Vehicle
KPI	Key Performance Indicator
NPV	Net Present Value
PBP	Payback Period
PV	Photovoltaic
SCR	Self Consumption Ratio
SOC	State of Charge
SSR	Self Sufficiency Ration
ROI	Return on Investment
V2B	Vehicle-to-Building
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home

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