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DEUTSCHLAND – KOREA

Battery Electric Vehicles for the Provision of Short-Term Flexibility

An Overview of the Potentials for Germany and Korea

Commissioned on behalf of the German Federal Ministry for Economic Affairs and Climate Action as part of the bilateral energy partnership

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Content

List of Abbreviations

BDEW	German Association of the Energy and Water Industries
BEV	Battery Electric Vehicle
BMDV	German Federal Ministry for Digital and Transport
BMJ	German Federal Ministry of Justice
BMWK	German Federal Ministry for Economic Affairs and Climate Action
BNetzA	German Federal Network Agency
BKartA	German Federal Cartel Office
BPLE	Basic Plan for Long-Term Electricity Supply and Demand
DR	Demand Side Response
DSO	Distribution System Operator
DSR	Demand Side Response
EC	European Commission
EEG	Renewable Energy Sources Act
EMS	Energy management system
EP	European Parliament
EU	European Union
FCEV	Fuel-Cell Electric Vehicle
GEIG	German Building Electromobility Infrastructure Act
IEA	International Energy Agency
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
KEPCO	Korea Electric Power Corporation
KOREC	Korean Electricity Regulatory Commission
KPX	Korean Power Exchange
KOTI	Korea Transport Institute
KSGI	Korea Smart Grid Institute
MOLIT	Korean Ministry of Land, Infrastructure and Transport
MOE	Korean Ministry of Environment
MOTIE	Korean Ministry of Trade, Industry and Energy
NLL	National Center for Charging Infrastructure
NOW	German National Organization Hydrogen and Fuel Cell Technology
PHEV	Plugin-hybrid electric vehicle
PPA	Power Purchasing Agreement
PtX	Power-to-X
SME	Small and medium-sized enterprise
ToU	Time-of-Use Pricing
TSO	Transmission System Operator
V1G	Smart charging (unidirectional power flow)
V2B	Vehicle-to-Building
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home
VDA	German Association of the Automotive Industry
VGI	Vehicle Grid Integration
VKU	German Association of Local Utilities
VPP	Virtual Power Plant

Executive Summary

The planned and managed grid integration of different flexibility options offers great potential as a non-wire alternative. Not only does it increase system efficiency, but it also brings down overall system costs. The grid integration of new end-users, such as battery electric vehicles (BEVs) or heat pumps, is often cited as a reason for concern, but also offers great potential as a flexible energy resource.

This study looks at the potentials and the current state of BEVs for the provision of flexibility in Germany and Korea. The objective of this study is to provide an overview over the status and future potentials on this topic, the identification of mutual learnings, best-practices and recommendations for potential future German Korean cooperation. Both countries aim to significantly reduce emissions, with Germany targeting carbon neutrality by 2045 and Korea by 2050. Renewable energy and BEVs are central to these efforts. BEVs are pivotal to decarbonizing the transport sectors in both countries. Germany aims for 15 million battery electric vehicles (BEVs) by 2030, while Korea targets 4.2 million BEVs.

Both nations face similar challenges in integrating BEVs into the grid and using them as flexible energy resources (BEVs). While technical solutions exist, regulatory frameworks need development to facilitate large-scale deployment. Herein lies significant potential for cooperation.

Both countries recognize the potential for BEVs to enhance grid flexibility and stability but must develop comprehensive regulatory and incentive systems to fully realize these benefits. Demand response (DR) programs and smart grid technologies are crucial for managing the increased electricity demand from BEVs. Germany is advancing smart-meter deployment and incentivizing off-peak charging, while Korea leads in smart-meter infrastructure but needs further regulatory support for DR programs.

The integration of Vehicle-to-Grid (V2G) technology presents technical possibilities but requires regulatory frameworks to address legal and economic barriers. Both countries are conducting research and demonstration projects to advance V2G technology, but large-scale deployment remains hindered by regulatory challenges.

Overall, Korea and Germany have opportunities for cooperation, especially in designing consumer incentives and standardizing technical requirements. Both countries must continue to adapt their regulatory frameworks to support the cost-effective and sustainable integration of renewable energy and BEVs into their grids

<u>Key areas for collaboration include:</u>

- Regulatory Frameworks: Sharing experiences and developing joint strategies to establish comprehensive regulatory frameworks for V2G technology can accelerate its deployment in both countries.
- Demand Response Programs: Both countries can benefit from exchanging best practices in designing effective demand response (DR) programs. Korea's advanced smart-meter infrastructure and Germany's evolving incentive systems offer complementary strengths.
- Standardization and Technical Requirements: Joint efforts in standardizing technical equipment and communication protocols can streamline EV integration and enhance market efficiency.
- Market Integration of Flexibility Resources: Collaborating on integrating flexible resources like aggregators and virtual power plants (VPPs) can improve grid stability and reduce reliance on traditional power plants.
- Smart Grid Development: Germany and Korea can share insights on smart grid technologies, with Korea's advanced metering infrastructure providing valuable lessons for Germany's ongoing developments.

By focusing on these cooperation areas, both countries can enhance their energy transitions, ensuring a more cost-effective and sustainable integration of renewable energy and EVs into their grids.

1 Introduction

Countries around the world push for the accelerated installation of renewable energy sources to increase affordable energy supply, to strengthen energy security and strive towards net-zero emissions in their respective power sectors. In the aftermath of the recovery from the global Covid-19 pandemic and the energy crisis resulting from Russia's war of aggression against Ukraine, a further record boost for investments for clean energy sources can be observed (IEA 2023f; IRENA 2023b).

Renewable energy sources offer a long-term cheap and clean alternative compared to traditional fossil fuels. Nonetheless, their integration into current power systems goes along with challenges, due to their seasonal and temporal variability, with volatile surpluses and periods of lower generation. The partial decommissioning of coal and nuclear power plants adds an additional layer of complexity for the balance of demand and supply. The general reinforcement of power grids and, where possible, additional alternating current and long-distance high voltage direct current interconnections between systems offer supply infrastructure options for addressing the variability in the new electricity system. Especially interconnected systems will be less affected by the impact of volatile renewable energy generation, as the potentially lower generation from renewables can be counterbalanced through imports from other regions (IRENA 2019).

However, these options presuppose sufficient pre-existing grid infrastructure. They require high investments, long-term planning processes for amendments, and still face limited transmission capacities in the near future, potentially resulting in additional costs to deal with issues like grid congestion (acatech et al. 2021). Furthermore, some countries have isolated systems and do not count with the possibility for interconnections due to geopolitical issues or geographical limitations.

Alongside the expansion of renewables, the electrification of different energy intensive industrial processes, mobility, heating and in other sectors, is expected to drive up the overall electricity demand. If the future grid build-up and flexible controllable reserves will be orientated at future demand peaks - e.g. during times of simultaneous charging of battery electric vehicles (BEV) in a country or region - countries and regions would face the risk of overinvesting into these barely used infrastructures and potentially stranded assets. Following the previous example, the coincidence of simultaneous widespread charging of BEVs with general peak electricity consumption at certain time periods of the day would additionally result in an increased demand for costly marginal generation units, e.g. gas and green hydrogen in the future, and thus in additional system costs even with sufficient grid capacity (IEA 2023d).

"The IEA points out that to maintain electricity security in the transition to more variable energy sources requires ways to help manage the variability and partial uncertainty in power systems (IEA 2023d). Flexible energy resources play a salient role to address the seasonal volatility. These resources count with the characteristic of being able to adjust their electrical consumption or production in response to an active or passive external signal. They will be required to balance the grids of the future as well as to secure a cost-effective and stable integration of renewables into the grid.

BEVs offer a promising option to showcase this potential, as their global uptake will further increase electricity demand to potentially challenging levels if the charging process is not controlled. At the same time, their aggregated battery capacities are enormous flexible energy storage units. BEVs offer the option for providing flexibility through smart-charging, e.g. by shifting demand or shortly stabilizing the grid in times of low energy supply through Vehicle-to-Grid (V2G) technologies.

These types of demand-side flexibility options offer great potential for facilitating the smooth integration of volatile renewable energy sources. They can help smooth out demand-peaks. In the case of BEVs this would work for example through dynamic price signals which make it more attractive to charge in times of lower demand. Low prices are often also correlated with a high share of renewables, so charging at low prices helps the smooth integration of surplus renewable energy. At the same time, it can reduce the carbon footprints of BEVs and save consumers money. BEVs can provide valuable services to the grid, if they are properly incentivized with appropriate technologies, policies and regulations. V2G services are for example estimated to potentially offer up to 600GW of flexible capacity globally and reduce electricity generation needs by 380 TWh during peak demand hours (IEA 2020a).

This study looks at the potentials and the current state of BEVs for the provision of flexibility in Germany and Korea. Both countries have the target of achieving net-zero in 2045 and 2050 respectively with energy systems running on clean energy sources. At the same time, they also aim for a high share of BEVs in their future transport sectors and count with innovative automobile industries. They face similar challenges regarding the proper grid integration of renewable energies and new users like BEVs. The objective of this study is to provide an overview over the status and future potentials on this topic, the identification of mutual learnings, best-practices and recommendations for potential future German Korean cooperation.

The subsequent chapter provides a brief overview over the different flexibility options and the specific use-case of BEVs, followed by the country studies on Germany and Korea. The study closes with a comparison of the status and progress made by both countries and finalizes with suggestions for cooperation potentials between Germany and Korea on the overall topic of the study on grid flexibilization and the efficient and grid-friendly grid integration of BEVs.

2 Overview Flexibility

2.1 Flexibility Options

The planned and managed grid integration of different flexibility options offers great potential as non-wire alternative. Not only to increase system efficiency, but additionally bring down overall system costs (IRENA 2019). Their usage will have to be accompanied by further grid reinforcement. Nonetheless, it reduces the costs and scale for the expansion of especially regional distribution grids, which will be particularly affected by new demand of end-users, such as BEVs or heat-pumps (Agora Verkehrswende 2023). Therefore, governments face the challenge to urgently address the existing asymmetry of long-winded grid permitting processes and the ramp-up of renewables. The IEA argues that is essential for the global energy transition to avoid the risks of underinvestment and bottlenecks. Integrated planning processes (for supply, demand and flexibility) have to be improved and adequate remuneration to incentivize smart grid deployment needs to be established (IEA 2022b).

Flexibility can be provided by different types of resources. It can stem from production, storage but also the demand side. It can be upward provision through increased production or reduced consumption and downward vice-versa. Thermal power plants are a common source of flexible controllable capacities nowadays (IEA 2020b). They predominantly run on unabated fossil fuels. These will need to be replaced with low and zero-emission energy sources, e.g. green hydrogen and its derivatives, in the wake of global energy transition (Sieler and Dörr 2023).

Flexibility does not only entail the production of electricity, but also the consumption and storage of surpluses for later use. For example, green hydrogen and its derivatives can be produced through electrolysis in times of a renewable surplus. This further facilitates the grid integration and efficient use of renewable energy sources, mitigating e.g. curtailments. Power-to-X technologies (PtX) can also entail other use of renewable surpluses, for example, for storage heating (Bloess et al. 2018). Further important long-duration flexible energy storage concepts entail pumped-storage hydropower, large-scale or small scale battery packs and other technologies like compressed air energy storage (German Energy Agency 2021; Okamura et al. 2022).

Additionally, the widespread electrification of many other sectors converts demand generally into a more flexible asset. The progressive electrification of different end-users like BEVs and heat pumps offers promising potential for sector coupling applications. In combination with smart, connected technologies they can be used as a source for the provision of flexibility through demand-side response (DSR) measures. DSR is "[...] the capability of any active customer to react to external signals and adjust their energy generation and consumption in a dynamic time-dependent way, individually as well as through aggregation" (smartEN and DNV 2022). DSR has already been in place for a long time. For example, storage heaters can shift their consumption to late hours. Thus, they benefit of lower electricity night tariffs. Large-scale industrial load shedding is another example for DSR measures already in use.

However, through the combination with smart technologies, DSR has become more dynamic, capable to react within real-time to different external signals, and more available for small-scale applications. Now, small scale resources like private BEVs are easier to access remotely in real time as potentially controllable loads. The electrification of end-users offers new opportunities for the smart grid integration of these technologies. Examples are load flexibility based on smart-charging strategies, energy storage concepts and even active balancing services through technologies like V2G for BEVs. The IEA considers buildings, electrolytic hydrogen production (PtX), BEVs and industry to be the main potential providers for DSR measures in the future (IEA 2023d).

DSR measures can be applied to reduce or even shed electricity demand in times of low output of renewables. On the other hand, they can increase their demand in times when the supply with renewables is exceeding the demand. At the same time, DSR can help industrial and private consumers to reduce their costs. DSR measures enable demand to be shifted to times of low electricity prices caused by renewable surpluses. Thus, DSR can generally contribute towards the smooth integration of these new technologies. At the same time, it facilitates the cost-efficient integration of renewables and sectoral decarbonization (IRENA 2023b).

DSR is expected to provide flexibility up from a few seconds of frequency regulation, to several minutes and hours, in particular if aggregated with other decentralized energy resources, e.g. as part of a virtual power plant (VPP) (IEA 2023d). Under different scenarios by the IEA DSR provides roughly a quarter of power system flexibility in 2050. In the IEA´s Net Zero Emission scenario, contribution from demand response rises to 500 GW in 2030 (Emi Bertoli 2022).

Power systems focused on conventional power generation from fossil fuels need an update that reflects the new reality of higher supply and demand side volatility. Supply side flexibility and demand response from large industrial users, e.g. for load shifting, is often already included in current systems. To untap the full potential of especially small-scale decentralized flexibility options, governments should put their focus on adequately incentivizing and rewarding their overall market participation (smartEN 2022). New small-scale decentralized energy resources can enhance competition, bring down procurement costs and improve market efficiency. A level playing field for different flexibility providers should be ensured by regulators. The revisions of market participation rules, like excessively high minimum bid size designed mainly for large providers, and clear participation rules for aggregators of small scale resources can be examples for this (Emi Bertoli 2022; Kim 2022). Additionally, to reap the benefits of DSR on all scales, individual consumers should be encouraged on the possibilities to provide their flexibility to the system. Governments should promote ways on how to use DSR in a serviceable manner for the energy system, but also for consumers through potential financial benefits (Kim 2022).

There are many different approaches and discussions for a market design to provide such an appropriate framework (IRENA 2019; Kim 2022; IRENA 2023a). However, diving deeper into this goes beyond the scope of this paper. In any case, designs need to consider many additional country or regional specific conditions. These can be existing infrastructure or interconnections, with no one-fits all solution.

Nonetheless, the implementation of smart grids and smart-metering will be indispensable. It is a prerequire for the successful integration of flexible resources and especially DSR measures. Smart grids are electricity networks which use digital technologies, allowing them to better and more precisely monitor and manage the transport of electricity. This facilitates the matching of all generation sources and the varying demands of end users (IEA 2022b). According to the IEA, smart-grids enable a system operation to run as efficiently as possible, minimizing costs and environmental impacts while maximizing system reliability, resilience, flexibility and stability (IEA 2022b). Real-time information on the state and capacities of transmission and distribution grids is the enabler for the integration of these resources. Additionally, information on the availability and possibility to activate or deactivate different flexible energy resource large or small scale is needed.

2.2 Use-Case: Battery Electric Vehicles (BEVs)

BEVs offer an especially interesting case. Their widescale uptake will further increase energy demand to potentially challenging levels. In 2022, the global electricity demand of BEVs was 110 TWh. Estimates for the global electricity demand of BEVs in 2030 range between 950 TWh up to almost 1,800 TWh (IEA 2023) and for 2040 between 3,000 TWh and 4,500 TWh (IRENA 2023). For Europe, estimates show that BEVs could mostly provide short-term flexibility during the day. They are estimated to provide around 5% of the required flexibility in 2030 to 20% in 2050 for Europe, through smart charging solutions or V2G-technology (Agora Energiewende 2023a). The IEA calculated that for the cases of China, India, the US and the EU, Time-of-Use-pricing (ToU), e.g. designed to shift BEV charging to off-peak periods at night, could avoid 60% of the peak load increase, compared to a scenario which assumes that 80% of BEV charging would take place during 18:00-00:00. V2G services could further offer 600GW of flexible capacity globally and reduce electricity generation needs by 380 TWh during peak demand (IEA 2020a). In another study, the IEA estimates the potential of BEVs between 21%-30% to meet the flexibility needs in a grid with a renewable share of over 70% - 90% in the electricity mix (IEA 2023d).

Other than most battery systems, cars are inherently mobile and have transportation of humans or goods as their primary application. This makes them not always available as a flexible energy resource. However, most cars are more frequently parked at home or at the workplace than actively used throughout an average day. In the case of BEVs, they are often connected with a charger when parked. They only require a short period to fully charge. The battery capacity of BEVs tends to exceed daily average requirements five- to ten-folds. (Agora Verkehrswende 2023) Passenger cars are estimated to be parked 95%-96% of the time and being actively charged only 10% of the time daily (Kim 2022). For BEV users it is important to have enough battery capacity at the moment of departure, a parameter which could also be previously defined, and not the actual time frame of charging. The most promising way to untap the flexibility potential of BEVs is through time-of-use pricing (ToU), smart charging and V2G technologies.

ToU-pricing generally works through static price signals to the consumers. The idea is to incentivize charging in hours of typically lower demand by offering lower prices for charging, e.g. during night hours with a lower overall electricity demand. In Korea, for example, specific static ToU tariffs exist for BEVs differentiated by season and the voltage level of the connection (KEPCO 2023a).

Smart charging commonly refers to more active measures. The charging process follows external signals. It is also referred to as V1G, as a unidirectional control over the flow of electricity from the grid to the BEV. The external signals can be price signals, on the state of the grid, or the share of renewables in the electricity mix. They can also be dynamic, even real-time tariffs with high prices in times of too much demand or low prices in times of less demand or an oversupply. This additionally tends to coincide with a high share of renewables in the grid, e.g. on a sunny or windy day. Smart charging can also be applied to focus on charging during times of a high share of renewables in the power system, independent of the price, emphasizing lower emissions intensity in the electricity mix and reducing the life-cycle carbon footprint of BEVs (Okamura et al. 2022; IRENA 2023a). German transmission system operator (TSO) TenneT recently launched a CO2-monitor, to allow consumers to track the CO2-intensity of the German electricity mix and potentially optimize their consumption accordingly (TenneT 2024).

Figure 1: Exemplary estimations of economic and system benefits of flexibility from BEVs

Source	Economic and system benefits of flexibility from BEVs
European Commission (2019)	• Real-time pricing can save up to 27% of power generation costs and reduce RE curtailment by 14%.
IEA (2020a)	• Time-of-Use (ToU) pricing could avoid 60% of peak load increase (in China, India, US, EU). • V2G could offer 600GW of flexible capacity and reduce electricity needs by 380 TWh in peak hours.
IEA (2022a)	• Around USD 210-660 million could be saved due to avoided peak capacity (in California). • Flexibility capacity of 6-13 GW with smart charging compared to uncontrolled charging. • V2G net savings/costs per EV per year range from EUR 2304 to EUR -955 depending on regulation.
smartEN and DNV (2022)	• EV owners could save up to 7 ct/kWh (EUR 176/year) in 2030 through smart charging and V2G
Agora Energiewende (2023a)	• EVs could provide around 5% (2030) to 20% (2050) of required flexibility in Europe.
Agora Verkehrswende (2023)	• Savings of EUR 10-45 per car per year by maximizing consumption from installed photovoltaic systems. • Savings of EUR 20-130 per car per year or 50% of total costs in reduced grid expansion investments. • Economic benefit of EUR 20-60 per car per year through market-oriented use of flexibility (dynamic tariffs). • Economic benefit of EUR 35-75 per car per year through provision of control capacity.
IEA (2023d)	• EVs could provide between 21-30% of the overall short-term flexibility needs in a grid with 70-90% RE.

Sources: own depiction based on Agora Energiewende (2023a), Agora Verkehrswende (2023), European Commission (2019), IEA (2020a), IEA (2022a), IEA (2023d), smartEN and DNV (2022)

Smart charging processes could be a direct reaction to active signals from TSOs or distribution system operators (DSOs). This can be orders to reduce the flow of electricity or even completely restrict it at certain times, to tailor to the needs of the grid. However, these direct interferences are critically discussed, due to the risk of reducing consumer acceptance to participate in smart-charging and overall acceptance of BEVs. A certain minimum threshold load of the BEV could be guaranteed to individual users to lower this risk. Other options try to incentivize participation in such DSR programs with lower network fees or special tariffs. Smart charging can thus contribute to a more optimized use of existing distribution grids and help avoid overloading and voltage instability, reducing the need for network reinforcement (Agora Verkehrswende et al. 2019).

V2G, on the other hand, allows a bidirectional flow of electricity. V2G technology allows the vehicle to discharge excess electricity into the grid, enabling more grid functions such as fast balancing services for TSOs. During supply shortages BEVs could charge or discharge their batteries within very short timeframes to help balance the energy flow in the grid. It further allows BEV users to market off their battery capacity. On average, BEV owners could save up to EUR 176 per year on their energy bills in 2030 with smart charging and V2G savings (smartEN and DNV 2022).

Further applications include possibilities like vehicle-to-home (V2H) and vehicle-to-building (V2B). This entails to use BEV batteries as a back-up power source or storage unit for individual homes or entire private and industrial buildings. These systems can become more attractive when connected with decentralized energy sources like roof-top PV. BEVs can be used as a storage unit, feeding surplus solar electricity back into the home or building during times of low radiation or at night. Through an energy management system (EMS), the BEV could even be charged in times of low-electricity prices to make this cheap electricity available to homeowners during higher priced periods. This could increase efficiency and save money for consumers and industry alike, additionally making optimized use of decentralized energy sources like private or industrial PV installations (Okamura et al. 2022; IRENA 2023a).

However, to introduce smart-charging and V2G systems can also present challenges. IRENA points out, that the use cases also differ, regarding the value of services and flexibility that BEVs can provide to the grid. In a system which already has a high share of different flexible generation options, such as good interconnections with neighboring regions, the added costs to implement a V2G system may not be competitive with other flexibility sources (IRENA 2023a). Additionally, different mobility and charging patterns of BEV users as well as the existing charging infrastructure need to be considered. In countries with a high share of public charging points, the times that BEVs are connected to the grid is likely to be lower, than in countries with a higher share of at home charging. This has effects on the times that BEV are available for grid services or smart charging strategies.

To be able to reap the benefits of smart charging, information on grid capacity, electricity supply and the different end-users needs to be accessible and connected. Smart metering devices will be key to receive and pass signals from the grid to the individual charging points to initiate or reduce a charging process. To assure consumer acceptance, smart charging and V2X-systems should be designed to run seamlessly in the background, without needing constant supervision or active decision making (IRENA 2023a). This automated processing mandates smart, digital metering and communication protocols, which enables the smooth communication between the grid, electric vehicle supply equipment and BEVs. This means that BEV users can, e.g., set certain parameters for their BEVs to start or stop charging. This decision can be based on certain price frames, upon a certain share of renewables in the grid or to reduce or even stop charging based on an increased overall electricity demand for peak smoothing (IRENA 2019).

To enable such processes, the charging points require appropriate communications- and control installations. To rollout and use certain smart-charging applications and V2G, the charging point and the BEV moreover need to be able to implement two-way communication and for V2G bidirectional energy flows, mandating adequate communication protocol standards, designed to include bidirectional charging, like for example ISO 15118 (-20) or the CHAdeMO standard (Okamura et al. 2022; Großmann and Eisele 2022).

Common communication protocols and standards for charging infrastructure and interoperability, allowing consumers to maintain access to diverse providers of charging points, are helpful for BEV market uptake. They can further push the flexible integration of BEVs, regardless of the vehicle model choice or electric vehicle system equipment, e.g. in the case of charging at home and at work using different systems. Lastly, this would increase the flexibility potential of BEV for the power system overall. The facilitation of interoperability through the use of common communication protocols would help standardize data flow and commands (IEA 2022a). Recommendations therefore call to governments to mandate or at least incentivize such interoperability, e.g. through tax credits, subsidies or tendering guidelines for private or public charging points, to avoid lock-in effects and for example, only subsidies charging points and stations which are capable of reacting to external signals and bidirectional electricity flows (IRENA 2019; IEA 2022a).

3 Overview status in Germany

3.1 Objectives and policy measures

3.1.1 Background of Germany's energy policy

Germany has the target to achieve climate neutrality by 2045. The transformation of the energy sector is essential for this. In 2023, Germany emitted 673 million tons of CO_2e, of which 210 million tons of CO_2e were generated through electricity production (Agora Energiewende 2024). In order to transform the power supply, the German government aims for a share of 80% of the electricity supply coming from renewable sources by 2030 and zero-emissions electricity by 2035 (Bundesregierung 2023a).

The Russian war of aggression against Ukraine and its impact on energy markets, supply and prices, has further motivated Germany to increase ambitions for the energy transition. Germany wants to achieve greater independence from fossil fuels and thus greater energy security. In 2023, the share of renewable energies in gross electricity consumption was 55% (BNetzA 2024b). Despite the increase of renewables in the electricity mix, the average system interruption has gradually decreased in recent years, indicating high system stability (BNetzA 2022b).

3.1.2 Key stakeholders and regulatory bodies

On the regulatory side, the key ministries regarding the topic of this study are the Federal Ministry of Economic Affairs and Climate Action (BMWK) and the Federal Ministry for Digital and Transport (BMDV). The federal authority responsible for grid expansion is the German Federal Network Agency (BNetzA). The federal agency aims to make the electricity system more flexible, e.g. with flexible electricity markets, grid dimensioning and congestions management. Furthermore, the BNetzA wants to improve access to flexibility in the future, e.g. compensations for grid flexibility providers, flexibility by storage, balancing markets, load restrictions or new forms of congestion management (BNetzA 2017, 2024c).

The National Organization Hydrogen and Fuel Cell Technology (NOW) is responsible for projects strengthening sustainable mobility. It is an important player in the context of grid flexibilization. NOW accompanies the expansion of the charging infrastructure and thus promotes the integration of BEVs into the existing power system. This is supported by the National Center for Charging Infrastructure (NLL), which operates under the supervision of NOW. The NLL is responsible for the coordination of activities to further expand the charging infrastructure in Germany (NOW GmbH 2021; NLL 2024b). Additionally, the NLL supports the grid integration of BEVs and promotes V2G in Germany in planning, implementing and financing the charging infrastructure. The NOW also finances projects for the development of V2G technologies directly (NOW GmbH 2023b).

Further important players are the German TSOs and DSOs. The four German TSOs are TenneT, 50Hertz, Amprion and TransnetBW. They are responsible for the construction, operation and maintenance of high voltage power lines in Germany, as well as to uphold system stability (BNetzA 2024d). DSOs play an important role to make the power grid more flexible through DSR-measures. In 2023, there were 866 DSOs in Germany, mainly municipal utilities or private energy companies (Statista 2023). They coordinate local energy supply with demand and enable consumers to access the grid. They are responsible for connecting decentralized generation units (e.g. rooftop PV systems) as well as new consumers (e.g. charging points for BEVs, heat pumps) and therefore have an interest in their controlled grid integration. Other tasks of DSOs include peak load and network congestion management (Reppert 2023). In addition, all market participants, i.e. electricity consumers and producers, especially those who consume and generate electricity on a large scale, are relevant stakeholders in the flexibilization of the grid.

3.1.3 Electrification of the mobility sector

The transport sector contributed around 22% of German GHG-emissions in 2023. Approximately 146 Mt. CO2e were emitted, with road transport being one of biggest emitters. The sector target for 2023 of 133 Mt. CO2e was not reached, despite an overall decrease of emissions compared to the previous year (UBA 2024). The electrification of road transport is one of the key pillars to reduce emissions in the sector.

Status and Targets for BEVs

In the coalition agreement of 2021, the German government has issued a target of 15 million fully electric passenger cars by 2030 (Bundesregierung 2022b). The fleet of BEVs in Germany counts just over 1.4 million vehicles at the end of 2023 with an average of 43,684 new registrations per month (KBA 2024). To reach the 2030 target, an average growth of 145,000 BEVs per month is needed. In addition, there are currently around 900,000 plug-in hybrids (PHEV) on German roads (NOW GmbH 2023a). Based on a survey with German automotive manufacturers, the NLL expects around 13.4 million BEVs by 2030, close to the government target, with an additional 3.2 million PHEVs (NOW GmbH 2024). Other studies estimate a BEV fleet of between 8 and 17 million BEV and between 3 and 8 million PHEV in Germany (Gnann et al. 2022; German Institute for Economic Research 2023).

To incentivize the market ramp-up of BEVs, the German government introduced a subsidy scheme in 2016. Until the end of 2023, around 2.1 million BEVs had been subsidized with up to EUR 4500 per BEV, totaling to a sum of around EUR 10 billion (Clean Energy Wire 2023). The subsidy program was considered as successful, stimulating the BEV market uptake in Germany. Concerns are that without the government subsidies, the targets for 2030 might not be reached (ADAC 2024). Despite the end of the subsidy scheme, newly registered BEVs will continue to be exempt from the German national vehicle tax until 2030. Further funding is available for public and private charging points (Finanztip 2024).

The German efforts are further connected with policy developments at the supranational level. The European Union (EU) decided in October 2022 that by 2035 all newly registered passenger cars in the EU must be emission-free (European Commission 2022). New standards will already apply by 2030: the average emissions of new cars must be reduced by 55%, and by 50% for vans. In addition to fully electric and fuel cell vehicles, emission-free cars also include vehicles that can be powered by internal combustion engines based on e-fuels (produced from renewable sources). Nonetheless, the focus is on BEVs. The targets under the REPowerEU agenda imply that the share of renewable energies in the transport sector should be 32% by 2030. The IEA (2023e) argues, however, that the EU is currently not on the targeted path. The IEA considers a share of 16% to 20% by 2027 to be realistic, only about half of what is to be achieved in 2030, provided that no more ambitious policy measures are implemented.

Status and Targets for Charging Infrastructure

Important for the roll-out of electric mobility is the simultaneous expansion of a dense network of charging points. The German government has set an objective of one million publicly and non-discriminatorily accessible charging points by 2030, with a particular focus on fast-charging infrastructure. The Charging Infrastructure Master Plan II serves as the overall political strategy for this (Bundesregierung 2022a). The master plan identifies the integration of charging infrastructure into the power system as one of the key challenges in the context of the "Charging Infrastructure 2030" mission. The efficient and future-proof integration is an essential goal and prerequisite for untapping the potential in the interaction between the power grid and the charging infrastructure, laid out by the masterplan. In addition to other measures, the aim is to enable and consider bidirectional charging from the outset in grid planning and grid expansion (Bundesregierung 2022a).

The BNetzA charging point register contains 89,106 normal public charging points and 17,800 fast public charging points that were in operation as of February 2024. A total of 4.65 GW of charging power can be provided simultaneously at the charging points (NLL 2024c). However, it is assumed that a large share of BEV owners will prefer to charge at home or at work, potentially reducing the overall need for public charging points (Sorge and Raymunt 2023). The NLL estimates the actual demand for publicly accessible charging infrastructure in 2030 at 440,000 to 843,000 charging points. The figure depends on how much private charging infrastructure is available and how busy the publicly accessible charging infrastructure is, but also on the charging behavior of users. The share of private charging is forecasted to reach 76 to 88% by 2030. In 2030, a charging point may be available at around 61% of private parking spaces (Windt and Arnhold 2020).

In terms of funding for the entire charging infrastructure, there were around 800,000 charging points funded by the German government in operation and around 200,000 more in the planning stage in 2023 (NLL 2023a). The total amount of funding deployed to date is around EUR 1.74 billion. The funding program for publicly accessible charging infrastructure with a volume of EUR 500 million will run until the end of 2025 (NLL 2023b). The corresponding funding guideline (BMDV 2021) quantifies the maximum funding amounts per charging station and grid connection and specifies the requirements for the charging infrastructure, including technical requirements, operation of the charging infrastructure, use of electricity from renewable sources, accessibility, labeling and reporting. Among other things, an open communication standard (e.g. OCPP), online connection and remote capability are technically required.

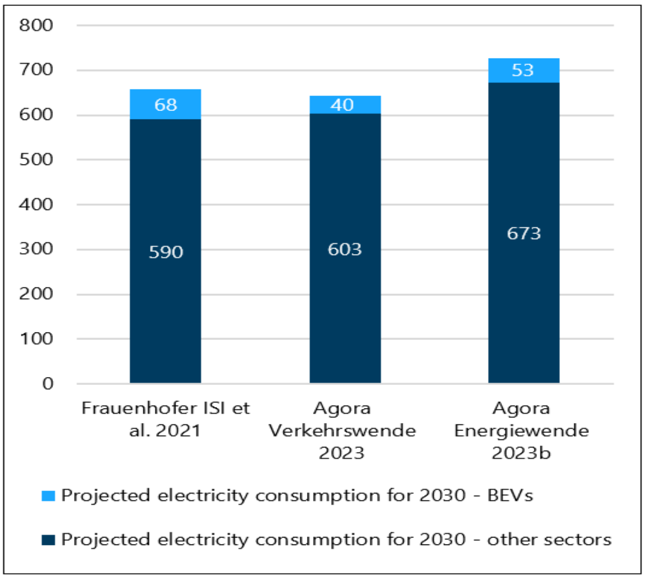
With regard to charging infrastructure, the EU adopted binding targets as part of the regulation for the deployment of alternative fuels infrastructure (AFIR) (European Council 2023; European Parliament 2023). For each registered BEV, an EU member state must provide 1.3 kW of publicly accessible charging infrastructure (European Council and European Parliament 2023). For the German target of 15 million BEVs by 2030, this would correspond to a mandated charging capacity of 19.5 million GW. Furthermore, in the Green Deal from 2019, the EU set a target for 1 million publicly accessible charging points by 2025 and identified a need for 3 million public charging stations by 2030 in the Sustainable and Smart Mobility Strategy (European Council 2023).

The legislative framework of the EU for regulating energy issues related to buildings is the Energy Performance of Building Directive (EPBD). The directive also aims to promote electromobility through adequate building policy. The EU Directive is implemented in the German legislation through the Building Electromobility Infrastructure Act (GEIG) (BMJ 2021). The GEIG requires that in any new residential building to be constructed with more than five parking spaces, each parking space shall be equipped with the cabling infrastructure for electric mobility. For newly constructed non-residential buildings with more than six parking spaces, at least every third parking space must be equipped with cabling infrastructure and a charging point must be installed. There are similar regulations for existing buildings in the case of a planned major renovation. For existing non-residential buildings with more than 20 parking spaces, a charging point must be installed from January 1, 2025 (BMWK 2021).

Current and Projected Electricity Consumption of BEVs

The gross electricity consumption in Germany was 556 TWh in 2020, 569 TWh in 2021, 551 TWh in 2022 and 529 TWh in 2023 (UBA 2023). A decline because of the Corona pandemic was particularly noticeable in 2020. The effects due to the Russian war of aggression against Ukraine are one reason for the lower figure for 2022. For 2030, a gross electricity consumption of 655 TWh (± 10 TWh) is estimated (Fraunhofer ISI et al. 2021). The annual electricity consumption of BEVs currently registered in Germany is around 2 TWh, which is less than 1% of total electricity consumption (Agora Verkehrswende 2023). Figure 2 showcases the results from different studies for the projected gross electricity consumption of BEVs.

Figure 2: Projected gross electricity consumption for BEVs as part of total demand for 2030 in Germany (in TWh)



Sources: own depiction based on Fraunhofer ISI et al. (2021), Agora Verkehrswende (2023), Agora Energiewende (2023b)

The projected added consumption of electricity is due to increased sector coupling, including in the industrial, heating and transport sectors. The additional consumption in the transport sector is particularly significant at 68 TWh, which is mainly attributed to the use of BEVs (approx. 10% of estimated gross electricity demand). The estimation assumes 16 million BEVs, plus 2.2 million plug-in hybrids (PHEVs) by 2030. Other studies calculate a gross electricity consumption of 726 TWh by 2030 attributing 53 TWh to electromobility, excluding heavy goods transport (Agora Energiewende 2023b). The think-tank Agora Verkehrswende (2023) forecasts an annual electricity demand of 40 TWh for 15 million BEVs, which would then correspond to around 6% of their forecasted gross electricity consumption in 2030 (643 TWh). Figure 3 summarizes this chapter, with the key policy targets and status for climate neutrality, renewables expansion, BEVs and the related charging infrastructure for Germany.

Figure 3: Key targets and current numbers for BEVs in Germany

Topic	Figures / objectives
Energy- and climate related figures	
Climate neutrality target	by 2045
Current share of RE in electricity generation	55% (2023)
Target share of RE in electricity generation	80% (2030)
Current electricity demand	549 TWh (2022)
Estimated electricity demand	655 TWh - 726 (2030)
BEV related figures	
Current BEV electricity demand	2 TWh (2021)
Projected BEV electricity demand	40-68 TWh (2030)
Current number of BEVs	1.4m (2023)
Target number of BEVs	15m (2030)
Current number of public charging stations	approx. 90,000 (2023)
Target number of public charging stations	1m (2030)

Sources: own depiction based on BReg (2023a), UBA (2023), Fraunhofer ISI et al. (2021), Agora Energiewende (2023b), DIW (2023), BReg (2022b), BNetzA (2023d), BReg (2023b), BNetzA (2022a), BMWK (2023a), EC (2020)

3.1.4 Smart grid rollout

The integration of renewable energies into the grid, long-distance transport of electricity, and the increasing interconnectedness of the European electricity market require an expansion of the German distribution and transmission grids in the coming years (BNetzA 2023f). Especially the expansion of the north-south connections is of great importance in order to transport renewable electricity from the offshore and onshore wind parks in the north to the industrial centers in the south of Germany (BNetzA 2024d).

The annual survey on the network status and planned network expansion of the DSOs states an expected grid expansion demand of EUR 42.27 billion for the next 10 years (BNetzA 2023b). The Electricity Network Development Plan 2037, with an outlook to 2045, regulates the network planning for the long-distance transmission networks. The plan includes, in particular, the integration of new and future capacity from renewable energies as well as innovations to make the grid fit for the future. The four German TSOs draw up the plan every two years, which then requires confirmation by the BNetzA for the measures suggested to optimize, reinforce and expand the extra-high voltage network. The current plan includes around 4,800 kilometers of new lines to be built and about 2,500 kilometers of existing lines to be reinforced (50Hertz Transmission et al. 2023; BNetzA 2024a).

The grid must not only be expanded. It must also be made smarter and more flexible. Smart metering technology will play an important role in the regulation of future power supply. It allows for a more efficient control of electricity consumption or feed-in. Additionally, consumers can monitor their own consumption easier and grid operators can observe grid utilization better. The German Energy Transition Digitization Act from 2016 focused on the general introduction of smart meters. However, it did not manage to sufficiently accelerate smart-meter deployment. The focus was on standardization and certification processes of necessary technology and technology provider. Partly missing and unclear technical regulations delayed subsequent actual smart-meter rollout (EY 2020).

Therefore, in April 2023, Germany adopted an act to restart the digitization of the energy transition. The act has two main objectives: to make the installation of smart metering technology less bureaucratic and to accelerate the planned rollout. The legislated roadmap for the smart meter rollout specifies an introduction in three phases (BMWK 2023a):

- An agile voluntary rollout starting immediately for consumers up to 100,000 kWh/year and generators up to 25 kW installed capacity.
- A mandatory rollout starting in 2025 for consumers from 6,000 to 100,000 kWh and generators from 7 to 100 kW installed capacity. For this category, there are targets set of at least 20% by the end of 2025, at least 50% by the end of 2028, and at least 95% by the end of 2030.
- Finally, a mandatory rollout from 2028 for consumers over 100,000 kWh/year and generators over 100 kW installed capacity. For this category, there are targets of at least 20% by the end of 2028, at least 50% by the end of 2030, and at least 95% by the end of 2032.

Around 5.2 million end-users are affected by the mandatory rollout (BNetzA and BKartA 2023). For small consumers, mainly private households, below 6,000 kWh/year and small generators from 1 to 7 kW installed capacity, there is no obligation. These consumers can opt for a smart meter, for example if they want to use dynamic electricity tariffs in the future (Statistisches Bundesamt 2022). Dynamic electricity tariffs based on current electricity supply and consumption must be offered by electricity suppliers from 2025 at the latest. Consumers will then be able to benefit from consuming electricity during lower priced periods of high supply relative to demand. There are already a few such offers in Germany, but they are considered to only be more attractive as soon as smart meters are more widely installed (Geißler 2023).

On the EU level, the deployment of smart grids is one of three priorities: smart electricity grids deployment, smart gas grids, and cross-border carbon dioxide network under the Trans-European Networks for Energy (TEN-E) regulation (European Commission 2023a, 2023b). Thinking about the power grid on an integrated European level provides additional scope in terms of flexibility. Smart interconnection of power grids across countries can balance out peaks and fluctuations of renewables. Different weather patterns across Europe can yield geographical smoothing effects. Increased integration of European electricity markets is estimated to have the potential to reduce the need for storage solutions and curtailment of renewables by a factor of 10, in times of high solar and wind energy supply through exports to regions with a lower grid load (Agora Energiewende 2015).

3.2 Flexibility and Demand Response for BEVs

3.2.1 Supply-side grid congestion management

On the supply side, Germany applies a broad set of measures to balance supply and demand within the grid. Redispatch refers to the adjustment of the power output of existing power generation facilities. This adjustment is usually relatively slow, in the timescale of minutes or hours, compared to the more rapid frequency containment and other restoration measures. In Germany, redispatch is still largely done using conventional power plants, mostly gas or coal. In 2022, the overall amount of redispatch used was 29,5 GWh, at a cost of around EUR 2.837m (BNetzA and BKartA 2023).

The active curtailment of renewable energy sources is a measure of last resort in Germany. Renewable energy sources are generally treated preferentially (§11 of the Renewable Energy Act 2023). However, they can be curtailed in specific circumstances if the grid has insufficient capacities and non-renewable plants have already been curtailed. In 2021, curtailment accounted for an overall power adjustment of 8,071 GW, an increase of around 2,2 GW from the year prior. Curtailment of renewables is becoming less relevant for TSOs over time – even though they currently still account for 73% of curtailment, while it increases in importance for DSOs (BNetzA and BKartA 2023).

Additionally, Germany benefits of the existing European interconnections and cross-border trading due to the integrated European electricity system. In the European system, electricity is produced where it is cheapest. The common internal market for electricity thus supports grid stability and cheaper electricity prices. Overall, Germany traded 96,3 TWh in 2023 (54,1 TWh of imports; 42,4 TWh of exports) (BNetzA 2024b). From 2003 to 2022 Germany was a net exporter of electricity (Statista 2024b). Germany thus often benefitted of low electricity prices in other regions, but also provided cheap renewables for others.

3.2.2 Demand-side grid congestion management

Energy Storage

The importance of energy storage in Germany is increasing. It supplies more flexibility than curtailment, while remaining below redispatch in significance. Due to its importance, for energy storage lower grid charges or a full exemption from grid charge is applied, if certain federal norms are fulfilled. Additionally, individual grid charges or additional discounts can be negotiated for individual facilities. On top of these discounts, the DSO redistributes avoided network charges to the operators of storage facilities operational before the 1. January 2023 according to §18 of the electricity grid charge regulation (StromNEV) (BNetzA and BKartA 2022). Storage facilities need to be registered. In 2023, there were 7 GW of power output for non-pump storage facilities and 6 GW of pump storage plus an additional 3.6 GW outside of Germany, with a connection to the German grid. In 2022, together, they provided around 9.2 TWh of electricity (BMWK 2023b).

Control Energy

Control energy is more short-term and designed to balance short-term deviations in grid frequency opposed to overall demand and supply management. Control energy is usually traded on markets, with both the operators of power plants as well as industrial consumers being able to participate in tenders. Control energy is split in three distinct types, namely frequency containment reserve (30 seconds to start), frequency restoration reserve with automatic activation (5 minutes) and frequency restoration reserve with manual activation (7.5 minutes) (BNetzA 2023g). The magnitude of control energy is much lower than redispatch or curtailment and was in the order of magnitude of 100 MW (automatic activation) and 200 MW (manual activation) in 2021 (BNetzA and BKartA 2022). Control energy is still dominated by conventional energy carriers, but Germany seeks to improve the participation of renewable energy in the market.

Load Management

A significant part of load management is done by the industry, with around 75 TWh in 2019 being load-managed, largely to reduce network tariffs or optimize electricity consumption based on electricity prices (German Energy Agency 2021). Even though this is mostly not actively managed by the network operators, it is a response to different potential cost reductions defined in the regulation on energy grid charges (StromNEV). In addition, large industrial consumers meeting the requirements can participate in control energy markets, which presents additional incentives for them to manage their load. Load shifting as a way of residential demand response has been used in Germany since the 1950s. Thermal storage heaters benefitted from reduced electricity rates at night and released the heat during the day. However, storage heaters have become increasingly unpopular due to their relative inefficiency and the rising costs of electricity (German Energy Agency 2021). In recent years, the importance of heat pumps has risen, which now represent a considerable share of residential load-shifting devices.

Article 14a of the energy industry act (EnWG) sets out the regulatory framework for grid-oriented load management, specifically for controllable consumer devices such charging points for BEV. Before a revision in 2023, grid operators could use the flexibility of customers if agreed upon. Overall, in 2022, this was used by 675 of 807 grid operators and covered 1,813,007 devices. Among those were 60% storage heaters, 37% heat pumps and 1% BEVs (BNetzA and BKartA 2022). Agreeing to provide flexibility to the DSOs lead to an average reduction of around 57% of the grid usage fee, with large differences depending on the company. However, only around 1% of participating heaters used modern remote-control technology, while 55% used conventional ripple control and around 1/3 were only controlled by timers. For cars, around 40% were not controllable at all, even though they also profited from the discount for flexibility (The Mobility House 2022). The lack of a unified approach, with each grid operator choosing whether and how to offer such contracts, could explain the low impact of the regulation.

To prepare the grids for the future connection of many new consumers, mainly heat-pumps and BEVs, article 14a was further developed by the BNetzA. The regulation obliges grid operators and consumers to enter into agreements on the grid-oriented control of loads in exchange for a reduction of grid tariffs. In Germany, these tariffs amount to around 20% of overall electricity costs for residential consumers. Thus, the range for electricity cost reductions through grid fees is limited, but still relevant. The updated regulation of 14a was published in November 2023 and went into effect on 1 January 2024 (BNetzA 2023a). This regulation is considered as essential for the future implementation of smart-charging measures in Germany. However, the discussions about potential load-shedding and the fear of consumers to not be able to charge their BEVs or heat their homes with a heat pump, has sparked a controversial discussion resulting in two consultations rounds. This underlines the importance of considering both the system, but also consumer perspective in the discussion on the implementation of smart-charging. Otherwise, targets for the deployment of BEVs or heat pumps can be put at risk.

The new regulation mandates participation in agreements on load control for both grid operators and owners of regulated controllable loads (private BEV charging points, heat pumps, cooling, and electricity storage) with more than 4.2 kW installed after the 31 December 2023. A load reduction is, however, only legitimate if it is objectively necessary in the context of a threat to grid stability or security, Additionally, at least 4.2 kW must still be provided in the case of such a reduction. This is therefore rather referred to as load dimming (BNetzA 2023c). This addresses the consumers worries of being cut off completely. Moreover, the new regulation also aims to accelerate the connection of new consumption units. Grid operators are now prohibited from rejecting or postponing the installation of new wallboxes and heat pumps, citing concerns about potential overloads on the local grid (Christian Schaudwet 11/28/2023).

To compensate consumers, the new regulation introduces a modular approach, accounting for different situations on the ground. This considers different levels of grid tariffs across Germany and focuses on ensuring transparency by the electricity supplier as the intermediary between producers and consumers. Three different compensation options are available. Consumers with controllable loads can choose from these. The first is a general discount on the network tariff depending on the network operator, varying between 110-190 EUR (gross) depending on the network area. This is estimated to be 50-95% of the network tariff payable for the annual consumption of an average BEV. The second option, which depends on a separate measuring point for the controllable load, is a reduction of 60% of the grid tariff specific to the controllable device. Other costs, however, are untouched by this regulation. A third option will be available from 2025 onwards. It introduces time-variable grid charges with different price levels for different times during the day and aims at incentivizing customers to shift their consumption to periods with lower demand. Option 3 will be offered only in combination with option 1 and is expected to be of special interest for customers with BEVs (BNetzA 2023e). The operators can design the levels according to their own needs and consumers are free to choose whether they want to take up such an offer. All reductions must be transparently communicated through the electricity supplier, who needs to clearly state the grid tariff reduction on the bill.

Reactions to the new regulation were generally positive. The industry stressed accompanying needs, such as the increased installation of smart meters. Others mentioned technological challenges for the grid operators to implement control and better monitoring of the status of low-voltage grids (Gabel 2023). The German Association of the Automotive Industry (VDA) voiced support especially for the introduction of time-varying grid tariffs, while highlighting that such preventive measures should be the priority. Load reductions should be limited to emergency situations to avoid a decreasing attractiveness of electric mobility (VDA 2023). The industry association BDEW welcomed the introduction of the regulation and emphasized that the inclusion of the threshold would ensure that households would still receive sufficient electricity and would be able to charge their EVs, albeit at a lower speed (BDEW 2023).

In addition to the previously mentioned developments regarding reduced grid tariffs and demand response of individual households, there is currently an effort underway to reform the German electricity market as well as a new power plant strategy, which in a first framework draft outlined the future fleet of power plants in Germany and related strategies, for example the usage of hydrogen-powered plants as back-up (BMWK 2024). As part of these debates, the German government started the “Platform Climate-neutral Electricity System” (Plattform Klimaneutrales Stromsystem, PKNS), which was tasked to develop suggestions for electricity market reform (Hermann et al. 2023). In this context, the German Renewable Energy Federation (BEE) has stressed that flexibility, for example through decentralized demand response measures like BEVs, could be a viable and cost-effective option to reduce the need for such back-up power plants and has called for an invigorated focus on flexibility to avoid fossil lock-in (BEE 2023). Such steps might additionally require a price signal in the electricity market that rewards providers of flexibility, something that has been proposed by industry actors (Becker 2023; ContextCrew Neue Energy GmbH 2023). Figure 4 further underlines the potential and highlights some of the estimated economic and system benefits of flexibility from BEVs in Germany, from both smart-charging strategies and the implementation of V2G.

Figure 4: Estimated economic and system benefits of flexibility from BEVs in Germany

Source	Est. economic and system benefits
Agora Energiewende (2023b)	• Flexibility potential of 28 GW net capacity in Germany in 2035, assuming that 25% of all BEVs (of a total of 28.3 million in 2035 expected) use V2G and 40% of these BEVs actually provide capacity to the electricity market. • Strong decrease of overall costs and increased system efficiency (less need for reserve capacity, dispatchment; curtailment)
Agora Verkehrswende et al. (2019)	• Smart charging potential to reduce cumulative distribution grid investment requirements in Germany until 2030 by 40% (with 6 million BEVs) or even 50% (with 15 million BEVs), corresponding to absolute savings of EUR 14 billion or EUR 36 billion, respectively. • In the case of full electrification (complete transition of the mobility sector to electric mobility with 30 to 45 million BEVs by 2050), estimated savings in Germany between EUR 26 and 33 billion.
Okamura et al. (2022)	• Estimation of a total storage capacity of all passenger BEVs in Germany at around 1.575 TWh by 2030 (with 15 million BEVs and 105 kWh average battery capacity per BEV).
Fraunhofer ISE et al. (2023)	• At the example of a single-family household with a BEV, a flexibility provision of more than 5 MWh is calculated with incentives through dynamic tariffs. • With a fixed electricity tariff, the expected amount of energy provided for flexibility is only about half, around 2.5 MWh.

Sources: own depiction based on Agora Energiewende (2023b), Agora Verkehrswende et al. (2019), Okamura et al. (2022), Fraunhofer ISE et al. (2023)

Vehicle-to-Grid (V2G)

Bidirectional charging, specifically V2G, is also discussed and tested as a future option for balancing the grid in Germany. A range of pilot programs have already shown the feasibility, and a range of currently commercially available vehicles theoretically support a technology allowing for bidirectional charging (Next Kraftwerke 2022). The current German government agreed to enable V2G in their coalition agreement (The Mobility House 2023b). However, it is not expected that the respective regulation will be passed in the remaining legislative period until mid-2025.

Regarding the widespread introduction of V2G and V2H several challenges remain still unsolved. The first one is that there are two competing technological concepts, AC and DC bidirectional charging, none of which is currently clearly established (The Mobility House 2023a), despite some indication that DC charging is more likely to become the norm. While some cars already support bidirectional DC charging, this approach requires the wallbox or charger to be equipped with additional technology, which not all chargers are - in particular slower household chargers, which theoretically hold more potential for V2G, as cars are connected to them for longer periods of time (Agora Verkehrswende 2023). The AC option would require additional technology in the BEVs themselves, which are currently not equipped and would make cars more expensive and heavier. On top of these charger or car-specific technologies, households would also need specific smart meters able to measure various electricity flows.

PILOT PROJECT

ELECTRIFY BUILDINGS FOR EVs (ELBE)

The Project:

The ELBE project included project partners from the city government, municipal utilities, technology companies, research institutions, distribution grid operators, charging station operators in the urban region of Hamburg. In it its first phase, it ran from October 2018 to December 2023. The project developed and tested an IT interface for controlled and grid-served charging between the distribution network in Hamburg and the charging point operators, to reduce load peaks in the power grid caused by charging BEVs. The specific goal was the installation and operation of up to 7,400 charging points on private property in the city of Hamburg, e.g. residential and commercial buildings. In the process, new business models were developed to enable the demand-based and efficient expansion and operation of charging infrastructure. The total investment volume of the project amounted to around EUR 21 million (hySOLUTIONS 2023, 2022a; Helmut Schmidt Universität 2022; The Mobility House 2023b; IFB Hamburg 2019).

Some Key Findings (Status: July 2022):

- Field tests have been conducted since 2019 through multiple charging operations at a total of 389 charging points.
- In the field tests, a 25% reduction in charging power was achieved. Customers affected by the reduction of the charging power were informed through their smartphones and could view the load curve.
- Findings:
    - 100,000 BEVs are expected in 2030. Peak load in the distribution network in Hamburg is expected to increase by 40% in the next 20 years.
    - No load limitation necessary for 25% BEV penetration scenario, 20% load limitation for 50-75% BEV penetration scenarios.
    - Smart planning and charging (estimated cost: EUR 2 million) could avoid EUR 20 million network investments.

(IRENA 2023a; Darvish et al. 2021; hySOLUTIONS 2022a; BDEW 2021)

Recommendations for Action:

The ELBE project showed that it is possible to avoid increased peak consumption and reduce the associated higher power charges on an annual basis through the grid-serving flexibilization. With the integrated approach, grid costs could be reduced by taking dynamic tariffs into account. From the ongoing project, recommendations for action were derived for further demand-oriented, grid-serving expansion of charging infrastructure: promote charging infrastructure with fixed lump sums, tighten building specifications for charging infrastructure, promote innovative charging concepts for densely populated neighborhoods, promote grid-serving integration of charging infrastructure, and set incentives for grid-serving charging (hySOLUTIONS 2022b; Institut für Innovation und Technik 2020; Darvish et al. 2021; Zivkovic 2021).

The second issue is the need to adapt current regulations to make V2G financially and practically viable. According to Mobility House, there would be a need for ensuring that BEVs are treated as other stationary batteries. Double taxation, when electricity is taxed for both when charged and when feed back into the grid, needs to be avoided to make V2G financially more attractive (The Mobility House 2023c). Additionally, Agora Verkehrswende stressed that it would be important to implement the regulatory framework early on to ensure the timely roll-out of the technology, especially suitable chargers, as soon as it is available (Agora Verkehrswende 2023).

In March 2024, the advisory board of the NLL presented a roadmap with necessary steps for introducing bidirectional charging in Germany, developed together with industry stakeholders. The roadmap follows the goal set out in the coalition agreement in 2021, as well as in measure 47 of the masterplan for charging infrastructure II, to introduce bidirectional charging nationwide and facilitate it in a non-discriminatory manner. The advisory board estimates that the first market-ready V2H applications will be ready from 2025, followed by commercialized V2G applications shortly after. From 2028, there may be a growing market for interoperable and standardized solutions for V2H and V2G. This would require that the relevant standards are determined by then. Additionally, the necessary regulatory and technical course must be introduced by the regulatory bodies. Moreover, the advisory board voiced their support for a seamless plug & play solution as most favorable. The standardization in the areas of electrical safety, grid connection and digital measurement is considered necessary for this. For a successful rollout of V2G technology, it recommends harmonizing the necessary regulations for using the data available from the vehicles at EU level (NLL 2024a).

In summary, the grid integration of BEVs holds significant potential to support grid flexibility and can support a decentralized, renewable-focused energy system. Germany has taken some important steps in this direction. The passing of Art. 14a on grid-oriented load management, specifically for controllable consumer devices, is key regulatory development, with a balanced approach prioritizing grid stability, while also addressing consumer needs. While load-shifting would clearly enable additional flexibility, bidirectional charging and V2G would be a significant additional step in this direction. While the current German government has agreed to enable V2G in principle, regulatory and technical barriers hindering large-scale adoption remain. In this context, it would be crucial to implement regulation ensuring the financial and practical viability of V2G to foster the roll-out of required technology and ensure that the regulatory landscape is ready in time for maturity of the technology, as detailed in the recently published roadmap by the NLL.

4 Overview status in Korea

4.1 Objectives and policy measures

4.1.1 Background of Korea's energy policy

Korea aims for climate neutrality by 2050. The transformation of society and economy will require fundamental changes in the energy sector regarding the power supply and its distribution through power grids. In 2022, Korea emitted 654.5 million tons of CO_2e. In the same year, 32.5% of electricity was generated by coal-fired plants, 29.6% by nuclear power and 8.9% by renewables (MOE 2024).

To reduce the emissions in the power sector, more specifically in electricity generation, Korea aims to increase the share of renewable energy in the electricity supply to 21.6% in 2030 and to 30.6% in 2036, according to the 10th Basic Plan for Long-Term Electricity Supply and Demand (BPLE). In addition, nuclear power is to play an important role in decarbonizing and stabilizing the electricity supply in Korea. The country targets a share of 32.4% by 2030 and 34.6% by 2036 for nuclear power generation (Enerdata 2023). The Korean power system has been one of the most reliable across the OECDs, with system stability indicators improving steadily in the past decades and years (IEA and KEEI 2021).

4.1.2 Key stakeholders and regulatory bodies

The key governmental institutions in Korea responsible for the transformation of the energy sector and the integration of renewable energies and BEVs into the power system are the Ministry of Trade, Industry and Energy (MOTIE), the Ministry of Environment (MOE), and the Ministry of Land, Infrastructure and Transport (MOLIT). MOE and MOLIT are mostly involved in the deployment of BEVs and charging infrastructure. The MOTIE is responsible for energy infrastructure and to determine the long-term energy targets, by issuing the BPLE (IEA and KEEI 2021).

The electricity market in Korea consists of a wholesale market which is operated by the Korea Power Exchange (KPX) and Power Purchasing Agreements (PPAs) that are negotiated between the independent power producers and the Korea Electric Power Corporation (KEPCO). KEPCO accounts for more than two thirds of the Korean power generation (IEA and KEEI 2021). However, most of the renewable energy produced, comes from independent power producers. KEPCO operates a regulated monopoly as the single buyer and retailer in the Korean power market. It is majority owned by the Korean government. KPX is the only transmission system operator for electricity supply in Korea and operates directly under the MOTIE. KEPCO, on the other hand, is responsible for distribution and transmission facility management as the asset owner. KPX and KEPCO therefore also have a central role to ensure grid stability and for the flexibilization of the grid. This includes the transition to a smart grid, the integration of decentralized power generation units as well as dealing with the new demand from heat pumps and BEVs (IEA 2023c).

The KEPCO Research Institute (KEPRI) develops and implements several research projects in their research on smart power distribution. KEPRI implements and funds projects revolving around V1G and V2G, together with other research institutions and industry stakeholders from Korea (KEPRI 2024). Additionally, a multitude of government funded institutions implement and support additional projects for the electrification of mobility and grid integration of BEVs. The Korea Transport Institute (KOTI) provides recommendations for the development of the Korean transport system and supports the rollout of BEVs and the respective charging infrastructure (KOTI 2024). The Korea Smart Grid Institute (KSGI) promotes the development of smart grids. The objective of the research institute is to accelerate the digital transformation of the energy sector and to spread the utilization of smart grids at the regional level based on distributed energy concepts. This also includes projects to develop bidirectional charging systems and utilization plans of BEVs for DSR measures (KSGI 2024).

Lastly, like Germany, both industry participants and consumers play pivotal roles as stakeholders. Companies within the industry are eager to innovate and conduct trials on new products that support smart charging and or V2G applications. For example, the Korea Smart Grid Association (KSGA) represents private companies which are active in the creation of a smart grid in Korea. The association has more than 150 members, that operate in different fields such as demand response, energy storage systems, construction, microgrids and electric car charging (KSGA 2024).

4.1.3 Electrification of the mobility sector

Based on preliminary numbers by the Korean government, the transport sector is estimated to have contributed around 16% of Korean GHG-emissions in 2023. Around 95 Mt CO2e were emitted, a slight decrease of 2.9% compared to the previous year (Yonhap News Agency 2024). Road transport continues to be the biggest source of emissions in the Korean transport sector (around 95% in 2022), despite strong growth in the clean vehicle sector. The Korean government's primary strategies for lowering emissions in the transport sector include the electrification of road transport and the adoption of hydrogen. According to the 2021 Korean carbon-neutrality scenario, these initiatives are expected to decrease GHG emissions in the sector by 90.6% to 97.1% by 2050, relative to 2018 levels (IEA 2024b; KAS and KOTI 2024).

Status and Targets for BEVs

The Korean National Basic Plan for Carbon Neutrality and Green Growth was announced in 2023. It sets the goal of 4.2 million BEVs and 0.3 million fuel-cell electric vehicles (FCEV) by 2030 (IEA 2024b; KAS and KOTI 2024). These numbers were adjusted compared to the smaller targets of the 4th Basic Plan for Eco-Friendly Vehicles. It had formulated objectives of 1.13 million BEVs by 2025 and 3 million BEVs by 2030, and 200,000 FCEVs by 2025 and 850,000 FCEVs by 2030 (MOTIE 2021). The number of BEVs has constantly increased in the past years in Korea. 120,000 new BEVs were sold in 2022 (IEA 2023a). In 2023, Korea reached a cumulative number of around 585,000 zero-emission vehicles, including FCEVs (Statista 2024a).

Korea currently leads the FCEV car growth worldwide with two-thirds of new FCEVs in 2022 being registered in Korea. The country holds over 40% of the global total FCEV stock, primarily consisting of approximately 33,000 passenger FCEVs (IEA 2024a). However, the FCEV market in Korea is struggling. Rising hydrogen fuel costs and supply shortages at the end of 2023 forced around 75% of the country's filling stations to temporarily close, coupled with declining overall demand for FCEVs despite available government subsidies (Hydrogeninsight 2024).

To continue the promotion of the penetration of BEVs in the transport sector, the MOE revised the subsidy scheme for BEVs in 2023. The reform plans comprise around KRW 2.56 trillion (EUR 1.756 billion). The amount of the subsidy is to be based on the price of the vehicle. EVs with a price of less than KRW 57 million (< EUR 39,000) will receive the full subsidy. Vehicles with a price between KRW 57 and 85 million (approx. EUR 39,000 – EUR 58,000) will receive a subsidy of up to 50% of the full subsidy. Vehicles with a price above KRW 85 million (> EUR 58,000) are not subsidized. In addition, buyers will receive a so-called performance subsidy, which is assessed based on the energy efficiency and mileage of the vehicle and ranges from KRW 3.5 to 5 million (approx. EUR 2,400 – EUR 3,400). Low-income families and small business owners will receive a 10% higher subsidy or 20% higher subsidy for the purchase of an ultra-compact BEV. In total, up to 215,000 vehicles can receive a subsidy, while last year the limit was 160,000 (MOE 2023).

Under the subsidy scheme, vehicles equipped with Vehicle-to-Load (V2L) technology receive an additional subsidy of KRW 200,000 (approx. EUR 140) per vehicle to promote the installation and diffusion of the technology in vehicles. BEV manufacturers that have installed at least 100 charging points in the last 3 years will also receive KRW 200,000 (approx. EUR 140) per car, the so-called charging infrastructure subsidy (MOE 2023). In September 2023, the Korean government announced a temporary overall increase in subsidies, as BEV sales had dropped by 34.1% compared to September 2022 (The Korea Times 2023). On the other hand, the Korean government discusses to generally reduce subsidies for individual BEVs in 2025 and instead commit to funding to electric vehicle supply equipment, such as charging points (IEA 2024a; The Korea Herald 2024).

Status and Targets for Charging Infrastructure

Globally, Korea has the highest ratio of public charging capacity to BEV (IEA 2024a). Nonetheless, in public perception charging infrastructure is still considered to be one of the key issues hindering the BEV market ramp-up.

The Korean government is striving to push ahead with the expansion of charging infrastructure based on the 4th Basic Plan for Eco-Friendly Vehicles from 2021 (to be revised by 2025). This includes areas of both living bases (residences, workplaces) and moving bases (car routes, highway rest areas), and incentives to stimulate private-sector business models in the field of charging infrastructure (MOTIE 2021). Korea is a very densely populated country, with many people living in multi-unit dwellings. This makes home charging more difficult. The installation of sufficient public charging infrastructure is therefore considered essential by the Korean government.

The target is to install more than 500,000 public charging points near living bases, mainly in or near residential and business buildings by 2025 and 1.23 million by 2030. To achieve this target, the mandatory installation rate for new buildings has been raised from 0.5% in 2020 to 5% in 2022 and to 10% in 2025. For existing buildings, a mandatory installation rate of 2% has been introduced in 2022 for public buildings and will be extended to private buildings in 2023. The target for moving bases, i.e. along car routes and highways, is to install 17,000 charging points through public-private partnerships. More than 630 charging stations are to be installed within existing gas or LPG stations ("hybrid stations") that are particularly accessible. At 197 highways super-fast chargers of 350 KWh are to be installed nationwide with 8 units per area in 2022 and 15 units per area in 2025. To have more than 2,600 super-fast chargers supplied by private businesses until 2025, up to 50% of the installation costs are subsidized (MOTIE 2021).

In 2022, there were approximately 200,000 publicly available EV charging points installed in Korea. Roughly 90% (180,000) of the charging points are slow charging points (charging points with less or equal to 22 kW of power output) and the remaining 10% (21,000) are fast charging points (charging points with more than 22 kW and up to 350 kW of power output). Despite a large proportion of public charging points being slow charging points, Korea has the highest ratio of public charging power capacity to the number of light-duty EVs (LDV) at 7 kW per vehicle. The global average lies at 2.4 kW per EV, at around 1.2 kW per EV in the EU and below 1 kW per EV in Germany. As of 2022, there were 2 LDVs per charging point in Korea compared to around 25 LDVs per charging point in Germany (IEA 2023b).

Current and Projected Electricity Consumption of BEVs

In 2022, the total electricity consumption in Korea was 568 TWh (Enerdata 2022). The Korean 10th BPLE estimates an increase to approximately 609 TWh in 2027, 660 TWh in 2032 and 703 TWh in 2036 due to increasing electrification, for example in the mobility sector, and increasing power demand of data centers (MOTIE 2023a, p. 5). The annual electricity consumption of BEVs registered in Korea, around 544,000 in 2023, can be estimated at around 1 TWh. A report by the Korea Energy Economics Institute estimates that with a penetration of 3 million BEVs by 2030, electricity consumption from BEVs in Korea would be around 6 TWh (KEEI 2017). As the target has been updated to 4.2 million BEVs by 2030 by the Korean government, the estimation of electricity consumption would be around 8.4 TWh for such a BEV penetration. In the previous 9th BPLE from 2020, the MOTIE calculated with a penetration of 4.85 million BEVs by 2034 and an expected resulting additional electricity consumption of 16.3 TWh (MOTIE 2020). As these estimates are all based on different BEV penetration numbers, not considering development in battery technologies, the numbers should be considered as rough approximations. Figure 5 summarizes these key policy targets and status for climate neutrality, renewables expansion, BEVs and the related charging infrastructure for Korea.

Figure 5: Key targets and current numbers for BEVs in Korea

Topic	Figure / objectives
Energy- and climate related figures	
Climate neutrality target	by 2050
Current share of RE in electricity generation	8.9% (2022)
Target share of RE in electricity generation	21.6% (2030)
Current electricity demand	568 TWh (2022)
Estimated electricity demand	660 TWh (2030)
BEV related figures	
Current BEV electricity demand	1 TWh (2023)
Projected BEV electricity demand	6-16.3 TWh (2034)
Current number of BEVs	544,000 (2023)
Target number of BEVs	4.2m (2030)
Current number of public charging stations	approx. 200,000 (2023)
Target number of public charging stations	1.23m (2030)

Sources: own depiction based on MOTIE (2023b), MOE (2023, 2024), Statista (2024a), IEA (2024b), KAS and KOTI (2024)

4.1.4 Smart grid rollout

In accordance with the 10th BPLE, KEPCO announced the 10th Long-Term Transmission and Substation Plan in May 2023. The plan details the necessary distribution and transmission power grid expansion and reinforcement in the period from 2023-2036. It is revised every two years. One of the main priorities is the development of a corridor from the West coast, where numerous offshore wind projects are planned, to the demand center near Seoul in the northwest (KEPCO 2023b). The Korean grid is an isolated system, without any cross-border transmission lines. The focus is therefore at the moment on domestic grid expansion only (Renewable Energy Institute 2023b).

Korea has already taken various steps toward developing a future-proof, intelligent electricity grid. The Korean government adopted a Smart Grid Roadmap back in 2010, that included the targets to build the "world's first smart grid Test City" by 2012, to establish a "consumer-oriented metropolitan wide smart grid" by 2020 and a "nationwide smart grid" by 2030. The roadmap defines five key areas: an intelligent power grid, intelligent consumers, intelligent transportation, intelligent renewables, and intelligent power services. The specific sub-goals behind these key areas are to build an open power platform, a prediction system for malfunctioning in the grid and automatic recovery, an intelligent metering infrastructure, energy management systems, a nationwide charging infrastructure that allows for V2G and ICT services, to expand renewable energies on a large scale, and to develop energy self-sufficient homes and buildings, different types of electricity pricing plans and an intelligent power trading system (KSGA 2024).

Every 5 years, in accordance with the Act to Promote the Establishment and Use of Smart Grid, a corresponding plan is prepared and implemented by MOTIE. The current 3rd Basic Plan for Smart Grid defines goals, strategies, priorities and investments for the period from 2023 to 2027. The 1st and 2nd Basic Plans covered the periods from 2012 to 2016 and from 2016 to 2022, respectively. The objective of the plans is to promote the development of an intelligent power grid. This includes the objective to increase the efficiency of electricity production and consumption through the expansion and use of smart grids, but also the idea to foster Korean industrial competitiveness in this area (MOTIE 2023a).

The Korean government has been at the forefront of the deployment of smart-metering devices and plans to equip all 22.5 million Korean households (low voltage units) with a smart meter by 2024 (IEA 2023c). By the end of 2022, almost 12 million units for advanced metering infrastructure (AMI) had been installed in Korea. To reach the target, about 5 million units need to be installed annually in the next two years.

In total, the 3rd Basic Plan for Smart Grid aims at an investment into smart grids in the next five years of around KRW 3.7 trillion (around EUR 2.6 billion). The plan envisages five priorities to achieve these goals. First, increasing the power supply flexibility by securing flexibility resources and introducing integrated virtual power plants (VPP). Second, building a smart electricity consumption system by expanding demand response markets, smart metering and time-of-use (ToU) tariffs. Third, digitizing the power grid by developing distributed energy technology, establishing distributed energy systems and building an ICT-based power system. Fourth, activating microgrids by developing a core microgrid model and by promoting energy prosumers. Fifth, establishing a smart grid industry ecosystem by promoting smart grid standards and certifications.

Another key objective of the 3rd Basic Plan is to increase the proportion of distributed energy resources in the electricity supply from 13.2% in 2022 to 18.6% in 2027. The 10th BPLE forecasts the proportion of distributed energy supply to reach 20.4% in 2030 and 23.3% in 2036. In June 2023, the Special Act to Promote Distributed Energy was enacted and came into effect in 2024. The law intends to additionally support the development towards a more decentralized energy system in which energy is predominantly produced where it is consumed. This is supposed to reduce the need for transmission grid expansion of longer distances. According to the law, projects considered as decentralized energy projects are small and medium-sized nuclear power plants, integrated power plants, e.g. cogeneration plants or power-to-x plants, fuel-cell electricity generation, hydrogen power generation, renewable power plants and energy storage facilities, which also includes BEVs. The scale on which decentralized power generation plants are to be established and supported has not yet been finally clarified. Experts assume 40 MW or below for power generation facilities, and 500 MW or below for integrated energy facilities (Shin & Kim LLC 2023). Furthermore, the law allows energy producers in specially designated decentralized energy areas to market their electricity directly to consumers without going through the electricity market. Businesses in certain geographical areas may be obliged to set up decentralized energy production facilities (KSGI 2023).

4.2 Flexibility and Demand Response for BEVs

4.2.1 Supply-side grid congestion management

The conventional approach in Korea to balance supply and demand within the grid is the adjustment of the power output of existing power generation facilities, e.g. during peak loads. This is mainly done with gas power plants. According to the 10th BPLE, 26 coal-fired plants that will be shut down in the future will be converted to gas power plants by 2036 to meet the additional electricity demand and flexibility requirements. Additionally, further new gas and hydrogen power plants are planned. The capacity of gas power plants is to be increased from 41.2GW to up to 63GW in 2036 (Solutions for Our Climate 2022).

Korea currently has no cross-border transmission lines, due to its isolated geography. It relies exclusively on local electricity production and is not able to use international trade to balance the power grid (IEA 2023c). Especially with the targeted rise of renewable energy production, this greatly increases the importance of flexibility options in the Korean grid. There have been talks about creating an "Asian Super Grid" for the long term, which would develop connections with other Northeast Asian countries. Initially, this could involve linking Korea and Japan to enhance supply security and lower overall system costs. However, political differences and tensions among the potential participating countries have prevented further progress on this idea. Reports also drew attention to the potential and technical feasibility of a subsea cable interconnection between Japan and Korea. Both Korea and Japan could reduce issues with curtailment and jointly benefit of cheap renewable energy resource in the region (Renewable Energy Institute 2023a).

Due to the currently relative low share of renewables in Korea, renewable energy curtailment has mainly been an issue in Jeju Island in the South of the Korean peninsula. Jeju Island, the largest island in Korea, is considered a pioneering region and at the same time a real-time laboratory for the energy transition in Korea. As part of the CFI 2030 (Carbon Free Island) vision, the island has accelerated its expansion and integration of renewable energy into the power grid. The island's share of renewables in the electricity supply is at 19.2% (2023) compared to around 9.1% (2022) at the national level in Korea (Invest Korea 2023). Wind power is most affected by curtailment in Jeju. No economic compensation is given for curtailment (Renewable Energy Institute 2023b).

In Korea's 3rd Basic Plan for a Smart Power Grid, Jeju takes a prominent role. One of the core initiatives of the strategy is the establishment of a smart energy management system (EMS) tested on the island that addresses curtailment issues and that can afterwards also be implemented on the mainland (MOTIE 2023a). Additionally, DSR measures are considered to address issues of curtailment and renewables integration.

4.2.2 Demand-side grid congestion management

Energy Storage

Korea is among the global leaders for the deployment of battery storage. As of 2022, the country had a cumulative installed battery storage capacity of 4.1 GW. To encourage charging during off-peak hours and mitigate the risk of grid congestion due to increased demand from storage, charging tariffs are discounted by 50% from 23:00 to 09:00 (Ahn 2023). The Korean government is committed to significantly further expand battery storage. In the 10th BPLE, a target of 24.5 GW of storage capacity until 2036 was set. This includes battery storage, but not pumped hydro storage. 20.85 GW of this capacity should be long-duration systems, e.g. to reduce renewable energy curtailment or for load leveling, and 3.66 GW are planned for short time-frames for frequency regulation (Renewable Energy Institute 2023b). Necessary investments of around EUR 31 billion are foreseen by the Korean government.

Load Management

In 2014, Korea launched a demand-side response market, in Korea abbreviated as DR, to better balance electricity supply and demand, which has quickly gained traction

(Kim 2023). As of 2022, there are 4.4 GW of DR capacity registered in Korea, while the government aims for 6.7 GW by 2036. The number of participants in the DR market has risen over the years and includes more than 12,000 as of 2022. The increase is partly due to the increase in the number of DR programs, such as the inclusion of households in 2019 (Kim 2023).

Overall, Korea has set up a range of demand-side measures aimed at different sectors. The first of these measures is reliability-focused DR. In this DR system, the government can order demand reduction measures as well as load-shedding in an emergency, following various levels of urgency. Companies that are subject to such mandated DR are then compensated through both a baseline compensation as well as an additional compensation based on the actual service provided (Solutions for Our Climate 2022). In extreme cases, it is also possible for the government, in coordination and communication with stakeholders, to order utilities to only supply electricity to the most relevant consumers (IEA 2023c). In 2021, the reliability-focused DR system led to a reduced amount of around 10.9 GWh (Solutions for Our Climate 2022).

Beyond the reliability-focused DR, there are several additional programs the Korean government has introduced to unlock the potential of voluntary DR and to enable flexibility trading on the whole sale markets (IEA and KEEI 2021). The longest running of these programs is the economic DR program, which enables flexibility trading. Until 2023 the program was limited to a day-ahead market with manual activation, which inhibited the program's ability to deal with short-term flexibility needs. In 2023, it was implemented additionally as a real-time market. This market is currently limited to Jeju Island and is planned to be expanded to the whole country by 2025 (Kim 2023). In 2021, the reduced demand of economic DR was at 492 GWh (Solutions for Our Climate 2022).

The most relevant customers participating in the DR market are large scale industrial companies, which provide demand side flexibility by adjusting operations scheduling, implementing demand reduction for non-vital use cases such as heating or cooling as well as by using backup generators. The DR program is managed by Korea's TSO, the Korean Power Exchange (KPX), which also handles monitoring and payment. Between KPX and the participating customers there are so called demand response aggregators, which recruit participating customers, pass on reduction orders and implement the payments (Solutions for Our Climate 2022).

In the current DR market, both gas power plants as well as reliability-based DR customers can bid and are compensated accordingly. However, there are differences favoring gas plants over DR when it comes to the provision of flexibility: For example potential compensation hours are limited for DR and DR is only compensated according to its actual contribution, while gas plants are compensated regardless of their actual participation (Solutions for Our Climate 2022).

Compensation for DR is generally organized according to different categories, with businesses participating only in economic DR and not in reliability-based DR receiving a fixed amount of KRW 27,800 in 2021 and an additional 46,600/KW if participating for 60 hours, which is the eligible maximum (Solutions for Our Climate 2022). However, the current pricing system means that flexibility is only employed if the bid cost is lower than the fuel cost for marginal generation, which, as experts criticized, would not reflect the full value of DR to the system. This pricing structure which considers only variable cost in the supply curve also has the consequence that DR only rarely wins the bidding (Solutions for Our Climate 2022).

Alongside the two bigger DR programs, the Korean government set up further smaller measures. Fast DR is aimed at providing flexibility options that can be dispatched faster. This measure aims specifically at the stabilization of grid frequency and has been implemented since 2020 (Kim 2023). Fast DR is still limited in scope. In 2021, 3,422 MW in total were reduced in 10-minute intervals (Solutions for Our Climate 2022). Additionally, Korea started Auto DR in 2022, enabling customers to connect devices that can automatically reduce consumption if a DR reduction request is sent, allowing for faster DR dispatch (Kim 2023).

Kookmin (national) DR is a DR program that aims to further integrate households, individuals, buildings and businesses, e.g. private charging points, into DR management in Korea by providing ToU pricing. However, the actual participation has been rather low with only about 10,000 people using Kookmin DR annually (Solutions for Our Climate 2022). The 3rd basic plan for smart grids plans to increase the share of participants in this DR segment to 20,000 by 2027 (MOTIE 2023a).

Lastly, Plus DR, is especially important in the context of renewable expansion and the potential of smart charging strategies. It is focused on increasing electricity demand during hours with excess electricity supply to avoid the curtailment of renewable energy. The additional revenue through avoided curtailment is then partly shared with the DR customers, which include for example BEV users, small factories, or hotels. After the system had only few customers and was rarely used early on, the number of registered customers has risen to more than 1,000 in 2022 (Electimes 2022; Kim 2023). The 3rd basic plan for smart grids aims to increase the market for DR Plus from 73.5 MW to 175 MW (MOTIE 2023a).

In the context of this study, the case of BEVs is most interesting as encouraging the charging of BEVs during hours of peak production plays a significant role in the overall project. KEPCO, has for instance registered around 400 chargers on Jeju Island in the demand response market and bids on DR. In case of a winning bid, information is transmitted through a dedicated brokerage platform, ChargeLink, and customers can benefit from discounts and reserve chargers at dedicated times (Kbiznews 2021). This project has also been extended to offer the same service to other charging providers (Energydaily 2023). So far, Plus DR only applies to Jeju Island, where the share of renewable energy is already significantly higher than in the country at large (Solutions for Our Climate 2022).

Additionally, in Korea there are different types of electricity tariff design, which have been and are being discussed, implemented and tested with the objective to create grid-serving incentives to consumers in order to better balance demand with energy supply. Looking specifically at BEVs, KEPCO for instance offers ToU tariffs for charging of BEVs that are differentiated by season (summer, spring/fall and winter), time period (off-, mid-, and on-peak) and voltage (low and high voltage) (KEPCO 2023a). More generally, KEPCO offers a variety of electricity tariffs which are differentiated depending on the use-case and two demand management tariffs offering reduced tariffs to customers in return for managing demand in peak times. However, as Korea has a very high share of public chargers, which often do not offer ToU-tariffs, but flat rates, the effect for load shifting is considered as limited in (Park et al. 2023).

Vehicle grid integration (VGI) / Vehicle-to-Grid (V2G)

Korean companies are also moving ahead and BEVs from Korean manufacturers were among the first to offer bidirectional charging capabilities and are used in pilot projects throughout the world, e.g. in Germany (electrive.net 2022). Regarding V2G solutions, Korea has implemented various pilot projects to explore the feasibility of the technology (Miha Jensterle, Regina Yoonmie Soh, Maike Venjakob, Oliver Wagner 2019; Businesswire 2023).

Even though there is no comprehensive regulation on V2G as of now, the Korean government did approve more extensive pilot projects under a regulatory sandbox scheme and the Third Energy Master Plan foresees the long-term inclusion of V2G in the electricity market (MOTIE 2019; He-rim 2021).

The Korean 3rd Basic Plan for Smart Grids also addresses BEV grid integration as part of the objective to increase power supply flexibility. The plan refers to it as vehicle grid integration (VGI), which also covers V2G. It highlights smart charging and discharging as crucial methods to facilitate VGI and aims to support business development in this area. This extends to the promotion of V2G technology. Furthermore, regulations for V2G technology are to be established including the classification of operators and performance standards for two-way chargers. Further, V2G is to be included in the definition of resources traded in the small-scale electricity market. The plan also envisages to introduce integrated virtual power plants (VPP) and plans for a 50 MW VPP demonstration project on Jeju Island, facilitating the integration of distributed energy resources, such as battery storages and BEVs (Lee 2023).

Already between 2018 to 2023, KEPCO initiated a large research project under the title: "EV-Grid Integration (VGI) control technology development and V2G field demonstration of EV as a DR resource". The project included industry stakeholders such as Hyundai and further research institutes. Key objectives were to demonstrate EVs as DR resources, to test the VGI-control system, and to develop commercial grade V2G-BEVs, V2G EVSE and a matching V2G-control system. Following several demonstration projects within the framework of this research project, KEPCO tries to further commercialize the results Park et al. (2023).

KEPCO signed a business agreement with the Korean company Gridwiz. Gridwiz is a demand management business operator, which is also active in the Plus DR project on Jeju-Island. The agreement also extends to three other Korean charging business operators (SKelectlink, Scalar Data, TBU). The goal of the signed deal is the promotion of a "Smart Charging (V1G)-based Electric Vehicle Charging National Demand response (DR) Project." The DR project is scheduled to start in the second half of 2024. KEPCO plans to upgrade the smart charging function of about 400 of its slow chargers nationwide and gradually expand the introduction of the function. The introduction of the system is meant to contribute to power stability considering the Korean deployment targets for BEVs by 2030. The project could be extended to more chargers upon success of the DR project. It is expected that the system will be similar to the previous KEPCO demonstration project (Energydaily 2024).

Figure 6: Estimated economic and system benefits of flexibility from BEVs in Korea

Source	Est. economic and system benefits
IEA (2021)	• Optimizing the charging patterns of 30% of the expected BEV fleet in Korea could reduce average operating and peak costs of the BEV fleet by 21% and 30%, respectively, and decrease BEV emissions by 21%.
IEA and KEEI (2021)	• Demand-side management, including smart-charging, is projected to lower peak demand in Korea by up to 12.6% from a business-as-usual level.
Wooyoung Jeon et al. (2021)	• Net benefit of BEV demand side management in Korea, can be estimated at 67% to 85% of monthly average fuel cost under a VPP with V2G capability.

Sources: own depiction based on IEA (2021), Park et al. (2023), IEA and KEEI (2021), Wooyoung Jeon et al. (2021)

PILOT PROJECT

JEJU: CARBON FREE ISLAND WITH SMART GRID TESTBED

Project background:

Jeju Island takes a prominent role in Korea's "3rd Basic Plan for a Smart Power Grid". One of the core initiatives of the strategy is the establishment of a smart energy management system (EMS) tested on the island. The largest island in Korea is considered a pioneering region for the energy transition in Korea. As part of the CFI 2030 (Carbon Free Island) vision, the island has accelerated its expansion and integration of renewable energy into the power grid. The island's share of renewables in the electricity supply is at 19.2% (2023) compared to around 9.1% (2022) at the national level in Korea (Invest Korea 2023). However, a study showed that Jeju also experienced a considerably high curtailment rate, e.g. of 2.09% in 2021. The excess power supply compared to demand, an insufficiently flexible power grid and lack of power storage capacity due to poor economic incentives for expansion are considered as the drivers for this situation (Solutions for Our Climate and NEXT Group 2021; Invest Korea 2023).

In 2021, the Korean government has started to introduce demand response measures titled “Plus DR” and “EV Plus DR” to better match power demand with supply and prevent the curtailment of renewable energy. The “EV Plus DR” model aims “to utilize EV batteries as new flexible resources for the power system”. It is one of the “world first positive demand response business model that provides incentives for consuming surplus power when curtailment is expected”. Real-time data is communicated through a platform called “ChargeLink” and enables demand response companies and eMobility service providers to immediately respond to grid needs. “Plus DR” is only being used on Jeju Island so far, but is planned to be rolled out nationwide in Korea (Solutions for Our Climate and NEXT Group 2021; Solutions for our Climate 2022).

Preliminary results:

The demonstration tests of the grid flexibilization business models completed under real conditions have highlighted that demand response using EV batteries is a useful means to secure flexible resources for the power system by achieving an increase in demand of 186% in the Jeju island setting. Expanding the model to the entire island could enable 50GWh of flexibility resource capacity by 2030. The battery capacity of EVs on Jeju Island lies at around 1.1 GWh (04/2021) and is projected to reach around 19 GWh by 2030, according to the energy startup Gridwiz that develops demand response, energy storage, renewable energy and e-mobility solutions, which are applied and tested within the Jeju project. In 2020, more than 18,000 electric vehicles were registered on Jeju Island, more than 20% of all EVs in Korea and more than in Seoul (Bae 2021).

5 Comparison

Korea and Germany face similar challenges to decarbonize their economies. Both are committed to carbon neutrality by 2045 and 2050. The two countries count with strong industrial, but also emission intensive sectors. On the other hand, there is only a limited domestic supply with energy resources, which results in a high import dependence. Renewable energies have been identified as one of the solutions to address the existing challenges in the strive for carbon neutrality. While Germany is committed to 80% renewables by 2030, and almost 100% by 2035, Korea aims for 21.6% by 2030 and to additionally decarbonize the power sector with nuclear energy. The share of renewables in the electricity mix of Germany is getting close to 60% in April of 2024. Despite this high share of more volatile energy generation, system stability has remained at a high level in Germany. High system stability is also given in Korea, however, with a much lower share of renewables at around 8.9%.

To achieve their carbon neutrality objectives, additional electrification of industrial and transport applications is necessary in both countries. BEVs take the leading role for decarbonization of the German and Korean transport sectors. Germany aims for 15 million and Korea for 4.2 million BEVs both by 2030. Korea wants to additionally introduce 300.000 FCEVs, which so far are of limited importance in Germany. After a steep increase of BEV numbers in the last years in both markets, sales have dropped due to decreasing government subsidies and still comparably higher starting prices of BEVs. In 2023, Germany had around 1.4 million and Korea around 544.000 registered BEVs. This puts the 2030 national targets at risk in both cases and discussions might turn to a reintroduction of government support to boost sales once again.

The gross electricity consumption in Germany in 2022 was around 549 TWh, in Korea around 568 TWh. The share of BEVs so far is of minor importance, with around 1 TWh in Korea and 2 TWh in Germany respectively. This share is expected to grow to 6-8.4 TWh in Korea and 40-68 TWh in Germany by 2030. This is not considered to threaten system stability. But, especially on the local distribution level, the increase in demand of BEVs can likely increase peak loads in the morning and evening hours, potentially leading to further congestion and grid management issues. The flexibilization demand, through ToU-pricing, smart-charging or V2G can be helpful to address these issues in both cases of this study.

Alongside the expansion of BEVs, the necessary charging infrastructure is deployed throughout Germany and Korea. The two countries recognized the importance to build up a dense supply network of public charging points, slow and fast chargers, to overcome range anxiety concerns of consumers. Nonetheless, an important difference between the cases is an additional stronger network of home chargers in Germany. Many Koreans live in densely populated cities in multi-unit dwellings without a charging possibility, resulting in a higher dependence on public charging. The Korean government tries to address this issue. By 2023, Korea had achieved the highest rate of public (slow) charging per BEV worldwide. The prevalence of public charging and expected shorter connection times of the BEVs can be a challenge to implement certain flexibilization measures, such as load shifting.

Figure 7: Overview of key figures, estimates and objectives in Korea and Germany

Topic	Korea	Germany
Energy- and climate related figures		
Climate neutrality target	by 2050	by 2045
Target share of RE in electricity	21.6% (2030)	80% (2030)
Current electricity demand	568 TWh (2022)	549 TWh (2022)
Estimated electricity demand	660 TWh (2032)	655 TWh - 726 TWh (2030)
EV related figures		
Current number of BEVs	544.000 (2023)	1.4m (2023)
Target number of BEVs	4.2m (2030)	15m (2030)
Current number of public charging stations	approx. 200,000 (2022)	approx. 90,000 (2023)
Target number of public charging stations	1,230,000 (2030)	1m (2030)
Current BEV electricity demand	1 TWh (2023)	2 TWh (2021)
Estim. BEV electricity demand	6–8.4 TWh (2030)	68 TWh (2030)

Sources: own depiction based on MOTIE (2023b), MOE (2023, 2024), Statista (2024a), IEA (2024b), KAS and KOTI (2024) for Korea and BReg (2023a), UBA (2023), Fraunhofer ISI et al. (2021), Agora Energiewende (2023b), DIW (2023), BReg (2022), BNetzA (2023d), BReg (2023b), BNetzA (2022a), BMWK (2023a), EC (2020) for Germany

To deal with the increasing electricity demand and higher share of volatile renewables, Korea and Germany expand their power grids. The flexible integration of BEVs will not change the need for additional transmission lines but facilitate the grid integration of renewables on the distribution level. Smart grids are an important prerequisite to tap into this potential. Both countries have recognized this but have made different progress in this regard so far, with Korea being among the trailblazers.

Germany aims to expand and accelerate the deployment of smart-metering technology to control and better measure the state of the grid and balance demand and supply but is still lacking behind in actual deployment of the respective technology. With the act on the restart of digitization of the energy transition in 2023, Germany laid the foundation to accelerate the much-needed smart-meter deployment. A roadmap sets clear targets to foster the voluntary smart-meter installation with small users and mandatory installation for large-scale users, to close the current implementation gap in Germany. Korea is much more advanced in installing smart metering infrastructure. The Korean government has been at the forefront of the deployment of smart-metering devices. The plan ambitious plan is to equip all 22.5 million Korean households (low voltage units) with a smart meter by the end of 2024.

In addition to this, both countries acknowledged the importance of expanding flexibility options, e.g. to address issues of curtailment of renewables and generally grid congestion, present in both countries. A key difference between the two cases, is that Germany can benefit of the European integrated power market and interconnections to its neighboring countries. These interconnections are an important and economical tool to balance demand and supply for the integration of renewable energy throughout Europe. Korea lacks such interconnections, despite technical potentials, due to diplomatic differences in the region, and needs to focus on imports and the domestic market. Nonetheless, demand flexibilization is of great importance and potential for both cases.

DSR-programs have been established in Germany and Korea alike. Industrial and economic DSR-measures have so far the biggest impact in both countries. Nonetheless, the two countries have recognized the potential to expand the scope of their DSR-programs and to tap into the potential of new consumers through residential DSR-programs, especially heat pumps and BEVs.

Germany has completed a milestone in this regard, with the passing of article 14a EnWG, considered as key for the market development of BEVs and grid stability at the same time. The regulation is trying to address worries of consumers of not being able to charge in times when they want it, by guaranteeing a minimum charging speed of 4.2KWh, if DSOs identify the need to reduce demand. However, by allowing DSOs to reduce the charging speed, grid stability can always be assured, while at the same time new consumers can be consistently connected. With lowered grid service charges, smart charging in off-peaks time is incentivized to reduce dimming to a measure of last resort. The additional mandatory offer of real time electricity prices by electricity retailers by 2025 is supposed to work as an additional incentive to better match demand and supply, with a high share of renewables and low prices normally coinciding. However, to untap the full potential of these measures in the future the beforementioned wide-spread installation of smart-meters is needed throughout Germany as fast as possible.

Korea on the other hand, already has the advanced metering infrastructure in place, but is partly still missing the supporting regulatory framework and incentives. The demand response programs at the moment are still in development and yet limited in scope, but with plans to be expanded to unfold their full potential in the future. The Korean Plus DR program, directly targeting BEV users, works with an incentive to better match demand of BEV charging and renewables integration. Charging in times of high shares of renewables in the grid is rewarded with financial benefits for consumers. With the future expansion of Plus DR, Korea is on track to facilitate the integration of new wind and PV power generation and use the flexibility potential of BEVs. The recently announced VGI-project, the promotion of smart charging and the introduction of a connected DR system, is an additional step in the right direction. Plans to upgrade the smart charging function of about 400 KEPCO slow chargers nationwide and the gradual nationwide expansion of the function is of high potential for the Korean efforts to use the potential of BEVs for the grid. However, with a monopolized, fixed electricity rate system, the incentive of such efforts is lowered. Static ToU pricing can help shift demand partially, but not follow the volatility of RE completely, especially as Korea is also planning to expand their wind capacity.

On V2G, both countries are still in the phase of developing regulatory approaches concretely. A lot of research and demonstration projects have been implemented in both countries. Industry seems to be ready to start larger trials and enter larger scale commercialization, but still a lot of regulatory question remain unclear. The recent passing of respective roadmaps in Germany and Korea are steps in the right direction to further address the existing issues and might initiate the needed legislative process soon.

6 Conclusion and Cooperation Potentials

For Korea and Germany, grid flexibilization and the managed grid integration of BEVs can be a key resource to balance the grids of the future as well as to secure a cost-effective and stable integration of renewables into the grid. The market ramp of BEVs in both economies has strongly increased in the last years. Despite a slowing uptake in the last year, the number of BEVs in Germany and Korea is still likely to reach a critical mass, with the related potential fears, challenges and opportunities for their grid integration.

Both countries have recognized the flexibility potential of BEVs. The promotion of smart grids and meters, as well as complementary financial incentives through tariff schemes and DR programs are important steps. These initiatives need to show results, and governments must continuously develop their regulatory frameworks. In the overall picture, it is also important to emphasize that Korea, with its isolated grid system, relies more on domestic flexibility options than Germany. Germany can benefit from cross-border electricity trading within Europe.

For flexibility options to become financially viable and widely implemented in both countries, the regulatory framework must be adjusted, and fair competitive market conditions must be established. Both, Korea and Germany, have taken some decisive steps in the last years to facilitate managed grid integration of BEVs. The success of this measures will need to be shown during actual implementation.

Korea is one of the world leaders regarding smart meter deployment. Almost all households are to be equipped with smart meters by the end of 2024, approximately 22.5 million devices. The various Korean demand response programs in place and their expansion to even more distributed energy resources such as households and charging points are very promising, and additional can facilitate the integration of aggregators and VPPs more into the market. Notably, the Plus DR program is among the world's first positive DR programs, offering incentives for the consumption of surplus electricity when renewable curtailment is expected, underlining Korean efforts.

As for V2G solutions, there is no comprehensive regulation for V2G in Korea yet. However, the Korean government has approved a more extensive pilot project in 2021, and the third Smart Grid Basic Plan envisages the inclusion of V2G in the electricity market and further commercialization of the technology, supporting the soon to be expected ripeness of the technology and its market introduction in Korea.

This year also saw some key regulatory developments in Germany. The act to relaunch the digitization of the energy transition aims to promote the installation of smart meters - unbureaucratically and quickly. It provides for a gradual expansion plan with binding targets by 2030. By 2025 at the latest, all owners of smart meters are to benefit from dynamic electricity tariffs: They will be able to draw electricity or charge their vehicle when prices are low, especially during periods of high electricity generation from renewables. Supply and demand should thus be better aligned and the grid integration of RE facilitated. Already today, depending on their grid operator, some customers can benefit from lower grid charges (which account for about 20-30% of their electricity bill) if they allow their charging to be managed. However, the number of customers taking advantage of this option is small. In the future, such agreements are to become mandatory. To this end, the regulation on controllable consumption devices is being further developed under Art. 14a of the Energy Industry Act. Network operators will be allowed to dim charging power by means of a control signal in the event of imminent network overloads. To keep such interventions to a minimum, however, consumers are to be motivated by time variable grid charges and the corresponding financial incentive to engage in grid-serving charging themselves. This is intended to strike a balance between the needs of grid operators to be able to guarantee grid stability despite new consumption units and the concerns of consumers about not being able to charge their vehicles in line with demand.

Regarding V2G, the situation in Germany is similar to Korea. In the 2021 coalition agreement and the 2022 Charging Infrastructure Master Plan II, the government committed to the importance and introduction of V2G. However, bidirectional charging (V2G) is currently only used in research and demonstration projects. To achieve large-scale deployment of V2G, legal and technical barriers need to further be removed, and a clear regulatory framework is needed to be established.

In conclusion, both countries have introduced appropriate tariff schemes and demand response programs to facilitate the flexible load-management of BEVs. Nonetheless, especially regarding V2G and the market integration of the flexibility and new actors like VPPs, there remains a lot to be done. Despite differences in, for instance, the design of the electricity market (liberalized vs. monopolized), problems and challenges for the introduction of BEVs as a flexible option in the electricity grid are similar in both countries. While the integration of V2G technology would already be possible from a technical point of view, both countries require a suitable regulatory framework that regulates the discharging of electricity from BEVs. Moreover, the design of incentive systems for private owners is of central importance, as participation in the electricity market through BEVs is currently often not yet economically viable for them.

Overall, there is great potential for further cooperation and exchange between Korea and Germany on topics such as the design of incentive schemes for consumers, standardization of technical equipment, market integration of flexibility options or the design of a regulatory framework. The large-scale integration of small consumption units, especially through aggregators, also offers great potential for flexibility. In both countries, the role of various flexible resources is currently being discussed, e.g., to what extent BEVs could reduce the need for new (reserve) gas-fired power plants and to what extent such traditional power plants are still favored by existing compensation mechanisms. This discussion should be picked up by governments and stakeholders in industry and research, to achieve the most cost-effective and sustainable energy transition and market possible

Further cooperation potentials are the following:

- <u>Design of DR programs/incentives:</u> How can the participation and motivation of small consumption units and consumers for demand response measures be ensured, without, for example, jeopardizing the market ramp-up of BEVs? Consumers do not necessarily have grid stability in mind. The design of DR programs to ensure ample participation rates is therefore a beneficial topic of exchange between both countries.
- <u>V2G:</u> Korea and Germany are among the leaders regarding research and demonstration projects. Regulatory exchange should continue to be promoted and data and findings from existing projects should be shared.
- <u>Standardization and definition of technical equipment/requirements</u> (e.g. of communication protocols) ask for further cooperation potentials, which are only partly exploited so far. Korean and Germany can take a leading role here as well.
- <u>General market integration of flexibility resources</u> and establishment of fair participation conditions as well as the handling and integration of new players (e.g. aggregators, VPPs) are suitable topics for exchanges of experiences.

List of figures

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Publication bibliography

50Hertz Transmission; Amprion; TenneT; TransnetBW (2023): Netzentwicklungsplan Strom 2037 mit Ausblick 2045, Version 2023. Erster Entwurf der Übertragungsnetzbetreiber. With assistance of Tim Drees, Birte Greve, Christian Brehm, Claudia Halici. Available online at https://www.netzentwicklungsplan.de/sites/default/files/2023-03/NEP_2037_2045_V2023_1_Entwurf_Teil1_5.pdf, checked on 6/7/2023.

acatech; Leopoldina; Akademienunion (2021): Grid congestion as a challenge for the electricity system. Options for a future market design. Edited by acatech – National Academy of Science and Engineering, German National Academy of Sciences Leopoldina, Union of the German Academies of Sciences and Humanities. Available online at https://en.acatech.de/publication/grid-congestion-as-a-challenge-electricity-system/, checked on 6/5/2024.

ADAC (2024): Pkw-Neuzulassungen April 2024: E-Autos kommen nicht in Fahrt. Available online at https://www.adac.de/news/neuzulassungen-kba/, updated on 5/6/2024, checked on 5/8/2024.

Agora Energiewende (2015): The Europea Power System in 2030: Flexibility Challenges and Integration Benefits. An Analysis with a Focus on the Pentalateral Energy Forum Region. With assistance of Mirjam Stappel, Ann-Katrin Gerlach, Angela Scholz, Carsten Pape. Available online at https://www.agora-energiewende.de/fileadmin/Projekte/2014/Ein-flexibler-Strommarkt-2030/Agora_European_Flexibility_Challenges_Integration_Benefits_WEB_Rev1.pdf, checked on 7/20/2023.

Agora Energiewende (2023a): Breaking free from fossil gas. A new path to a climate-neutral Europe. Version 1.1. With assistance of Andreas Graf, Murielle Gagnebin, Matthias Buck. Available online at https://static.agora-energiewende.de/fileadmin/Projekte/2021/2021_07_EU_GEXIT/A-EW_292_Breaking_free_WEB.pdf, checked on 7/20/2023.

Agora Energiewende (2023b): Climate-neutral power sytem 2035. How the German power sector can become climate-neutral by 2035. Executive Summary. With assistance of Elias Althoff, Hans Dambeck, Hanno Falkenberg, Aurel Wünsch, Inka Ziegenhagen, Christoph Maurer et al. Edited by Agora Energiewende. Available online at https://static.agora-energiewende.de/fileadmin/Projekte/2021/2021_11_DE_KNStrom2035/AEW_KNStrom2035_Summary_EN.pdf, checked on 6/7/2023.

Agora Energiewende (2024): Die Energiewende in Deutschland: Stand der Dinge 2023. Rückblick auf die wesentlichen Entwicklungen sowie Ausblick auf 2024. Available online at https://www.agora-energiewende.de/fileadmin/Projekte/2023/2023-35_DE_JAW23/A-EW_317_JAW23_WEB.pdf, checked on 5/7/2024.

Agora Verkehrswende (2023): Gesteuertes Laden. Warum es sich lohnt, beim Laden von Elektrofahrzeugen auf Stromangebot und Netzauslastung zu achten. With assistance of Luise Bangert, Wolfgang Fritz, Linke Christian. Available online at https://www.agora-verkehrswende.de/fileadmin/Projekte/2023/Gesteuertes-Laden/97_Analyse-Gesteuertes_Laden.pdf.

Agora Verkehrswende; Agora Energiewende; Regulatory Assistance Project (RAP) (2019): Verteilnetzausbau für die Energiewende - Elektromobilität im Fokus. With assistance of Urs Maier, Frank Peter, Andreas Jahn. Available online at https://static.agora-energiewende.de/fileadmin/Projekte/2018/Netzausbau_Elektromobilitaet/AgoraRAP2019_VerteilnetzausbauElektromobilitaet.pdf, checked on 7/13/2023.

Ahn, Jongbo (2023): Overview on status & policies for ESS in Korea. KETEP.

BDEW (2023): BDEW zur Festlegung der Bundesnetzagentur zum §14a Energiewirtschaftsgesetz. Pressemitteilung. Available online at https://www.bdew.de/presse/presseinformationen/bdew-zur-festlegung-der-bundesnetzagentur-zum-14a-energiewirtschaftsgesetz/, updated on 12/6/2023, checked on 12/6/2023.

Becker, Sven (2023): Flexibilität in Erzeugung und Verbrauch: der natürliche Partner der erneuerbaren Energien. Edited by Handelsblatt live. Available online at https://live.handelsblatt.com/flexibilitaet-in-erzeugung-und-verbrauch-der-natuerliche-partner-der-erneuerbaren-energien/, updated on 4/5/2023, checked on 8/10/2023.

BEE (2023): Krafwerksstrategie zu einer ganzheitlichen Flexibilitätsstrategie weiterentwickeln. Thesenpapier zur geplanten Kraftwerksstrategie der Bundesregierung. With assistance of Matthias Stark, Sandra Rostek. Edited by Bundesverband Erneuerbare Energie e.V. Available online at https://www.bee-ev.de/fileadmin/Redaktion/Bilder/Meldungen/Positionspapiere/2023/20230417_BEE_Thesenpapier_Kraftwerksstrategie.pdf, checked on 8/10/2023.

Bloess, Andreas; Schill, Wolf-Peter; Zerrahn, Alexander (2018): Power-to-heat for renewable energy integration: A review of technologies, modeling approaches, and flexibility potentials. In *Applied Energy* 212, pp. 1611–1626. DOI: 10.1016/j.apenergy.2017.12.073.

BMDV (2021): Förderrichtlinie "Öffentlich zugängliche Ladeinfrastruktur für Elektrofahrzeuge in Deutschland". Edited by Bundesministerium für Digitales und Verkehr. Available online at https://bmdv.bund.de/SharedDocs/DE/Anlage/G/foerderrichtlinie-oeffentlich-zugaengliche-ladeinfrastruktur.pdf?__blob=publicationFile, checked on 7/20/2023.

BMJ (2021): GEIG - Gesetz zum Aufbau einer gebäudeintegrierten Lade- und Leitungsinfrastruktur für die Elektromobilität. Edited by Bundesministerium der Justiz. Available online at https://www.gesetze-im-internet.de/geig/BJNR035400021.html, updated on 7/20/2023, checked on 7/20/2023.

BMWK (2021): Gebäude-Elektromobilitätsinfrastruktur-Gesetz (GEIG). BMWI. Available online at https://www.bmwk.de/Redaktion/DE/Artikel/Service/Gesetzesvorhaben/gebaeude-elektromobilitaetsinfrastruktur-gesetz.html, updated on 3/5/2021, checked on 5/8/2024.

BMWK (2023a): Gesetzlicher Smart-Meter-Rolloutfahrplan. Edited by Bundesministerium für Wirtschaft und Klimaschutz. Available online at https://www.bmwk.de/Redaktion/DE/Downloads/I/Infografiken/infografik-smart-meter-rolloutfahrplan.pdf?__blob=publicationFile&v=5, updated on 2023, checked on 6/7/2023.

BMWK (2023b): Stromspeicher-Strategie. Handlungsfelder und Maßnahmen für eine anhaltende Ausbaudynamik und optimale Systemintegration von Stromspeichern. Available online at https://www.bmwk.de/Redaktion/DE/Downloads/S-T/stromspeicherstrategie-231208.pdf?__blob=publicationFile&v=8, checked on 5/13/2024.

BMWK (2024): Agreement on Power Station Strategy. With assistance of BMWK. BMWK. Available online at https://www.bmwk.de/Redaktion/EN/Pressemitteilungen/2024/02/20240205-agreement-on-power-station-strategy.html, updated on 2/5/2024, checked on 5/13/2024.

BNetzA (2017): Flexibility in the electricity system. Status quo, obstacles and approaches for a better use of flexibility. Discussion Paper. Edited by Bundesnetzagentur. Available online at https://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/Areas/ElectricityGas/FlexibilityPaper_EN.pdf?__blob=publicationFile&v=2, checked on 6/7/2023.

BNetzA (2022a): Bericht zum Zustand und Ausbau der Verteilernetze 2021. Edited by Bundesnetzagentur. Available online at https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Energie/Unternehmen_Institutionen/NetzentwicklungUndSmartGrid/ZustandAusbauVerteilernetze2021.pdf?__blob=publicationFile&v=4, checked on 7/20/2023.

BNetzA (2022b): Kennzahlen der Versorgungsunterbrechungen Strom. Edited by Bundesnetzagentur. Available online at https://www.bundesnetzagentur.de/DE/Fachthemen/ElektrizitaetundGas/Versorgungssicherheit/Versorgungsunterbrechungen/Auswertung_Strom/start.html, updated on 7/19/2023, checked on 7/19/2023.

BNetzA (2023a): § 14a EnWG | Entgeltmodell. 2. Konsultation | BK8-22/010-A. Bundesnetzagentur. Bonn. Available online at https://www.bundesnetzagentur.de/DE/Beschlusskammern/BK08/BK8_06_Netzentgelte/68_%C2%A7%2014a%20EnWG/Downloads/BK8-22-010-A_erl%C3%A4uternde_Pr%C3%A4sentation_zweite_Kons.pdf;jsessionid=F9132460F5FFD85A11700E66E5ED8838?__blob=publicationFile&v=2, updated on 2023, checked on 7/20/2023.

BNetzA (2023b): Bericht zum Zustand und Ausbau der Verteilernetze 2022. Available online at https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Energie/Unternehmen_Institutionen/NetzentwicklungUndSmartGrid/ZustandAusbauVerteilernetze2022.pdf?__blob=publicationFile&v=1, checked on 5/15/2024.

BNetzA (2023c): Beschluss zur Integration von steuerbaren Verbrauchseinrichtungen und steuerbaren Netzanschlüssen nach § 14a Energiewirtschaftsgesetz (EnWG). Beschlusskammer 6. Available online at https://www.bundesnetzagentur.de/DE/Beschlusskammern/1_GZ/BK6-GZ/2022/BK6-22-300/Beschluss/BK6-22-300_Beschluss_20231127.pdf?__blob=publicationFile&v=1, checked on 12/6/2023.

BNetzA (2023d): Elektromobilität: Öffentliche Ladeinfrastruktur. Edited by Bundesnetzagentur. Available online at https://www.bundesnetzagentur.de/DE/Fachthemen/ElektrizitaetundGas/E-Mobilitaet/start.html, updated on 7/20/2023, checked on 7/20/2023.

BNetzA (2023e): Festlegung von Netzentgelten für steuerbare Anschlüsse und Verbrauchseinrichtungen (NSAVER) nach § 14a EnWG. Beschlusskammer 8. Available online at https://www.bundesnetzagentur.de/DE/Beschlusskammern/1_GZ/BK8-GZ/2022/2022_4-Steller/BK8-22-0010/BK8-22-0010-A_Festlegung_Download.pdf?__blob=publicationFile&v=5, checked on 12/6/2023.

BNetzA (2023f): Netzentwicklung und Intelligente Systeme. Edited by Bundesnetzagentur. Available online at https://www.bundesnetzagentur.de/DE/Fachthemen/ElektrizitaetundGas/NetzentwicklungSmartGrid/start.html, updated on 7/20/2023, checked on 7/20/2023.

BNetzA (2023g): Regelenergie. Bundesnetzagentur. Available online at https://www.bundesnetzagentur.de/DE/Fachthemen/ElektrizitaetundGas/Versorgungssicherheit/Netzengpassmanagement/Engpassmanagement/Regelenergie/start.html, updated on 8/10/2023, checked on 8/10/2023.

BNetzA (2024a): Bundesnetzagentur bestätigt mit dem Netzentwicklungsplan Strom 2023-2037/2045 das Übertragungsnetz für die Klimaneutralität. Available online at https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/DE/2024/20240301_NEP.html, updated on 3/1/2024, checked on 5/8/2024.

BNetzA (2024b): Bundesnetzagentur veröffentlicht Daten zum Strommarkt 2023. Available online at https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/DE/2024/20240103_SMARD.html, updated on 1/3/2024, checked on 5/8/2024.

BNetzA (2024c): Grid development and intelligent networks. Available online at https://www.bundesnetzagentur.de/EN/Areas/Energy/GridDevelopment/start.html, updated on 5/15/2024, checked on 5/15/2024.

BNetzA (2024d): Transmission system operators in Germany. Available online at https://www.smard.de/page/en/wiki-article/5884/205528, updated on 5/8/2024, checked on 5/8/2024.

BNetzA; BKartA (2022): Monitoringbericht 2022. Monitoringbericht gemäß § 63 Abs. 3 i. V. m. § 35 EnWG und § 48 Abs. 3 i. V. m. § 53 Abs. 3 GWB. Stand: 14. Dezember 2022. Bundesnetzagentur; Bundeskartellamt. Bonn. Available online at https://www.bundesnetzagentur.de/SharedDocs/Mediathek/Monitoringberichte/MonitoringberichtEnergie2022.pdf?__blob=publicationFile&v=6, checked on 7/20/2023.

BNetzA; BKartA (2023): Monitoringbericht 2023. Available online at https://data.bundesnetzagentur.de/Bundesnetzagentur/SharedDocs/Mediathek/Monitoringberichte/MonitoringberichtEnergie2023.pdf, checked on 5/13/2024.

Bundesregierung (2022a): Masterplan Ladeinfrastruktur II der Bundesregierung. Edited by Bundesregierung, Bundesministerium für Digitales und Verkehr. Available online at https://bmdv.bund.de/SharedDocs/DE/Anlage/G/masterplan-ladeinfrastruktur-2.pdf?__blob=publicationFile, checked on 6/7/2023.

Bundesregierung (2022b): Nachhaltige Mobilität - Nicht weniger fortbewegen, sondern anders. Edited by Bundesregierung. Available online at https://www.bundesregierung.de/breg-de/themen/klimaschutz/eenergie-und-mobilitaet/nachhaltige-mobilitaet-2044132, updated on 6/7/2023, checked on 6/7/2023.

Bundesregierung (2023a): EEG 2023 - Ausbau erneuerbarer Energien beschleunigen. Edited by Bundesregierung. Available online at https://www.bundesregierung.de/breg-de/themen/klimaschutz/novelle-eeg-gesetz-2023-2023972, updated on 6/7/2023, checked on 6/7/2023.

Bundesregierung (2023b): Mehr Ladepunkte für E-Autos. Edited by Bundesregierung. Available online at https://www.bundesregierung.de/breg-de/suche/ladepunkte-in-deutschland-1884666, updated on 7/20/2023, checked on 7/20/2023.

Businesswire (2023): Gridwiz Celebrates Successful V2G Projects in South Korea. Available online at https://www.businesswire.com/news/home/20230629370000/en/Gridwiz-Celebrates-Successful-V2G-Projects-in-South-Korea, updated on 6/29/2023, checked on 5/14/2024.

Christian Schaudwet (11/28/2023): Netzbetreiber dürfen ab Januar Verbrauch mitsteuern. Tagesspiegel Background. Available online at https://background.tagesspiegel.de/energie-klima/netzbetreiber-duerfen-ab-januar-verbrauch-mitsteuern.

Clean Energy Wire (2023): Abrupt end to German electric car subsidies fuels doubts about green mobility target. Available online at https://www.cleanenergywire.org/news/abrupt-end-german-electric-car-subsidies-fuels-doubts-about-green-mobility-target, updated on 12/18/2023, checked on 5/8/2024.

ContextCrew Neue Energy GmbH (2023): Im Blickpunkt: Flexibilitätsmärkte zur Stabilisierung des Stromnetzes. Available online at https://www.contextcrew.de/im-blickpunkt-flexibilitaetsmaerkte-zur-stabilisierung-des-stromnetzes/, updated on 7/15/2023, checked on 8/10/2023.

Electimes (2022): Jeju Island Plus DR issued only 3 times in 6 months. Available online at https://www.electimes.com/news/articleView.html?idxno=302917, updated on 4/4/2022, checked on 5/14/2024.

electrive.net (2022): Hyundai plant V2G-Funktionen für Elektroautos - electrive.net. Available online at https://www.electrive.net/2022/04/12/hyundai-plant-v2g-funktionen-fuer-elektroautos/, updated on 4/12/2022, checked on 5/14/2024.

Emi Bertoli (2022): Demand Response. Technology deep dive. With assistance of Emi Bertoli, Vida Rozite, Pauline Henriot, Sungjin Oh, Timothy Goodson. Edited by IEA. IEA. Available online at https://www.iea.org/reports/demand-response, updated on 6/22/2023, checked on 6/22/2023.

Enerdata (2022): South Korea Energy Information. Available online at https://www.enerdata.net/estore/energy-market/south-korea/, updated on 8/16/2023, checked on 8/16/2023.

Enerdata (2023): South Korea targets 34.6% nuclear and 30.6% renewable power generation in 2036. Available online at https://www.enerdata.net/publications/daily-energy-news/south-korea-targets-346-nuclear-and-306-renewable-power-generation-2036.html, updated on 3/27/2023, checked on 8/16/2023.

Energydaily (2023): KEPCO implements electric vehicle charging ‘Plus DR’ system. Available online at https://www.energydaily.co.kr/news/articleView.html?idxno=136679, updated on 5/14/2024, checked on 5/14/2024.

Energydaily (2024): KEPCO takes the lead in stabilizing the power system with electric vehicle smart charging (V1G) technology. Available online at http://www.energydaily.co.kr/news/articleView.html?idxno=145337, updated on 4/3/2024, checked on 5/22/2024.

European Commission (2019): Effect of electromobility on the power system and the integration of RES - Publications Office of the EU. With assistance of Annika Klettke, Albert Moser, Tobias Bossmann, Paul Barberi, Laurent Fournié. Edited by European Commission. Available online at https://op.europa.eu/en/publication-detail/-/publication/0d44e933-6d4d-11e9-9f05-01aa75ed71a1/language-en, checked on 7/20/2023.

European Commission (2020): Benchmarking smart metering deployment in the EU-28. With assistance of Directorate-General for Energy, Clément Alaton, Frédéric Tounquet. Edited by European Commission. Brussels. Available online at https://op.europa.eu/en/publication-detail/-/publication/b397ef73-698f-11ea-b735-01aa75ed71a1/language-en?WT_mc_id=Searchresult&WT_ria_c=37085&WT_ria_f=3608&WT_ria_ev=search, checked on 7/20/2023.

European Commission (2022): Zero emission vehicles: first ‘Fit for 55' deal will end the sale of new CO2 emitting cars in Europe by 2035. With assistance of Tim McPhie, Ana Crespo Parrondo. European Commission. Brussels. Available online at https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6462, updated on 10/28/2022, checked on 6/5/2024.

European Commission (2023a): Smart grids and meters. Smart grids and smart meters enable better management of energy networks and more efficient consumption. Edited by European Commission ((Keine Angabe)). Available online at https://energy.ec.europa.eu/topics/markets-and-consumers/smart-grids-and-meters_en, updated on 7/20/2023, checked on 7/20/2023.

European Commission (2023b): Trans-European Networks for Energy. Linking the energy infrastructure of EU countries. Edited by European Commission. Available online at https://energy.ec.europa.eu/topics/infrastructure/trans-european-networks-energy_en#priority-thematic-areas, updated on 7/20/2023, checked on 7/20/2023.

European Council (2023): Alternative fuels infrastructure: Council adopts new law for more recharging and refuelling stations across Europe. Press release. With assistance of Dimosthenis Mammonas. Edited by Council of the European Uniion. Available online at https://www.consilium.europa.eu/en/press/press-releases/2023/07/25/alternative-fuels-infrastructure-council-adopts-new-law-for-more-recharging-and-refuelling-stations-across-europe/, updated on 8/10/2023, checked on 8/10/2023.

European Council; European Parliament (2023): Regulation of the European Parliament and of the Council on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU. European Council; European Parliament. Available online at https://data.consilium.europa.eu/doc/document/PE-25-2023-INIT/en/pdf, updated on 2023, checked on 8/10/2023.

European Parliament (2023): Fit for 55: deal on charging and fuelling stations for alternative fuels. With assistance of Gediminas Vilkas. Edited by European Parliament. Available online at https://www.europarl.europa.eu/news/en/press-room/20230327IPR78504/fit-for-55-deal-on-charging-and-fuelling-stations-for-alternative-fuels, updated on 7/19/2023, checked on 7/19/2023.

EY (2020): Barometer - Digitalisierung der Energiewende. Digitalisierung 2020: Spürbare Fortschritte sowie neue Hindernisse bei Regulierung und Umsetzung. Edited by BMWK. Available online at https://www.bmwk.de/Redaktion/DE/Publikationen/Studien/barometer-digitalisierung-der-energiewende-berichtsjahr-2020.pdf?__blob=publicationFile&v=18, checked on 5/13/2024.

Finanztip (2024): E-Auto Förderung 2024: Umweltbonus weg: So gibt's noch Zuschüsse für ein E-Auto. Available online at https://www.finanztip.de/neuwagen-kaufen/e-auto-foerderung/, updated on 2/2/2024, checked on 5/8/2024.

Fraunhofer ISE; Fraunhofer IEE; Becker Büttner Held (2023): Neues Strommarktdesign. Neues Strommarktdesign für die Integration fluktuierender Erneuerbarer Energien. Edited by Bundesverband Erneuerbare Energie e.V. Kassel, Freiburg, Berlin. Available online at https://www.klimaneutrales-stromsystem.de/pdf/Strommarktdesignstudie_BEE_final_Stand_14_12_2021.pdf, checked on 8/10/2023.

Fraunhofer ISI; Öko-Institut; Prognos AG (2021): Entwicklung des Bruttostromverbrauchs bis 2030. Berechnungsergebnisse aus dem Szenario 1. With assistance of Andreas Kemmler, Aurel Wünsch, Heiko Burret. Edited by Fraunhofer ISI, Öko-Institut, Prognos AG. Available online at https://www.prognos.com/sites/default/files/2021-11/20211116_Kurzpaper_Bruttostromverbrauch2018-2030.pdf, checked on 6/7/2023.

Gabel, Mathias (2023): Stabile Verteilnetze für die schnelle Integration der neuen flexiblen Lasten. Anhörung Bundesnetzagentur § 14a Festlegungen. Edited by Netze BW. Available online at https://www.bundesnetzagentur.de/DE/Beschlusskammern/BK08/BK8_06_Netzentgelte/68_%C2%A7%2014a%20EnWG/Downloads/BK8-22-0010-A%20_Vortrag_Netze_BW.pdf;jsessionid=F9132460F5FFD85A11700E66E5ED8838?__blob=publicationFile&v=2, checked on 7/20/2023.

Geißler, Ralf (2023): Für wen sich variable Stromtarife wirklich lohnen. Available online at https://www.mdr.de/nachrichten/deutschland/wirtschaft/variabler-strompreis-boerse-sparen-hohe-kosten-100.html, updated on 4/19/2023, checked on 6/7/2023.

German Energy Agency (2021): Flexibility for the Turkish and German Electricity Grids. With assistance of Jens Völler, Katerina Simou, Yannick Severin dos Santos, Lea-Valeska Giebel, Matthias Simolka, Meric Tokyay, Elif Koyuncuoglu. Edited by Deutsche Energie-Agentur GmbH (dena). Berlin.

German Institute for Economic Research (2023): Ampel-Monitor Energiewende #5: Eine Million Elektrofahrzeuge, Zulassungsrekord im Dezember. Blogbeitrag vom 05. Januar 2023. With assistance of Wolf-Peter Schill. Edited by Deutsches Institut für Wirtschaftsforschung. Berlin. Available online at https://www.diw.de/de/diw_01.c.862674.de/nachrichten/ampel-monitor_energiewende__5__eine_million_elektrofahrzeuge__zulassungsrekord_im_dezember.html, updated on 6/7/2023, checked on 6/7/2023.

Gnann, Till; Speth, Daniel; Plötz, Patrick; Wietschel, Martin; Krail, Michael (2022): Markthochlaufszenarien für Elektrofahrzeuge - Rückblick und Ausblick bis 2030. Working Paper Sustainability and Innovation. Edited by Fraunhofer ISI. Karlsruhe (05/2022). Available online at https://www.isi.fraunhofer.de/content/dam/isi/dokumente/sustainability-innovation/2022/WP05-2022_Markthochlaufszenarien_E-Fahrzeuge_GNT-final.pdf, checked on 7/19/2023.

Großmann, Dirk; Eisele, Fabian (2022): Intelligentes Laden von E-Autos nach ISO-15118-20-Standard. Available online at https://www.all-electronics.de/e-mobility/laden/intelligentes-laden-nach-iso-15118-20-standard-97-83-277.html, updated on 10/24/2022, checked on 7/13/2023.

He-rim, Jo (2021): Vehicle-to-grid service approved under regulatory sandbox - The Korea Herald. Available online at https://www.koreaherald.com/view.php?ud=20210728000850, updated on 7/28/2021, checked on 5/14/2024.

Hermann, Hauke; Weibelzahl, Martin; Kemfert, Claudia; Leprich, Uwe (2023): Neues Strommarkt-Design: Welches passt am besten zu Wind und Sonne? Edited by Science Media Center Germany. Available online at https://www.sciencemediacenter.de/alle-angebote/science-response/details/news/neues-strommarkt-design-welches-passt-am-besten-zu-wind-und-sonne/, updated on 8/10/2023, checked on 8/10/2023.

Hydrogeninsight (2024): South Korea's largest operator of hydrogen filling stations in crisis after top shareholder refuses to invest more capital. Available online at https://www.hydrogeninsight.com/transport/south-koreas-largest-operator-of-hydrogen-filling-stations-in-crisis-after-top-shareholder-refuses-to-invest-more-capital/2-1-1607209, updated on 3/4/2024, checked on 5/21/2024.

IEA (2020a): Global EV Outlook 2020. Entering the decade of electric drive? Edited by International Energy Agency. International Energy Agency. Available online at https://iea.blob.core.windows.net/assets/af46e012-18c2-44d6-becd-bad21fa844fd/Global_EV_Outlook_2020.pdf, checked on 7/14/2023.

IEA (2020b): The role of CCUS in low-carbon power systems. Edited by International Energy Agency. Available online at https://iea.blob.core.windows.net/assets/ccdcb6b3-f6dd-4f9a-98c3-8366f4671427/The_role_of_CCUS_in_low-carbon_power_systems.pdf, checked on 7/20/2023.

IEA (2021): Reforming Korea's Electricity Market for Net Zero. International Energy Agency. Available online at https://iea.blob.core.windows.net/assets/ab5343c6-5220-4154-a88e-750de58b9c8c/ReformingKoreasElectricityMarketforNetZero.pdf, checked on 5/6/2024.

IEA (2022a): Grid Integration of Electric Vehicles. A manual for policy makers. Edited by International Energy Agency. International Energy Agency. Available online at https://iea.blob.core.windows.net/assets/21fe1dcb-c7ca-4e32-91d4-928715c9d14b/GridIntegrationofElectricVehicles.pdf, checked on 7/11/2023.

IEA (2022b): Smart Grids. Infrastructure deep dive. With assistance of Pablo Gonzalez. Edited by IEA. Available online at https://www.iea.org/reports/smart-grids, updated on 6/22/2023, checked on 6/22/2023.

IEA (2023a): Global EV Data Explorer. Korea. Edited by International Energy Agency. Available online at https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer, updated on 4/26/2023, checked on 6/19/2023.

IEA (2023b): Global EV Outlook 2023. Catching up with climate ambitions. Edited by International Energy Agency. Available online at https://iea.blob.core.windows.net/assets/dacf14d2-eabc-498a-8263-9f97fd5dc327/GEVO2023.pdf, checked on 6/19/2023.

IEA (2023c): Korea Electricity Security Policy. Edited by International Energy Agency. Available online at https://www.iea.org/articles/korea-electricity-security-policy, checked on 6/19/2023.

IEA (2023d): Managing Seasonal and Interannual Variability of Renewables. Edited by International Energy Agency. International Energy Agency. Available online at https://iea.blob.core.windows.net/assets/bfe623d2-f44e-49cb-ae25-90add42d750c/ManagingSeasonalandInterannualVariabilityofRenewables.pdf, checked on 6/23/2023.

IEA (2023e): Renewables 2022. Analysis and forecast to 2027. Revised Version, January 2023. Edited by International Energy Agency. Available online at https://iea.blob.core.windows.net/assets/ada7af90-e280-46c4-a577-df2e4fb44254/Renewables2022.pdf, checked on 7/19/2023.

IEA (2023f): World Energy Investment 2023. Edited by International Energy Agency. International Energy Agency. Available online at https://iea.blob.core.windows.net/assets/54a781e5-05ab-4d43-bb7f-752c27495680/WorldEnergyInvestment2023.pdf, checked on 6/23/2023.

IEA (2024a): Global EV Outlook 2024. Moving towards increased affordability. Paris. Available online at https://iea.blob.core.windows.net/assets/a9e3544b-0b12-4e15-b407-65f5c8ce1b5f/GlobalEVOutlook2024.pdf, checked on 5/21/2024.

IEA (2024b): Korea. Available online at https://www.iea.org/countries/korea/emissions/, updated on 5/21/2024, checked on 5/21/2024.

IEA; KEEI (2021): Korea Electricity Security Review. A joint report with the Korea Energy Economics Institute. Edited by International Energy Agency, Korea Energy Economics Institute. Available online at https://iea.blob.core.windows.net/assets/a8539b34-fb1b-42cc-ba09-e08637a59bc1/KoreaElectricitySecurityReview.pdf, checked on 8/16/2023.

Invest Korea (2023): Jeju Island Strives to Become a Distributed Energy Specialized Area. Edited by Yonhap News. Available online at https://www.investkorea.org/jj-en/bbs/i-1497/detail.do?ntt_sn=491338, updated on 8/10/2023, checked on 8/10/2023.

IRENA (2019): Innovation Outlook: Smart charging for electric vehicles. Edited by International Renewable Energy Agency. International Renewable Energy Agency. Abu Dhabi. Available online at https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Innovation_Outlook_EV_smart_charging_2019.pdf?rev=41ac5142c4f140779c2d91679658cade, checked on 6/23/2023.

IRENA (2023a): Innovation landscape for smart electrification: Decarbonising end-use sectors with renewable power. Edited by International Renewable Energy Agency. International Renewable Energy Agency. Available online at https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2023/Jun/IRENA_Innovation_landscape_smart_electrification_2023.pdf?rev=786ef5cd85024414b21bc32d0af8be3c, checked on 7/13/2023.

IRENA (2023b): World Energy Transitions Outlook 2023: 1.5°C Pathway. Volume 1. Edited by International Renewable Energy Agency. International Renewable Energy Agency. Available online at https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2023/Jun/IRENA_World_energy_transitions_outlook_v_1_2023.pdf?rev=b1d4be858ad549a9a750921d0f2b5d53.

KAS; KOTI (2024): Mobility Transformation. Republic of Korea. Available online at https://www.kasmobilitytransformation.com/, checked on 6/4/2024.

KBA (2024): Der Fahrzeugbestand am 1. Januar 2024. Available online at https://www.kba.de/DE/Presse/Pressemitteilungen/Fahrzeugbestand/2024/pm08_fz_bestand_pm_komplett.html?snn=3662144, updated on 3/4/2024, checked on 5/8/2024.

Kbiznews (2021): KEPCO uses electric vehicles as a demand resource. Available online at http://www.kbiznews.co.kr/news/articleView.html?idxno=87047, updated on 5/14/2024, checked on 5/14/2024.

KEEI (2017): Study on strategies for the energy industry to respond to the growth of e-mobility (1/4). Available online at http://www.keei.re.kr/keei/download/KIP2017.pdf, checked on 5/22/2024.

KEPCO (2023a): Electric Rates Table. Available online at https://home.kepco.co.kr/kepco/EN/F/htmlView/ENFBHP00109.do?menuCd=EN060201, checked on 6/19/2023.

KEPCO (2023b): Establishment of the 10th long-term transmission and substation facility plan to establish national energy security. Available online at https://home.kepco.co.kr/kepco/PR/ntcob/ntcobView.do?pageIndex=1&boardCd=BRD_000117&boardSeq=21061873&menuCd=FN06030103, updated on 5/8/2023, checked on 5/22/2024.

KEPRI (2024): Fields of our research. Smart Power Distribution. KEPRI. Available online at https://www.kepri.re.kr:20808/eng/group/field-11, updated on 5/21/2024, checked on 5/21/2024.

Kim, Doyob (2022): Unlocking the Potential of Distributed Energy Resources. Power system opportunities and best practices. Edited by International Energy Agency. International Energy Agency. Available online at https://iea.blob.core.windows.net/assets/3520710c-c828-4001-911c-ae78b645ce67/UnlockingthePotentialofDERs_Powersystemopportunitiesandbestpractices.pdf, checked on 7/12/2023.

Kim, Eun-Hwan (2023): Environmental changes and opportunity factors in the demand response market. Available online at http://www.keaj.kr/news/articleView.html?idxno=4900, updated on 2023, checked on 5/13/2024.

KOTI (2024): General Research. Available online at https://www.koti.re.kr/eng/bbs/generalRschList.do, updated on 5/13/2024, checked on 5/13/2024.

KSGA (2024): Roadmap for Smart Grid. Edited by Korea Smart Grid Association. Available online at https://www.ksga.org/eng/info/roadmap.do, updated on 5/21/2024, checked on 5/21/2024.

KSGI (2023): Special Act on Promotion of Distributed Energy passed by the National Assembly. Available online at https://www.smartgrid.or.kr/bbs/board.php?tbl=bbs51&mode=VIEW&num=24&category=&findType=&findWord=&sort1=&sort2=&it_id=&shop_flag=&mobile_flag=&page=1#, updated on 6/5/2023, checked on 5/22/2024.

KSGI (2024): About KSGI. Vision & Goals. Edited by Korea Smart Grid Institute. Available online at https://www.smartgrid.or.kr/sub01/sub03.php, updated on 8/16/2023, checked on 8/16/2023.

Lee, Kumjung (2023): Technology trends & Policy developments on Smart grids in Korea. KETEP.

Miha Jensterle, Regina Yoonmie Soh, Maike Venjakob, Oliver Wagner (2019): System Integration of Renewables and Smart Grids in Korea. adelphi, Wuppertal Institut. Available online at https://www.energypartnership-korea.org/fileadmin/user_upload/korea/media_elements/8-Study_2019_System_Integration_of_RE_and_Smart_Grids_in_Korea.pdf, checked on 5/14/2024.

MOE (2023): Environment ministry to reform rule on subsidies for the purchase of EVs in 2023 to popularize EVs. Available online at https://eng.me.go.kr/eng/web/board/read.do?menuId=461&boardMasterId=522&boardId=1582640, updated on 2/24/2023, checked on 5/21/2024.

MOE (2024): Announcement of the First Carbon Neutrality and Green Growth Implementation Review Results with Direct Participation of Climate Crisis Stakeholders. Available online at https://eng.me.go.kr/eng/web/board/read.do?pagerOffset=0&maxPageItems=10&maxIndexPages=10&searchKey=titleOrContent&searchValue=greenhouse+gas+emissions&menuId=461&orgCd=&boardId=1648880&boardMasterId=522&boardCategoryId=&decorator, updated on 1/4/2024, checked on 5/13/2024.

MOTIE (2019): Third Energy Master Plan. A New Energy Paradigm for the Future. Available online at https://www.etrans.or.kr/ebook/05/files/assets/common/downloads/Third%20Energy%20Master%20Plan.pdf, checked on 5/14/2024.

MOTIE (2020): 9th Basic Plan for Power Supply and Demand. Available online at https://policy.asiapacificenergy.org/sites/default/files/9th%20Basic%20Plan%20for%20Power%20Supply%20and%20Demand%20.pdf, checked on 5/22/2024.

MOTIE (2021): 4th Basic Plan for the Eco-friendly Vehicles (2021-2025). Edited by Ministry of Trade, Industry and Energy. Available online at http://www.motie.go.kr/motie/ne/presse/press2/bbs/bbsView.do?bbs_seq_n=163830&bbs_cd_n=81&currentPage=1&search_key_n=&cate_n=1&dept_v=&search_val_v=, updated on 8/17/2023, checked on 8/17/2023.

MOTIE (2023a): 3rd Basic Plan for Smart Grid.

MOTIE (2023b): The 10th Basic Plan for Long-Term Electricity Supply and Demand.

Next Kraftwerke (2022): Honda und Next Kraftwerke präqualifizieren E-Auto-Flotte für Primärregelleistung in Amprions Netzgebiet. Next Kraftwerke. Available online at https://www.next-kraftwerke.de/neues/regelleistung-honda, updated on 11/25/2022, checked on 6/4/2024.

NLL (2023a): Förderung von Infrastuktur durch die Bundesregierung. Available online at https://nationale-leitstelle.de/verstehen/forderung_von_ladeinfrastruktur_durch_die_bundesregierung/, updated on 6/7/2023, checked on 6/7/2023.

NLL (2023b): Übersicht Förderprogramme und Förderrichtlinien. Available online at https://nationale-leitstelle.de/foerdern/#Das_Deutschlandnetz, updated on 7/20/2023, checked on 7/20/2023.

NLL (2024a): Bidirektionales Laden flächendeckend ermöglichen. Beirat der Nationalen Leitstelle Ladeinfrastruktur präsentiert Handlungsempfehlungen im BMDV. Available online at https://nationale-leitstelle.de/bidirektionales-laden-flaechendeckend-ermoeglichen-beirat-der-nationalen-leitstelle-ladeinfrastruktur-praesentiert-handlungsempfehlungen-im-bmdv/, updated on 3/11/2024, checked on 5/13/2024.

NLL (2024b): Nationale Leitstelle Ladeinfrastruktur für E-Mobilität in Deutschland. Available online at https://nationale-leitstelle.de/, updated on 5/15/2024, checked on 5/15/2024.

NLL (2024c): Öffentliche Ladeinfrastruktur. Report der Nationalen Leitstelle Ladeinfrastruktur Dezember 2023 - Februar 2024. Available online at https://nationale-leitstelle.de/wp-content/uploads/2024/02/oeLIS_Report_2023_Dez_2024_Feb.pdf, checked on 5/8/2024.

NOW GmbH (2021): Charging Infrastructure - NOW GmbH. Available online at https://www.now-gmbh.de/en/sectors-themes/mobility-infrastructure-provision/electricity/, updated on 6/16/2021, checked on 5/8/2024.

NOW GmbH (2023a): Bestand nach Fahrzeugklassen. Edited by Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie. Available online at https://www.now-gmbh.de/datenfinder/bestand-pkw-lkw-bus-zugmaschinen/, updated on 3/21/2023, checked on 6/7/2023.

NOW GmbH (2023b): Universelles, bidirektionales und kostenoptimiertes Onboard-Ladegerät (UniCharge). Available online at https://www.now-gmbh.de/projektfinder/universelles-bidirektionales-und-kostenoptimiertes-onboard-ladegeraet-unicharge/, updated on 2/21/2023, checked on 5/8/2024.

NOW GmbH (2024): Herstellerbefragung E-Pkw. Marktentwicklung und Technologietrends. Available online at https://www.now-gmbh.de/wp-content/uploads/2024/04/NOW_Factsheet-Herstellerbefragung-E-Pkw.pdf, checked on 5/8/2024.

Okamura, Toshiya; Doi, Naoko; Thomas, Stefan; Kolde, Lisa (2022): The role of batteries towards carbon neutrality: How can distributed electricity storage contributed to balancing supply and demand in power markets as well as in power grids? Study for the GJETC. Edited by Wuppertal Institute for Climate, Environment and Energy, The Institute for Energy Economics, Japan, German-Japanese Energy Transition Council (GJETC). Available online at https://gjetc.org/wp-content/uploads/2022/06/GJETC_Role-of-batteries-towards-carbon-neutrality.pdf, checked on 6/30/2023.

Park, Kijun; Jang, Dongsik; Kim, Sangok; Lim, Youseok; Lee, Jungho (2023): A Grid-Friendly Electric Vehicle Infrastructure: The Korean Approach. In *IEEE Power and Energy Mag.* 21 (6), pp. 28–37. DOI: 10.1109/MPE.2023.3308232.

Renewable Energy Institute (2023a): International Power Interconnections Progress and Help Countries in the Energy Crisis. With assistance of Romain Zissler. Available online at https://www.renewable-ei.org/en/activities/column/REupdate/20230119.php, updated on 1/19/2023, checked on 5/22/2024.

Renewable Energy Institute (2023b): South Korea: Low Renewable Energy Ambitions Result in High Nuclear and Fossil Power Dependencies. Available online at https://www.renewable-ei.org/pdfdownload/activities/REI_SKoreaReport_202311_EN.pdf, checked on 5/22/2024.

Reppert, Thorsten (2023): Local-level ownership of electricity grids: An analysis of Germany's distribution system operators (DSOs). In *Utilities Policy* 85, p. 101678. DOI: 10.1016/j.jup.2023.101678.

Shin & Kim LLC (2023): Enactment of the Dispersed Energy Promotion Special Act. Available online at https://www.shinkim.com/eng/media/newsletter/2131?page=0&code=&keyword=, updated on 6/16/2023, checked on 5/22/2024.

Sieler, Roman; Dörr, Henri (2023): Certification of green and low-carbon hydrogen. An overview of international and national initiatives. Edited by Japanese-German Energy Partnership Team. Japanese-German Energy Partnership Team. Available online at https://www.energypartnership.jp/fileadmin/user_upload/japan/media_elements/adelphi_-_International_Overview_-_Certification_of_Clean_and_Green_Hydrogen.pdf.

smartEN (2022): Local Flexibility Markets. smartEN Spotlight. Edited by Smart Energy Europe. Brussels. Available online at https://smarten.eu/wp-content/uploads/2022/07/Spotlight-Local-Flexibility-Markets.pdf, checked on 8/8/2023.

smartEN; DNV (2022): Demand-side flexibility in the EU. Quantification of benefits in 2030. With assistance of Aurora Sáez Armenteros, Hans de Heer, Laura Fiorini, María Miranda Castillo, Thijs Slot, Andrés Pinto-Bello Gómez. Edited by Smart Energy Europe: DNV. Available online at https://smarten.eu/wp-content/uploads/2022/09/SmartEN-DSF-benefits-2030-Report_DIGITAL.pdf, checked on 7/19/2023.

Solutions for Our Climate (2022): The Unlevel Playing Field. How the Power Market Structure Discriminates Against Demand Response to Favor Gas Power Generation. With assistance of Gyuri Cho, Gayeong Son. Available online at https://forourclimate.org/hubfs/%5BENG%5D%20The%20Unlevel%20Playing%20Field_How%20the%20Power%20Market%20Structure%20Discriminates%20Against%20Demand%20Response%20to%20Favor%20Gas%20Power%20Generation.pdf, checked on 5/13/2024.

Sorge, Petra; Raymunt, Monica (2023): Germany to Drop Electric Car Charging Goals as People Plug EVs at Home. Available online at https://www.bloomberg.com/news/articles/2023-06-08/germany-to-walk-back-charging-goal-as-people-plug-evs-at-home#xj4y7vzkg, updated on 6/8/2023, checked on 7/20/2023.

Statista (2023): Stromnetzbetreiber in Deutschland. Available online at https://de.statista.com/statistik/studie/id/21844/dokument/stromnetzbetreiber-in-deutschland/, checked on 5/8/2024.

Statista (2024a): South Korea: total number of registered electric vehicles 2023. Available online at https://www.statista.com/statistics/1097976/south-korea-total-registration-number-of-electric-vehicles/, updated on 4/9/2024, checked on 5/21/2024.

Statista (2024b): Stromaustauschsaldo Deutschlands in den Jahren 1990 bis 2023. Available online at https://de.statista.com/statistik/daten/studie/153533/umfrage/stromimportsaldo-von-deutschland-seit-1990/, updated on 5/13/2024, checked on 5/13/2024.

Statistisches Bundesamt (2022): Stromverbrauch der privaten Haushalte nach Haushaltsgrößenklassen. Umweltökonomische Gesamtrechnungen. Available online at https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Umwelt/UGR/private-haushalte/Tabellen/stromverbrauch-haushalte.html, updated on 12/16/2022, checked on 6/7/2023.

TenneT (2024): TenneT und FfE entwickeln CO2-Monitor für deutschen Strommix. Available online at https://www.tennet.eu/de/news/tennet-und-ffe-entwickeln-co2-monitor-fuer-deutschen-strommix, updated on 5/7/2024, checked on 5/7/2024.

The Korea Herald (2024): Govt. mulls further cutting EV subsidies. Available online at https://www.koreaherald.com/view.php?ud=20240331050057, updated on 3/31/2024, checked on 5/21/2024.

The Korea Times (2023): Korea boosts subsidies to rev up falling EV sales. Available online at https://www.koreatimes.co.kr/www/tech/2023/09/129_359848.html, updated on 9/22/2023, checked on 5/21/2024.

The Mobility House (2022): §14a EnWG funktioniert für Elektroautos heute schon – Wenn die Netzbetreiber wollen, sparen Kund:innen bis zu 120 Euro pro EV und Jahr. Available online at https://www.mobilityhouse.com/de_de/knowledge-center/artikel/schon-heute-mit-dem-enwg-fuer-elektroautos-sparen, updated on 8/10/2023, checked on 8/10/2023.

The Mobility House (2023a): Die Umsetzung von V2G. Available online at https://www.mobilityhouse.com/de_de/knowledge-center/artikel/umsetzung-von-v2g, updated on 8/10/2023, checked on 8/10/2023.

The Mobility House (2023b): V2G-Status-Quo – welches Land ist wie weit. Available online at https://www.mobilityhouse.com/de_de/knowledge-center/artikel/v2g-welches-land-ist-wie-weit, updated on 8/10/2023, checked on 8/10/2023.

The Mobility House (2023c): Vehicle-to-Grid: Elektroauto als Stromspeicher nutzen. Available online at https://www.mobilityhouse.com/de_de/vehicle-to-grid, updated on 8/10/2023, checked on 8/10/2023.

UBA (2023): Stromverbrauch in Deutschland. Edited by Umweltbundesamt. Available online at https://www.umweltbundesamt.de/daten/energie/stromverbrauch, updated on 6/7/2023, checked on 6/7/2023.

UBA (2024): Klimaschutz im Verkehr. Available online at https://www.umweltbundesamt.de/themen/verkehr/klimaschutz-im-verkehr#rolle, updated on 4/30/2024, checked on 5/8/2024.

VDA (2023): Zum Start des Festlegungsverfahrens nach § 14a des EnWG. Stabilisierung der Stromnetze. Edited by Verband der Automobilindustrie. Available online at https://www.vda.de/de/aktuelles/artikel/2023/zum-start-des-festlegungsverfahrens-nach---14a-des-enwg-, updated on 7/20/2023, checked on 7/20/2023.

VKU (2023): Stabile Stromnetze dank steuerbarer Verbrauchseinrichtungen. Pressemitteilung. Available online at https://www.vku.de/presse/pressemitteilungen/vku-stabile-stromnetze-dank-steuerbarer-verbrauchseinrichtungen/, updated on 12/6/2023, checked on 12/6/2023.

Windt, Alexander; Arnhold, Oliver (2020): Ladeinfrastruktur nach 2025/2030: Szenarien für den Markthochlauf. Studie im Auftrag des BMVI. With assistance of Alexander Windt, Oliver Arnhold. Edited by Nationale Leitstelle Ladeinfrastruktur. Reiner Lemoine Institut. Berlin. Available online at https://nationale-leitstelle.de/wp-content/pdf/broschuere-lis-2025-2030-final.pdf, checked on 7/19/2023.

Wooyoung Jeon; Sangmin Cho; Ilhyun Cho (2021): The Economics Value of Electric Vehicle Demand Resource under the Energy Transition Plan. In *Environmental and Resource Economics Review* 2021 (30), Article 2, pp. 237–268. Available online at https://koreascience.kr/article/JAKO202119759427819.pdf, checked on 5/21/2024.

Yonhap News Agency (2024): Estimates show S. Korea's greenhouse gas emissions fell in 2023 for 2nd consecutive year. Seoul. Available online at https://en.yna.co.kr/view/AEN20240407002100315, updated on 4/7/2024, checked on 5/21/2024.