Smoothing the wave:
EVs enable significant peak shaving

Battery-powered electric vehicles are set to play a key role as storage solutions and electricity suppliers for future grids. But how extensive is this potential? To make it more concrete, we conducted an analysis to quantify the V2G (vehicle-to-grid) power potential for Munich in 2030. The findings clearly indicate that battery-powered EVs will be crucial for the stability of future energy systems.

The shift towards a sustainable energy system is vital to prevent some of the most extreme climate change scenarios and establish a carbon-free economy. A significant challenge in this process is the need for large-scale power storage capacity to effectively incorporate intermittent renewables and stabilize transmission and distribution networks. Experts predict that as battery electric vehicles (BEVs) become more prevalent, it will be feasible to use the batteries of grid-connected cars and heavy vehicles to create a distributed power storage network. While the viability of this solution depends on various factors, a projected 2030 scenario for Munich shows the potential of V2G capabilities.

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Munich, the capital of Bavaria, has a population of over 1.5 million. As a prominent European city, it serves as a hub for scientific research, technology, and industry. Munich's developed distribution grid, combined with high electricity consumption, makes it an interesting location to explore the potential of V2G energy supply. Limited photovoltaic (PV) energy supply means it doesn't face issues of electricity input bottlenecks into the grid or the challenges of redistributing excess PV-generated electricity during off-peak periods. Therefore, the primary application of V2G technology in Munich revolves around adjusting the overall load profile based on spot prices and renewable energy generation within the German power market.

V2G capacity paints encouraging picture

Private and commercial EVs complement each other well as far as V2G power is concerned. Private vehicles, commonly parked during work hours, offer flexibility when loads are high during the day. Meanwhile, many commercial vehicles, with their larger batteries, can provide a similar contribution by supplying power when not in use during nights and weekends.

The combined V2G power of private and commercial vehicles will sum up to around 200 MW by 2030, a substantial portion of Munich's peak load of 1,000 MW during summer months. Consequently, V2G technology serves as a valuable buffer for peak load management in our specific scenario.

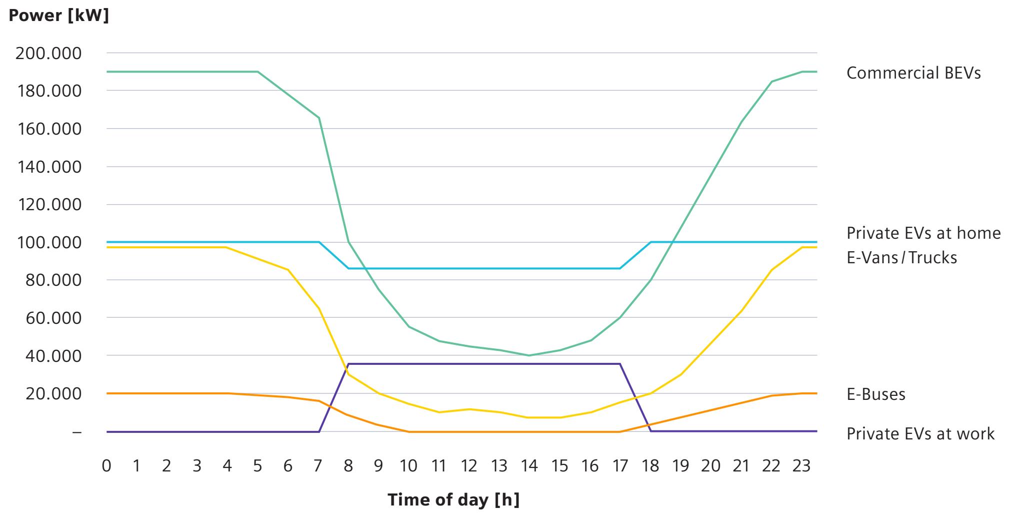
When examining distinct vehicle categories, the V2G power potential of private vehicles reaches nearly 140 MW on workdays. This encompasses about 85 MW from private EVs parked at home, 35 MW from those parked at workplaces and 20 MW parked at public charge points. With 35 kWh battery capacity available for V2G per vehicle and 11 kW discharge power per charge point, the capacity might cover approximately up to three hours of power consumption. Ideally, this capacity could be distributed over time to evenly distribute loads during peak hours from 8 am to 8 pm.

When specifically looking at commercial passenger cars and small vans, they could contribute up to 50 MW during the day and 190 MW at night. Our analysis reveals a potential daytime V2G power ranging from 10 MW to 90 MW for trucks, and up to 20 MW at night for buses. Trucks and buses are especially promising due to their sizable battery capacities, robust charging infrastructure, and predictable travel schedules.

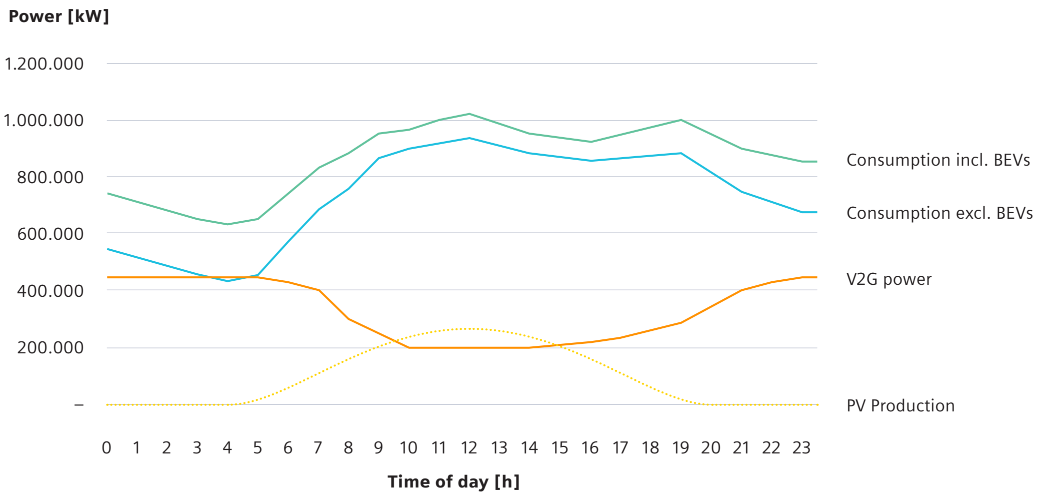
Collectively, commercial vehicles could offer anywhere from 60 MW during daytime to 300 MW overnight. The latter is particularly important as renewable energy input increases and the necessity for load shifting emerges.

These V2G power projections are grounded in current data on power consumption and supply, the EV count in Munich, battery capacities, state-of-charge ranges, and charging patterns. Existing trends and regulatory guidelines have also been considered.

V2G power by type of vehicle



Load and supply during 24 hours



Shaving peaks, emissions, and electricity bills

Power harnessed from V2G could offer substantial flexibility to Munich's energy system by 2030. It has the capability to balance the city's load profile and store excess renewable energy generated in the surrounding region. This storage capacity could be particularly useful in compensating for weather fluctuations that impact solar and wind power. Given the notable distinctions between the urban landscape and the rural surroundings, Munich presents an interesting case for implementing V2G to manage renewable generation and load on a regional scale, instead of the simpler task of doing it at a local level. Indeed, the scenario hints that cities could evolve into reservoirs of sorts, storing energy for the broader regions around them.

Employing V2G for load balancing carries the advantage of reducing the necessity for conventional peak load generation capacity. This reduction would subsequently lead to a decrease in CO2 emissions, as well as a decline in the overall expenses associated with electricity generation. As well as this, it would allow planners to avert the construction of excessively large renewable generation facilities, while potentially enhancing the flexibility of demand on the consumer side. This approach could also reduce the need to build additional storage infrastructures. Ultimately, for both EV drivers and fleet operators, engaging in V2G activities could optimize expenses over the lifespan of BEVs.

The ability to store surplus electricity produced from renewable sources would help avoid further waste due to throttling or shutting down of generation capacity – in 2021, Germany's energy system had to throttle about 5.8 terawatt-hours worth of wind power in order to ensure grid stability. Clean electricity stored in distributed BEV batteries could also compensate for renewable generation shortfalls if weather patterns deviate from forecasts, making conventional supply reserves obsolete.

Climate and financial benefits

The main beneficiaries of such a decentralized power reserve would be our overheated planet and the inhabitants that call it home. Implementing peak shaving strategies could lead to substantial emission reductions. By introducing V2G storage capacity for excess generation, we could greatly increase our reliance on renewable energy sources, enabling us to compensate for stochastic in-feed and successfully integrate more zero-carbon electricity sources into our grids. Through effectively harnessing the full potential of V2G and sidestepping losses from intentional throttling, we could minimize the need for alternative forms of storage capacity, as well as prevent the construction of oversized solar or wind farms, preserving finite resources and materials.

Both individual vehicle owners and corporate fleet operators would stand to gain from connecting their BEV storage capacity to the grid, seeing not only ecological but also financial benefits. They could lower the overall expenses tied to electricity generation by removing the requirement for conventional peak-load generation capacity, while enhancing demand-side flexibility. Additionally, the automated optimization of BEV usage and operational costs promises further tangible advantages.

The study shows that the potential of V2G is there for the taking; now, it is up to the regulators to seize the opportunity by creating a legal framework as well as incentives that foster the development of this technology. Then, operators will develop business models to offer tariffs via V2G and sell the aggregated power on spot markets.

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On the study

This study aims to assess probable scenarios for the potential of V2G in Munich. The focus is the perspective of available BEVs in 2030 and their theoretical capability to provide V2G services. The size of this potential across different markets, such as spot markets or flexibility markets, is not the focus of the study.

Definitions

Load profiles
The load profiles are taken from the information on medium voltage level power peaks (Hochlastzeitfenster) provided by Stadtwerke München Infrastruktur for winter, spring, summer, and autumn. Those load profiles usually relate to weekdays – specific weekend data is not available.

PV generation
The PV (photovoltaic) generation profile was formulated through the following steps: Firstly, the cumulative peak power across all registered assets is extracted from the Marktstammdatenregister. After this, this peak power is put into a PV simulation tool, creating a unified PV system profile based on geographical positioning and orientation. This profile is generated using weather data from 2019. The resulting hourly load profile for an entire year is then divided into four distinct seasons: winter, spring, summer, and autumn. These seasonal profiles are condensed to form an average one-day profile for each season.

As of now, Munich possesses an installed capacity of approximately 133,000 kWp, while the Landkreis Munich (Munich's surrounding district) has an installed capacity of 245,000 kWp. The German government has set an ambitious target for PV capacity in Germany, aiming for over 200 GW by 2030 – a figure roughly three times the present capacity of 60 GW. Given the inherent challenges of installing PV systems within urban environments, as opposed to more rural areas, the goal of scaling up Munich's capacity to 400,000 kWp appears very ambitious. To achieve a situation where PV generation in Munich surpasses local demand, the installed capacity would need to exceed at least 1,000,000 kWp.

Current numbers of BEVs in Munich
Data on numbers of registered BEVs have been obtained from the Kraftfahrtbundesamt (KBA) and the Office for Mobility of the city of Munich. The numbers for the city of Munich are from December 2022, the numbers of KBA are from January 2022.

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City of Munich (31.12.2022)

Private BEVs:	8,252 (of 520,000)
Commercial BEVs:	16,712 (of 220,000)
E-Buses:	55 (of 1,400)

KBA (01.01.2022)

Private BEVs:	4,900 (of 520,000)
Commercial BEVs:	10,586 (of 220,000)
E-Buses:	46 (of 1,400)
Trucks:	635 (of 44,000)

Assumptions

Assumptions on the development of BEVs by 2030 in Munich

Private BEVs:	8,252 to 160,000 (of 520,000)
Commercial BEVs:	16,712 to 200,000 (of 220,000)
E-Buses:	50 to 750 (of 1,500)
Trucks:	635 to 10,000 (of 44,000)

Assumptions on charging by 2030 in Munich

Home charging:
20% of all BEVs can be charged at home.

Public charging:
Restricted to pure charging and not available for V2G

Workplace charging:
40% of private used BEVs can be charged at work.

Share of commuters with BEV:
30% of BEVs are frequently used for commuting on
3 days a week, with an average of a 16 km commute distance

Battery assumptions

For V2G operations, the state of charge (SOC) range of the battery is limited to between 25% and 85%.

Private BEVs:
65 kWh (39 kWh usable for V2G within the available SOC range)

Commercial BEVs:
70 kWh (42 kWh usable for V2G) – an average figure for this category is difficult to assume, because it includes different types of vehicles, which range from the Streetscooter Work (40 kWh) to the VW Buzz (77kWh) to the Mercedes EQS with 90kWh or Tesla Model S with 100 kWh.

Trucks:
125 kWh (75 kWh usable for V2G) – the range of batteries goes from 85 kWh (Orten) to 7,5, to trucks up to 540 kWh (Volvo). Assuming that smaller trucks will enroll faster, an average value of 125 kWh will be applied here

E-Buses:
300 kWh (180 kWh usable for V2G) – as an average figure between models from MAN, Valeo and Solaris

Evaluation

Evaluation on private BEVs
The potential for V2G use among private vehicles is dependent on the availability of charging infrastructure for BEV owners, encompassing private wall boxes, public charging points, and workplace charging.

Home charging
Through private charging points, a V2G potential of approximately 100 MW is achievable in off-peak hours within our scenario. The slight reduction in potential during peak hours can be attributed to a combination of factors, including a portion of BEV owners who commute to work and the prevalence of home office arrangements, which is particularly significant in an urban setting like Munich.

Charging at the workplace
Charging at the workplace is beneficial from the perspective of the electricity grid. Commuting to and from work typically requires less than a full battery charge. This implies that power charged during nighttime or morning hours could be utilized, in part, from lunchtime until evening, a period when electricity demand typically peaks.

In our scenario, the projected capacity of 35 MW for workplace charging has a promising outlook. Considering that users require an additional 4 kWh for an average commute from work to home (covering 16 km), this leaves approximately 35 kWh for V2G utilization. Given a capacity of 11 kW per charging point, this capacity might span around 3 hours of operation.

Synergies between charging at home and at the workplace
The cumulated power of private charging and charging at workplace achieves almost 140 MW in our scenario, which represents a significant share of the peak load of Munich (up to 1200 MW). With the assumptions of this scenario, power could be provided for around 3 hours. In all likelihood, extending the duration of usage, even at the expense of power capacity, would be preferable to evenly distributing peak hours between 8 am and 8 pm.

Commercial vehicles, trucks, and buses

Within the group of enterprise registered BEVs, a division is made into three categories: "commercial vehicles" (including personal cars and small vans), "trucks and large vans," and "buses”.

The largest potential could be found in the group of commercial vehicles due to their large number and their assumed fast scale-up. Our scenario suggests a potential ranging from 50 MW during the day to 190 MW at night. However, this category encompasses several subgroups, such as employee company cars, fleets for various services, mini vans for urban logistics, vehicles from car rental companies serving nationally, and prototype cars from OEMs. The shares of these subgroups are unknown, and their usage patterns and charging behaviors may differ considerably. For example, company cars are often used for personal purposes, while service fleet cars and mini vans follow more traditional fleet patterns – on the road during the day and parked in depots at night. Because of this, evaluating the precise potential of this category proves challenging.

The potential within the truck category also appears substantial. This is due to their rapidly increasing numbers, substantial battery capacities, robust charging capabilities, and especially their predictability in terms of schedules. Our scenario indicates a potential ranging from 10 MW during the day to 90 MW at night.

In Munich, the current registered number of buses is around 1,475. The city of Munich's aim for complete electrification of its bus fleet by 2030 targets around 550 buses. The usage status of the remaining 800-900 buses is uncertain, as they might be registered in Munich but in service elsewhere, therefore making them unavailable for V2G purposes. Based on our scenario involving 750 buses, a potential of up to 20 MW is attainable at night. Electric buses share similar V2G benefits with trucks, including sizable battery capacities, potent charging infrastructure and predictable schedules.

Throughout this study, the behavior of commercial BEVs is presumed to align closely with fleet utilization – on the road during the day and parked in depots at night. Consequently, commercial vehicles could amass significant V2G potential during nighttime hours and weekends. This is particularly relevant as the share of renewable electricity generation in Germany increases, creating a heightened demand for nighttime flexibility to counter forecast deviations or temporary generation shortfalls.

In total, our scenario suggests a V2G potential ranging from 60 MW during the day to 300 MW at night. However, it's important to emphasize that these figures strongly correlate with the assumed charging point power and, therefore, offer a rough estimate of the potential.

Weekend

At the weekend, a larger share of commercial BEVs, e-trucks and e-buses are supposed to be available for V2G, also during the day. This could result in the replacement of private BEVs in terms of availability for V2G services, as private BEVs might be more frequently used for extended trips during weekends. This shift in availability could lead to an optimal redistribution of V2G potential.

Appendix

Input data and assumptions

Period	Number
Year	2030
Season	Summer (Jun-Aug)

Private BEV	Number
Number of vehicles (2023 - BEV: 8,200, all: 525,439	160,000
Kilometers per year per BEV	12,000
BEV kWh consump. per 100 km	22

Characterization of all BEV owners	Number
Share of BEV commuters	30%
Share with private wallbox	20%
Share with charging opportunity at work	40%
Number of days at the workplace per week	3
Share of con. BEV with V2G	30%

Battery private BEV	Number
Capacity kWh	65
Low. limit SOC	25%
Upp. limit SOC	85%
Avail. capacity kWh	39

Charging power private BEV	Number
Private CP kWh	11
Public CP kWh	11
Employer CP kWh	11

Commercial BEVs	Number
Number of vehicles (2022: BEV: 13,000, all: 219,387)	200,000
Kilometers per day	30
Consumption kWh per km	0.22
Charging power kW	22
V2G availability	5%
Capacity kWh	70
Low. limit SOC	25%
Upp. limit SOC	85%
Avail. capacity kWh	42

E-Vans / trucks	Number
Number of vehicles (2022: BEV: 635, all: 44,429)	10,000
Kilometers per day	100
Consumption kWh per km	0.5
Charging power kW	50
V2G availability	20%
Capacity kWh	125
Low. limit SOC	25%
Upp. limit SOC	85%
Avail. capacity kWh	75

E-Buses	Number
Number of vehicles (2022: BEV: 50, all: 1,475)	750
Kilometers per day	200
Consumption kWh per km	1.2
Charging power kW	150
V2G availability	20%
Capacity kWh	300
Low. limit SOC	25%
Upp. limit SOC	85%
Avail. capacity kWh	180

Energy consumption	Number
Increase of consumption yearly	2%

PV capacity in Munich	Number
Nominal power of PV in Munich in 2023	133,564
Nominal power of PV in Munich in target year	400,000

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