GAMES INDUSTRY WHITEPAPER

NEW BUSINESS OPPORTUNITIES LEVERAGING THE FLEXIBILITY POTENTIAL OF ELECTRIC SHARED VEHICLE FLEETS

VERSION 1.0

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TABLE OF CONTENTS

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Co-creating with partners that help to understand the needs of relevant stakeholders, we team up with intermediaries to provide an innovation eco-system supporting consortia for research, innovation, technical development, piloting and demonstration activities. These co-operations pave the way towards implementation in real-life environments and market introduction.

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ABSTRACT

The overall concept of using EVs as flexible storage seems simple and convincing: There are countless cars spread out throughout our cities, moving during rush hour but idle most of the day. With modern cars having battery capacities from 50 up to 100 kWh, this sums up to vast amounts of battery storage being available for supporting electricity grids and shifting energy demand towards times of renewable surplus generation. But what sounds like a low hanging fruit in theory faces a lot of practical barriers: How to coordinate all those cars in an efficient manner? Does it affect the lifespan of the batteries? And most importantly, is there actually a viable business model for both fleet owners and energy industry? Focussing on the latter question, this report investigates potential business opportunities in three distinctive case studies: from PV self-consumption optimisation at a company headquarter in Austria, peak shaving for better grid stability in the city of Zurich, to using PV surplus generation in a (possibly) highly solar energy system of Tel Aviv metropolitan area in the year 2030 – all made possible by deploying smart charging strategies of electric vehicles, operated as shared vehicle fleets. Based on these case studies, the authors want to find out more about the energy prices, tariff structures, fleet sizes and much more that are needed in order to make such business models happen as soon as possible. The analysis is based on real and simulated mobility data retrieved from the national partners in Switzerland (Mobility.ch and SUPSI university) and Israel (AutoTel and Reichman University) and uses the “e7 flexibility model”, specifically developed for the GAMES project by the Austrian research and consulting company e7 energy innovation & engineering.

1 ELECTRIC VEHICLE FLEETS AS FLEXIBLE ENERGY STORAGE

The energy transition also means a mobility transition! Whereas all over Europe a reduction of greenhouse gas emission has been achieved in many economic sectors, the mobility sector has remained more or less in stagnation during the last years [1]. The solution for accelerating the mobility transition is twofold: A massive **reduction of cars** and a **fuel switch** towards emission-free electric vehicles (EVs).

THE GAMES VISION

Both solutions mentioned above are tackled by the GAMES project. GAMES stands for Grid-Aware Mobility and Energy Sharing and has a clear focus on **electric shared vehicle fleets**, which essentially are all types of public carsharing fleets and shared company fleets, used for business trips. Sharing can reduce the overall demand for cars and parking area, also cutting down long idle times. Making the most out of the necessary fuel switch, the GAMES project sees **EVs as a valuable resource** to run the future electricity system. EVs can be managed in a grid-aware manner, **avoiding grid problems** arising from skyrocketing energy demand in a full-electric society. As a battery on four wheels, EVs can also **provide storage services** and generate revenues for its owner.

All this is possible when deploying advanced charging modes. GAMES distinguishes between controlled unidirectional charging (further summarised as **smart charging**) and bidirectional charging (further summarised as **vehicle-to-grid** or, for short, V2G). Both concepts can be deployed for various use cases supporting the grid or balancing energy portfolios.

Figure 1: The GAMES vision

SCOPE OF THIS WHITEPAPER

This industry whitepaper is set out to give directions on what is the potential of smart charging and V2G in terms of **impact on the energy transition**, but also **economic cost savings** for businesses and the society as a whole. By doing so, following questions (and many more) are tackled:

- What are **profitable flexibility use cases for EVs**? On which markets can the flexibility of EVs add value?
- What is a **minimum viable size of a fleet** to have an impact?
- What are optimal **fleet characteristics?** This includes charging power, battery size, idle times, etc.
- Which **market conditions** have an influence? This could be the energy mix or energy prices.
- What are **tariffing schemes** that allow feasible business cases? This especially goes for grid tariffs.
- Which **regulatory barriers** currently exist, making business models unviable?
- Are there other **techno-economical constraints**, such as battery degradation etc.?

This study has not been done merely based on qualitative discussions, but by analysing quantitative results from **three case studies in Austria, Switzerland and Israel**. In all these studies, real fleet data have been collected and based on them future scenarios for using the fleets flexibility have been simulated by an **energy system optimisation model**. For each of the case studies, different fleets, user behaviour, national contexts and flexibility use cases have been analysed. Conclusions are drawn from a societal perspective (i.e., macro-economic and ecological impact) and from the individual businessperson (i.e. viable future business models). But firstly, the following chapter introduces the topic of smart charging and V2G in terms of business strategy.

2 FRAMING THE BUSINESS OPPORTUNITIES

When trying to capture suitable business models that use the energy flexibility of EV fleets, the GAMES project accounts for the current business context:

- ✓ ***Extending existing business models is not ideal***

  When presenting novel innovations, relying on traditional business approaches – e.g., longstanding business models of (incumbent) energy and mobility companies – frequently fall short in capturing market attention. Instead, optimal results are achieved by pairing new products with corresponding new business models [2].

- ✓ ***Adaptability of energy sector is essential***

  Although technological advancements have reached a high level, the energy sector's adaptability is trailing behind [3]. To some in the energy sector, the novel charging innovations in e-mobility still pose a mystery, mainly due to the wealth of stakeholders involved who all have diverse properties [4], [5]. Consequently, companies must confront reluctance towards change and embrace calculated risks to formulate inventive business models that integrate renewable energy systems and electrified mobility [3].

- ✓ ***Inter-firm & inter-sectoral partnerships are the new norm***

  Over the past thirty years, a transformation has taken shape, with a departure from large, self-contained companies solely focused on safeguarding their market presence towards both companies that simultaneously collaborate and compete with other firms [2], [6]. Referred to as "co-opetition," firms contribute to an ecosystem to reach a collective goal. Consequently, they generate more substantial advantages compared to what they could have achieved independently [6].

- ✓ ***The mobility and energy sector are following suit***

  Partnerships amongst firms in the energy and mobility sector in particular are growing. This brings with it a closer alignment of players who normally would not have cooperated with one another. Whether it is among vehicle manufacturers to develop electric vehicle charging, or among a vehicle manufacturer and an energy retailer to trial grid-optimised charging, such contact points across the ecosystem with innovative partnerships are increasingly taking precedence [7]. Such partnerships prove particularly beneficial in industries characterized by rapid technological advancements or demanding significant investment costs [8].

- ✓ ***Therefore, a wide lens of business model possibilities is necessary***

  Here, relying solely on firm-level business models like the business model canvas or value proposition canvas might prove limited and inadequate in addressing the broader ecosystem and processes at play.

EXPLORATORY ANALYSIS WITHIN THE GAMES PROJECT

Until now, numerous researchers have highlighted the innovation ecosystem attributes within the realm of electrified mobility (e.g., [2], [9]). Nevertheless, our novel contribution within the GAMES project is the extension of this ecosystem approach of e-mobility to its inherent ties with the energy sector. Therefore, the stakeholders involved with this new technology can be defined, and their associated interconnections with one another can be revealed. This preliminary ecosystem analysis can set the foundation for shaping tailored business models aligned to grid-optimised charging.

WHICH FLEXIBILITY SERVICES HAVE THE BEST BUSINESS CASE?

Upon developing our custom classification of flexibility services, it becomes clear that from the extensive array of services made possible from vehicle-grid integration, only a select few seem to be practical for implementation in the context of EV fleets. A detailed analysis of available markets and services has been previously conducted as part of the GAMES policy brief [10]. Based on this assessment, the GAMES project surmises that these particular services will provide the most favourable corresponding business models. With that being said, these use cases (*balancing services for the TSO, peak shaving for the DSO, portfolio optimization for BRPs, and collective self-consumption*) will be concentrated on in the GAMES project's economic assessment and business model validation:

(1)
Balancing services for the TSO

While stringent prequalification criteria are in place, an advantageous aspect of this service for the Transmission System Operator (TSO) is the presence of well-established organized markets for trading balancing products. Furthermore, the settlement prices per kWh, on average, rank as the highest among all the markets examined in this analysis.

(2)
Peak shaving for the DSO

Distribution System Operators (DSOs) possess a significant motivation to mitigate peak power expenses. The primary benefit stems from the fact that through peak power tariffs, DSOs can acquire a standardized flexibility product from all grid users within their jurisdiction.

(3)
Portfolio optimization for BRPs

Balance Responsible Parties (BRPs) are actively working to enhance their portfolio optimization to minimize imbalance costs. Leveraging EVs as a flexible resource holds great potential, especially since energy suppliers frequently serve as Charge Point Operators (CPOs) or Electric Mobility Service Providers (eMSPs).

(4)
Collective self-consumption

Energy communities characterized by a substantial proportion of photovoltaic (PV) generation are also expected to soon integrate their excess energy with collectively utilized Electric Vehicle (EV) fleets. This use case can be applied not only to energy communities, but also to office parks or factory sites with one common grid connection.

Figure 2: Use cases of energy flexibility services concentrated on in GAMES

2.1 A new business ecosystem

Taking on this view, the success of vehicle-grid integration's business case hinges on the unique contributions made by each stakeholder within an integrated system. These contributions result in complementary outcomes that collectively enhance the value proposition (EVP) of the ecosystem: *energy-aware sustainable mobility*. Consequently, the GAMES project has employed an ecosystem-wide methodology in order to comprehend the unique needs, obstacles, and objectives of each stakeholder in the context of a vehicle-grid innovation ecosystem. As each stakeholder's individual resources, activities, level of risk and level of ecosystem dependence are all taken into account, the creation of a co-modelled integrated system is enabled that benefits all market participants – further fostering grid-optimised charging's effective implementation [9]. To identify the key players within the vehicle-grid ecosystem, a typology of 16 applicable stakeholders was formulated.

Sectoral representation of the stakeholders:

6	8	1
In the energy sector	In the mobility sector	In the public sector
Energy generators, network operators, aggregators, end-of-life recycling providers, energy retailers & *energy communities*	*Corporate/carsharing fleets, public transport fleets, vehicle manufacturers, battery manufacturers, e-mobility service providers, charge point operators, charging technology providers* & *car dealers*	*State & municipal government*

As a result of ecosystem actors' individual activities, the productive component contributing to the ecosystem is referred to as the actor's *value addition.* An actor's value addition is either necessary to achieve the ecosystem value proposition (EVP) or not required, yet greatly enhance the EVP [9]. The prime value addition of the pertinent stakeholders within this system is below:

Table 1: Stakeholders in the electric vehicle/energy nexus and their value adding activities to the ecosystem [11]

Stakeholder	Ecosystem value addition
(Renewable) energy generators	● Increase share of renewables ● Provide supplemental energy when needed
Network operators (TSOs/DSOs)	● Ensure grid stability
Aggregators	● Represent groups of EVs as an intermediary ● Serve as large-scale energy flexibility/stability provider
Corporate/carsharing fleets	● Replace old fleet/chargers with V1G/V2G capabilities ● Provide V1G/V2G services when EVs are idle

Public transport fleets	● Complement V1G/V2G with other intermodal transport ● Replace fleet with new V1G/V2G capable EVs
Government (state & municipal)	● Encourage V1G/V2G uptake via various policy mechanisms
Vehicle manufacturers (OEMs)	● Develop and produce high-tech, sustainable V1G/V2G-capable EVs
Battery manufacturers	● Develop and produce high-capacity, long-lasting V1G/V2G-capable EV batteries
End-of-life recycling providers	● Repurpose and utilize used EV batteries as secondary storage systems
E-mobility service providers (eMSPs)	● Create advanced billing to enable V1G/V2G ● Ensure a positive user experience with V1G/V2G
Charge point operators (CPOs)	● Implement V1G/V2G energy management technology, charging technology, and protocols
Charging technology providers	● Replace existing chargers with V1G/V2G capabilities ● Sell software knowhow to other charging providers
Car dealers	● Inform customers about V1G/V2G ● Sell V1G/V2G-capable EVs and equipment
Energy retailers (Utilities)	● Provide smart meters ● Install V1G/V2G charging points ● Provide optimized energy
Energy communities	● Produce and consume self-sufficient energy from distributed energy resources ● Lessen the dependence on (increasingly intermittent) grid energy ● Provides a large source of flexibility resources
End user: EV driver	● Provide capital for V1G/V2G ● Serve as critical exposure for V1G/V2G ● Trial V1G/V2G for feasibility and improvements

Each stakeholder contributes unique resources, undertakes specific activities, captures value, exhibits a certain level of dependency on the ecosystem and presents risks to the ecosystem that they do not deliver their complementary contribution. The GAMES project's elaborated ecosystem pie of grid-aware mobility, adapted from [9], is below. During our desk research and stakeholder workshops later in the project, the ecosystem pie served as not only a useful boundary object within the GAMES team to simplify the complex system of stakeholders, but it also helped when presenting it during the expert workshops. For more information on the methodology, please consult [9], and for more information on our adaption of the pie, please consult [11].

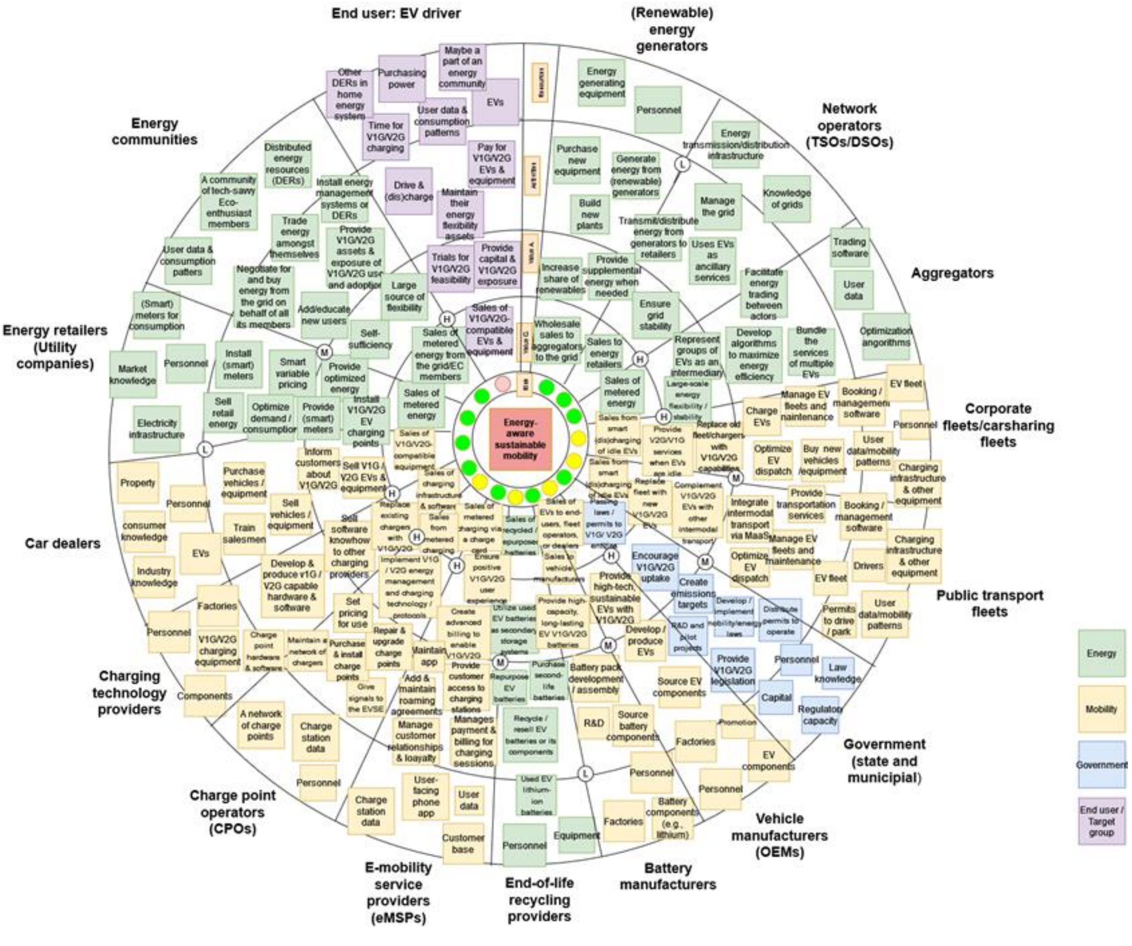


Figure 3: Ecosystem of grid-aware mobility [11]

2.2 The users' expectations: Open Idea Campaign

In order to avoid a narrow view when it comes to the research and development of the GAMES project objectives, a layman audience was approached to offer their opinions on grid-optimised charging from their own view. Salzburg Research's proprietary open innovation platform, Open-Innovation Salzburg (https://www.openinnovation-salzburg.at/), has been in operation since 2019 and has network of 1.400+ active members. The platform employs a gamification approach among its members where one can collect points and are given various extrinsic awards for their community participation. From 15 November to 23 February 2023, the open idea campaign “Energy Sharing with Benefits” was set in motion on behalf of the GAMES project. This enabled a variety of interested citizens to be involved in the value creation process by voicing their perspectives on grid-optimised charging with like-minded users. Not only did the existing community base participate in the competition, but new participants were also recruited from nearby universities and colleges with an expertise in energy and mobility in order to produce rich feedback.

Figure 4: The progression of the GAMES idea competition

Ultimately, the purpose of the ideation campaign was to discover concrete ideas and solutions “from the crowd” with the following questions in mind:

- What can motivate owners of EVs, company/car sharing fleets and e-charging stations or mobility hubs to make their batteries available for smart/intelligent charging?
- How can consumers be encouraged to align their flexible smart charging behaviour more closely with the needs of the power grid?
- Which (new) services and cooperation opportunities or business models will emerge from smart charging?

Figure 5: WordCloud of the most discussed terms during from the idea campaign

Throughout the campaign duration, a total of 44 ideas were submitted. Thereafter, the ideas were rated by the expert jury members from e7 energy innovation & engineering, Green Energy Lab, Salzburg Research, Scharinger Consulting, Sustainable Earth Logic, Renault Austria, Windkraft Simonsfeld, Salzburg AG, goUrban e-Mobility, and the Automobil-Cluster. The ideas were ranked based off their (1) *originality*, (2) *idea utility and reach*, (3) *sustainability* and (4) *feasibility* on a point-by-point basis. The winning ideas proved useful for decision-makers in the realm of vehicle-grid integration to gain another perspective and maybe even develop an initial idea further. By submitting ideas on the platform, there is no intellectual property associated with the idea; therefore, the ideas can be readily adapted and utilised for managerial, governing or academic purposes.

The top ranked ideas were seen across many dimensions to be the most robust and applicable for applied practice. The top three recommendations were:

- *Transform ski resort with (bidirectional) charging stations into convenient ski and hiking destinations;*
- *Battery-as-a-Service (BaaS) incorporated with grid-optimized (dis-)charging;*
- *Smart charging in real-time with the eFriends energy sharing community.*

To make the idea submissions more tangible and applied in GAMES project’s economic assessment and business model validation, the idea entries were categorised by counting the core themes mentioned:

Table 2: Idea mentions by keyword during the idea campaign

Idea Topic (by number of entries with the said topic)	
Location	Housing (6) - Residential detached houses (3) - Apartment complex housing (3) (Semi-)public points (9) - Public charging points (3) - Airport (2) - Workplace (2) - Hotels/ski resorts (2)
Type of charging	Bidirectional discharging (11) Unidirectional smart charging (4) Combination of both (2)
Novel business model	Reduced cost/free EV charging (8) App platform interfaces (8) Integration of other products/services (7) Renumeration via vouchers (4) Transfer of ownership of battery or charger (3) Physical battery sharing (2)
Main beneficiary	Individuals/prosumers (12) Energy suppliers (3) DSOs/TSOs (3) Hotels/ski resorts (2) Housing complexes (1) Airports (1) Aggregators (1)
Barriers of smart or bidirectional charging	Range anxiety (3) Excess grid costs when reselling electricity (3) Owning an EV/cost of owning an EV or its battery (3) Lack of real-life application (2) Closed electricity markets (2) Battery recycle/resale (1) Cost of bidirectional chargers (1) Battery degradation (1)

Some common themes from the open idea campaign entries which could be deduced were that the entries predominantly focused on (1) the specific locations ideal for smart charging/V2G to take place, (2) how smart charging/V2G can be integrated into people's everyday activities and (3) taking advantage of dynamic electricity pricing mechanisms to reduce EV charging costs. Additionally, one of the participants' greatest perceived barriers, range anxiety, could be solved by setting guaranteed minimum state of charge (SoC). Furthermore, the barrier of closed electricity markets and excess grid costs when reselling electricity could be alleviated by a greater liberalisation of electricity markets, with corresponding legislation encouraging electricity pro-sumption among citizens.

2.3 The Stakeholders' views: Workshops

Additionally, Salzburg Research and e7 jointly launched two stakeholder co-creation workshops, primarily among academic and industry experts in the mobility and energy sector. During the sampling process, particular detail was given to selecting participants from a wide variety of professional backgrounds in the relevant sectors and with differing roles and geographic backgrounds (with a focus on the countries of the GAMES project consortium: Austria, Switzerland and Israel). Such participants included but are not limited to national/regional grid operators, automotive manufacturers and EV charging developers. The first stakeholder workshop consisted of eight experts from Israel and Switzerland, while the second domestic workshop consisted of 20 experts from Austria.

During the first workshops, smart charging and vehicle-to-grid's specific barriers, benefits and suitable business models were discussed, with the following result:

Table 3: First Stakeholder Workshop Input

Barriers	Benefits	Business Models
- ***Regulation*** (double taxation, lack of regulation to support, enforce or delineate roles) **- *Chargers*** (cost of capable chargers, lack of uniformity of charging protocols) **- *Battery degradation*** **- *User acceptance*** (lack of practical pilot projects, too complex for consumers, too many user requirements) **- *Grid infrastructure*** (lack of smart meters, the grid isn't adapted for vehicle-grid integration)	**- *For TSOs & DSOs*** (peak shaving/valley filling/other load management, save money on grid upgrades) **- *For users & energy communities*** (increase local self-consumption of renewable energies, reduce grid dependence, reduce energy cost, reduce the EV's total cost of ownership) **- *For all stakeholders*** - open up new markets, new market segments and new value streams	***- For fleet operators with predictable (dis-)charging patterns*** (revenue while idle) **- *For vehicle OEMS with V1G/V2G by default*** (manufacturing competitive advantage) **- *For small/local energy aggregators*** **- *For private users*** (revenue while idle, exploit time-of-use tariffs, energy arbitrage)

The second stakeholder workshop asked the experts (1) which fleets were most suitable for vehicle-grid integration, (2) between smart charging and vehicle-to-grid, which charging method would be the most promising, and (3) which stakeholders would enter this market and with which business models, which garnered the following outcome:

Table 4: Second Stakeholder Workshop Input

Ideal Type of Fleet	Type of Charging	Business Models
- Dependent on a locality's geographic and temporal mobility needs - Energy community fleets with load management - Fleet vehicles that charge in same direction as the grid - Private vehicle fleets aggregated together - Commercially owned vehicle fleets - Corporate fleets favoured over carsharing fleets - Entire Austrian vehicle fleet (role of large parking lots)	- Smart charging's lower complexity to start - Later, V2G as the final cure & replace functions of distribution network (via paternalistic measures) - Dependent on where infrastructure is needed & network's need - V2C (vehicle-to-customer)	- For aggregators & e-suppliers - For energy communities - For local governments - For mobility providers (as dual energy providers) - For energy suppliers with charging stations - For vehicle OEMs - For CPOs - For grid operators ***! No clear trend emerging***

2.4 The need for viable business models

So what can be learnt from this process engaging a broad range of stakeholders as well as potential users? In a nutshell, following overall picture arises:

- The route of **technology development** is more or less clear: Standardisation is in progress, so smart charging and V2G will reach market maturity and will be implemented both in EVs and charging infrastructure in the near future.

- From the view of the **users**, frontrunners are already asking for V2G-ready products. Also, users are expecting the opportunity to achieve relevant **cost savings** through smart charging and V2G and they expect this service to be **integrated in existing offerings** (when purchasing a car or charging services etc.).

- However, from the **business** stakeholders, there seems to be still **no clear strategy**. So, it remains open as to which businesses will drive the market (energy supplier, car manufacturers, start-ups?).

The gap which needs to be addressed by GAMES and by this paper can therefore be concluded as follows:

In ***which scenarios*** *(i.e. which fleets and use cases), smart charging and V2G can create a tangible impact and* ***significant monetary value****? Can the expectations of users and stakeholders be met in these scenarios?*

Answering this question allows to identify specific viable business models and brings clarity about the actual contribution of smart charging and V2G in driving the energy and mobility transition.

3 MODELLING THE ECONOMIC BENEFITS

3.1 Model description

During the course of the GAMES-project, four different case studies are presented which analyse the economic and ecological potential of stationary EV car-sharing fleets. The potential analysis is accomplished with the utilisation of mathematical optimisation, employing the optimisation software "GAMS" (Generic Algebraic Modeling System). The optimisation model is formulated as a linear optimisation problem and is applied in different variations for the various case studies. In every version, it contains the following three core elements:

- **Objective function:** core formula of the optimisation model. By maximizing or minimizing the objective function, the maximum potential of the fleet can be determined.

$$\begin{aligned} TotalCost = &\sum_{t,a} p_{\mathrm{sup}(t,a)} * E_{\mathrm{sup}(t,a)} - \sum_{t,a} p_{fi(t,a)} * E_{fi(t,a)} \\ &+ \sum_{t,a,cs} \frac{E_{EVd(t,a,cs)}}{eta_{EVd(cs)}} * p_{batdeg} + \sum_{t,a,cs} \frac{E_{EVc(t,a,cs)}}{eta_{EVc(cs)}} * p_{batdeg} \end{aligned}$$

The $TotalCost$ is a function of the energy supplied E_{sup} by the grid (subject to the price p_{sup} and the energy fed back E_{fi} (subject to the price p_{fi}) into the grid via V2G in a certain timestep t. In addition, the costs for battery degradation due to more frequent charging and discharging are taken into account based on p_{batdeg}. eta_{EVc} and eta_{EVd} stand for the efficiency of charging and discharging. E_{EVc} and E_{EVd} denote the energy that is charged into an EV and the energy that is discharged from a vehicle. The included variables and parameters of the model are dependent on t (time step), a (actor: charging station) and cs (charging session).

- **Energy balance equation:** essential formula to ensure an equilibrium of the aggregated energy flows per time step in the respective energy system.

$$\begin{aligned} E_{fi(t,a)} + E_{sold(t,a)} + \sum_{cs} E_{EVc(t,a,cs)} - \sum_{cs} E_{EVd(t,a,cs)} - E_{\mathrm{sup}(t,a)} \\ - E_{bought(t,a)} = E_{PV(t,a)} - E_{demand(t,a)} \end{aligned}$$

$E_{sold(t,a)}$ represents the amount of energy directly sold inside a local energy market. $E_{bought(t,a)}$ stands for energy bought directly inside a local energy market. These transactions and transfers of energy occur independently of the conventional electricity grid. $E_{PV(t,a)}$

represent potential energy generated via PV. $E_{demand(t,a)}$ refers to the energy demand of a non-EV actor (e.g. a city) within the modelled energy system.

- **EV battery equation:** the equation incorporates the battery state of charge of each EV at each time step into the model. SOC represents the state of charge of the EVs batteries. $\mathrm{SOC}_{\mathrm{arr}}$ denotes the state of charge at the timestep of arrival. Note that $SOC_{arr(t,a,cs)}$ is set to 0 at timesteps of non-arrival.

$$\mathrm{SOC}_{(\mathrm{t,a,cs})} = \mathrm{SOC}_{\mathrm{arr(t,a,cs)}} + \mathrm{SOC}_{\mathrm{t-1,a,cs)}} + \mathrm{E}_{\mathrm{EVc(t,a,cs)}} * \mathrm{eta}_{\mathrm{EVc(cs)}} - \frac{\mathrm{E}_{\mathrm{EVd(t,a,cs)}}}{\mathrm{eta}_{\mathrm{EVd(cs)}}}$$

In addition to the core equations described above, the model versions contain various constrains or other additional elements to address the respective research questions. For example, in the second case study, costs of a peak power tariff are included to the objective function. Constraints generally ensure realistic charging behaviour; for example they force the EVs to charge and discharge energy within their battery capacities.

Figure 6 shows a schematic illustration of the core elements of the optimisation model. It represents the maximum possible applications of the model. Please note that the individual case studies presented later do not contain all but only parts of the energy system illustrated. Depending on the case study and the scenario investigated, certain sub-elements of the optimisation model are applied, and the results analysed.

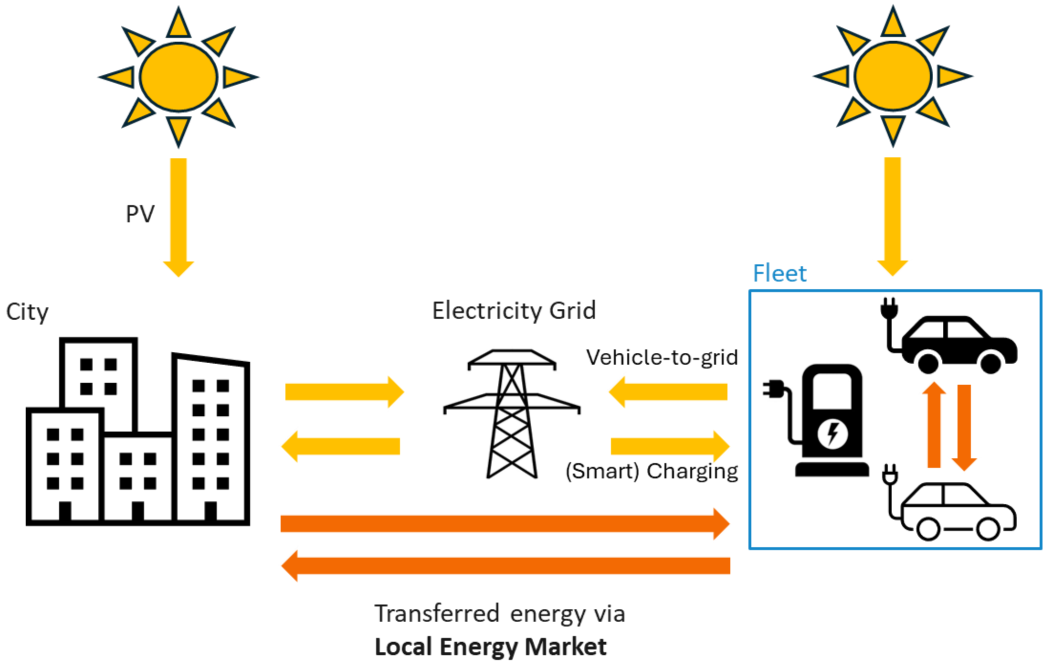


Figure 6: Overall model outline

3.2 Case Study Windkraft Simonsfeld

3.2.1 Introduction & Use Cases

Windkraft Simonsfeld AG is a wind farm operator in the eastern part of Austria. The headquarters in the village of Ernstbrunn is a plus-energy building with a large sized rooftop PV plant and a fully electric company fleet. This vehicle fleet consists of 26 EVs (mainly Renault Zoe, Hyundai Kona and VW ID3), 13 of which are operated as pool vehicles. The cars are mainly used for business trips in the region, but can also be used by employees for private trips, depending on availability. The vehicles are generally parked in front of the headquarters in Ernstbrunn, where the charging station with 26 charging points (AC charging) is also located. In addition, some vehicles are also charged at public charging points; however, this analysis focusses on the charging infrastructure on-site. Essentially, the model in this case study is intended to investigate the potential for optimising self-consumption in conjunction with the 70 kW_p rooftop PV, as well as the use of dynamic electricity prices. In both cases, the monetary benefits of smart charging and V2G need to be analysed.

Figure 7: EVs of the company fleet of Windkraft Simonsfeld (left) and 70 kWp rooftop PV (right)

Thus, the research focus of this case study is on the business case of smart and bidirectional charging for an actual company fleet. This includes on the one hand the **use case of self-consumption optimisation** on site with the rooftop PV, which currently generates large amounts of surplus electricity and on the other hand **dynamic pricing schemes** which are already available on the market. Moreover, the question is addressed, if bidirectional charging points (once broadly available) could be viable investments for reducing costs in such company fleets.

Research questions:

- Cost saving potential for an actual company fleet
    - Through self-consumption optimisation on site
    - Through dynamic energy pricing schemes
- Comparison of smart charging and bidirectional charging

This case study has been previously presented in German at the EnInnov conference 2024 in Graz, Austria [12].

3.2.2 Study description

Mobility data

The underlying mobility data and the PV generation profile come from the period October 2021 to September 2022. In order to simulate the driving behaviour of the fleet, the arrival and departure times of the individual vehicles at the charging stations, as well as the SoC are required. Two separate data sets are available for the case study in the project: Driver logbooks and records from the charging stations. In the logbooks, all the necessary data (arrival time, departure time, mileage) is recorded for each vehicle, but it is not possible to see whether a charging process takes place at the end of a journey or whether the vehicle is parked at a charging station at all. On the other hand, it is not clear from the charging station records which vehicle is charging at which station. This makes a direct comparison of the two data sources practically impossible. In addition, charging takes place at the fleet's own charging stations (i.e. at the company location) on the one hand and at public charging stations on the other, but only the former are relevant for the analysis in the case study.

Therefore, a probabilistic approach has been chosen: The records of the fleet's own charging stations determine the arrival and departure times. A trip milage is then randomly determined for each car upon arrival at the station, using a distribution function. The distribution functions were set up based on the mileage in the logbooks for each month and different times of day, as these two parameters seem to have the most significant influence on the distribution. Figure 8 shows an example of the cumulative distribution function for journeys arriving at the charging station between 9 am and 5 pm in November.

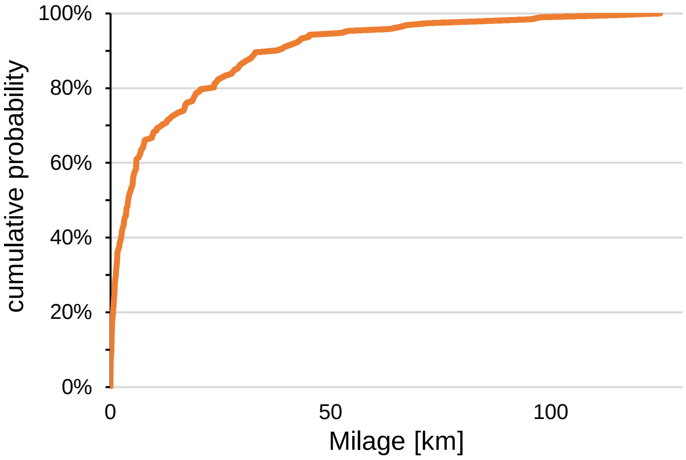


Figure 8: Cumulative distribution function for the milage per trip in the month November from 9 am to 5 pm

The resulting milage is converted into a SoC, assuming that the vehicle started the journey with a full battery. In addition to this mobility data, technical data of the vehicle batteries, i.e. battery size and charging capacity (incl. charging losses) are also defined as model inputs.

Price structure

For the dynamic electricity prices, more recent data (October 2022 to September 2023) was obtained from the day-ahead electricity exchange [13] and a premium of 1.5 cent/kWh was applied, as it is typical for currently available dynamic pricing schemes in Austria (e.g. Awattar or Spotty). The current standard tariff for commercial customers at Wien Energie (a local incumbent energy supplier in Austria) was used for static electricity prices (22.3 cent/kWh net) [14]. For energy quantities fed into the grid, a reduction of 40% of the supply price is assumed for both static and dynamic prices.

3.2.3 Scenarios and results

Scenarios defined

Several scenarios have been modelled and compared in this case study. The variables varied are price structure, availability of PV, capability of bidirectional charging and active price optimisation towards dynamic electricity prices. The additional costs of battery degradation due to bidirectional charging are also taken into account in some scenarios. The scenarios are modelled for the winter semester (October - March), with the exception of the comparative scenario 12, in which the summer semester (April - September) is considered. All scenarios are listed in Table 5.

Table 5: Scenarios of the case study at Windkraft Simonsfeld

Scenario	Prices	PV	V2G	Price optimisation	Battery degradation	Semester
1	static	yes	no	no	No	winter
2	static	yes	no	yes	No	winter
3	static	yes	yes	yes	No	winter
4	dynamic	no	no	no	No	winter
5	dynamic	no	no	yes	No	winter
6	dynamic	no	yes	yes	No	winter
7	dynamic	yes	no	no	No	winter
8	dynamic	yes	no	yes	No	winter
9	dynamic	yes	yes	yes	No	winter
10	dynamic	yes	yes	yes	yes, not optimised	winter
11	dynamic	yes	yes	yes	yes, optimised	winter
12	dynamic	yes	yes	yes	No	summer

In order to define a common vehicle type for the model in this case study, following specifications have been made:

- Net battery capacity: 58 kWh
- Maximum charging and discharging rate (AC): 11 kW
- Efficiency ratio of charging and discharging: 95%

Results

In the first comparison, the results of scenarios 1, 2 and 3 are compared. In scenario 1, there is no optimisation of self-consumption, i.e. the vehicles charge in an uncontrolled manner and use the PV electricity currently available. In scenario 2, self-consumption of PV electricity is optimised by means of controlled unidirectional charging processes (smart charging). In scenario 3, bidirectional charging (V2G) is also possible, which means that PV electricity can be temporarily stored in vehicle batteries and later supplied to other vehicles that are plugged in at the same time. Note that surplus PV energy is sold to the grid at a profit if it is not charged into the vehicle's batteries. Figure 9 compares the revenues from PV feed-in and the costs of drawing electricity from the grid. The balance is revenues minus costs.

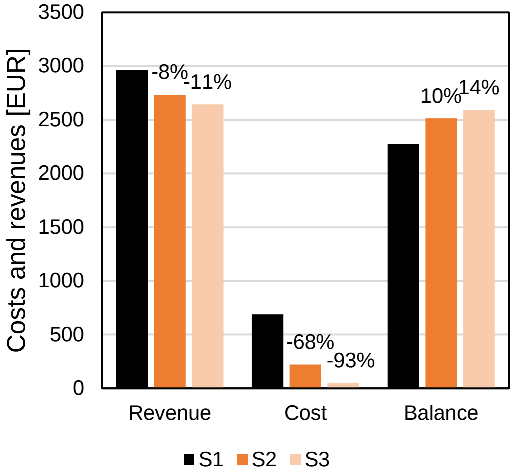
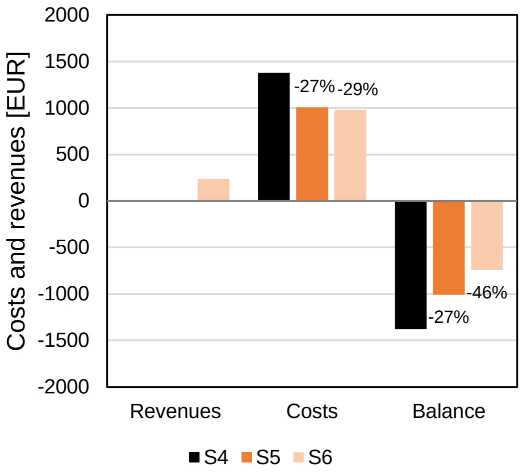


Figure 9: Revenues, costs and resulting balance in scenarios 1, 2 and 3

The result shows that the use of smart charging and V2G reduces both feed-in revenues and energy consumption costs, as the feed-in and consumption volumes decrease to the same extent. Smart charging contributes the majority of the monetary benefit with a 10% increase in the balance, while V2G only increases the balance by a further 4%.

The second comparison looks at the benefits of smart charging and V2G assuming dynamic electricity prices (changing in 15-minute intervals). The PV system is not taken into account here. In scenario 4, there is no price optimisation, while in scenario 5 smart charging and in scenario 6 V2G are used for price optimisation. Figure 10 again shows the monetary results, while figure 11 shows the feed-in to the grid and the supply from the grid in energy quantities.



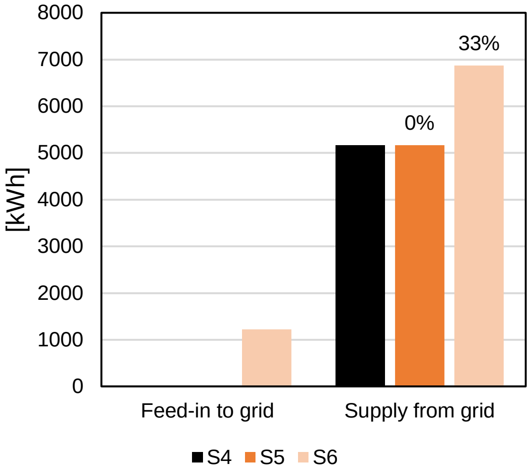


Figure 10: Revenues, costs and resulting balance in scenarios 4, 5 and 6

Figure 11: Feed-in and supply quantities in scenario 4, 5 and 6

As there is no PV system in this comparison, V2G only feeds electricity into the grid in scenario 6. The energy supply costs can be reduced by 27% through smart charging (scenario 5), while V2G only results in an additional saving of 2%. It should be noted that with smart charging (scenario 5), the total supply volumes remain the same and are only shifted to low-price periods. V2G increases the total supply volume, as the vehicles are partly used purely as storage facilities to utilise arbitrage profits (supply at low prices and feed-in at high prices). Note that the difference between the additional energy bought from the grid and the amount of energy sold to the grid in scenario 6 can be explained by charging and discharging efficiencies.

The third comparison combines the use of dynamic prices and self-consumption optimisation with the PV system. In scenario 7, self-consumption optimisation already takes place, but without optimisation for dynamic prices. In scenarios 8 and 9, price optimisation by means of smart charging or V2G is added. On balance, however, the combination with V2G and the corresponding feed-in revenues in scenario 9 shows a significant improvement with a reduction in total costs totalling 46%. Figure 12 shows revenues and costs, and Figure 13 demonstrates the energy volumes.

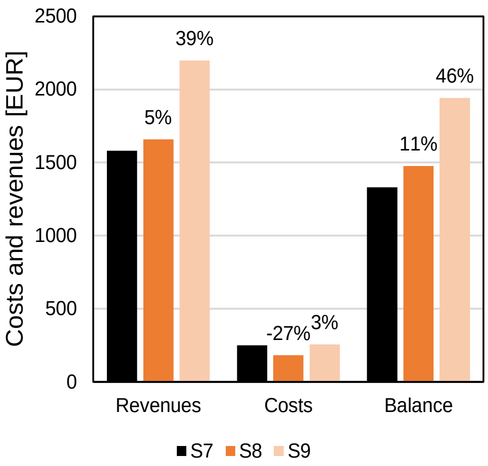


Figure 12: Revenues, costs and resulting balance in scenario 7, 8 and 9

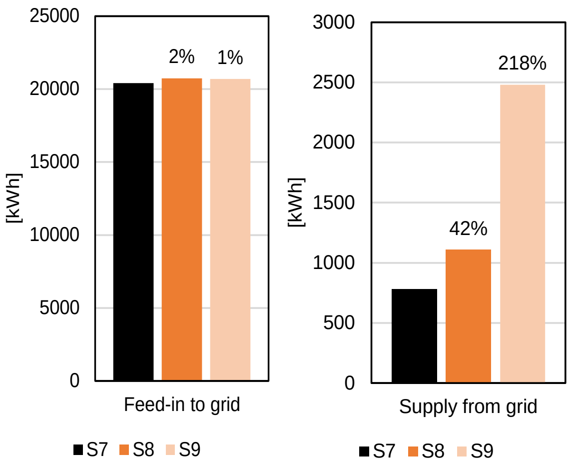


Figure 13: Feed- in and supply quantities in scenario 7, 8 and 9

A differentiated picture emerges in this comparison due to the PV system. The feed-in revenues increase slightly with smart charging (scenario 8) and significantly with V2G (scenario 9). The reason for this is that only with V2G do the vehicles serve as storage for the PV electricity and the energy can therefore be fed in at times of high prices. The quantities supplied from the grid increase with smart charging, as it is often more lucrative to purchase electricity from the grid at low-price times instead of charging at times when PV electricity is available. Particularly with V2G, the supply volumes increase rapidly, as arbitrage trading can be carried out there. It should be noted that the increased consumption is of course also reflected in higher absolute feed-in quantities, but due to the size of the PV system, this increase is small in relative terms. In the balance, this comparison shows a clear added value of V2G compared to smart charging.

The fourth comparison analyses the effect of additional costs incurred with V2G due to increased battery degradation. As the reference scenario in this comparison, scenario 10 essentially corresponds to the previous scenario 9 (V2G and price optimisation), but the degradation costs are added here. In scenario 11, on the other hand, these degradation costs are integrated into the model and are taken into account in the optimisation. Figure 14 again shows the revenues and costs and Figure 15 demonstrates the energy quantities.

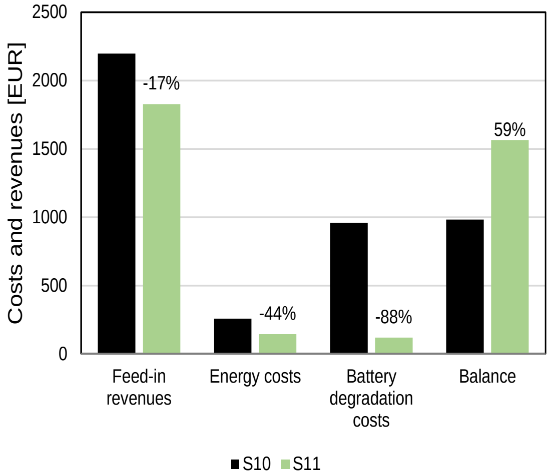


Figure 14: Revenues, costs and resulting balance in scenario 10 and 11

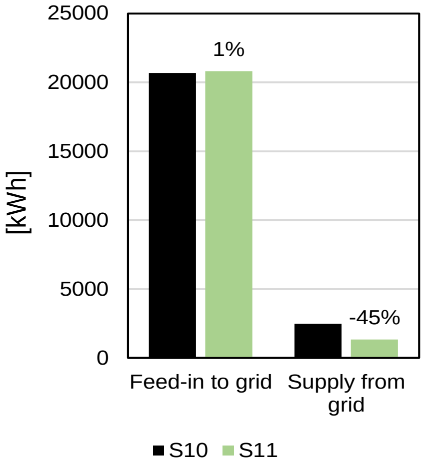


Figure 15: Feed-in and supply quantities in scenario 10 and 11

Compared with the previous scenarios, it can be seen that the degradation costs (if they are not taken into account in the optimisation) amount to approx. 1000 EUR and have a strong influence on the balance. If the degradation costs are taken into account in the optimisation, they fall to around EUR 100. Due to this cost factor, V2G operations decrease, which in turn leads to lower supply quantities.

The fifth and final comparison compares the winter half-year (scenario 9) with the summer half-year (scenario 12), in which the majority of the PV yield is generated. Figure 16 shows the monetary results and figure 17 the energy quantities.

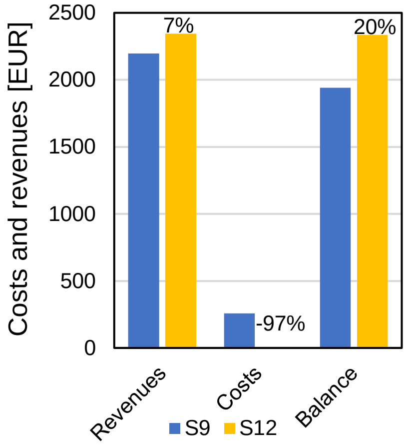


Figure 16: Revenues, costs and resulting balance in scenario 9 and 12

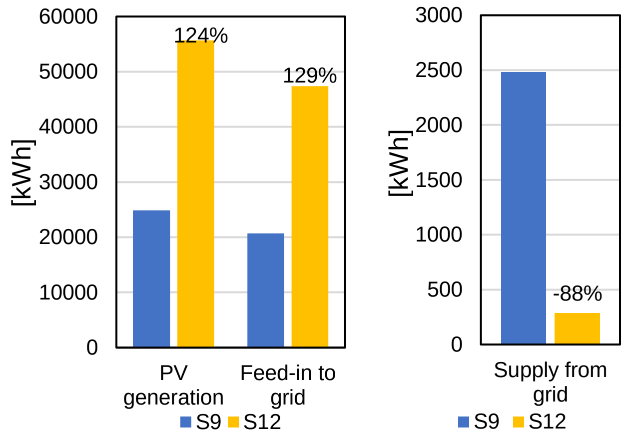


Figure 17: Feed- in and supply quantities in scenario 9 and 12

Due to the high level of PV generation, feed-in is significantly higher in the summer half-year, but consumption also falls sharply, which suggests a higher level of self-consumption optimisation. While price optimisation is more relevant during the winter season, self-consumption optimisation is more relevant in the summer season.

3.2.4 Conclusions

Key findings	Description
1	**Smart charging as a low hanging fruit.** Controlled unidirectional charging can be implemented relatively easily with solutions already on the market both for self-consumption optimisation and dynamic energy prices. Also, in most scenarios it offers the majority of the achievable cost reductions.
2	**Vehicle-to-grid as an add-on with high complexity.** Bidirectional charging requires bidirectional communication protocols between EV and charging station. The case study shows that there is a benefit from V2G in all scenarios, but mostly smaller than for smart charging. One exception is the comprehensive scenario (PV & dynamic prices included), in which both self-consumption optimisation and dynamic price optimisation is done at the same time.
3	**Vehicle-to-grid enables notable benefits.** Despite the disadvantages resulting from the increased complexity and costs of V2G, the application of V2G enables notable benefits. In combination with a sufficiently large PV production, V2G makes it possible to drastically reduce the costs of energy purchased from the grid by up to **93%**. Without PV energy, V2G can reduce energy costs by up to **46%**, if a dynamic energy price is selected. If a large PV production is available and energy prices are dynamic, V2G manages to increase profits through energy trading by up to **46%**.
4	**Self-consumption summer, dynamic prices in winter.** As PV generation is clearly more dominant in summer, self-consumption optimisation is more profitable in the summer months, whereas price optimisation can be profitable in winter as well.
5	**The monetary values of smart charging and vehicle-to-grid per vehicle are modest.** In this case study, the additional monetary values of smart charging and V2G lie between approx. **2,1 - 4,1€** per month per vehicle, depending on the set-up.
6	**Battery degradation costs are relevant.** Taking into account the costs for battery degradation in the optimisation reduces the V2G-potential, as these costs have a significant impact on the results. However, it still can be discussed if the battery lifespan is a limiting factor for EVs at all, as a total number of 3000 battery cycles equals to more than 20 years of usage, which is usually more than the average lifespan of a car.

3.3 Case Study Zurich 1 – Peak shaving

3.3.1 Introduction & Use Cases

This section presents the first of two case studies, both located in Zurich, which examine the flexibility potential of EVs. Both studies use data from a station-based car-sharing fleet. This (the first) case study focuses on the potential of a large-scale EV fleet to stabilise the electricity grid. More specifically, the study considers how a large number of EVs, e.g., organised as a car-sharing or company fleet, can provide flexibility services to the electricity grid. This means a reduction of the peak load in Zurich, which is made possible by EVs feeding in energy or postponing charging. A real load profile for the city of Zurich is used for this purpose. Especially in combination with fluctuating energy prices, EVs may have a significant potential for grid stabilisation. The authors therefore investigate whether the coordinated use of smart and bi-directional charging can have a significant impact on peak load and grid stability.

The primary objective of the study is to examine the peak load and the role of the DSO as price-setter. The DSO has an interest in reducing overall fluctuations in electricity demand, with a particular focus on reducing the maximum demand (peak shaving). The aforementioned objective can be achieved through the implementation of an optimal price structure for peak load, commonly referred to as a peak power tariff.

Furthermore, the case study examines the charging and discharging behaviour of an EV fleet reacting to price incentives provided by a DSO and to different energy tariffs. From the perspective of the fleet manager, the total energy costs for charging are analysed in respective scenarios as well.

Research questions

- Quantifying the potential of a large EV fleet on grid stability
    - Effects of different peak power tariffs on the peak load
    - Effects of different energy price structures on the peak load
    - Effects of smart and bidirectional charging on the peak load

3.3.2 Study description

Data

The input data for the economic dispatch model of the first Zurich study is based on real mobility data provided by the Swiss car-sharing provider "mobility.ch". Using the real data with the help of a pipeline to simulate car sharing booking patterns, a synthetic logbook was created that provides information on the driving and idling times of each car in an artificial car-sharing fleet. The simulation process generated realistic reservations and driving patterns, along with user demands for mobility services. A transportation mode choice model was applied to determine whether a carsharing ride is selected by one of the users. This resulted in arrival and departure times at the charging stations as well as the state of charge on arrival for different car types. Realistic characteristics about each EV in the fleet was also generated (battery capacity, charging power, etc. [15], [16]).

The data used in the study includes the following key information about the synthetic fleet:

- Number of EVs: 274
- Number of charging stations: 154
- Number of charging sessions: 420
- Average idle time between trips: 9h 22m
- Start first charging session: 1 Jan.2019 – 07:42
- End last charging session: 2 Jan.2019 - 22:54
- Average battery capacity: 42,16 kWh
- Average charging power: 19,94 kW
- Average range: 234,41 km
- Average km driven per trip: 20,293 km
- Average SoC start of the trip: 85,90%
- Average SoC end of the trip 76,32%

In words, the input data contains a list of 420 charging sessions (idle times) from 274 different EVs using 154 charging stations. Some EVs charge several times and some charging stations are used more often. The time horizon is approximately 39 hours from 7:42 am to 10:54 pm the following day. In total, 274 EVs provide their batteries as flexible energy storage between their trips.

Figure 18 illustrates the duration of the individual charging sessions (idle times) and where they are located in the time period examined (188 timesteps per 15 min). There are no charging sessions in the off-peak periods. Most of the charging sessions occur approximately in the middle of the time horizon. The average arrival time is 6:00 pm on the first day and the average departure time is 5:45 am on the second day.

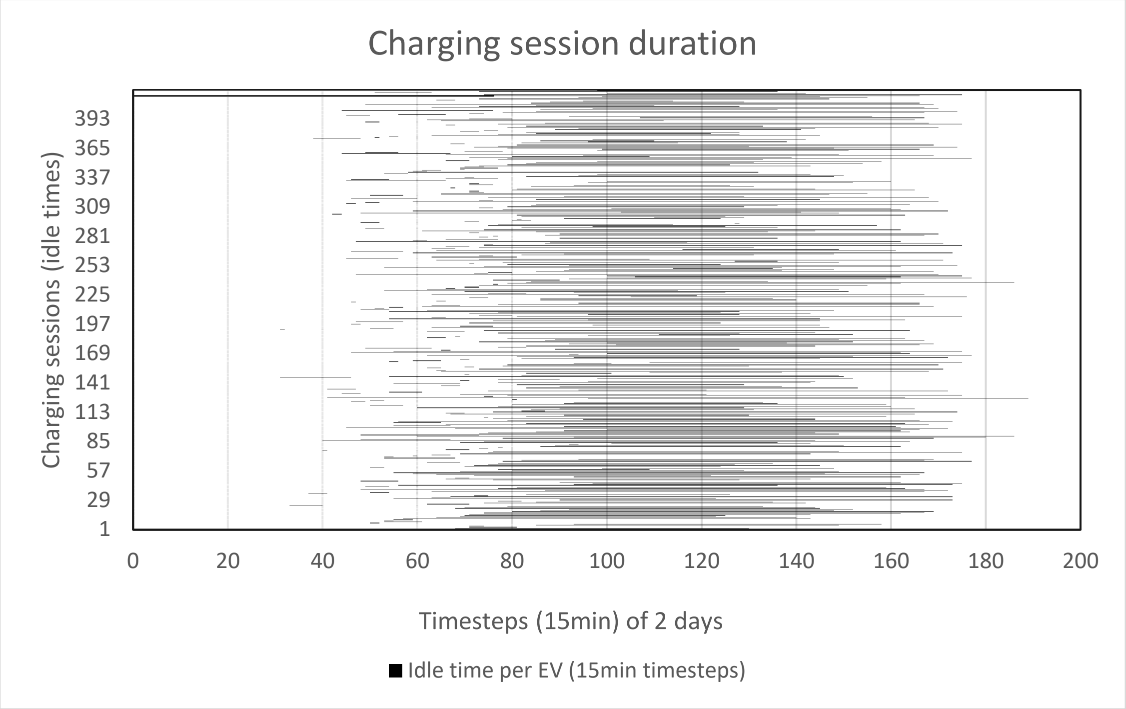


Figure 18: Duration of the individual charging sessions

At the end of each idle period, the EVs must have the same SoC as at the start of the trip. Each vehicle must therefore fully recharge the energy lost through driving.

Rescaling the load profile

To study the impact of a large and intelligently charging EV fleet on the load profile, it is necessary to scale up the number of EVs. However, since the data set only includes 274 EVs, the load profile is scaled down instead.

To achieve this, the gross load profile of the grid area of Zurich (year 2023) has been retrieved [17]. In particular, the time horizon of two days including the highest peak load of the year is used in this study. The two selected days are Monday 23rd January and Tuesday 24th January. The peak load of 110362,98 kWh occurred on 23rd January at approximately 12:15 pm.

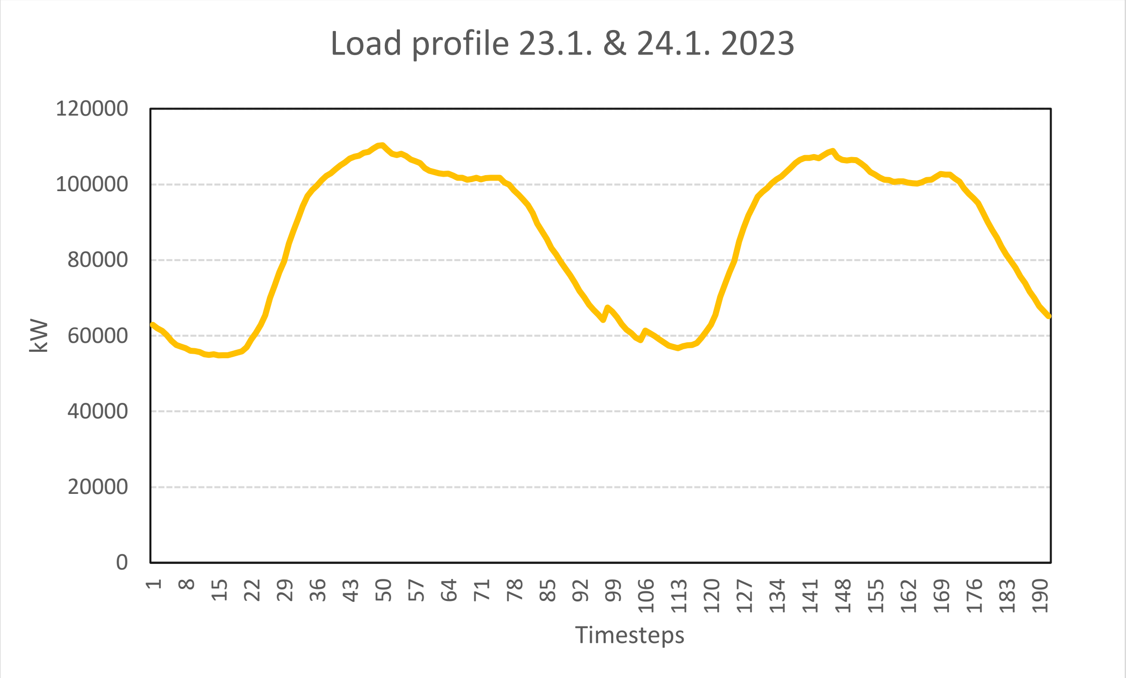


Figure 19: Load profile of the city of Zurich in the observed timeframe

The rescaling process is based on two assumptions:

- The future gross load profile in 2030 is similar to the real profile of 2023
- The charging behaviour of Zurich's EV fleet in 2020 has no relevant effect on the gross load profile.

The scaling factor is the ratio between the expected number of EVs in Zurich in 2030 and the 274 EVs from the data.

Based on historic data provided by the City of Zurich, there were about 6 000 EVs in Zurich in 2023 and about 8 000 new vehicle registrations can be expected every year until 2030 [18]. Considering "Swiss eMoblity's" forecast of future EV shares (percent of new registrations) per year [18], the annual absolute growth figures for EVs in Zurich can be calculated. Consequently, the anticipated number of EVs (battery electric vehicles) in Zurich is approximately 24 000. This figure is derived from a conservative calculation, representing a robust and realistic estimate. In the final step, the load profile is divided by (24 000/274), which yields 87,59.

Price structure

The study examines the charging behaviour of EVs in relation to different price structures. The various price structures are presented with a brief description in the following tables [19], [20], [21]. The first table includes most realistic price structures from the years 2023 and 2024 applied in the City Zurich. Dynamic prices from 2023 are more volatile (higher variance) and therefore allow more room for EVs to trade profitably. The second table represents differently adjusted dynamic prices from the year 2023. Dynamic prices are based on the Swiss day ahead spot market prices. The dynamic prices from 2023 are based on prices of the 23rd and 24th of January 2023. Dynamic prices from 2024 are based on prices of the 22nd and 23rd of January 2024. The standard peak power price accounts to the actual price per kW to be paid by the DSO to the Swiss TSO at the point of common coupling (PCC) [22]. This price is doubled in S9 and increased 18,7 times in S10. The conversion from Swiss francs to Euros is calculated using an exchange rate of EUR/CHF = 0,95. "Supply" stands for the energy purchased from the grid. "Feed in" stands for the energy sold to the grid.

Table 6: Overview price structure. Static prices are based on [20], [21]. Dynamic prices are based on [19].

Price category	Description	Average price
1: Static prices 2023/2024 – Supply	Prices based on tariff structure by local energy supplier EWZ (Elektrizitätswerk der Stadt Zürich) – 2023 & 2024	0,219 CHF/kWh 0,230 EUR/kWh
2: Static prices 2023/2024 – Feed in	Prices based on tariff structure by local energy supplier EWZ (Elektrizitätswerk der Stadt Zürich) – 2023 & 2024	0,130 CHF/kWh 0,137 EUR/kWh
3: Dynamic prices 2024 - Supply	Prices based on Swiss day ahead prices provided by ENTSO-E in **2024**. Prices per timestep: 100% of day ahead price + 0,1 CHF/kWh grid fee + 0,015 CHF/kWh energy supplier fee.	0,188 CHF/kWh 0,198 EUR/kWh
4: Dynamic prices 2024 – Feed in	Prices based on Swiss day ahead prices provided by ENTSO-E in **2024**. Prices per timestep: 80% of day ahead price - 0,015 CHF/kWh energy supplier fee.	0,044 CHF/kWh 0,046 EUR/kWh
5: Dynamic prices 2023 - Supply	Prices based on Swiss day ahead prices provided by ENTSO-E in **2023**. Prices per timestep: 100% of day ahead price + 0,1 CHF/kWh grid fee + 0,015 CHF/kWh energy supplier fee.	0,304 CHF/kWh 0,320 EUR/kWH
6: Dynamic prices 2023 – Feed in	Prices based on Swiss day ahead prices provided by ENTSO-E in **2023**. Prices per timestep:	0,137 CHF/kWh

	80% of day ahead price - 0,015 CHF/kWh energy supplier fee.	0,144 EUR/kWh

Table 7: Overview price structure. Dynamic prices are based on [19]. Peak power tariff is based on [22].

Price category	Description	Average price
7: Adjusted dynamic prices (Version 1) 2023 - Supply	Prices based on Swiss day ahead prices provided by ENTSO-E in **2023**. Prices per timestep: 100% of day ahead price + **0,03** CHF/kWh grid fee + 0,015 CHF/kWh energy supplier fee.	0,235 CHF/kWh 0,247 EUR/kWh
8: Adjusted dynamic prices (Version 1) 2023 – Feed in	Prices based on Swiss day ahead prices provided by ENTSO-E in **2023**. Prices per timestep: 100% of day ahead price - 0,015 CHF/kWh energy supplier fee.	0,175 CHF/kWh 0,184 EUR/kWh
9: Adjusted dynamic prices (Version 2) 2023 - Supply	Prices based on Swiss day ahead prices provided by ENTSO-E in **2023**. Prices per timestep: 100% of day ahead price + **0** CHF/kWh grid fee + 0,015 CHF/kWh energy supplier fee.	0,205 CHF/kWh 0,216 EUR/kWh
10: Adjusted dynamic prices (Version 2) 2023 – Feed in	Prices based on Swiss day ahead prices provided by ENTSO-E in **2023**. Prices per timestep: 100% of day ahead prices - 0,015 CHF/kWh energy supplier fee.	0,175 CHF/kWh 0,184 EUR/kWh
11: Peak power tariff	Standard peak power price based on the actual price per kW to be paid by the DSO to the Swiss TSO at the point of common coupling.	46 380 CHF/MW 48 821 EUR/MW

3.3.3 Scenarios and results

This section presents the various scenarios designed for this case study and their results. Table 8 provides an overview of the respective features.

- **Static price:** Constant price in every time step, for both supply and feed in
- **Dynamic price:** Prices (feed in & supply) per time step based on Swiss spot market day ahead prices.
- **Smart charging:** EV charging depends on price signals and tariff structure to minimise total costs.
- **V2G:** Bidirectional charging is enabled. EVs are able to feed in electricity back into the grid.
- **Peak power optimisation:** EVs consider the Zurich load profile when charging. This is achieved through a realistic peak power tariff, which is applied by the Swiss TSO “Swissgrid”.
- **Battery degradation:** EVs consider the degradation of their batteries for each charging and discharging process.

Table 8 provides an overview about the different scenarios and their set ups. In scenarios 9 - 10, "*" stands for modified input parameters, such as a modified dynamic price.

Table 8: Scenario overview case study Zurich 1

Scenario	1	2	3	4	5	6	7	8	9	10
Static price	✓	✓	✓							
Dynamic price				✓	✓	✓	✓	✓	✓*	✓*
Smart charging	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
V2G			✓			✓	✓	✓	✓	✓
Peak power optimisation		✓	✓		✓		✓	✓	✓*	✓*
Battery deg.	✓	✓	✓	✓	✓	✓	✓	✓	✓*	✓

The following three figures summarize the main results of each Scenario. Figure 20 shows the total costs of all actors (EV fleet and the city of Zurich). Figure 21 presents the load peak of each scenario and the respective costs due to the applied peak power tariff. Figure 22 breaks down the costs for the EV fleet into energy, discharging and charging costs. The latter are battery degradation costs.

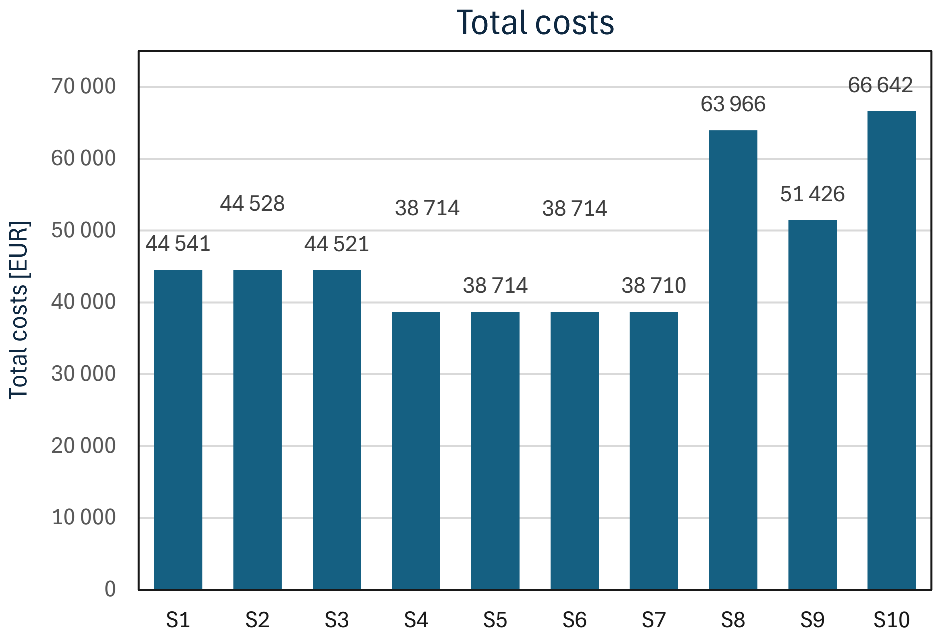


Figure 20: Total costs (Costs of Zurich + Costs of fleet)

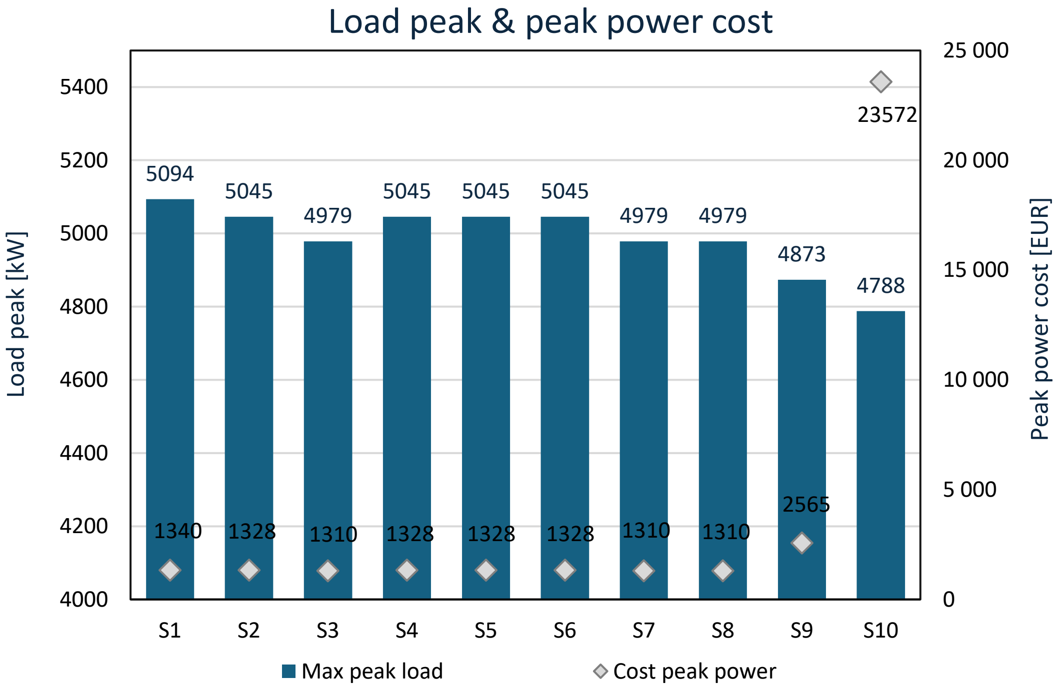


Figure 21: Load peak and the associated peak power costs of each scenario

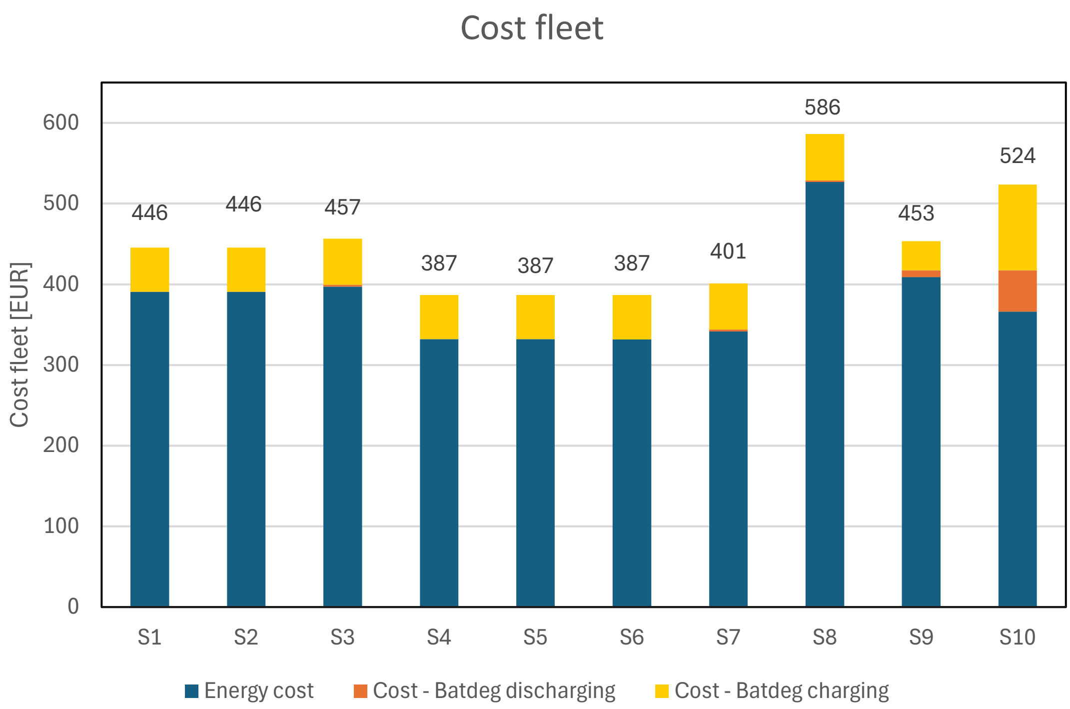


Figure 22: Costs fleet (energy costs + battery degradation costs for charging and discharging)

In addition to the figures above, Table 9 describes the different scenario set-ups in words and addresses the respective numerical results.

Table 9: Description of results per scenario in case study Zurich 1. For detailed results see figure 20-20.

Scenario	Description & Results	Price structure
1	Basic benchmark scenario with realistic static prices. EVs simply charge the amount of energy they need. Battery degradation costs included. **Results**: See figure 20-22.	1 & 2
2	Peak power tariff included. EVs now consider the Zurich load profile and get an incentive for peak shaving. **Results:** load peak is reduced slightly **(-0,77%)**. Therefore, total costs are reduced as well. Costs fleet of do not change.	1 & 2
3	Bidirectional charging (V2G) enabled. EVs are enabled to feed in (sell) energy. **Results:** load peak is again reduced slightly **(-2,26%)**, as well as total costs. EV sell a very small amount of energy to reduce the load peak. Fleet costs increase slightly due to more energy trading activities.	1 & 2
4	Basic benchmark scenario with realistic dynamic prices. If possible, EVs charge when prices are low. **Results:** Lower costs due to overall lower energy prices.	3 & 4
5	Peak power tariff included.	3 & 4

	Results: All costs and peak load remain as in S4. Additional peak power tariff does not provide EVs with sufficient incentives to change their charging behaviour.	
6	Benchmark scenario with V2G and dynamic prices. **Results:** Same results as in S4 & S5. Can be compared with S4, however V2G ability does not provide incentives to trade energy due to the low price range. Battery degradation is always higher than possible trading income.	3 & 4
7	Peak power tariff included. **Results:** With V2G enabled and a peak power tariff implemented, EVs adapt their charging behaviour. Load peak is reduced by -**2,26%**, as in Scenario 3. Energy trading only to reduce load peak.	3 & 4
8	As Scenario 7, but with more volatile (higher variance) dynamic prices from 2023. **Results:** As in S3 & S7 there occurs only a very small amount of energy trading to reduce the load peak **(-2,26%),** even with more dynamic prices. Price range is still too small for profitable energy trading. Costs are generally higher due to higher energy prices.	5 & 6
9	As Scenario 8, but with some adjustments/assumptions. 1: Double peak power tariff. 2: Half battery degradation costs. 3: Adjusted dynamic price structure to give EVs more possibilities to trade profitably (lower supply costs and higher feed in revenue). **Results:** The higher power tariff leads to a greater load peak reduction **(-4,33%)**. Overall costs are generally lower as in S8 due to lower energy costs.	7 & 8
10	Artificial scenario where revenue of DSO is restructured. 0 grid fees but a much higher peak power tariff as compensation. Missing fee income is 100% compensated. **Results:** load peak reduction by **6%** and therefore more energy trading activities. As a result, fleet costs are higher as in 9 (despite cheaper energy). Energy sold to reduce the load peak must be repurchased.	9 & 10

In addition to the numerical results, selected charts are presented to illustrate the potential of the EV fleet for grid stabilisation. The following two charts refer to scenario 1 (baseline scenario) and scenario 10 and show the respective load curve, the balance of bought and sold energy and the two price curves (supply and feed in).

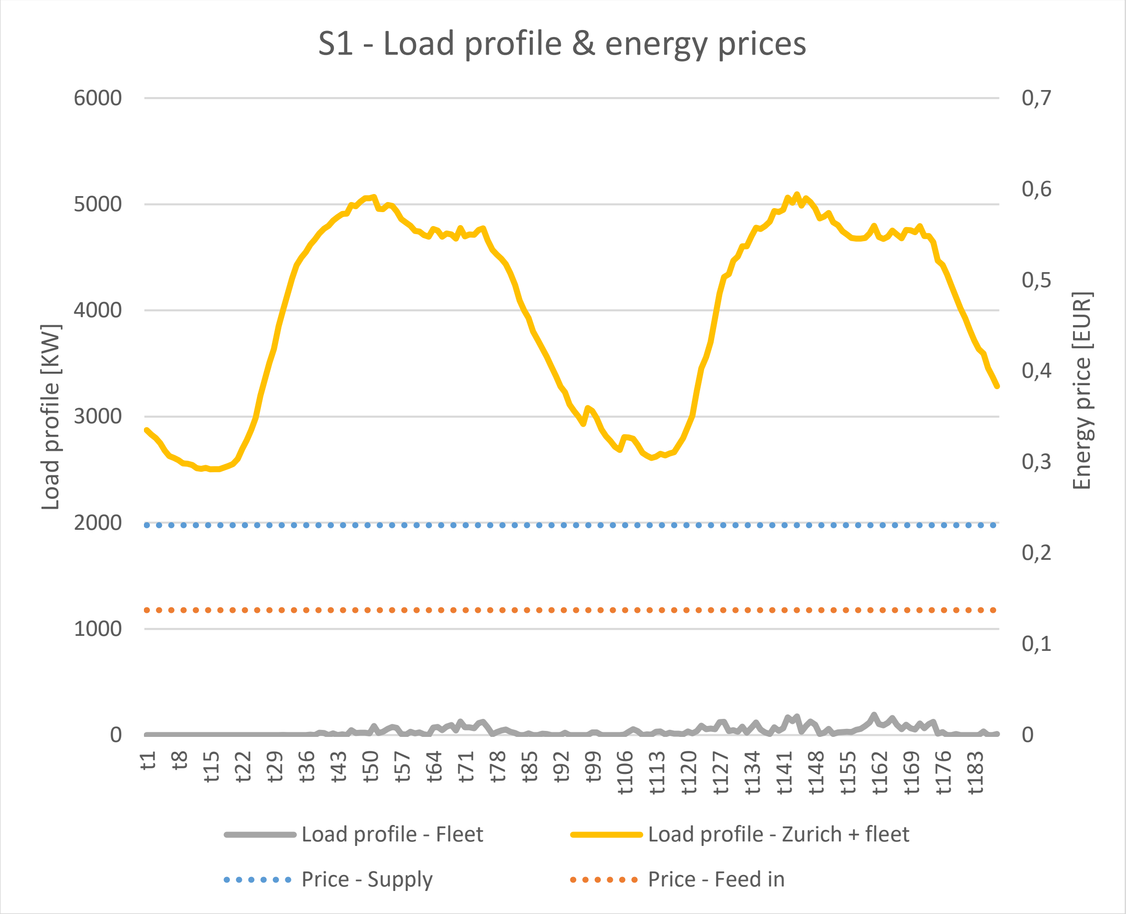


Figure 23: S1, chart of load profile, energy balance and price structure.

Figure 23 shows the impact of a non-intelligently charging EV fleet on Zurich's load profile. The chart can be compared with the load profile excluding EVs in Figure 19. The effects of uncontrolled charging on the load profile are negligible.

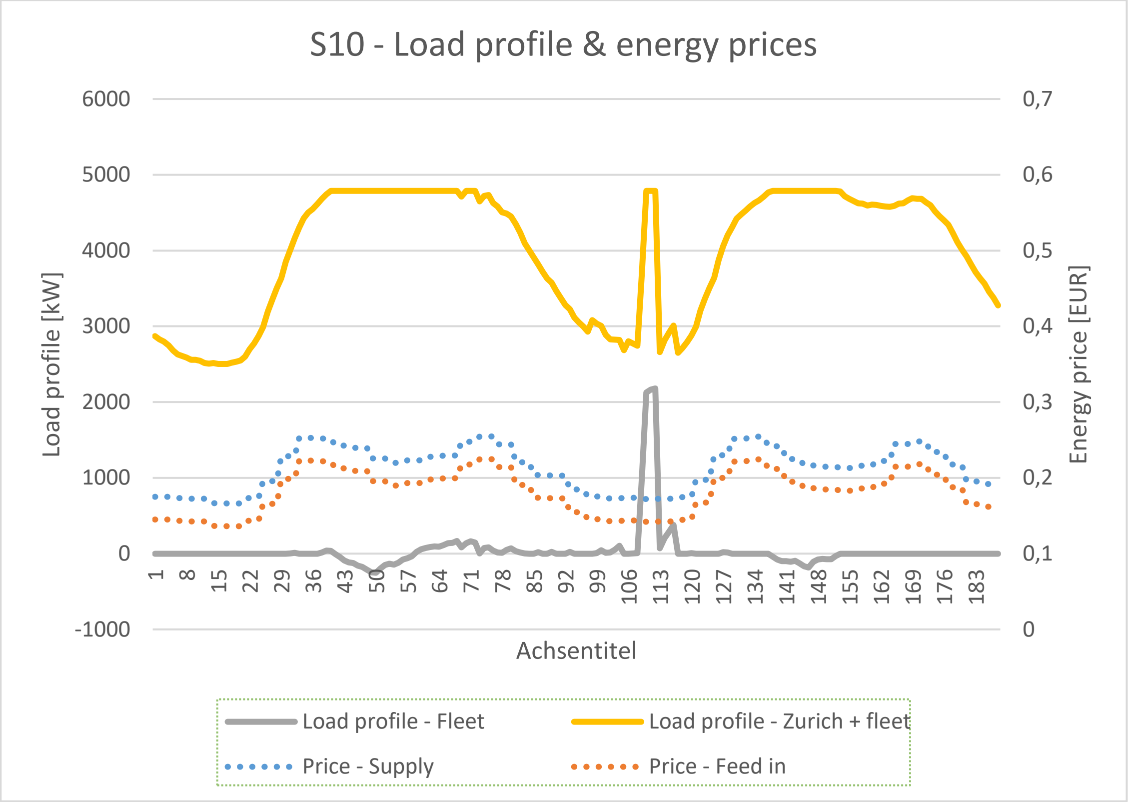


Figure 24: S10, chart of load profile, energy balance and price structure.

Figure 24 shows the impact of an intelligently charging EV fleet on Zurich's load profile. Compared with 3, we see a smoothed load profile with a reduced load peak. In addition, the chart shows that energy is largely sold to reduce the load peak, not to make trading profits. Relatively large amounts of energy are charged in timesteps when the purchase price is attractively low. Furthermore, figure 24 shows that the aggregated battery capacity of the EV fleet has the potential for significant load profile stabilization. Moreover, taking into account the idle times of the EVs (Figure 18), the chart shows that smoothing naturally only begins as soon as there is sufficient available battery capacity. The reduction potential is reduced accordingly if there are few or no EVs available. However, it is sufficient if a small percentage of the available aggregated battery capacity is available for grid stabilisation.

3.3.4 Conclusions

This study focussed on the potential of a relatively large EV fleet on grid stability in Zurich. The analysis of 10 scenarios leads to the following conclusions:

Key findings	Description
1	**EV fleets have the potential for grid stabilisation.** A sufficiently large number of V2G-capable EVs has the potential to provide noticeable grid stabilisation. This case study calculated with about 1 EV per 17 inhabitants (conservative calculation). The aggregated battery capacity is sufficient to enable shifts in the load peak curve in the multi-digit percentage range.
2	**A minimum amount of battery capacity must always be available.** Since realistic peak shaving means a reduced load peak over a certain period, corresponding battery capacities must also be available throughout. However, it is sufficient if a small percentage of the available aggregated battery capacity is available for grid stabilisation.
3	**Realistic price structures hardly incentivise peak shaving.** A realistic peak power tariff and electricity prices from 2023/2024 located in Zurich offer very little incentive for peak shaving. Under realistic conditions with V2G-capable EVs, a reduction in the load peak of -2,26% can be achieved. It does not matter whether static or dynamic prices are applied. Without V2G, only a reduction of -0,77% is achieved. For the total system, a peak load reduction of -2,26% equals approx. **344 000€** in cost reduction over the period of one year. These savings are negligible compared to the hundreds of million Euros in electricity costs for a city like Zurich.
4	**Economic incentives for peak shaving require a sufficiently high peak load tariff.** In this case study, a slightly greater load peak reduction of -4,33% is achieved with the help of a double peak power tariff in combination with lower battery degradation costs. A much higher peak load tariff (18,7 times) achieves a reduction of 6%. However, the reduction potential in this case study is limited by the fact that the EV battery capacity is not continuously available and is most likely much higher under other conditions.
5	**Profits from electricity trading require a sufficiently wide price range.** Profits from electricity trading are only possible if there is a sufficiently large difference between buying and selling prices. Dynamic prices must offer opportunities to sell energy with real profits, otherwise the V2G technology (bidirectional charging) will not be utilised. The price range must therefore exceed grid fees, taxes, and battery degradation costs.

6	**Battery degradation costs are relevant.** Battery degradation costs are a relevant factor in the cost structure of the EV fleet and can make the difference between trading energy profitably or standing still.

3.4 Case Study Zurich 2 – Economic dispatch

3.4.1 Introduction & Use Cases

This section presents the second of two case studies located in the city of Zurich. The second study can be seen as addition to the first one, which focussed on EV fleets and grid stability. This case study will exclude the topic of grid stability and will only focus on economic aspects of an EV fleet from the fleet operator's perspective. The fleet will once again be a station-based EV fleet.

Accordingly, the research questions concern economic cost reduction in conjunction with various electricity tariffs and technological possibilities:

Research Questions:

- Effects of different energy tariffs (static or dynamic) on EV fleet energy costs
- Effects of optimal use of a dynamic tariff
- Effects of bidirectional charging (V2G) on EV fleet energy costs

3.4.2 Study description

Data

See 3.3.2, this study is based on the same data as the previous one, with the exception of introducing so-called "dummy vehicles".

Dummy vehicles

In contrast to the previous case study, the data for the EV fleet is modified. In addition to the 274 active EVs, a certain number (221) of inactive "dummy vehicles" are also considered. These "dummy vehicles" are not booked by costumers but are available for electricity trading. The "dummy vehicles" have average EV characteristics (battery capacity, charging power) in line with the rest of the fleet. This allows to consider a relatively large EV fleet (495 EVs) with a realistic utilization rate. Furthermore, a full 48 hours of battery capacity is available, which allows a better extrapolation to 1 year.

Price structure

The study examines the charging behaviour of EVs in relation to different price structures. The prices are presented with a brief description in the following table [19], [20], [21]. The two static prices are most realistic price structures from the years

2023 and 2024 applied in the City of Zurich. The first pair of dynamic prices are based on the average dynamic prices from 2023. An average price for the year 2023 is calculated for each hour of the day. The calculated 24 mean prices are combined to form a representative dynamic average price. This 24-hour price structure is applied twice in succession in the study to cover the 2 days of data. The second pair of dynamic prices represents the 48-hour period from 2023 with the largest price fluctuation (2-3.7.2023). The dynamic price trends can be seen in Figure 25 and Figure 26.

The conversion from Swiss francs to Euros is calculated using an exchange rate of EUR/CHF = 0,95. “Supply” stands for the energy purchased from the grid, whereas “feed in” denotes the energy sold to the grid.

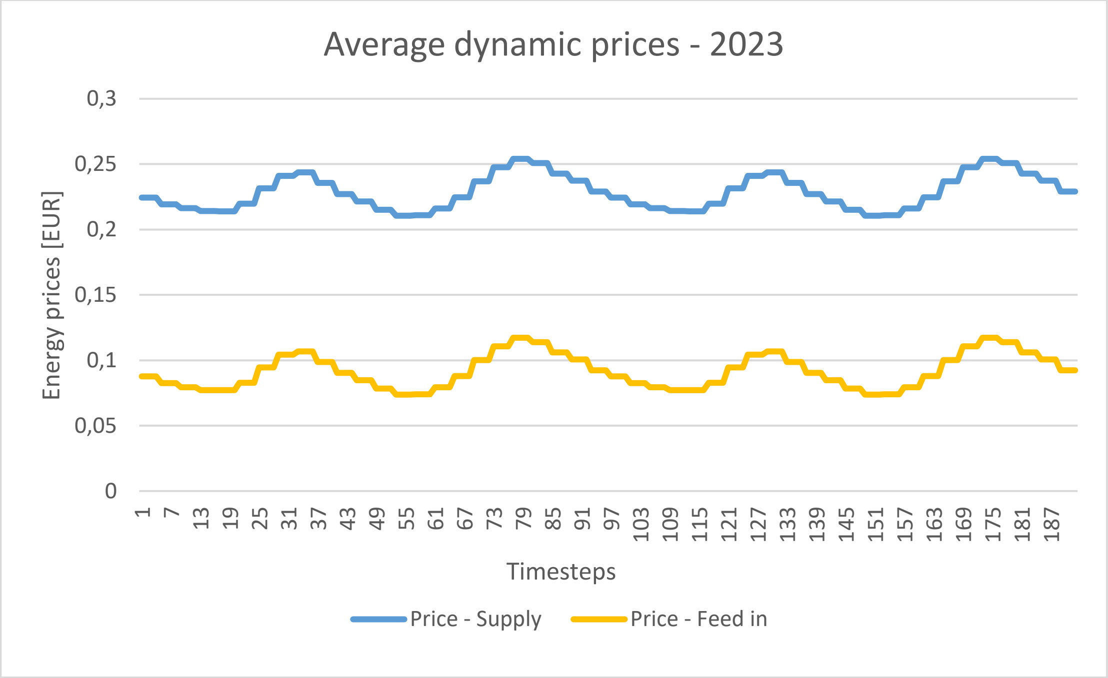


Figure 25: Average dynamic prices in the year 2023 for grid supplied energy and feed-in

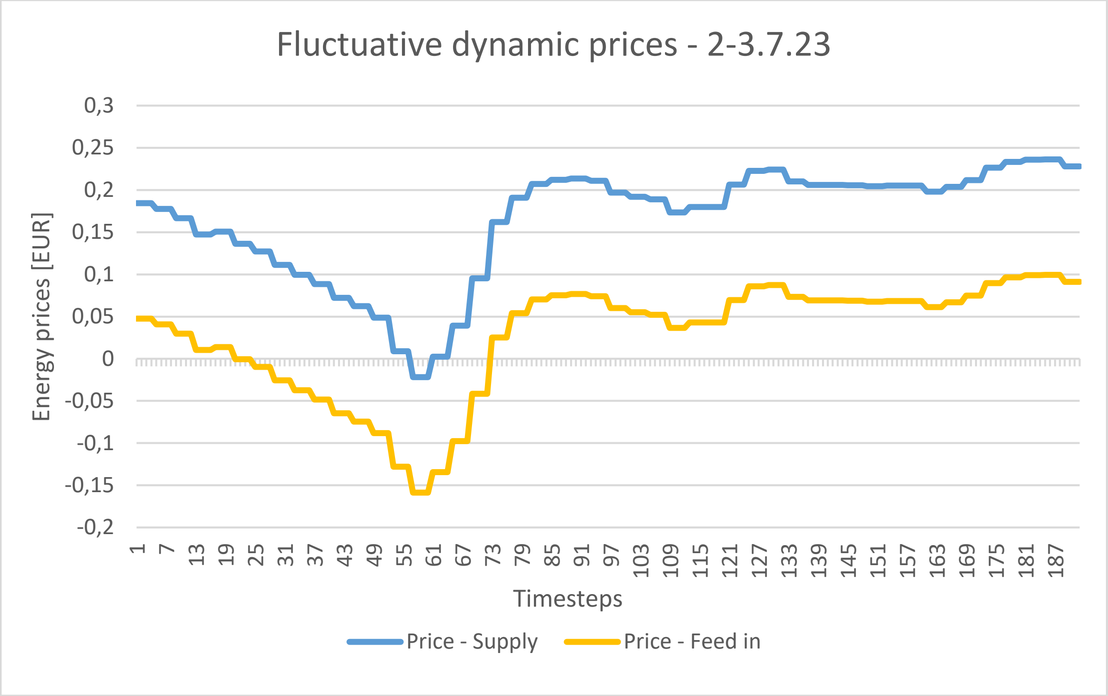


Figure 26: Dynamic prices for grid supplied energy and feed in at the day of highest price fluctuation in 2023

Table 10: Static prices are based on [20], [21]. Dynamic prices are based on [19]

Price category	Description	Average price
1: Static prices 2023/2024 – Supply	Prices based on tariff structure by local energy supplier EWZ (Elektrizitätswerk der Stadt Zürich) – 2023 & 2024	0,219 CHF/kWh 0,230 EUR/kWh
2: Static prices 2023/2024 – Feed in	Prices based on tariff structure by local energy supplier EWZ (Elektrizitätswerk der Stadt Zürich) – 2023 & 2024	0,130 CHF/kWh 0,137 EUR/kWh
3: Average dynamic prices 2023 - Supply	Prices based on Swiss day ahead prices provided by ENTSO-E in 2023. The average dynamic price for each hour of the representative day is calculated by averaging the respective hour's price across the entirety of 2023. Prices per timestep: 100% of average day ahead price + 0,1 CHF/kWh grid fee + 0,015 CHF/kWh energy supplier fee.	0,217 CHF/kWh 0,228 EUR/kWh

4: Average dynamic prices 2023 – Feed in	See 3: Average dynamic price above Prices per timestep: 100% of average day ahead price - 0,015 CHF/kWh energy supplier fee.	0,087 CHF/kWh 0,0915 EUR/kWh
5: Dynamic prices 2023 (selected period) - Supply	Prices based on Swiss day ahead prices provided by ENTSO-E in **2023**. The 48-hour period with the greatest price fluctuation from 2023 was selected (2- 3.7.23) Prices per timestep: 100% of day ahead price + 0,1 CHF/kWh grid fee + 0,015 CHF/kWh energy supplier fee.	0,155 CHF/kWh 0,163 EUR/kWh
6: Dynamic prices 2023 (Selected period) – Feed in	See 5: Dynamic prices above Prices per timestep: 100% of day ahead price - 0,015 CHF/kWh energy supplier fee.	0,025 CHF/kWh 0,026 EUR/kWh

3.4.3 Scenarios and results

This section presents the different scenarios designed for this case study and their results. Table 11 provides an overview of the respective features. "*" stands for modified input parameters, such as a modified dynamic price.

- **Static price:** Constant price in every time step, for both supply and feed in.
- **Dynamic price:** Prices (feed in & supply) per time step based on Swiss spot market day ahead prices.
- **Smart charging:** EV charging depends on price signals and tariff structure to minimise total costs.
- **V2G:** Bidirectional charging is enabled. EVs are able to feed in electricity back into the grid.
- **Battery degradation:** EVs consider the degradation of their batteries for each charging and discharging process.

Table 11. Scenario overview case study Zurich 2

Scenario	1	2	3	4	5	6
Static price	✓	✓*				
Dynamic price			✓	✓	✓*	✓*
Smart charging	✓	✓	✓	✓	✓	✓
V2G				✓		✓
Battery degradation	✓	✓	✓	✓	✓	✓

The following figures show the numerical results of the various scenarios. Figure 27 shows the total costs, Figure 28 illustrates the energy flows. The results of scenario 6 are also broken down into active EVs and dummy vehicles. The active EVs are booked by costumers and are only available for energy trading to a limited extent within the 2-day period. In contrast, the dummy vehicles are available for the full period. Thus, the potential of an EV fleet solely dedicated to electricity trading can be assessed. The results of the active vehicles are shown in figure 29 and 30, and the results of the inactive dummy vehicles are presented in figure 31 and 32.

Table 12 summarises the design of the individual scenarios and their results, where the main focus in on scenario 6.

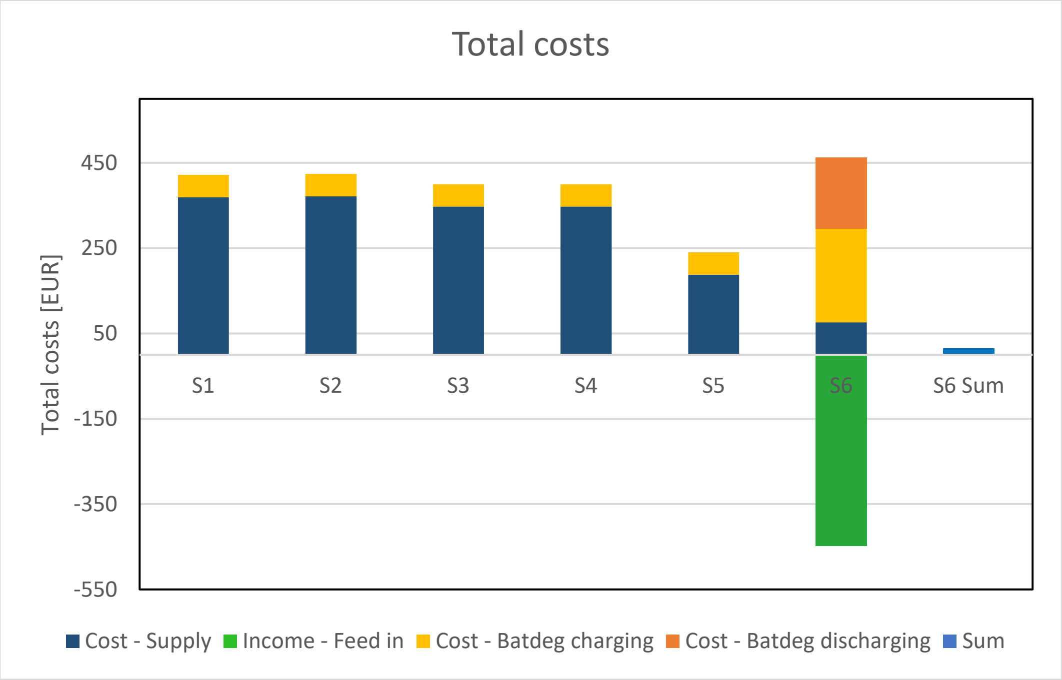


Figure 27: Total costs of fleet

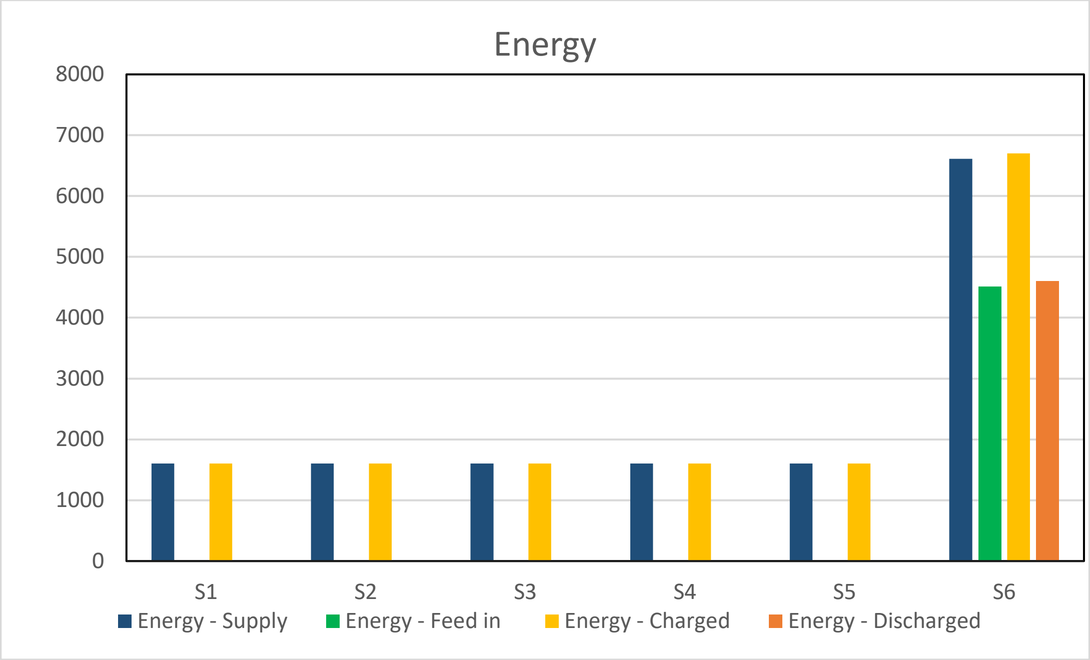


Figure 28: Energy flows for charging the fleet

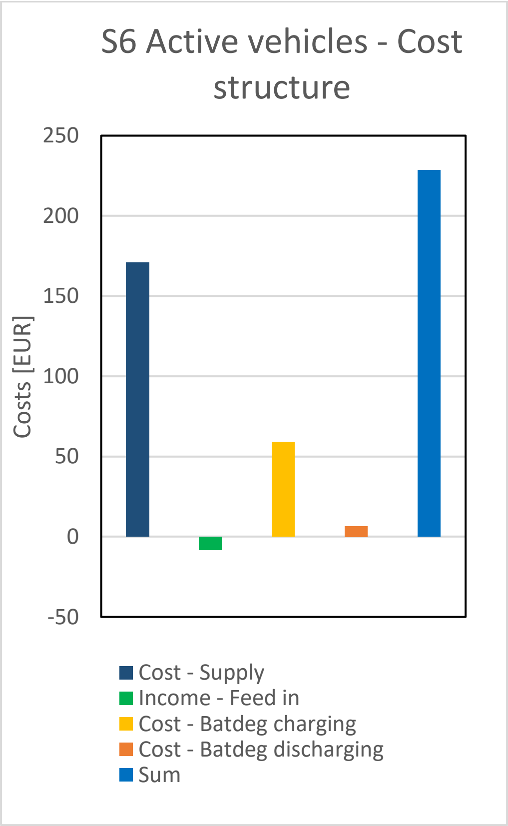


Figure 29: Costs of active vehicles (no dummy vehicles) in scenario 6

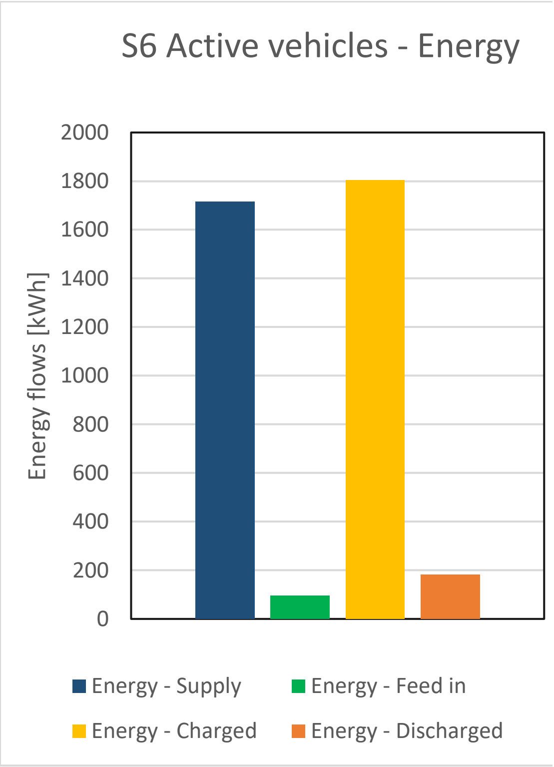


Figure 30: Energy flows for charging active vehicles (no dummy vehicles) in scenario 6

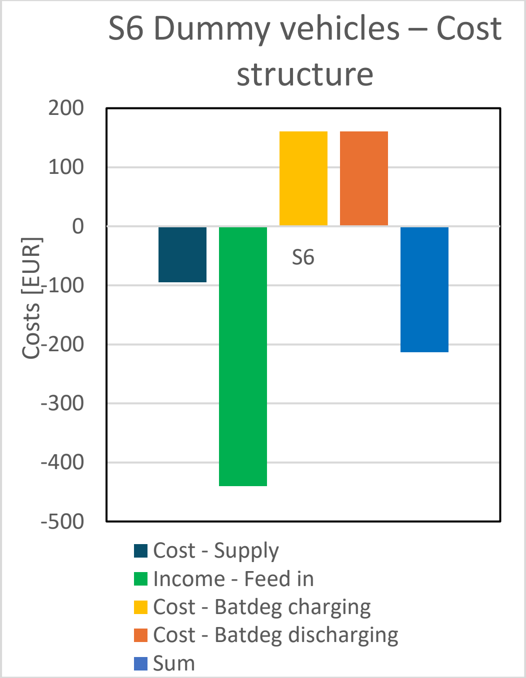


Figure 31: Costs of dummy vehicles only in scenario 6

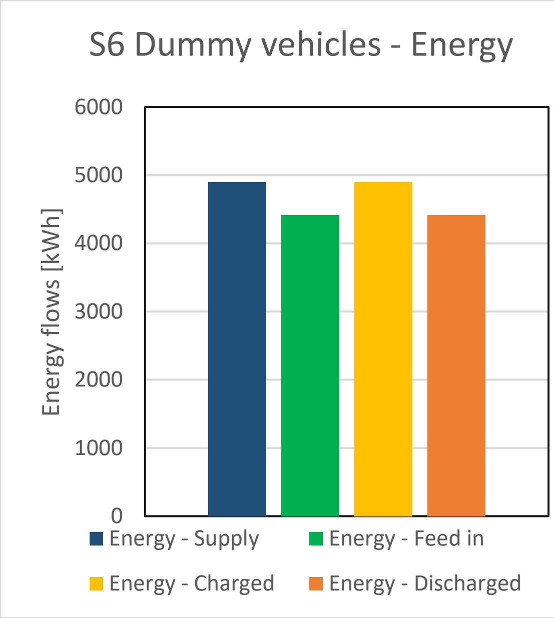


Figure 32: Energy flows for charging dummy vehicles in scenario 6

Table 12: Description of results per scenario in case study Zurich 2. For detailed results see figure 27-32

Scenario	Description & Results	Price structure
1	Basic benchmark scenario with realistic static prices. EVs simply charge the amount of energy they need. Battery degradation costs included. **Results:** EVs just buy the necessary amount of energy and charge it.	1 & 2
2	Similar to S1 but dynamic prices are charged instead of static prices. **Results:** Results are nearly the same, because the average dynamic prices are similar to the static prices	3 & 4
3	Basic benchmark scenario with realistic average dynamic prices and no V2G. If possible, EVs charge when prices are low. **Results:** Slightly lower energy costs **(-5,9%** compared to S1) due to dynamic prices.	3 & 4
4	Basic benchmark scenario with realistic average dynamic prices and V2G. If possible, EVs charge when prices are low. EVs can sell electricity to the grid. **Results**: Same as S3, EVs do not trade electricity, because of low price gap. Possible trading profits are too low to compensate for high battery degradation costs.	3 & 4
5	Scenario with most fluctuating dynamic prices in 2023 and no V2G. EVs charge when prices are low. **Results:** Lower energy	5 & 6

	costs (**-46%** compared to S4 and **-49%** compared to S1) due to more favourable price structure.	
6	Scenario with most fluctuation dynamic prices in 2023 and V2G. EV charge when prices are low and can sell electricity back to the grid. **Results:** Energy costs reduced by **59,4%** compared to S5. Furthermore, fleet generates income due to energy feed in (447€). However, this income is almost offset by the battery degradation costs. Total costs are reduced by **94%** compared to S5. A relevant amount of energy is traded. **Results active EVs**: EVs basically buy the amount of energy required for charging. A small amount of energy is traded. **Results dummy vehicles:** Dummy vehicles manage to generate an income of 213€ with the help of energy trading, despite relative high battery degradation costs. A substantial amount of energy is traded.	5 & 6

3.4.4 Conclusions

This study focussed on the economic potential of energy trading with the help of a relatively large EV fleet in Zurich. The analysis of 6 scenarios leads to the following conclusions:

Key findings	**Description**
1	**Bidirectional charging (V2G) and dynamic prices have the potential to significantly reduce energy and total costs.** Average dynamic prices instead of static prices can reduce energy costs by around **5,9%** (no V2G) as energy purchases are made at lower prices. Strongly fluctuating but rarely occurring dynamic prices can further reduce energy costs by up to **49%**. In combination with a strongly fluctuating dynamic price, V2G makes it possible to reduce the energy costs of a fleet by up to **59%** and the total costs by up to **94%.**
2	**An EV fleet only used for energy trading generates minimal profits.** A fleet of 221 average EVs (only used for electricity trading) can generate profits from trading of a maximum of **213€ within two days**. However, these profits only materialise with dynamic electricity prices in general and on rare days with strongly fluctuating electricity prices. The projected profits amount to a maximum of about **3 200€ per month** and bear no relation to the comparatively high investment costs of an EV fleet, including the necessary V2G technology.

3	**Realistic price structures offer hardly any opportunities for energy trading**. Realistic price structures (static and average dynamic prices) applied in Zurich in 2023/24 offer very little opportunities for energy trading. Under realistic conditions with V2G-capable EVs, energy trading is virtually non-existent. Profitable energy trading only occurs on very rare days of the year with very high price fluctuations.
4	**Profits from electricity trading require a sufficiently wide price range.** Profits from electricity trading are only possible if there is a sufficiently large difference between buying and selling prices. Dynamic prices must offer opportunities to sell energy with real profits, otherwise the V2G technology (bidirectional charging) will not be utilised. The price range must therefore exceed grid fees, taxes, and battery degradation costs.
5	**Battery degradation costs are relevant.** Battery degradation costs are a relevant factor in the cost structure of the EV fleet and can make the difference between trading energy profitably or standing still.

3.5 Case Study Tel Aviv

3.5.1 Introduction & Use Cases

The following section covers the final case study, which is located in the city of Tel Aviv. The case study is situated within the context of the year 2030. It analyses the possible utilization of surplus energy generated during peak PV periods with the help of an EV fleet.

Although the reduction of fossil energy sources within the energy mix allows carbon emissions to be reduced, the missing amount of energy must be replaced by alternative forms such as solar or wind energy. A fundamental characteristic of renewable energy is its considerable fluctuation, represented in this study by a relatively high PV surplus at midday. The main focus of this case study is to evaluate the potential of a large car-sharing fleet (with a realistic mobility profile) to store surplus PV energy for utilisation during periods of scarcity. As in the previous case studies, this is made possible by EVs storing surplus energy and feeding it back into the grid at certain times using bidirectional charging (V2G). Moreover, the benefits of smart charging (self-consumption optimisation) are analysed as well. Main components of this analysis are realistic fleet mobility data, a PV generation profile and energy consumption figures from Tel Aviv.

Furthermore, this case study examines the potential for savings in CO_2 emissions from the standpoint of both an individual EV and the city of Tel Aviv as a whole. Finally, it is also analysed whether an alternative distribution of fleet vehicles within the urban area of Tel Aviv leads to relevant changes in the results.

Research questions:

- Impact of smart charging on PV surplus utilization on city level
- Impact of bidirectional charging (V2G) on PV surplus utilization
- CO_2 saving potential through smart and bidirectional charging
- Impact of a vehicle redistribution on results

3.5.2 Study description

Data

Input data regarding the mobility behaviour of the car-sharing fleet is based on real mobility data provided by the car-sharing provider “Autotel” located in Tel Aviv. Specifically, based on the real data, a simulation strategy is proposed to simulate mobility data under two relocation polices, including mobility incentives for relocation and to boost users’ participation:

- **Purely crew-led relocation strategy** without user incentives for relocation. Relocation is carried out by a relocation crew
- **A dynamic hybrid user-crew relocation strategy**. Participation by users is enhanced by applying departure incentives and arrival incentives

A gymnasium environment, which adopts and efficient event-based algorithmic procedure, is used to simulate system dynamics, including the acceptance or rejection of car-sharing offers and matching mobility demand with available vehicles and incentives. The simulation adjusts trip destination incentives to test different levels of user engagement, providing insights into how varying incentive levels affect system efficiency. The simulation spans a 3-month period with hourly frequency and starts by initializing two identical car-sharing fleets of 150 electric vehicles. Incentives obtained from the different policies (crew-led and hybrid) are applied at each hour of the simulation, thus influencing the fleet state and mobility patterns. Key metrics such as vehicle rentals, energy consumption, and user participation in relocation were analysed, illustrating how destination and origin incentives shape fleet dynamics, mobility revenues, and costs [23].

To summarize, the results of this case study are based on two different data sets of simulated car-sharing EV fleets. One is a baseline scenario, and the other is a scenario in which the EVs are actively redistributed/relocated around the city. Both simulated scenarios are based on real data provided by the car-sharing company “Autotel”. To make the results of the two data sets comparable, both map the mobility behaviour of 150 vehicles over a period of 121 days (about 4 months). The following table provides an overview of the most important characteristics of each scenario.

Table 13:Fleet characteristics in the Tel Aviv case study

Fleet characteristic	**Baseline**	**Relocation**
Number of EVs	150	150
Time period	121 days	121 days
Number of charging stations	10	10
Number of charging sessions	1087	2997
Average idle time between trips	33,64 h	10,48 h
Average battery capacity	46,57 kWh	43,25 kWh
Average charging power	11,09 kW	10,75 kW
Average SOC – Start of idle period (%)	9,98%	9,96%
Average SOC – End of idle period (%)	62,34%	57,38%
Share of idle time (%) *	7,21%	8,40%
Share of idle time (vehicle equivalent) **	10,82/150	12,59/150

* ”Share of idle time” describes the percentage of the fleet’s total standing time over the period of 121 days.
** As in *, expressed as vehicle equivalent. E.g., in the Baseline scenario, an equivalent of 10,82 out of 150 EVs are standing still over the 121 day time period.

To summarise, the relocation scenario contains around 3 times as many trips (and idle times between) as the baseline scenario, which results in significantly shorter (3 times) idle times between trips. In addition, in the relocation scenario, the EVs in the fleet are stationary for slightly longer (about 16%) than in the baseline scenario. The average SoCs at the beginning and end of the idle periods are comparable.

Tel Aviv: demand, photovoltaic and price structure

In order to answer the previously formulated research questions, three further components are required in addition to the fleet mobility data:

- **Energy demand** in Tel Aviv: As the study deals with possible scenarios for the year 2030, Tel Aviv’s estimated electricity demand for this year is used as the basis for the calculations. As exact energy consumption data is not published for Tel Aviv or Israel, consumption is calculated indirectly. These calculations are based on the assumption that Israel (with the exception of energy exports to Palestinian territory) has a closed electricity system and, as a result, energy demand/consumption is roughly equivalent to energy production. Consequently, the available hourly energy production data of Israel from the year 2022 [24] is firstly scaled up to the estimated demand of the year 2030 (89 TWh minus future exports of around 7 TWh) [24], [25], [26] and secondly scaled down to the size of Tel Aviv. As a result, this method provides hourly energy consumption data for the greater Tel Aviv area in 2030.

- **Photovoltaic production** in Tel Aviv: The previously described production data from 2022 breaks down energy production into various energy sources, including PV production. Therefore, it is possible to extrapolate future PV production for 2030 and then scale it up depending on various PV expansion targets. In this study, the authors use two different PV expansion targets, 33% and 50% of future energy production provided by PV. The 50% target in particular is quite ambitious and significantly increases PV production but can be considered a realistic long-term target beyond 2030.

- **Price structure:**

Table 14: Static price structure of Tel Aviv case study

Price category	Description	Average price
1: Static prices 2022 – Supply	Static price as median of wholesale market prices. Real time rate form Isreal (System marginal price) Exchange rate: ₪4,12/€1	0,12 NIS(₪)/kWh 0,029 EUR/kWh
2: Static prices 2022 – Feed in	In this case study, the scenarios analysed assume a PV surplus at peak times which cannot be exported or sold due to the closed energy system in Israel. Consequently, there is no demand and no pricing mechanism (feed-in price equals 0)	0 NIS(₪)//kWh 0 EUR/kWh

As in the previous case studies located in Zurich, the original fleet size (150 EVs included in the fleet mobility data) must also be scaled up to a reasonable future number of EVs in Tel Aviv in 2030. Based on [24], the possible number of EVs is estimated. As the forecasts vary greatly and the ramp-up of electromobility is not linear, 2 different scenarios are considered.

- Small fleet consisting of **10 500** EVs: conservative calculation based on very cautious projections regarding the ramp up of electromobility
- Big fleet consisting of **42 000** EVs: based on optimistic projections regarding the ramp up of electromobility

As the mobility data (including 150 EVs) is fixed, the number of EVs is not scaled upwards, but energy demand and PV production are scaled downwards. This enables the previously formulated research questions to be answered in a meaningful manner.

3.5.3 Scenarios and results

3.5.3.1 City & fleet

The following pages will introduce the various scenarios and present the main result (PV surplus utilization). The results of this section refer to the whole energy system consisting of city and fleet. In other words, the charging and discharging behaviour of the EV fleet is presented in the context of the entire electricity system.

In this case study, surplus energy from the city’s PV plants can be used to cover the energy demands of the fleet’s charging vehicles. Electricity is de facto shifted from the PV systems to the batteries of EVs. This mechanism works in the opposite direction as well, energy can be transferred from the fleet to the city (in scenarios where V2G is enabled). Besides that, surplus PV energy cannot be fed into the national grid or exported and needs to be curtailed, which is due to following assumptions:

- In a highly solar-driven energy system, also neighbouring regions do not have a need for energy in times of surplus (e.g. sunny midday hours)
- There are no other energy storage options, as this study wants to explicitly analyse the storage potential of EVs

In all scenarios, no energy-based grid fees are incurred in both directions, as grid tariffs are mainly based on power-based charges in Israel.

The PV production figures used in this study (33% or 50% PV expansion targets) imply an average PV surplus in the midday hours. During this time period, the energy generated by PV exceeds the consumption/demand of the city and the EV fleet. In the scenarios in which the 50% PV target is included, the regular PV surplus is considerable, representing 8,6% of the city's total consumption and therefore a potentially usable surplus. In contrast, the PV production of the 33% expansion target is only very rarely sufficient to generate s surplus. In this case, this means a surplus of only 0,56% of total consumption.

The key features of the different scenarios are described briefly in the following lines.
Fleet mobility data:

- Baseline: Baseline fleet mobility data
- Relocation: fleet mobility data including active vehicle relocations based on user demand

Fleet size:

- 10500: 10500 EVs as a stationary car sharing fleet
- 42000: 42000 EVs as a stationary car sharing fleet

Charing behaviour:

- Uncontrolled: EVs charge the required amount of energy directly before their next trip, regardless of a possible PV surplus
- Smart charging: EVs consider periods of PV surplus and charge, if possible, during surplus hours
- V2G: bidirectional charging technology. EVs are able to discharge energy and transfer it to the city of Tel Aviv in times of demand

PV production goal:

- 33%: 33% of energy produced is generated by PV
- 50%: 50% of energy produced is generated by PV

The features and sequence of the scenarios are based on the following logic: the first 12 scenarios consider the baseline mobility data. The remaining 6 scenarios analyse select set-ups based on the relocation fleet mobility data. The first 3 scenarios start with a small fleet and the lower PV target (33%). In the next block of 3, the PV target Is changed to 50%. The following 6 (Scenario 7-12) repeat the described pattern of the first 6, with the exception that the largest number of EVs is assumed (big fleet of 42000). Scenario 13-18 repeat the previous pattern of 7-12, except that the fleet mobility data of the relocation scenario is applied.

Table 15: Model scenarios of the Tel Aviv case study

Scenario	Fleet mobility data	Fleet size	Charging behaviour	PV production goal
1	Baseline	10500	Uncontrolled	33%
2	Baseline	10500	Smart charging	33%
3	Baseline	10500	V2G	33%
4	Baseline	10500	Uncontrolled	50%
5	Baseline	10500	Smart charging	50%
6	Baseline	10500	V2G	50%
7	Baseline	42000	Uncontrolled	33%
8	Baseline	42000	Smart charging	33%
9	Baseline	42000	V2G	33%
10	Baseline	42000	Uncontrolled	50%
11	Baseline	42000	Smart charging	50%
12	Baseline	42000	V2G	50%
13	Relocation	42000	Uncontrolled	33%
14	Relocation	42000	Smart charging	33%
15	Relocation	42000	V2G	33%
16	Relocation	42000	Uncontrolled	50%
17	Relocation	42000	Smart charging	50%
18	Relocation	42000	V2G	50%

The following table presents the main result of each scenario and a corresponding description. The key result in this study is the share of surplus PV that can be used by the fleet or the city of Tel Aviv. In addition, the absolute amount of utilized surplus energy is listed as well. Absolute energy figures are comparable in scenarios with identical fleet size. The PV surplus utilisation rate can be compared within all scenarios.

Table 16: Key results per scenario, Tel Aviv case study

Scenario	Description	PV surplus utilization rate & amount of energy utilised
1	First scenario as baseline, small fleet size (10500 EVs) and 33% PV target. No smart charging and no V2G. Only a negligible share of surplus PV is used to charge the fleet.	**0,61%** 0,13 GWh
2	Smart charging instead of uncontrolled charging. EVs anticipate times of PV surplus and charge, if possible, in hours of excess. Higher but still small PV utilization rate. Significantly larger absolute amount of transferred energy.	**2,0%** 0,43 GWh
3	V2G technology included. V2G achieves a PV utilization rate of 5,91%.	**5,91%** 1,26 GWh
4	As scenario 1, but 50% PV goal. More energy is shifted in absolute terms than in S1, but the utilisation rate is lower due to the higher PV production.	**0,16%** 0,50 GWh
5	Smart charging instead of uncontrolled charging. PV utilization rate negligible.	**0,33%** 1,11 GWh
6	V2G included. V2G achieves a significantly higher absolute amount of transferred energy than in S5. PV utilization rate negligible.	**1,26%** 3,99 GWh
7	33% PV goal and big fleet size (42000 EVs).	**2,42%** 0,52 GWh
8	Smart charging instead of uncontrolled charging.	**7,73%** 1,65 GWh
9	V2G included. The PV utilisation rate is notably high in comparison to other Scenarios.	**22,39%** 4,79 GWh
10	50% PV goal and big fleet size. Baseline.	**0,63%** 2,00 GWh
11	Smart charging instead of uncontrolled charging.	**1,3%** 4,11 GWh
12	V2G included. PV utilization rate 4,99%.	**4,99%** 15,77 GWh
13	Baseline scenario of relocation data. Big fleet (42000 EVs) and 33% PV goal. EVs have more trips and therefore shorter idle times (charging sessions). EVs within the relocation scenario achieve a higher PV	**3,76%** 0,80 GWh

	utilization rate and higher absolute amount of transferred energy, in comparison to S7. Still small utilization rate.	Compare with S7
14	Smart charging included. 9,26% PV utilization rate.	**9,26%** 1,98 GWh Compare with S8
15	V2G included. Fleet achieves 18,22% PV utilization rate. Significant PV utilization rate, as in S9 (Big fleet and lower PV target).	**18,22%** 3,92 GWh Compare with S9
16	Baseline scenario of relocation data. Big fleet (42000 EVs (and 50% PV goal. Can be compared to S10.	**1,17%** 3,71 GWh Compare with S10
17	Smart charging included. PV utilization rate 1,9%.	**1,90%** 6,04 GWh Compare with S11
18	V2G included. PV utilization rate 3,72%.	**3,72%** 11,83 GWh Compare with S12

While Table 16 lists the scenarios and their results separately, Figure 33 provides an overall overview.

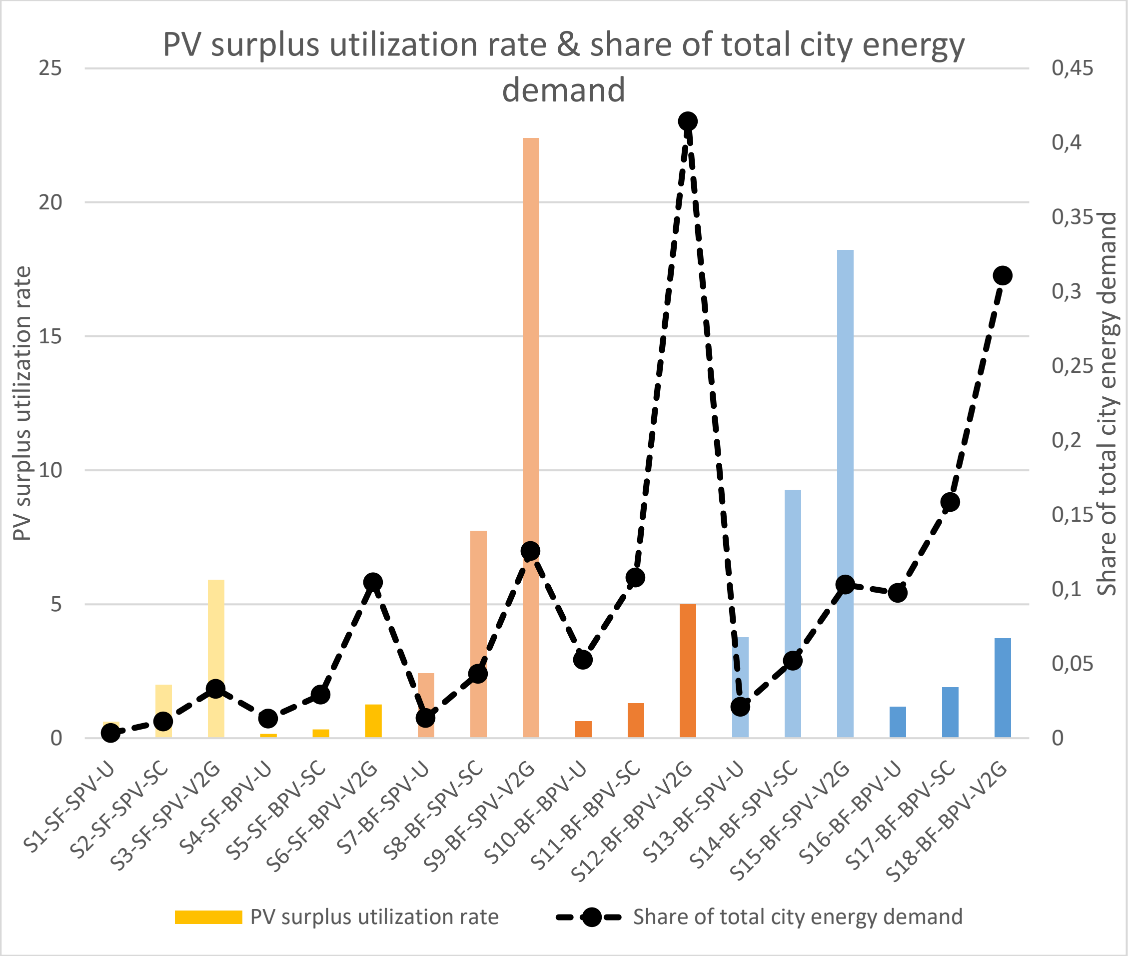


Figure 33: Illustrates the major result, the PV surplus utilization rate, across all scenarios. In addition, figure 33 shows the absolute amount of utilized PV surplus as share of the total city energy demand. S1-S12 are based on the baseline date, S13-S18 are based on the relocation data. Dark-coloured bars represent scenarios with 50% PV.
U=Uncontrolled charging, SC = Smart charging, V2G = Vehicle to grid.
SF = Small fleet (10500 EVs), BF = Big fleet (42000 EVs).
SPV = Small PV (33% target), BPV = Big PV (50% target).

Based on the presented results, the following conclusions can be drawn:

- **Smart charging and V2G technology increase the PV surplus utilization rate** in every scenario block. V2G always achieves the highest utilization rate.
- The **highest PV utilization rate of 22,39%** is realised in scenario 9. The set-up includes a big fleet (42 000 EVs) and a small (33% target) PV. Intuitively, it is not surprising that a big fleet can utilize a relatively large proportion of a comparatively small PV surplus. The same scenario set-up, but based on the relocation data (S15), reaches 18%.
- A **comparison of the baseline data and the relocation data** can be achieved through the examination of the orange and blue bars. The uncontrolled relocation scenarios (S13 & S16) both achieve a

higher PV utilization rate than the uncontrolled baseline scenarios (S7-S10). This can be explained, on the one hand, by slightly longer standing times in the relocation data and, on the other hand, by mobility behaviour that is advantageous for surplus PV utilization (more standing time in PV surplus periods). Smart charging scenarios of the relocation data (S14 & S17) achieve higher results as their baseline counterparts (S8 & S11) due to basically the same reasons. However, S15 & S18 including V2G achieve lower results than their baseline counterparts (S9 & S12). This can be explained by shorter average standing times, which reduces the potential for V2G.

- While the relatively high PV surplus utilization rates in some scenarios appear promising at first glance, a different picture emerges if one also considers the proportion of PV surplus energy utilized in relation to total city energy consumption. The **PV surplus energy utilized accounts for at most 0,41% of total city energy consumption.** Unsurprisingly, this result is reached in S12, which includes a large fleet in combination with a large PV system. Consequently, 5% of the surplus PV energy is utilized.
- In an alternative version of scenario 12, in which the EV fleet has on average **twice the battery capacity and twice the charging power**, a PV surplus utilization rate of **9,42%** (in comparison to 4,99%) is achieved. In another alternative version of S12 (only twice the battery capacity), a PV surplus utilization rate of 6,76 is reached. These numbers emphasise that not only the aggregated battery capacity is important, but also the charging power is crucial to realise a high PV surplus utilization rate. This is particularly the case for short idle times.

As a final summary of the results presented, it can be stated that a sufficiently large fleet of EVs, organised in the form of car sharing, can store a certain amount of PV surplus for later use. However, the relative share of utilised surplus PV energy is only considerable if the PV is small. Moreover, the proportion of utilised PV surplus is insignificant in comparison to the total energy consumption of the city. In addition, it can be observed that the mobility behaviour of the fleet and its customers has an influence on the results. These differences caused by mobility behaviour are significant in relative terms.

The results presented above contain many figures from various scenarios. The following selected illustrations attempt to graphically depict the events and contribute to a better understanding. The illustrations show the respective scenarios based on an average day. The entire modelled period (4 months) is summarised as an average day. The following 3 figures represent scenario 10-12, which include a large PV and a large fleet in the baseline scenario. The upper part in each figure shows the energy consumption of the city and the PV output. The lower figure presents the average free battery capacity of the fleet as well as the average state of charge of the total fleet.

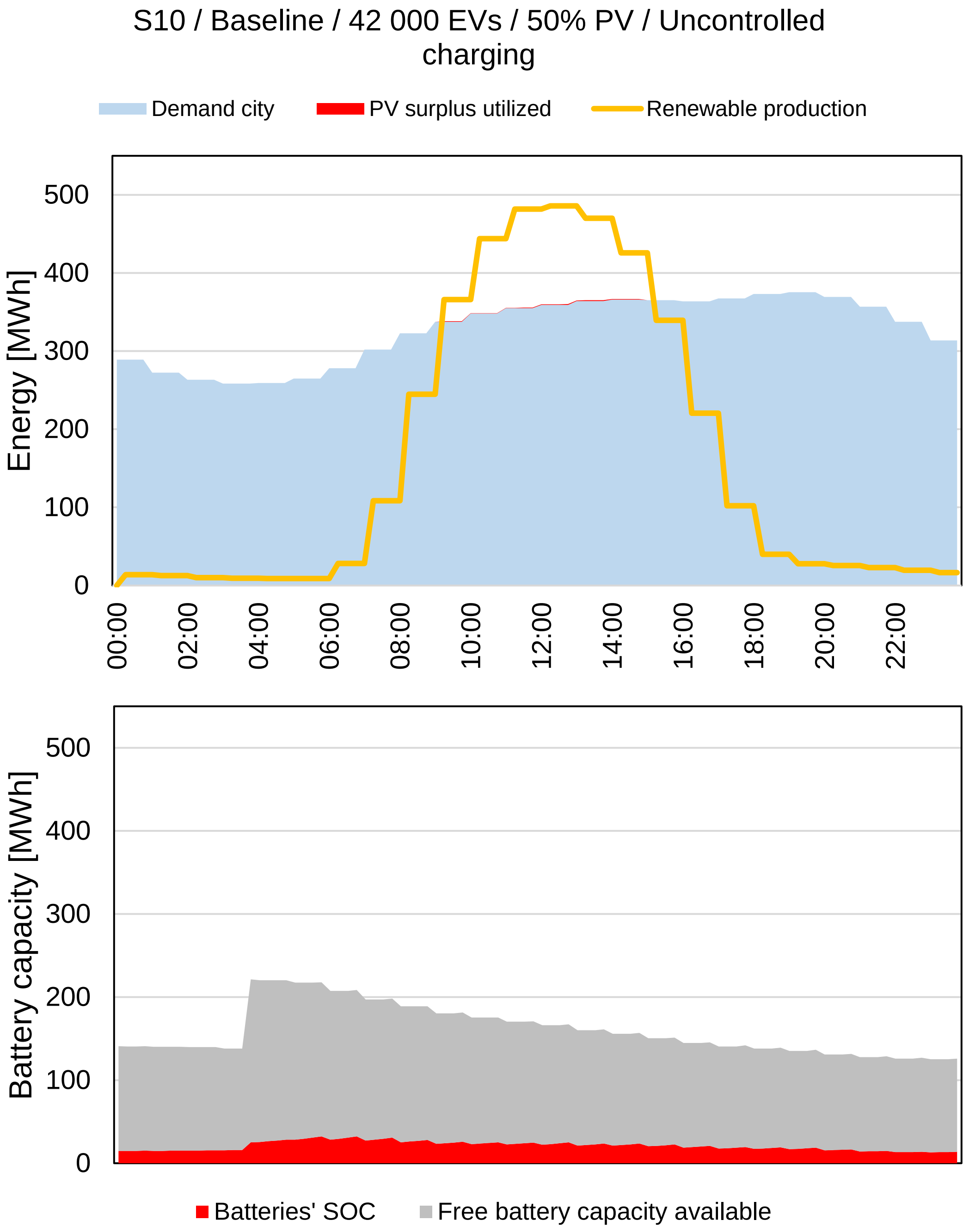


Figure 34: Illustrates S10 summarized as average day. The upper part shows the demand of the city every timestep as well as the PV production. The lower part presents the average free battery capacity and the average state of charge of the idle fleet.

Fehler! Verweisquelle konnte nicht gefunden werden. describes a scenario of uncontrolled charging. The EVs are unaware of a possible PV surplus and charge the required amount of energy shortly before their next journey. It shows that the amount of transferred surplus PV energy is minimal, in comparison to the total demand of the city. The surplus energy can hardly be seen. There appears to be a relatively large amount of empty storage capacity available throughout the average day. The amount of free capacity is roughly in the same order of magnitude as the city's energy consumption. The baseline scenario is modelled in such a way that in the very early morning hours, the vehicles are mostly brought back to their charging stations, which explains the peak of free battery capacity at 4 am. The batteries are relatively empty on average and the charging processes happen independently of surplus PV periods. This is evident from an examination of the data, the aggregated battery capacity at the beginning of the surplus period is 23,30 MWh and 23,83 MWh at the end.

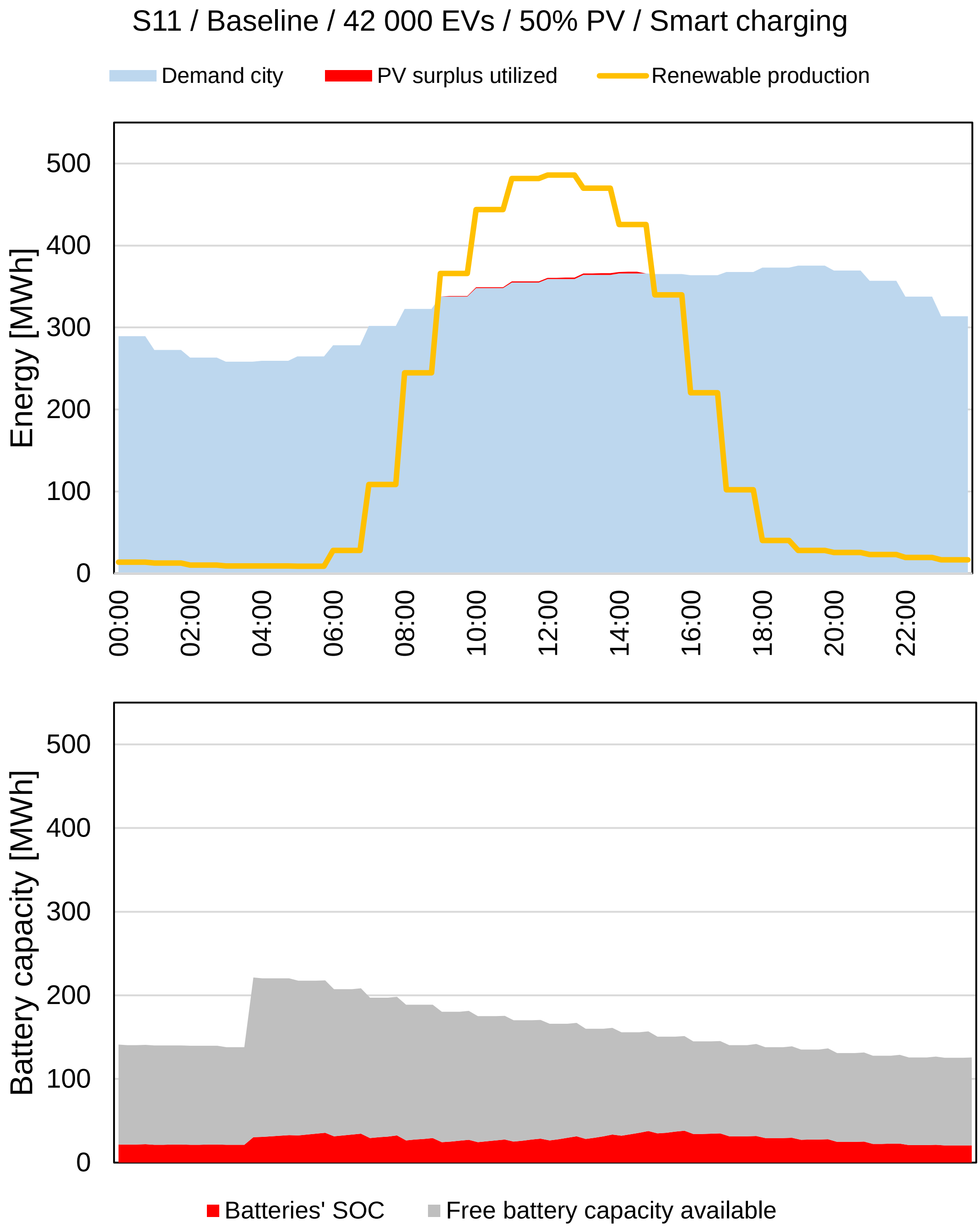


Figure 35: Illustrates S11 summarized as average day. The upper part shows the demand of the city every timestep as well as the PV production. The lower part presents the average free battery capacity and the average state of charge of the idle fleet.

Figure 35 describes a scenario including smart charging. The EVs are aware of a possible PV surplus and charge the required amount of energy accordingly. Although it is not immediately recognisable at the first glance, the aggregate state of charge at the beginning of the surplus period is relatively low, while it gradually increases over the time of PV surplus. According to the data, the aggregated battery capacity at the beginning of the surplus period is 24,44 MWh and 37,8 MWh at the end. Again, the transferred surplus PV energy is hardly visible.

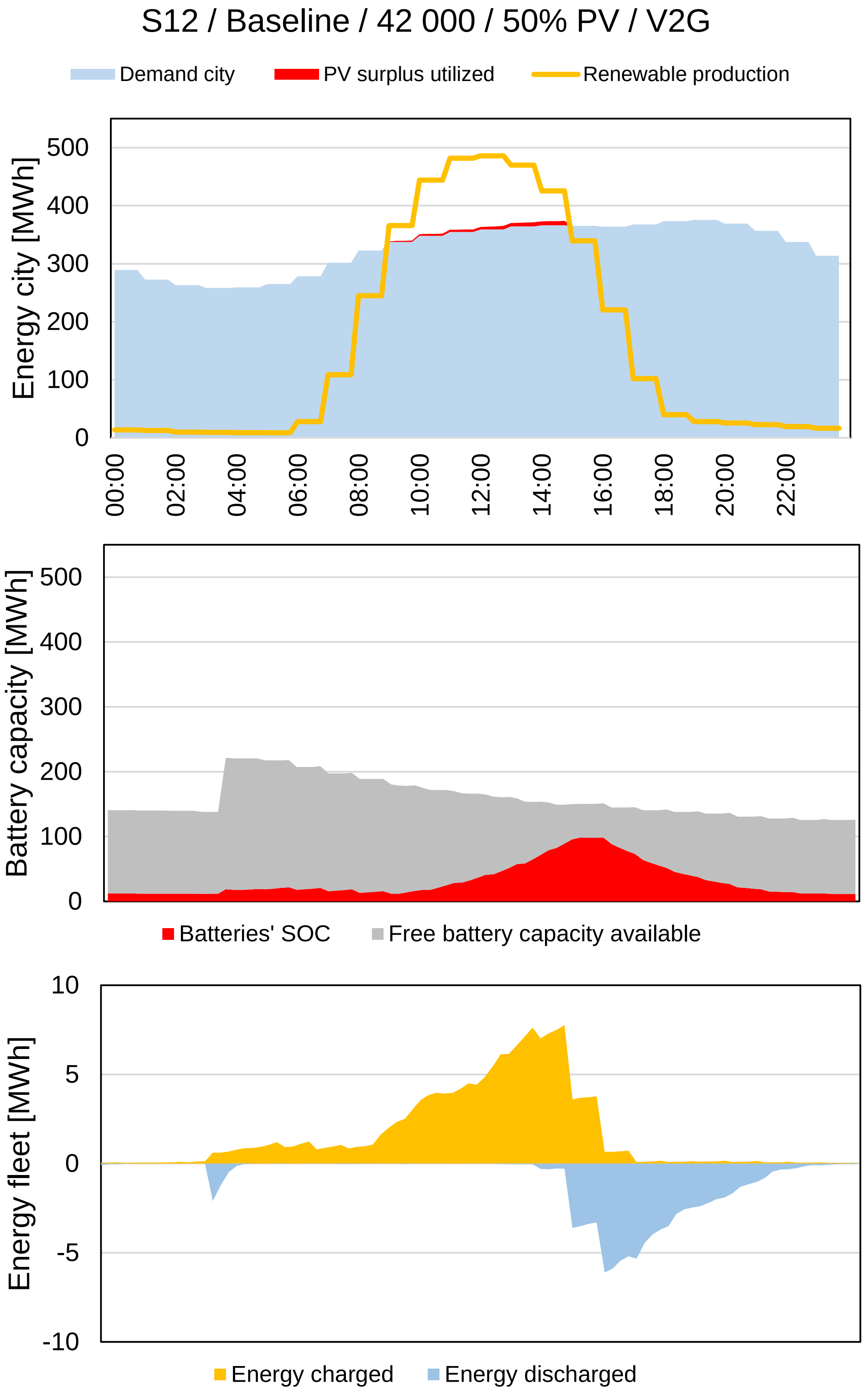


Figure 36: Illustrates S12 summarized as average day. The upper part shows the demand of the city every timestep as well as the PV production. In addition, the amount of utilized surplus PV energy is visualized. The middle part presents the average free battery capacity and the

average state of charge of the idle fleet. Furthermore, in the lower part, the amount of energy charged and discharged by the fleet is presented.

Figure 36 describes a scenario including V2G. The EVs are aware of a possible PV surplus and charge the required amount of energy accordingly. Furthermore, they are able to storge surplus energy and transfer it to the city or other vehicles. In addition to the previous 2 figures, the amount of charged and discharged energy by the fleet is included as an extra chart. The transferred PV surplus energy still appears minimal, although it is significantly larger than in the previous figure. Figure 12 provides a clear illustration of the following facts:

- In relative terms, only a very small amount of surplus energy is utilized, which corresponds to the previously presented 5% PV surplus utilization rate of S12
- During the PV surplus time, the gradual charging process of the fleet is clearly visible. Charging culminates at the end of the surplus period and is followed by a phase of discharging in which most of the stored energy is shifted to the city
- While the available battery capacity appears relatively large, it is evident that a small proportion of the surplus PV is sufficient to almost utilise the battery capacities over the surplus period

3.5.3.2 Fleet perspective & grid energy savings

The results presented in the previous section include the EV fleet and the city and consider both parts as one overall system. However, in this section, the scenario results are presented from a different point of view, solely from a fleet perspective.

Figure 37 presents the potential reduction of purchased grid energy by utilising surplus PV energy. In other words, energy bought from the grid is replaced by surplus PV energy. In this study, the remaining energy mix (without PV) provided by the grid is considered as fossil energy. For the sake of completeness, it must be mentioned that the results of Figure 37 relate exclusively to how much less energy the fleet itself has to purchase from the grid. Energy that potentially flows back into the city from the fleet is not included, this will be discussed later.

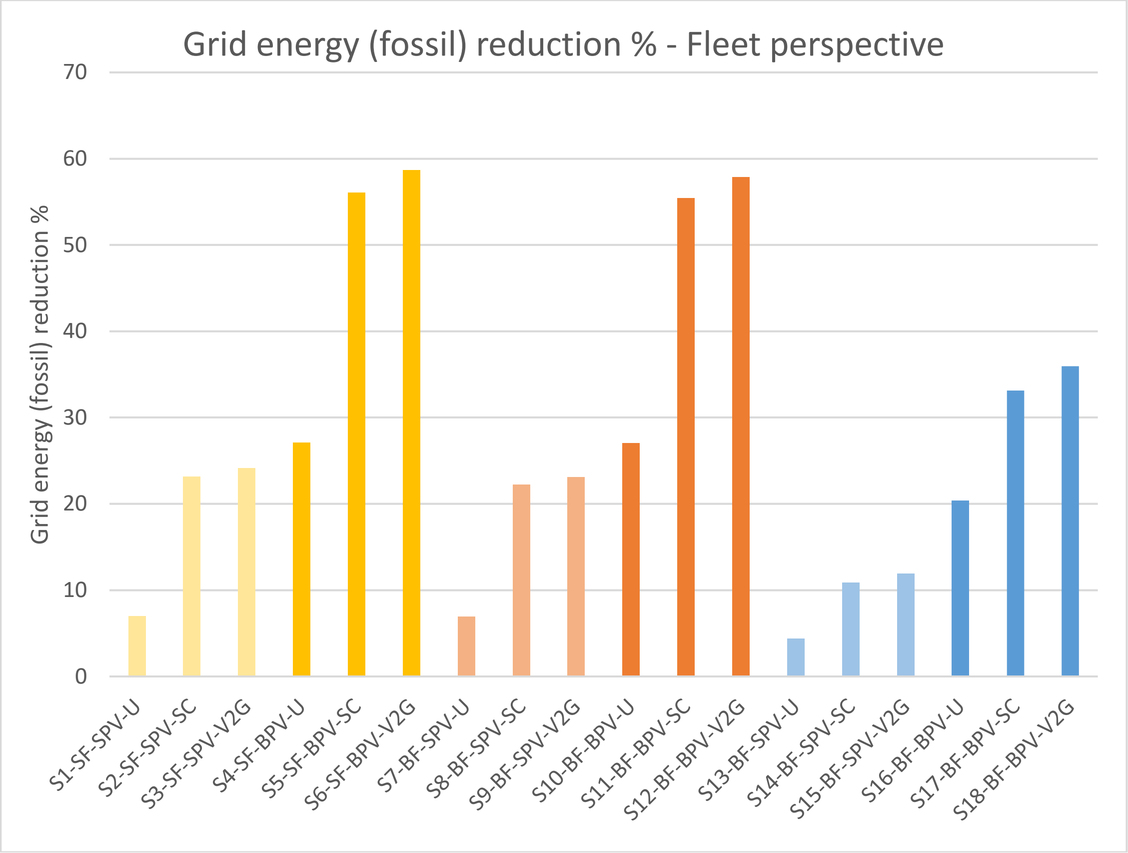


Figure 37: Shows how much less energy the fleet needs to buy from the grid, because it can use surplus PV energy instead. S1-S12 are based on the baseline data, S13-S18 are based on the relocation data. Dark-coloured bars represent scenarios with 50% PV.
U=Uncontrolled charging, SC = Smart charging, V2G = Vehicle to grid.
SF = Small fleet (10500 EVs), BF = Big fleet (42000 EVs).
SPV = Small PV (33% target), BPV = Big PV (50% target).

The analysis leads to the following conclusions:

- The fleet can cut fossil grid energy by up to 58%. This result is achieved in scenario 6, with the set-up of a small fleet and a large PV, applying V2G
- In general, smart charging and V2G enable energy savings in all scenario blocks, in comparison to the respective uncontrolled baseline scenarios. However, V2G does not realise much greater reduction than smart charging. This is explained by the design of Figure 37, energy that flows back into the city is not included in this figure; therefore the bars of the V2G scenarios generally appear artificially smaller. One possible conclusion is therefore that V2G in the form of V2V (vehicle to vehicle), which can be seen the figure as differences between smart charging and V2G, is not very pronounced. If there is surplus energy in the batteries, it is mainly transferred back to the city and not to other EVs of the fleet. This behaviour can be explained by charging and discharging efficiencies

and battery degradation. Energy cannot be transferred 100% from EV to EV without losses. Therefore, more energy is sent back to the city, resulting in slightly fewer losses.

- More PV production equals more reduction of grid energy. This very intuitive fact can be easily seen in figure 37, since dark coloured bars are all larger than their respective comparison scenarios with less PV.
- The differences in the results between a big fleet (orange bars) and a small fleet (yellow bars) are minimal. The size of the fleet does not affect grid energy reduction (in percentage terms). This can be attributed to the fact that as soon as there is a surplus PV, it is of such a magnitude that both fleet sizes are able to utilise their full displacement potential. The large fleet (42 000) therefore almost reaches the potential of the small fleet (10 500), as the PV surplus for the small fleet is overshooting and sufficient for the large one.

3.5.3.3 Fleet perspective & carbon emissions

In the next section of this case study, all energy flows are now fully incorporated from a fleet perspective. In addition, the aspect of a possible CO_2 reduction through the utilisation of surplus PV is considered in the analysis. In a first step, the energy flows from selected scenario are mapped. S10-12 and S16-18 are chosen to allow an additional comparison between the baseline dataset and the relocation data. Figure 38 provides a simple illustration of the fleet's energy flows. The results of scenario 12 are shown in figure 38 the figures of the other scenarios are presented in Table 17.

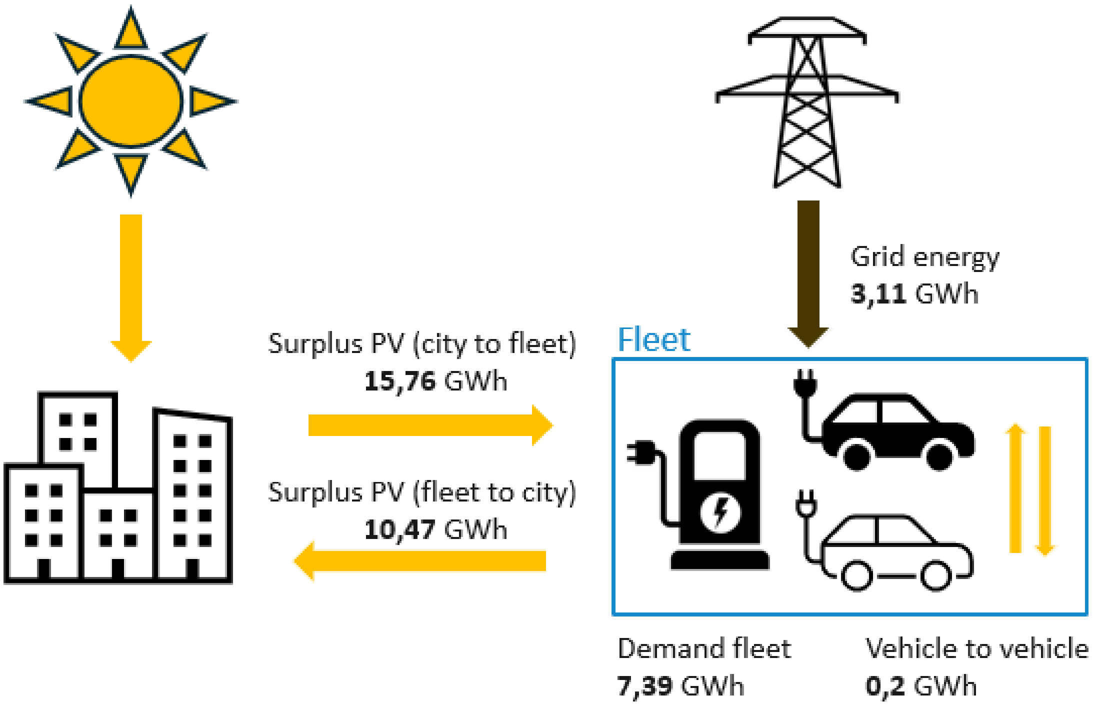


Figure 38: Illustrates the energy flows of the fleet based on scenario 12 (big fleet, big PV). Note that the total demand of the fleet does not exactly correspond to the balance of energy flowing in and out, due to charging and discharging efficiencies.

Figure 38 describes the energy flows relevant for the fleet based on scenario 12. 15,76 GWh of surplus PV energy are transferred from the city to the fleet. The majority (10,40 GWh) is stored in the batteries and later shifted back to the city, while a small proportion (0,2 GWh) is transferred within in the fleet. Overall, to meet its demand of 7,39 GWh, the fleet requires only 3,11 GWh to be purchased from the grid. Note that the total demand of the fleet does not exactly correspond to the balance of energy flowing in and out, due to charging and discharging

The following Table 17 presents the energy flow figures of S10-12 and S16-18, which are labelled as in Figure 38.

Table 17: Scenario results from fleet perspective, Tel Aviv case study

Scenario	Surplus PV (city to fleet)	Surplus PV (fleet to city)	Purchased grid energy	V2V (vehicle to vehicle)	Total demand fleet
10	1,99	0	5,40	0	7,39
11	4,09	0	3,30	0	7,39
12	15,76	10,47	3,11	0,20	7,39
16	3,72	0	14,50	0	18,23
17	6,05	0	12,18	0	18,23
18	11,79	4,98	11,67	0,50	18,23

A direct comparison between Scenario 12 and 18 is feasible. In Scenario 18, 11,79 GWh of surplus PV is transferred from the city to the fleet. 4,98 GWh are shifted back to the city, 0,50 GWh are utilized for V2V. Out of 18,23 GWh demand, 11,67 must be purchased. Considering scenario 12, it is noticeable that a relatively large amount of surplus PV energy is transferred to the fleet compared to fleet consumption. To be precise, the figure is more than twice as much. In addition, the fleet itself can significantly reduce the amount of energy purchased from the grid. Given the substantial contribution of PV energy, which can be considered a low-emissions technology, it is appropriate to present the results of the selected 6 scenarios, including CO_2 related key figures.

The CO_2 emissions for PV energy (renewable) and non-renewable sources are calculated by using emission factors for the whole lifecycle of consumed fuels and used power plants, as displayed in the project “electricitymaps” [27]. As the renewable profile (PV production) used in this case study represents the whole renewable energy produced in Tel Aviv region, the remaining energy needed (grid energy) is assumed with a mix of fossil fuels (coal, gas, other) with typical ratios for Israel [IEC Annual Report 2023]. Table 18 summarises the grams of $C0_2$ equivalent per kWh ($gC0_2eq/kWh$) produced used in the following calculations.

Table 18: Emission factors, Tel Aviv case study

Energy source	**Emission factor [gCO_2eq/kWh]**
Renewable (PV)	45
Non-Renewable (grid)	500

In other words, the emission factor of grid-related energy is high and that of PV energy is low. The $C0_2$ emissions are calculated for S10-12 (baseline) and S16-18 (relocation), all scenarios include a big fleet (42 000 EVs) and a big PV (50% target). The resulting emissions are given in the tables below (table 19 and 20), consisting of emissions form the fleet and the city. They describe how much $C0_2$ is emitted by the city and by the fleet, and by how much the emissions are reduced using smart charging and V2G.

Table 19: CO_2 emissions baseline scenario, 4 months

	Fleet		**City**		**Sum**	
Scenario	***Grid energy [GWh]***	***PV [GWh]***	***Grid energy [GWh]***	***PV [GWh]***	***CO_2 [t]***	***CO_2 reduction [t]***
10	5,41	2,00	2209	1586	1 178 728	***0***
11	3,31	4,11	2209	1586	1 177 771	***956***
12	3,13	4,29	2198	1597	1 172 987	***5740***

Table 20: CO_2 emissions, relocation scenario

	Fleet		**City**		**Sum**	
Scenario	***Grid energy [GWh]***	***PV [GWh]***	***Grid energy [GWh]***	***PV [GWh]***	***CO_2 [t]***	***CO_2 reduction [t]***
16	14,51	3,71	2209	1586	1 183 354	***0***
17	12,18	6,04	2209	1586	1 182 298	***1056***
18	11,67	6,55	2204	1591	1 179 941	***3412***

Since the total kilometres driven and the total energy consumption of the fleet are known from the data used, a CO_2 emission per kilometre driven can now be calculated for each scenario in conjunction with the previously presented emission reduction figures. For the uncontrolled scenario, the fleet's CO_2 intensity per km travelled is retrieved. To calculate the specific emissions in the smart charging and V2G scenario, the overall achieved CO_2 savings are divided by the km travelled and subtracted from the value in the uncontrolled scenario.

The exact figures will be included in the following Table 21. Note, that the gCO_2/km becomes negative in the V2G scenario as low-emission PV energy is reused and as a result the CO_2 consumption of the city is reduced. As an additional step, the calculated gCO_2/km feeds into a life cycle analysis to measure the impact of smart charging and V2G over the whole lifetime of an EV. The final results are based on a life cycle analysis for different vehicle drive-technologies[28]. Note, that only the values for the emissions of fuel/energy are adapted in the present study.

Table 21: Baseline data set – emission equivalents per vehicle type per km. The bottom 3 rows refer to S10-12.

CO_{2eq} [g/km]	Vehicle production	Battery production	Maintenance	Fuel/energy	Usage/driving	Sum
Diesel fuel	36,7	0	7,3	26,3	143,1	213,4
petrol	35,0	0	7,1	42,1	163,9	248,1
EV fleet - Uncontrolled	39,1	19,2	6,9	60,3	0	***125,5***
EV fleet - Smart charging	39,1	19,2	6,9	39,7	0	***104,9***
EV fleet - V2G	39,1	19,2	6,9	-63,5	0	***1,7***

Table 22: Relocation data set – emission equivalents per vehicle type per km. The bottom 3 rows refer to S16-18

CO_{2eq} [g/km]	Vehicle productioni	Battery production	Maintenance	Fuel/energy	Usage/driving	Sum
Diesel fuel	36,7	0	7,3	26,3	143,1	213,4
petrol	35	0	7,1	42,1	163,9	248,1
EV fleet - Uncontrolled	39,1	19,2	6,9	65,2	0	***130,4***
EV fleet - Smart charging	39,1	19,2	6,9	55,9	0	***121,1***
EV fleet - V2G	39,1	19,2	6,9	35,2	0	***100,4***

Based on the results, it can be observed that the emissions per km are generally higher in the relocation than in the baseline scenario. This is due to the fact, that in the relocation scenario, the EVs are travelling more, and idle time is lower, which means that the EVs have less flexibility to wait for the optimal timestep to charge when surplus energy is available (and also discharge in the optimal timestep in the V2G scenario). Furthermore, the very low CO_2 equivalent per km for the category “EV fleet - V2G” (scenario 12) in Table 21 is noticeable. An average EV in the set-up of scenario 12 (large fleet, large PV) is therefore almost CO_2 neutral per kilometre driven over its life cycle. Compared to the result from the previous scenario (EV fleet - Smart charging), this represents a reduction of approx. 98%.

As evidenced by the data presented in the preceding tables, the baseline scenario demonstrably outperforms the relocation scenario. The CO_2 equivalents per kilometre are notably lower, with the biggest and significant difference between the V2G scenarios. However, this argument can be countered by the fact that many more kilometres are driven in the relocation scenario (406 000 km in comparison to 165 000 km) than in the baseline scenario, which means that additional mobility demand is covered. In the baseline scenario, these additional mobility needs would not be met by the EV fleet but by more conventional means of transport (combustion engines), which would result in a different carbon footprint. Table 23 presents the results, expressed in tonnes of CO_2, with these considerations incorporated.

Table 23: CO_2 emissions in baseline vs. relocation scenario, considering the same mobility needs in both scenarios

[tCO_2]	**Relocation scenario**	**Baseline scenario + diesel powered fleet**	**Baseline scenario + uncontrolled EV fleet**
Uncontrolled	14 847	20 229	14 293
Smart charging	13 791	19 273	13 337
V2G	11 434	14 488	8 553

Column 2 shows the fleet consumption of the relocation scenario expressed in tonnes of CO_2. To enable a kilometre-adjusted comparison, column 3 presents the CO_2 consumption of the baseline scenario, including the additional CO_2 emissions of a diesel-powered fleet that covers the missing 241 000 kilometres. Furthermore, column 4 shows the CO_2 baseline consumption, including additional emissions of an EV fleet using uncontrolled charging. In conclusion, it can be stated that the relocation scenario has a better (lower) carbon footprint, if the missing kilometres of the baseline scenario are compensated by a diesel-powered fleet. However, if they are supplemented by an EV fleet using uncontrolled charging, the baseline scenario performs better.

3.5.3.4 Key economic take aways

In the course of this study, many figures were presented, most of which related to transferred energy quantities. For a better understanding of the subject matter covered, the following figure 39 and table 24 present a summary of the study's results and contents in monetary terms. This will contribute to a better assessment of the orders of magnitude. The monetary results are calculated for a period of one year.

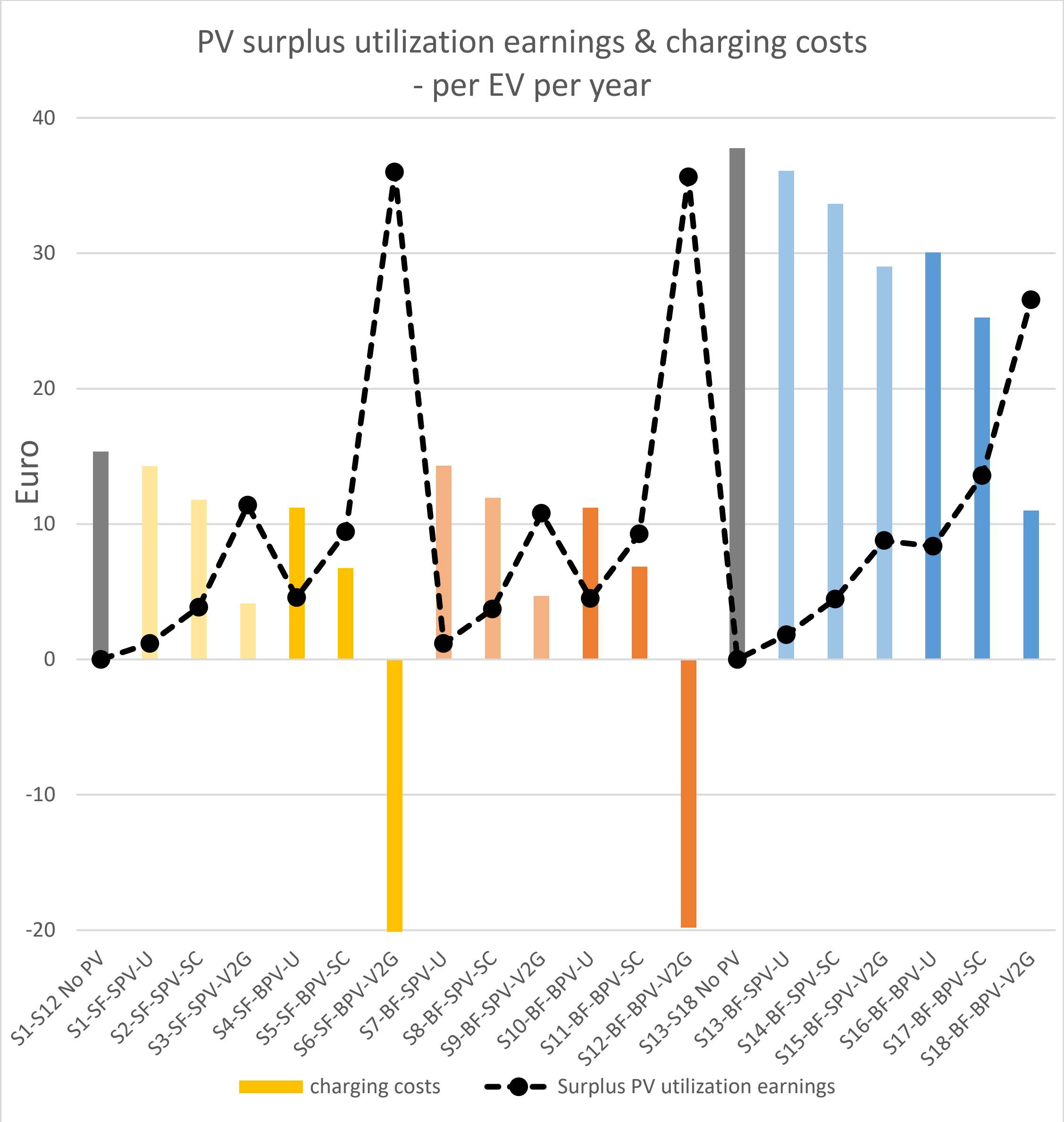


Figure 39: Illustrates the monetary value of PV surplus utilization and the charging costs of each scenario per vehicle per year, expressed in Euro. The grey bars represent baseline scenarios without any PV energy. S1-S12 are based on baseline data, S13-S18 are based on relocation data. Dark-coloured bars represent scenarios with 50% PV.
U=Uncontrolled charging, SC = Smart charging, V2G = Vehicle to grid.
SF = Small fleet (10500 EVs), BF = Big fleet (42000 EVs).
SPV = Small PV (33% target), BPV = Big PV (50% target).

Figure 39 illustrates PV surplus utilization earnings as well as charging costs per vehicle per year expressed in Euro. The grey bars show the charging costs for S1-S12 and S13-S18 as base costs without PV. Figure 39 demonstrates the following points:

- Charging costs per EV are reduced with each technology level
- V2G (S6 & S12) can even generate profits, if a big PV production is available

- In the relocation data, charging costs are decreasing as well. However, a profit is not achieved due to the fleet mobility behaviour
- In general, monetary figures are very low. This is attributable to the fact that very low energy costs are used in this case study. In addition, although the EVs are not at their charging stations for long periods of time, they cover relatively few kilometres and therefore require less energy to charge

Table 24: Summary of economic key take aways.

Case study result/content	Description & monetary value
PV surplus (33% target)	Assuming that 33% of energy demand is covered by PV energy, this results in PV surplus energy worth around **2 023 000€**.
PV surplus utilization rate – 22,39% of 33% PV target	In this study, a maximum of 22,39% (S9, big fleet of 42 000 EVs) of surplus energy is utilized, which corresponds to approx. **453 000€**. This is equivalent to 0,12% of total energy consumption of Tel Aviv region, which is valued in monetary terms at 361 000 000€. Note that S9 includes V2G technology, with which the fleet would need to be equipped.
PV surplus (50% target)	Assuming that 50% of energy demand is covered by PV energy, this results in PV surplus energy worth around **29 991 000€**.
PV surplus utilization rate – 4,99% of 50% PV target	In this study, the highest PV surplus utilization rate in absolute terms is achieved with 0,41% of the city's total energy consumption. 4,99% (S12, big fleet of 42 000) of surplus energy is utilized, which corresponds to approx. **1 499 000€**. This equivalent to 0,41% of total energy consumption of Tel Aviv, valued at 361 000 000€. Note that S12 includes V2G technology, with which the fleet would need to be equipped.
PV surplus utilization per vehicle considering battery degradation costs	Three scenarios are selected to verbally describe a monetary value per EV: S3, S12 & S18. S3 & S12 include the baseline data, S18 the relocation data. S3 includes a small fleet and a small PV. S12 & S18 include a big fleet and a big PV. Note that if battery degradation costs of the fleet due to V2G (additional transferred energy) are included, the monetary value per vehicle decreases. A battery degradation of 2 cent/kWh is assumed [29] . • S3: a small fleet (10 500 EVs) manages to utilize 5,91% of surplus PV (small PV) worth 2 023 000€. This is equivalent to approx. 119 000€ in total and around **11,3€ per EV per year**. If these profits are allocated completely to the fleet, charging costs decrease from about 15,3€ to 4€. Note that charging costs from the comparable S2 (no V2G only smart charging) are approx. 11,8€ which are reduced to 4€ by using V2G. This reduction of 7,8€ causes an additional 9€ battery degradation costs per EV per year.

	• S12: a big fleet (42 000 EVs) manages to utilize 4,99% of surplus PV (big PV) worth 29 991 000€. This is equivalent to approx. 1 499 000€ in total and around **35,7€ per EV per year**. If these profits are allocated completely to the fleet, charging costs decrease from about 15,3€ to -20,4€. Note that charging costs from the comparable S11 (no V2G only smart charging) are approx. 6,8€ which are reduced to -20,4€ by V2G. This reduction of 27,2€ causes an additional 31,7€ battery degradation costs per EV per year. • S18: a big fleet (42 000 EVs) manages to utilize 3,72% of surplus PV (big PV) worth 29 991 000€. This is equivalent to approx. 1 115 000€ in total and around **26,6€ per EV per year.** If these profits are allocated completely to the fleet, charging costs decrease from about 37,7€ to 11,1€. Note that charging costs from the comparable S17 (no V2G only smart charging) are approx. 25,2€ which are reduced to 11,1€ by V2G. This reduction of 14,1€ causes an additional 15,4€ battery degradation costs per EV per year.
PV surplus utilization per vehicle – including $C0_2$ emissions	If a possible CO_2 is incorporated into the previous calculations, the results are improved by the emission savings. A relatively high CO_2 price of 100€/tCO_2 is applied. • S3: In addition to the 119 000€ based on PV surplus utilization, **142 000€ in emission savings** are added. Therefore, the monetary value per EV per year changes to **24,86€ per EV per year** and 15,86€ including battery degradation. • S12: In addition to the 1 499 000€ based on PV surplus utilization, **1 722 000€ in emission savings** are added. Therefore, the monetary value per EV per year changes to **76,69€ per EV per year** and 44,99€ including battery degradation. • S18: In addition to the 1 115 000€ based on PV surplus utilization, **1 023 000€ in emission savings** are added. Therefore, the monetary value per EV per year changes to **50,90€ per EV per year** and 35,4€ including battery degradation.

The following **economic key take aways** summarize the results presented in figure 39 and table 24. In addition, further economic considerations are formulated:

- Based on the results presented in figure 39 and table 24, an average EV can utilize PV surplus energy worth between about 1,2€ and 36€ per year.

    - However, the low figures are mainly due to the extremely low energy costs assumed in this case study in combination with short standing times of the vehicles.
- In the scenarios in which uncontrolled or smart charging is applied, possible battery degradation plays a subordinate role, as the EVs must (re)charge anyway. The situation is different in the V2G scenarios, in which the battery damage exceeds the monetary gain from additional transferred energy (PV surplus utilization).
- However, if a $C0_2$ price is included in the considerations, the application of V2G turns profitable despite high battery degradation costs.
- In the specific set-up of this case study, which includes very low energy prices, potential earnings from CO_2 reduction may even exceed the monetary gains from surplus PV utilization using V2G.
- In general, the monetary values of surplus PV utilization appear low. Even in the maximum scenario (S12), surplus PV energy worth 1,5 million Euro is utilized, which is insignificant compared to the city's total consumption of about 360 million Euro.
- In a different set-up, for example located in central Europe, the monetary values per vehicle could be significantly higher. Energy costs per kWh could be up to 10 times higher (30 Euro cents/kWh) in central Europe. In combination with longer idle times of the fleet and larger battery capacities, even 20 times higher figures would be possible. That would mean a monetary value per year and EV of over 700€. On this scale, CO_2 savings and battery degradation costs hardly matter.

3.5.4 Conclusions

This case study focusses on the utilization of surplus PV energy, with the help of an EV fleet. The question is addressed from perspective of the overall system (city & fleet) and from the fleet perspective. The following conclusions are drawn:

Key findings	Description
1	**A limited proportion of surplus PV energy can be utilized by an EV fleet.** Assuming a comparatively small amount of surplus PV energy, an ambitious EV fleet of 42 000 EVs (equivalent to 1 EV per 35 residents) manages to utilise up to **22,4%** of the surplus energy. However, assuming a large amount of surplus PV energy, the same fleet can utilise only **5%** of this energy. (The values refer to the urban area of the Tel Aviv district, with approx. 1,5 million residents.)
2	**The amount of surplus PV energy utilized is not system relevant.** In comparison to the total energy consumption of the entire system (Tel Aviv district & EV fleet), the amount of utilized surplus PV energy is minimal. An EV fleet of 42 000 EVs only manages to utilize up to **0,41%** of the total energy consumed. Expressed in monetary terms, this equates to **1,5 million Euros** being utilized in comparison to a total energy consumption worth **360 million Euros.**
3	**Mobility behaviour affects the fleet's potential for surplus PV energy utilization.** If the EVs of the fleet are more active with correspondingly more frequent but shorter standing times, the potential of V2G decreases (3,72% surplus PV utilization in comparison to 4,99%).
4	**Smart charging can significantly reduce the energy costs of an EV fleet. V2G can even generate profits.** Smart charging can reduce energy costs by up to **56%**. In monetary terms, this equates to a reduction of charging costs per year per vehicle from 15,4€ to 6,7€. V2G can even turn the **costs of 15,4€** into **profits worth 20,2€.**
5	**Monetary values per vehicle are highly dependent on energy prices.** The monetary values per EV per year calculated in this case study are remarkably low, as they are based on extremely low energy prices compared to prices in central Europe. If charging costs of 30 Euro cents per kWh are assumed instead, monetary figures per EV per year increase from **35,6€** to **356€.** Furthermore, it is conceivable that these figures could reach approx. **720€** per year per vehicle if, for instance, the battery capacity and charging

	power per EV were considerably higher in conjunction with extended standing periods.
6	**Battery degradation costs are relevant**. In this case study, possible battery degradation costs per kWh have the potential to significantly influence the charging behaviour of the EV fleet. In several scenarios of this study, V2G would not be applied at all because the battery degradation costs would exceed the profits from traded energy. For example, the added value of **27,2€** due to V2G would be offset by costs of **31,7€**. As energy costs rise, the percentage significance of battery degradation costs naturally decreases.
7	**V2G can enable a nearly climate-neutral vehicle.** The application of V2G has a CO_2-reducing effect on the overall system, as low-emission surplus PV energy is used instead of emission-intensive grid energy. For example, in this study, the grams of CO_2 per kilometre driven can be reduced from **60,3 CO_{2eq} [g/km]** to up to **-63,5 CO_{2eq} [g/km]**. If this emission reduction is included in the overall CO_2 balance of an EV over its entire life cycle, the result is a virtually **climate-neutral vehicle per kilometre driven**.
8	**If energy prices are low, the monetary value of CO_2 reduction can be financially significant.** If V2G is applied in the set-up of this study, the monetary value of the reduced emissions corresponds approximately to the financial gain of surplus PV energy utilization. For example, in addition to **1,5 million Euros**, approx. **1,7 million Euros** can be generated through CO_2 reduction. These results are based on relatively low energy prices in combination with ambitious carbon permit pricing. If the assumed energy prices approach an average central European level, the share of profits from emission reduction decreases accordingly.
9	**Large scale surplus PV energy utilization requires a tremendous EV fleet.** The aggregated battery capacities of an ambitious (42 000 EVs – equivalent to 1 EV per 35 residents) future EV fleet are not sufficient to store and utilise surplus PV energy to a system-relevant level. Multiple times larger aggregated battery capacities are essential for surplus PV energy utilisation on a large scale. In addition, a correspondingly high charging power per EV in combination with sufficient long idle times (especially during PV surplus periods) is crucial as well.

4 CONCLUSION ON THE ECONOMIC AND ECOLOGIC BENEFIT

This chapter will summarise the key findings of the previous case studies and relate them to economic and ecological aspects. The aim is to emphasise the respective economic and ecological benefits. Some of the findings cannot be clearly categorised.

4.1 Case Study Windkraft Simonsfeld

A business fleet comprising 26 EVs, in combination with a relatively large PV system (70 kWp), can achieve the following economic and ecologic outcomes over a period of six months. The results mainly relate to the winter half-year from October to March inclusive.

Key findings	Description
Economic benefits	**Smart charging** The total monetary added value from the utilisation of smart charging in comparison to uncontrolled charging lies between **146€** and **369€**. 146€ are realised in a set-up including dynamic prices and a PV system. The revenue from the sale of PV surplus is increased by 11% (equals 146€) through smart charging. 369€ are achieved with a dynamic price and no PV. In this set-up, smart charging reduces the energy costs by 27% (equals 369€). The monetary figures correspond to a financial added value of between **0,9€ and 2,4€ per vehicle per month.** **Vehicle-to-grid** The monetary added value of V2G in comparison to uncontrolled charging lies between approx. **316€** and **636€**. 316€ are realised in a scenario with static prices and a large PV. In this scenario, surplus PV is stored and sold, but price-dependent energy trading does not occur. As a result, revenue from sold PV surplus energy is increased by 14% (316€). 636€ are realised with dynamic prices without a PV. This figure is solely achieved through energy trading. 636€ corresponds to a 46% reduction of energy costs. This corresponds to a financial added value of between approx. **2,0€** and **4,1€ per vehicle per month.**

	Addendum The notably low added monetary values are due to the relatively low absolute energy consumption of the business fleet and low dynamic energy prices (0,13€/kWh on average). In relative terms, smart charging and V2G enable notable benefits: • With dynamic prices, but no PV, V2G can reduce energy costs by up to **46%**. • Dynamic prices in combination with PV and V2G can increase profits through energy trading by up to **46%**. • In comparison, V2G in combination with static prices and a PV system can increase profits through sold surplus PV energy by **14%.** **Battery degradation costs** are a relevant factor. For example, in a set-up with dynamic prices, PV and V2G, battery degradation costs reduce the fleet's total profit by around **43%**. During the **summer period**, the benefits of V2G increase. For example, during summer, the profits of the fleet increase by **20%** due to more PV surplus energy in a set-up including dynamic prices, a PV and V2G. Consequently, the amount of purchased energy from the grid decreases by 97%.
Ecological benefits	**Smart charging** With static prices and a PV system, smart charging manages to reduce the amount of purchased energy from the grid by up to **68%** and V2G by up to **93%**. During the summer period, purchased energy can be reduced by up to **97%**. Note that, if dynamic prices are applied, the fleet purchases additional energy for later sale. Consequently, there is no reduction in the amount of purchased energy.

4.2 Case Study Zurich 1 – Peak shaving

This case study examines the potential of a stationary EV car-sharing fleet (24 000 EVs) to stabilise the electricity grid. Specifically, the vehicles in the fleet assist in reducing the peak load by discharging energy and supplying it to the grid. The results of this case study are mainly related to economic aspects.

Key findings	Description
Economic benefits	**EV fleets have the potential for grid stabilisation.** A sufficiently large number of V2G-capable EVs has the capacity to provide noticeable grid stabilisation. The aggregated battery capacity is sufficient to enable shifts in the load peak curve in the multi-digit percentage range. However, a minimum amount of battery capacity must of course always be available. **Realistic price structures hardy incentivises peak shaving.** A realistic peak power tariff and electricity prices from 2023/2024 located in Zurich offer very little incentive for peak shaving. Under realistic conditions with V2G-capable EVs, a reduction in the load peak of -2,26% can be achieved. It does not matter whether static or dynamic prices are applied. Without V2G, only a reduction of -0,77% is achieved. For the total system, a peak load reduction of -2,26% equals approx. **344 000€** in cost reduction over the period of one year. These savings are negligible compared to the hundreds of million Euros in electricity costs for a city like Zurich. **Economic incentives for peak shaving require a sufficiently high peak load tariff.** In this case study, a slightly greater load peak reduction of -4,33% is achieved with the help of a double peak power tariff in combination with low battery degradation costs. A much higher peak load tariff (18,7 times) achieves a reduction of 6%. However, the reduction potential increases with the aggregated battery capacity of the fleet and naturally becomes greater the more EVs are feely available at peak times. **Profits from electricity trading require a sufficiently wide price range.** Profits from electricity trading are only possible if there is a sufficiently large difference between buying and selling prices. The price range must therefore exceed grid fees, taxes, and battery degradation costs. **Battery degradation costs are relevant.** Battery

	degradation costs are a relevant factor in the cost structure of the EV fleet and can make the difference between trading energy profitably or standing still.

4.3 Case Study Zurich 2 – Economic dispatch

This case study will exclude the topic of grid stability and will only focus on economic aspects of an EV fleet from the fleet operator's perspective. The fleet will again be a station-based EV fleet, consisting of 24 000 EVs.

Key findings	Description
Economic benefits	**Bidirectional charging (V2G) and dynamic prices have the potential to significantly reduce energy and total costs.** Average dynamic prices instead of static prices can reduce energy costs by around **5,9%** (no V2G) as energy purchases are made at lower prices. Strongly fluctuating but rarely occurring dynamic prices can further reduce energy costs by up to **49%**. In combination with a strongly fluctuating dynamic price, V2G makes it possible to reduce the energy costs of a fleet by up to **59%** and the total costs by up to **94%.** **An EV fleet only used for energy trading generates minimal profits.** A fleet of 221 average EVs (only used for electricity trading) can generate profits from trading of a maximum of **213€ within two days**. The projected profits amount to a maximum of about **3 200€ per month in total and 14,4€ per vehicle per month.** However, these profits only materialise with dynamic electricity prices in general and on rare days with strongly fluctuating electricity prices. **Battery degradation costs are relevant.** Battery degradation costs are a relevant factor in the cost structure of the EV fleet and can make the difference between trading energy profitably or standing still.

4.4 Case Study Tel Aviv

The case study is situated within the context of the year 2030. It analyses the possible utilization of surplus energy generated during peak PV periods with the help of a stationary EV fleet. The different scenarios in the study differ mainly in terms of the assumed fleet size (10 500 & 42 000 EVs), PV production (33% & 50% of total energy demand) and mobility behaviour.

Economic benefits	**33% of energy demand via PV** Assuming that 33% of energy demand is covered by PV energy, this results in PV surplus energy worth around **2 023 000€**. In this study, a maximum of 22,39% surplus energy is utilized, which corresponds to approx. **453 000€**. This is equivalent to 0,12% of total energy consumption of Tel Aviv region, which is valued in monetary terms at 361 000 000€. **50% of energy demand via PV** If 50% of energy demand is covered by PV energy, this results in PV surplus energy worth around **29 991 000€**. In this study, a maximum of 4,99% surplus energy can be utilized, which corresponds to approx. **1 499 000€**. This equivalent to **0,41**% of total energy consumption of Tel Aviv, valued at 361 000 000€. **Surplus PV utilization per vehicle** Based on the results presented in in the case study, an average EV can utilize PV surplus energy worth between about **1,2€** and **36€** per year. If battery degradation costs are included in the calculations, the results per vehicle turn negative in many scenarios. The degradation costs can be higher as the monetary value of utilized surplus PV energy. Note that the low figures per EV are based on extremely low energy prices used in the case study. In a different set-up, monetary values per EV can be significantly higher (up to 720€ per EV per year). **Smart charging and vehicle-to-grid** Smart charging can reduce energy costs by up to **56%**. In monetary terms, this equates to a reduction of charging costs per year per vehicle from 15,4€ to 6,7€. V2G can even turn the **costs of 15,4€** into **profits worth 20,2€.** Low figures are based on low energy prices used in the case study.

Ecological benefits	**A limited proportion of surplus PV energy can be utilized by an EV fleet.** Assuming a comparatively small amount of surplus PV energy, an ambitious EV fleet of 42 000 EVs (equivalent to 1 EV per 35 residents) manages to utilise up to 22,4% of the surplus energy. However, assuming a large amount of surplus PV energy, the same fleet can utilise only 5% of this energy. (The figures refer to the urban area of the Tel Aviv district, with approx. 1,5 million residents.) **Smart charging in combination with PV production can reduce energy costs significantly.** With the help of smart charging, the fleet can cut fossil grid energy by up to 56% and use clean PV energy instead. **V2G can enable a nearly climate-neutral vehicle.** The application of V2G has a CO_2-reducing effect on the overall system, as low-emission surplus PV energy is used instead of emission-intensive grid energy. For example, in this study, the grams of CO_2 per kilometre driven can be reduced from **60,3 CO_{2eq} [g/km]** to up to **-63,5 CO_{2eq} [g/km]**. If this emission reduction is included in the overall CO_2 balance of an EV over its entire life cycle, the result is a virtually **climate-neutral vehicle per kilometre driven**. **If energy prices are low, the monetary value of CO_2 reduction can be financially significant.** If V2G is applied in the set-up of this study, the monetary value of the reduced emissions corresponds approximately to the financial gain of surplus PV energy utilization. For example, in addition to **1,5 million Euros**, approx. **1,7 million Euros** can be generated through CO_2 reduction. As a result, the monetary value per EV per year can reach up **76,69€** and 44,99€ including battery degradation These results are based on relatively low energy prices in combination with ambitious carbon permit pricing (100€/tCO_2). If the assumed energy prices approach an average central European level, the share of profits from emission reduction decreases accordingly.

5 DERIVING FUTURE BUSINESS MODELS

In contrast to the overall economic discussion of the results above, this chapter aims to derive conclusions for prospective businesses entering the market of smart and bidirectional charging. In this final section the authors want to underline the decisive determinants that make up a valid business scenario, leveraging the flexibility of EVs for the electricity system.

To do so, a customised canvas has been drafted, guiding this discussion (figure 40).

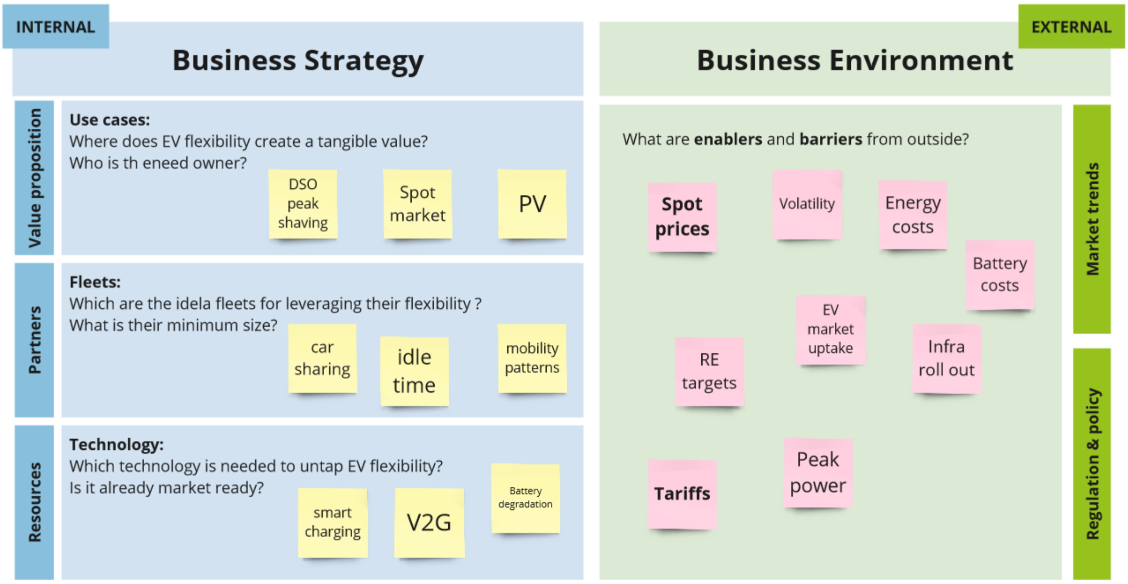


Figure 40: Customised canvas to derive future business models.

Internal factors, guiding a decision on the **business strategy** include the flexibility use cases as the value proposition, the fleets participating in such a scheme as the key partners and the technology as necessary resources.

5.1 Value proposition

The value proposition is the core of any business model. If there is a clear value proposition for the customer, a service provider can develop a business strategy and enter the market. In this case, it is hard to define customers as it is rather a multi-sided business model with flexibility providers (the fleets) and flexibility consumers (players in the energy system), which we all refer here to as partners. However, a tangible value proposition needs to be in place for all partners in order to launch a service offering. As an outcome of the initial stakeholder workshops, it can be argued that it is still not fully clear which type of businesses will play the main role in these services, so it is expected that business models will only emerge, if all partners see a convincing benefit for them in their business sphere. This means OEMs need to see growing customer demand for smart charging features, fleets need to find tailored flexibility schemes on the market and flexibility aggregators need to see a demand for flexibility provision either from energy suppliers, grid operators or renewable energy producers.

Therefore, it is crucial to assess the profitability of the different **flexibility use cases**, which was done in the case studies of this paper. The key conclusions per use case are summarized in Table 25.

Table 25: Key conclusions per flexibility use case

Use case	Conclusion	Pros (+) / Cons (-)
PV self-consumption	Currently the **simplest** and **most profitable** flexibility use case for EVs. Smart charging can save energy costs, V2G can generate profits.	+ also saving (energy-based) grid fees + no external barriers to this use case + feed-in prices will decrease - only for sites with PV
DSO peak shaving	Not expected to be market-ready in the medium term, **significant regulatory changes needed** to make it profitable.	- limited impact by EVs on big urban grid - peak load costs of DSO too low - market platform or dynamic grid tariff needed
Profit-optimized energy trading	Currently **not a standalone business case** but can create meaningful cost savings on **specific days** with high price volatility.	+ will be more profitable with increasing volatility - savings only on energy price - double grid charges - price spread mostly too low for V2G
Large scale PV surplus utilization	Under current conditions not feasible. Ramp-up of electromobility is not yet sufficiently advanced.	- requires a multiple of today's EVs and PV production - minimal financial incentive for players in the energy system

The main advantage for **PV self-consumption optimisation** through smart charging and V2G is that savings are not limited to the energy costs, but also the energy-based grid charges, which do not apply for the PV energy both generated and consumed on-site. Hence, this use case is especially relevant in countries and grid levels, where the energy-based grid charge is the dominant part of the grid tariff. Usually the energy-based component is higher for small consumers (households) whereas the power-based component is higher for large consumers. However, depending on the size of the PV on site, the case study showed that by using V2G, the company fleet can be nearly fully run on solar energy (93%). It is even expected that this use case will get more profitable even without regulatory or technological advances, as feed in remuneration is likely to decrease steadily. This is because with further PV market uptake, surplus energy will increase and concentrate at sunny hours (around noon). Hence, the monetary value of surplus electricity during these times will be dwindling or even turn more and more to negative prices. As there are no external barriers to this use case, it is ready to be applied for most fleets that are charged at a site with local PV generation. Hence, it can be referred to as the most straight forward and most profitable flexibility use case for EVs so far.

Using **dynamic energy prices** is also a promising flexibility use case for EVs, however, facing some intrinsic barriers. Firstly, profits from electricity trading are only possible if there is a sufficiently large difference between buying and selling prices. Secondly, cost savings only apply to the energy price, not the grid charge. Thirdly, energy-based grid charges also apply for energy that is charged and discharged later to the grid in times of high prices. This makes V2G very unattractive in this use case and only makes sense in a few times of a year, as suggested by the case studies. However, this use case turned out to be quite profitable in the Austrian case study in the aftermath of the electricity price crises (October 2022 – October 2023), with cost savings of up to 46%. In contrast, when analysing the second Swiss case study, it becomes clear, that the revenue is generated only in view of favourable situations, where volatility is at its maximum. On average days, the savings are minimal. Therefore, it can be argued that generally the price spread is too low, which makes it currently not relevant as a standalone business case, especially if the cars are frequently used and have low idle times. In the future, this use case might get more relevant, as with more renewable energy, market prices are expected to be more volatile than nowadays.

Consumer peak shaving has not been analysed in one of the case studies, but it is relevant in countries and grid levels with high power-based grid charges. In such a scenario, individual consumers would aim to reduce their peak load, as it determines their grid charges. However, this is not relevant for individual public charging points (which might be the case for urban free floating car sharing), but very relevant for larger carparks (company fleets or larger stations at station based carsharing).

DSO peak shaving has been analysed in the first Swiss case study. It shows that a realistic peak power tariff offers very little incentive for peak shaving at the DSO level. Under realistic conditions with V2G-capable EVs, a reduction in the load peak of -2,26% can be achieved. Moreover, this equals to approx. 344 000€ in cost reduction over the period of one year, which is very small for a DSO of a large city such as Zurich. To make this use case more relevant, a sufficiently higher peak load tariff is required. In the case study, a slightly greater load peak reduction of -4,33% is achieved with the help of a double peak power tariff and a much higher peak load tariff (18,7 times) achieves a reduction of 6%. These values suggest that the reduction potential is very limited. One major reason is that in large urban grids, the peak loads are already well distributed and “smoothed out” due to its size, making it difficult to reduce peak loads. Moreover, such an analysis is very hypothetical, as there needs to be an instrument in place, that incentivises users (EVs) to engage in peak shaving for the DSO’s cumulated load profile. For this purpose, a market platform (such as a local flexibility market) or dynamic grid tariffs would be needed.

5.2 Fleet partners

The success of such a business model will highly depend on finding the ideal EV fleet. In this context, two main parameters need to be discussed: **Fleet size** and **idle times**.

A certain **fleet size** is important in some but not all use cases. For PV self-consumption there needs to be a balance between the size of the fleet and the size of the PV; otherwise no meaningful savings can be achieved through smart charging and V2G. For using dynamic prices, there is no such requirement, as even households with an EV can subscribe to a dynamic energy contract and use their smart wallbox for optimisation. A minimum fleet size is only relevant in cases when businesses need to generate a certain minimum revenue, e.g. to cover transaction costs or investment cost. This is because all the case studies showed that even when the relative cost savings in percent are high, the absolute savings per EV are low and amount to only a few euros per year. Therefore, aggregators entering the market for EV flexibility will need an easily scalable solution and have to opt for a mass market approach in order to generate tangible revenues from the very low margins per EV.

Idle time is a crucial element, as short idle times mean a high productivity of the fleet, whereas long idle times mean more available battery resources for flexibility. The results show clearly that there is no scenario where keeping an EV idle in order to provide flexibility is more profitable than using the EV to provide mobility. Therefore, the available idle time should just be seen as an unused resource that can be used for flexibility. The comparison of two datasets with different overall idle times in the Tel Aviv case study (baseline vs. relocation) shows the quantitative impact of idle times on the achievable cost savings. If the EVs of the fleet are more active with correspondingly more frequent but shorter idle times, the potential of V2G decreases (in this case 3,72% surplus PV utilization in comparison to 4,99%). Generally, one can argue that the ideal fleet would always have their cars plugged in at a charging station when there is either an exceptionally high or low market price or also high PV generation or high electricity demand on-site.

5.3 Resources: Enabling technology

Business models for EV flexibility build on technological advancements, which can be referred to as key resources. A main discussion point is which charging technology is needed to leverage the monetary benefit of EV flexibility: does it take bidirectional V2G or is unidirectional smart charging sufficient?

The results suggest that **smart charging** can be framed as low hanging fruit. Controlled unidirectional charging can be implemented relatively easy with solutions already on the market. Current state of the art charging stations fulfil all requirements to engage in PV self-consumption optimisation or dynamic price optimisation. Only a live internet connection and a central controller is needed to realise charging management. Also, in most scenarios analysed in the case studies, smart charging offers the majority of the achievable cost reductions. Additionally,

V2G can be referred to as an add-on, but with significantly higher complexity. Bidirectional charging requires bidirectional communication protocols between EV and charging station. The case studies show that there is a benefit from V2G in all scenarios, but mostly smaller than for smart charging. Also, the investment costs for V2G-ready equipment are a relevant determinant. However, market-ready products for V2G (both EVs and charging stations) are still very scarce and therefore the economic trade-off is still unclear.

Another technological aspect that potentially reduces the economically viable potential of V2G is the cost of **battery degradation**. In the model, a conservative assumption has been made with relatively high battery degradation costs. Long term trials of current EV batteries will show if this assumption was correct, or if battery degradation can be assumed much lower. For example, it still can be discussed if the battery lifespan is a limiting factor for EVs at all, as a total number of 3000 battery cycles equals to more than 20 years of usage, which is usually more than the average lifespan of a car. Therefore, it depends on the scope of the question, if battery degradation is a limiting factor for V2G.

5.4 Business environment

The following external drivers and barriers decisively influence the success of business models dealing with EV flexibility:

EV market uptake: The case study results suggest that these business models can only leverage sufficient flexibility potential when assuming optimistic growth rates of EVs and also an optimistic view on EVs participating in flexibility programmes. The Tel Aviv case study showed quite clear that a meaningful impact on the electricity system (and thus meaningful revenues for flexibility businesses) can only be achieved with an ambitious EV roll out. But in the same way, **targets for renewable energy** generation need to be met, initiating the need for flexibility in the first place. Moreover, along with the roll-out of EVs, the accompanying charging infrastructure needs to be ready for smart charging and V2G and also be standardised, so businesses can access the flexibility without technical barriers.

Energy market development: All scenarios presented are dependent on the price situation in the electricity markets. This goes for static energy prices as well as dynamic spot market prices:

- **Static prices:** Especially the difference between energy supply prices and feed in remuneration is relevant
- **Spot market prices:** The price range during a day is especially relevant for EVs that are frequently used, but also weekly changes are relevant for cars with high idle times. The case studies showed that currently the price range is too small on most days, to enable arbitrage trading (also considering factors such as grid tariffs and battery degradation)

Tariff changes: When it comes to flexibility for supporting the grid (consumer peak shaving or DSO peak shaving), regulated tariffs decide if a business scenario is viable or not. As clearly shown in the first Swiss case study, there is currently no incentive to engage in peak shaving, as peak power prices are set too low to leverage any flexibility. Moreover, V2G suffers from “double grid tariffs”, as grid energy-based grid tariffs apply when charging the storage even when it is just for arbitrage trading. To enable such business scenarios, a regulatory exemption is needed.

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6.2 Figures

6.3 Tables