The Electrification of Transportation and its Impact on the Austrian Electricity Demand Curve with a Special Emphasis on European Resource Adequacy Studies

Dennis Meier[1], Johannes Hierzer[1], Marlene Petz[1], Kurt Misak[1], Daniel Stahleder[2], Felix Lehfuss[2]

[1]Austrian Power Grid AG, Wagramerstraße 19, 1220 Wien, +43 664 8285407, dennis.meier@apg.at, www.apg.at

[2]AIT Austrian Institute of Technology GmbH, Giefinggasse 4, 1210 Wien, +43 50550-6365, daniel.stahleder@ait.ac.at, www.ait.ac.at

Abstract: In order to assess security levels of supply, it is imperative for a Transmission System Operator to have detailed information on the expected evolution of the demand curve. One of the main demand components in the currently ongoing transition of the power system is represented by electric vehicles, since they do not only add extra load to the energy system, but can also provide additional flexibility (e.g. time shiftable load, vehicle-to-grid, etc.). In this paper, common research of Austrian Power Grid AG and AIT Austrian Institute of Technology GmbH on the evolution of electric vehicles until 2040 is presented. A special emphasis is given on how different shares of price sensitive electric vehicles affect the demand curve. Furthermore, the potential of additional flexibility to prevent or mitigate events of scarcity is illustrated in an academic test model.

Keywords: Demand Side Response, demand evolution, flexible charging of electric vehicles, security of supply, power system modelling, European Resource Adequacy Assessment.

1 Introduction

One of the main tasks of a Transmission System Operator (TSO) is to ensure the security of energy supply – which could be a challenge in the upcoming years. More precisely, this means that the balance between supply and demand across the interconnected power grid has to be maintained at any given time throughout the year. In order to evaluate levels of security of supply, different studies are carried out by the European Network of Transmission System Operators for Electricity (ENTSO-E), as well as by TSOs. These studies may vary in their geographical and temporal scope as well as in their methodological approach, hence providing different complementary viewpoints on the resilience of (parts of) the European power system. The most prominent process for the detection of resource adequacy concerns is the European Resource Adequacy Assessment (ERAA) [1], which is coordinated by ENTSO-E. The scope of the ERAA is to assess power system resource adequacy of up to ten years ahead, using probabilistic methods accounting for variability in climate conditions and unplanned outages of grid elements and power plants. The ERAA is the successor of the Mid-term Adequacy

Forecast (MAF) and is tailored towards meeting the needs, which come with the Clean Energy for all Europeans Package (CEP) [2].

One of the main challenges in carrying out resource adequacy assessments like the ERAA is to take accurately into account the rapidly changing structure of the power system. In order to reduce greenhouse gas emissions and to be compliant with the EU's Paris Agreement commitments, the European power system is currently facing its largest transformation since it came into existence. More specifically, to reach climate neutrality until 2050, the European Commission suggests a reduction of greenhouse gas emissions by 2030 to at least 55% compared to the level of 1990 [3]. Therefore, power generation relying on fossil fuels (e.g. coal, lignite, oil) is gradually replaced by renewable generation assets, such as wind farms and photovoltaic plants, adding more volatility to the system. In addition, the demand side is undergoing drastic changes. New demand components such as heat pumps, electric vehicles or battery home storages are becoming more and more important and – through their characteristic behavior – reshape the overall demand curve. One of the key drivers of this development are electric vehicles (EVs). The evolution of EVs, their contribution to the Austrian electricity demand curve and consequently their impact on the security of supply is of high interest for Austrian Power Grid AG (APG) and thus constitute the main focus of this paper.

In order to provide well-founded estimates on how the ongoing electrification of transportation is going to affect Austria's future demand curve, APG together with the Austrian Institute of Technology (AIT) conducted common research, which is based on the best knowledge available. Under consideration of political guidelines and goals, projections on size and structure of Austria's future EV fleet are derived and respective annual demand profiles are constructed. In a second step, the obtained data enters a test model, which is based on the official ERAA 2021 model. By this means, various assumptions on price sensitivity and load shifting behaviour of EVs and their corresponding impact on key adequacy metrics like Expected Energy not Served (EENS) and Loss of Load Expectation (LOLE) are analysed. Moreover, novel modelling approaches concerning EVs can be assessed and the findings may serve as valuable feedback for the ERAA model building stream.

2 Methodology

This section provides an overview of the methodologies used for the assessments within this paper.

2.1 ERAA Methodology

The ERAA is a pan-European study with focus on power system resource adequacy and aims to model the European power system in order to identify supply/demand mismatch risks, taking into account a wide variety of different scenarios.

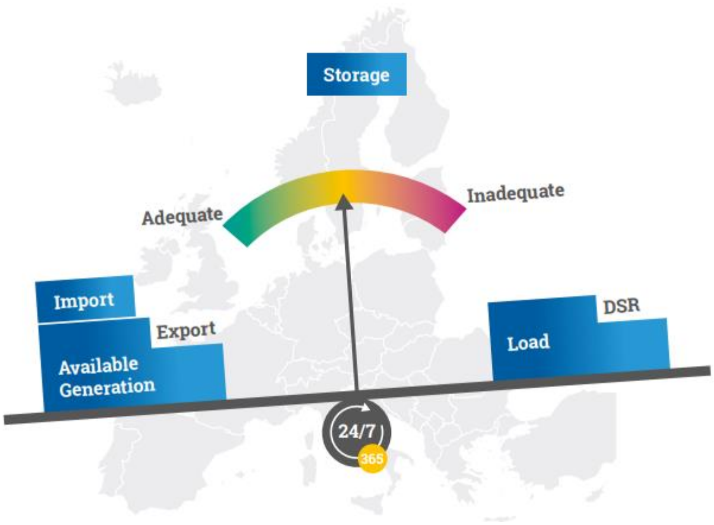

Figure 1: Schematic scope of resource adequacy

Building on the experience gathered from several editions of the MAF, the ERAA 2021 extends this framework and includes for the first time the implementation of an Economic Viability Assessment for a scenario with and a scenario without Capacity Mechanisms as well as a proof of concept analysis for the implementation of Flow-Based Market Coupling in upcoming editions. These needs arise from Regulation (EU) 943/2019 (“Electricity Regulation”) [4] and Regulation (EU) 941/2019 (“Risk Preparedness Regulation”) [5], adopted as part of the CEP.

Concerning its geographical scope, 56 biddings zones in 37 countries are modelled explicitly in ERAA 2021. In the spirit of a resource adequacy assessment with focus on the balance of demand and supply, the power grid is only modelled via interconnections between different bidding zones, while power flows within a zone are neglected. Regarding the time horizon and resolution, the ERAA target methodology aims to identify adequacy risks up to a ten year horizon on an annual granularity [6]. In view of a stepwise implementation, ERAA 2021 focuses on target years (TYs) 2025 and 2030, gradually increasing the number of TYs in upcoming editions.

For the sake of reflecting uncertainty related to various climate conditions (e.g. hydrological inflows, wind speed, irradiance), 35 different historic climate years (1982 to 2016) serve as basic input to build time series for renewable generation and demand. These time series are then randomly related with unplanned outages for generating units or interconnectors. Within this approach, each of the randomly created Monte-Carlo Scenarios is assigned to a Unit Commitment and Economic Dispatch (UCED) problem, which is solved in an hourly granularity.

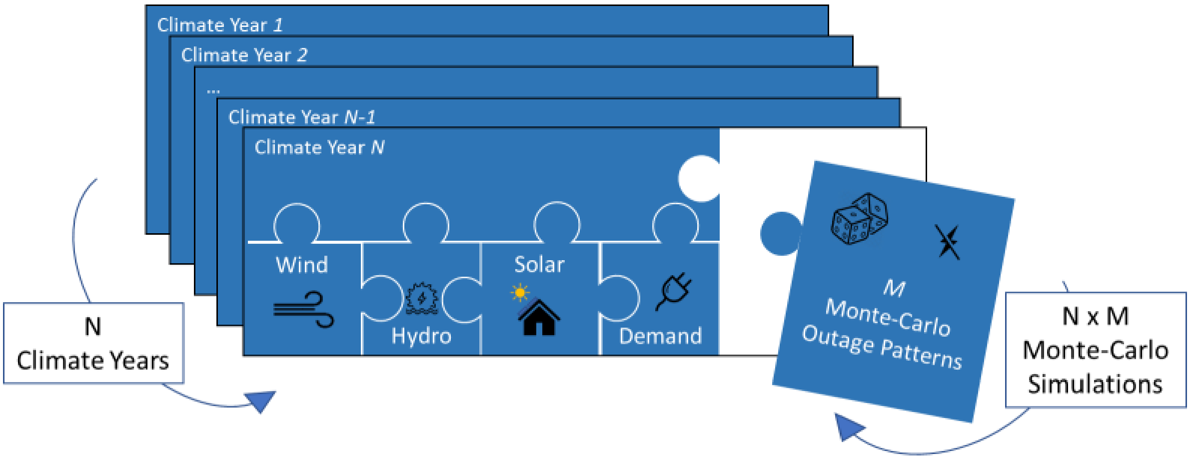

Figure 2: Monte-Carlo simulation principle [7]

The key simulation outputs to evaluate system adequacy are given by the Expected Energy not Served (EENS) in gigawatt hours and the Loss of Load Expectation (LOLE) in hours:

$$EENS = \frac{1}{K}\sum_{k=1}^{K} ENS_k \qquad \text{and} \qquad LOLE = \frac{1}{K}\sum_{k=1}^{K} LLD_k,$$

where

- K denotes the total number of Monte-Carlo Years.
- ENS_k the Energy not Served in Monte-Carlo year $k \in \{1, \dots, K\}$.
- LLD_k the Loss of Load Duration in Monte-Carlo year $k \in \{1, \dots, K\}$.

2.2 Demand Time Series creation

One of the most crucial inputs to an adequacy assessment like the ERAA are the demand time series per bidding zone. The hourly demand within an ERAA model determines – together with the current availability of power generation assets and grid elements – if security of supply can be guaranteed in a given bidding zone at a given hour. Thus, the availability of high quality demand forecasts is crucial for the overall success of the entire ERAA process.

For most of the bidding zones modelled in the ERAA, hourly demand forecasts are calculated centrally at ENTSO-E, using a software called TRAPUNTA (Temperature Regression and loAd Projection with UNcertainty Analysis), developed by Milano Multiphysics. In the following, a brief overview of the TRAPUNTA methodology – which can be divided into two separate steps – is provided.

Step 1. Model training and base load prediction

The TRAPUNTA methodology is based on the extraction of orthogonal load components via a singular value decomposition (SVD) of the available daily loads which are used for model training. These load components represent optimal basis functions for the reconstruction of a generic daily load profile $P(t; m_1, \dots, m_n)$ as

$$P(t; m_1, \dots, m_n) = \sum_{i=1}^{N} C_i(m_1, \dots, m_n)\, \Phi_i(t),$$

where N denotes the number of load components, Φ_i the i-th load component, C_i its associated weight and $m_1, \ldots, m_n$ the climatic variables used in the model training. In order to determine the weights C_i, a polynomial regression on the available data (historical electrical load data and corresponding climate data) is performed.

The data used for model training consists of climatic data like population weighted temperature, city temperature, irradiance and wind speed as well as historic load time series and information on bank holidays of the bidding zone.

Step 2. Technological development

In order to obtain a model which can be used for forecasting load time series for future years, the correlation of climatic variables and electric load is drawn in the first step. However, technological developments not inherent in the historic load data have to be considered exogenously in an additional step. In particular, predictions concerning the development of electric vehicles, heat pumps, batteries, additional base loads and energy demand increase can be included. The expected growth figures regarding these technologies are provided by the respective TSOs within the Pan-European Market Modelling Database (PEMMDB).

As mentioned above, for most of the bidding zones the demand forecasts are calculated by ENTSO-E using TRAPUNTA. However, some bidding zones (e.g. Poland and Belgium) decided to provide their own forecasts using their own tools and methodologies. APG also creates its own demand forecasts, using the following hybrid approach: For the base load, the TRAPUNTA approach as explained in step one is applied, while for the technological developments on heat pumps and electric vehicles, external tools developed by AIT are exploited. In a final step, using post processing methods which have been developed internally at APG, the demand time series for different components are harmonized in a way that they can be added up to a total demand time series.

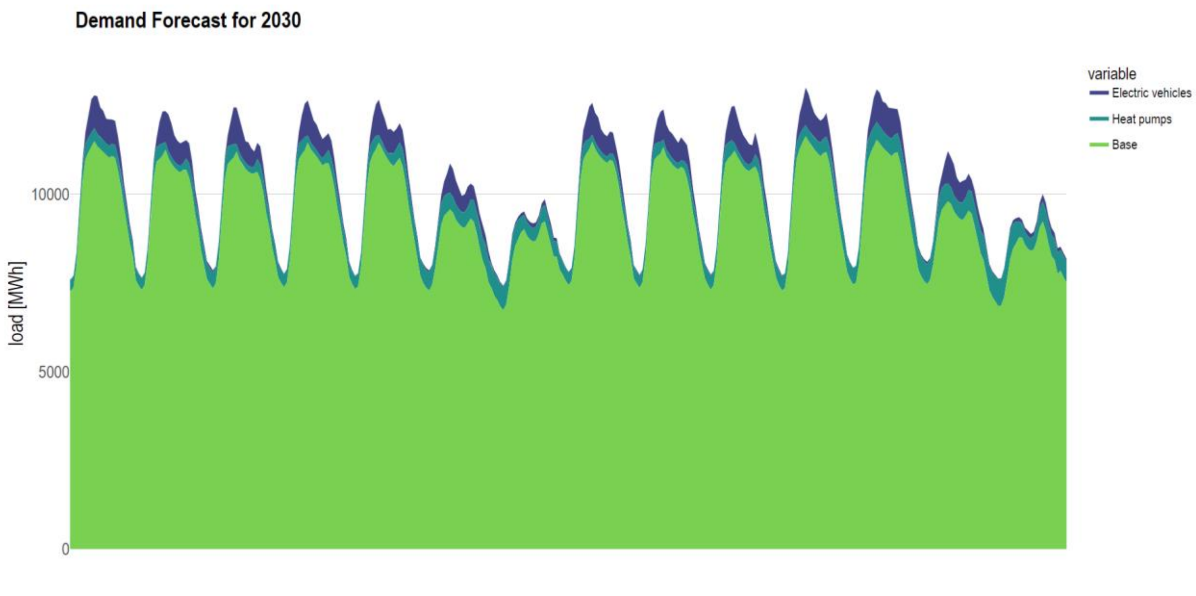

Figure 3: stacked demand forecast for two weeks in October 2030

2.3 AIT common research on EV development

Within the given project – as a first step – the aim was to assess future levels of EV penetration in Austria for the target years related to the ERAA process (until 2030) and to provide an outlook until 2040. According to an earlier study conducted by APG, for 2040, the aim is to achieve the goal of a 100% climate neutral energy system in Austria. Therefore, for the time horizon up until 2030, the IEA Sustainable Development Scenario (SDS) of the global EV outlook [8] served as basis for estimation, whereas for 2040 the output of the ONE100 study [9] was taken into account for determining the penetration target.

Within the project, the differentiation between the following two types of electric vehicles were applied:

1. private EVs
2. non-private EVs ("business")

which were additionally specified according to their charging behavior:

1. pure electrical charging (EVs)
2. mixed plug-in hybrid EVs (PHEV)
3. light commercial vehicles (LCV)

Taking the above described differentiations and the penetration targets of [8] and [9] into account and by modelling the overall development by a logistic function, the following picture for EV penetration in Austria arises:

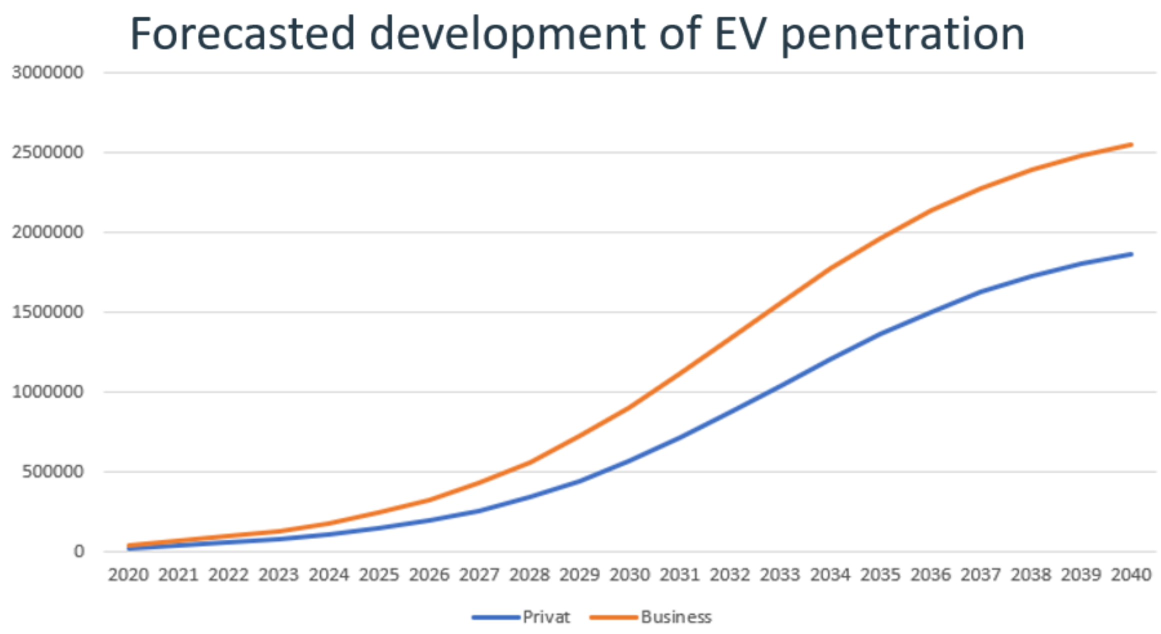

Figure 4: forecast of the EV penetration in Austria following a logistic model

In a second step – based on the above retrieved penetration rates – a simulation model [10] for the charging behaviour of EVs developed by AIT was applied. For the application of this model, the parameters for the ten most common types of EVs in Austria were taken from the online database “EV-Database”[1]. In addition, the temperature dependency entered this model by means of a scaling function, which is based on the work performed in [11]. Temperature dependency plays an important role also for adequacy modelling. Thus, this needs to be reflected by the climatic input variables provided by the Pan European Climate Database (PECD) and accordingly taken up by the load time series generator. Figure 5 displays the temperature dependency of electric vehicles. Especially the load increase during cold winter days is crucial for adequacy assessments and therefore needs to be taken into account properly.

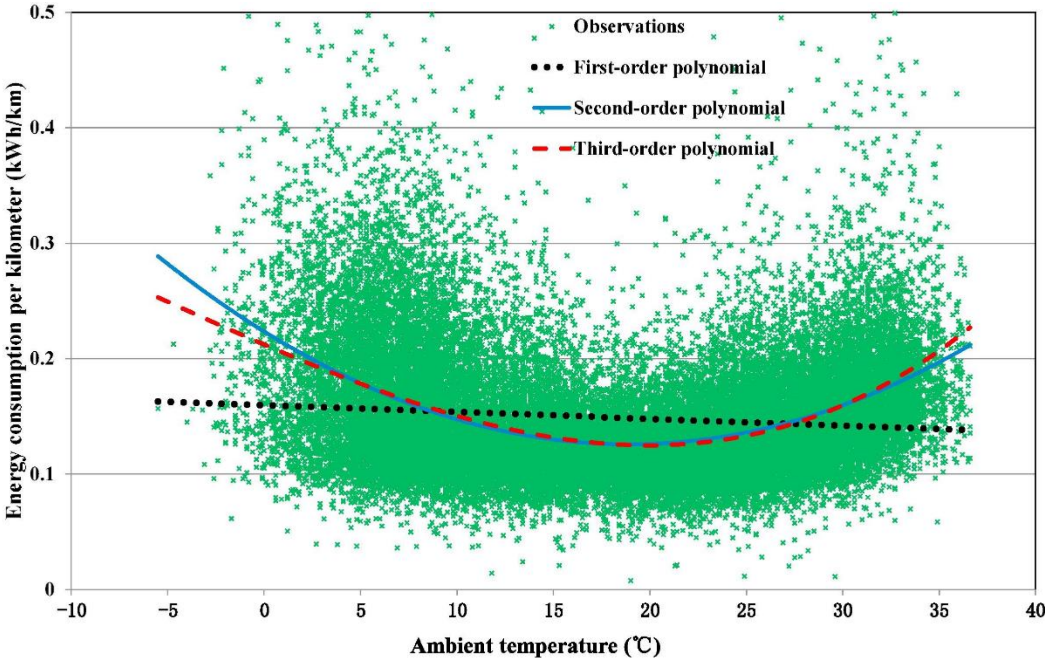

Figure 5: Temperature dependency of EVs [11]

To reflect on the mobility behaviour of the individual EVs, a probability distribution of the arrival times of the different user types was extracted from the study “Österreich unterwegs 2013/2014” [12]. Even though this study dates back to 2013, it is assumed that the behaviour for Austria did not change significantly until today. To retrieve information on the driving performance, information from Statistik Austria (Mikrozensus über den Energieeinsatz der Haushalte) was extracted and combined with results of [12]. Table 1 lists the average travel distances, which were assumed in the study:

Table 1: average daily travel distance for private and business EVs

	Business (km / day)	Private (km / day)
Week day	53	36,25
Saturday	42,13	27,94
Sunday / bank holiday	0	25,59

[1] https://ev-database.de/

Next to the average daily travel distance, the commuter flows between the 35 NUTS3[2] regions of Austria entered the simulator. Those were separated according to the targets "travel", "shopping" and "business" – detailed investigations were performed by AIT and are excluded in the current work for simplification reasons. The NUTS3 resolution was chosen due to the circumstance that the load profile generator can be executed for the different NUTS3 regions within Austria, thus whenever a process is in the need of a higher resolution than Member State level, the time series for EVs can also be generated on a more granular resolution.

Additionally, it was assumed that upon arrival the drivers connect their vehicle to the grid, in order to kick off a charging procedure. Furthermore, charging of EVs entering Austria from external countries was also not considered. The reasoning behind this assumption is that since also drivers from Austria travelling abroad mainly charge their electric vehicles within Austria.

For private user types – next to charging at home or at work – also public charging at EV charging points needs to be accounted for. Figure 6 displays the chosen approach for the split between home, work and shop charging.

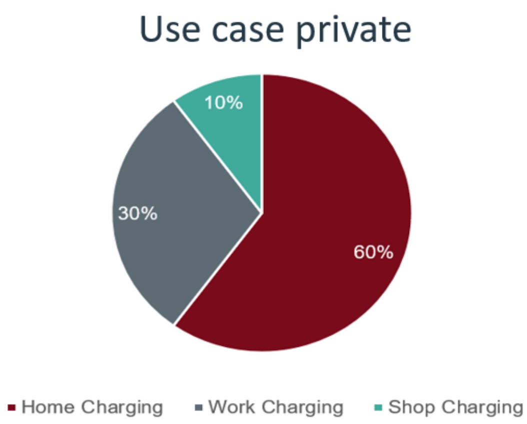

Figure 6: distribution of private charging – home, work and shop charging

For the three private charging types, relative charging capacities were assumed. Table 2 lists the maximum charging capacities of private and business EVs.

Table 2: maximum charging of private and business EVs

Maximum charging power output	Home charging	Work charging	Shop charging	Business charging
11 kW	95 %	80 %	70 %	45 %
22 kW	5 %	20 %	10 %	40 %
50 kW			20 %	10 %
150 kW				5 %

For business charging, capacities of 11 kW (45%), 22 kW (40%), 50 kW (10%) and 150 kW (5%) were assumed.

2 https://ec.europa.eu/eurostat/de/web/nuts/local-administrative-units

Having all the above listed input data available, the demand time series for EVs were created mainly based on weather assumptions (meteonorm – available at AIT) for the relative forecasted years. In order to serve the ERAA process, also the time series for the 35 historic climate years (1982 – 2016) have been prepared.

Following the meteonorm weather forecast using the time series generator tool of AIT, the following amount of additional EV load can be summarised. Figure 7 presents the yearly energy consumption of private and business EVs in Austria until 2040.

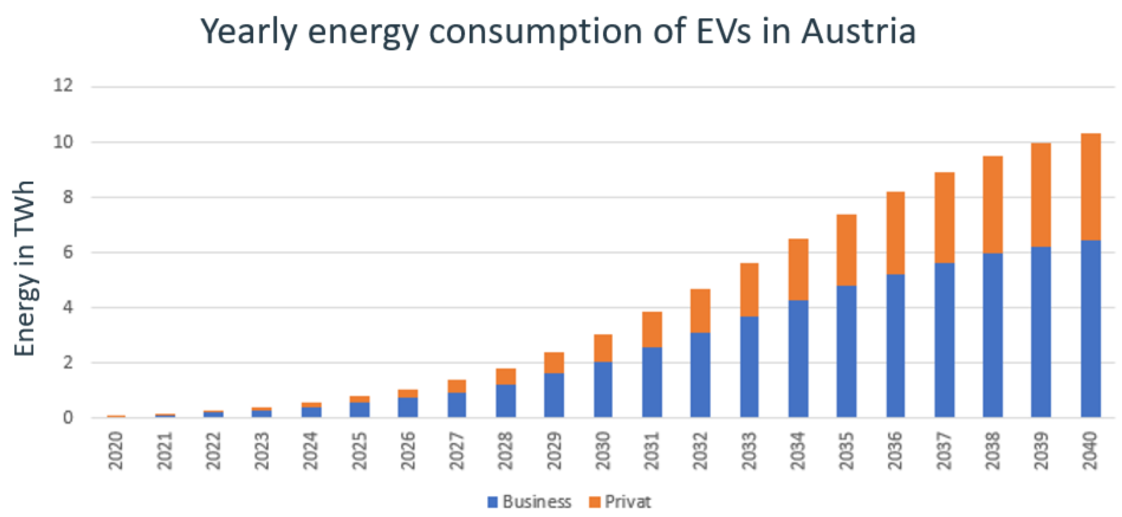

Figure 7: yearly energy consumption of private and business EVs in Austria

Figure 8 summarises the contribution of both, private EVs and business EVs to the demand curve. Peak values for each target years are presented in the bar chart. For the year 2030, a total of 1,3 GW additional peak load due to electric vehicles can be assumed for Austria.

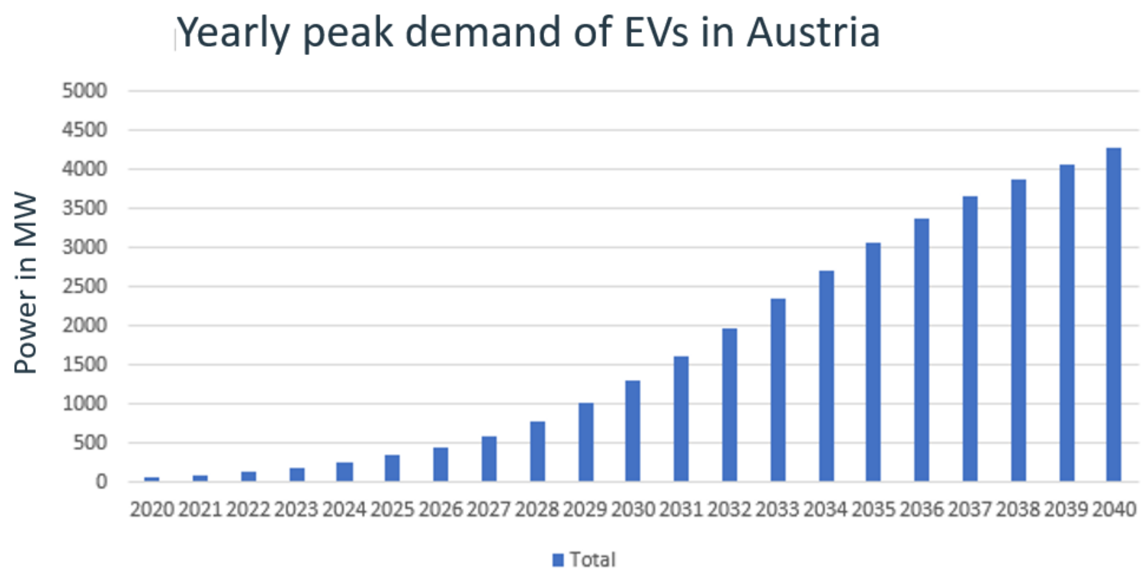

Figure 8: yearly peak demand of EVs in Austria

3 Impact Assessment

In order to provide a first estimate of the potential of flexible EV charging in adequacy assessments, a trilateral test model was set up. Compared to the full ERAA model, it is reduced in its geographical scope and only encompasses Austria besides two neighbouring bidding zones. Due to its reduced geographical scope, the model is particularly suitable for studying different sensitivities on input data and modelling assumptions.

The test model is set up in the large scale Monte-Carlo Simulator ANTARES [13], which is an open source software developed by the French Transmission System Operator RTE, especially designed for adequacy simulations. Within the model – next to the base case where no flexible EV charging is possible – three different sensitivities regarding the share of EVs with flexible charging capability have been implemented: 10%, 20% and 50%. Hereby, the assumption was made that the respective EV share with flexible charging can shift its load within a moving six hours time frame (for further details, see [14]). The target year of consideration is 2030.

For the simulation, 35 climate years and 20 different unplanned outage patterns – resulting in 700 Monte-Carlo years – have been chosen. For the ten Monte-Carlo years where the additional flexibility of the EV fleet displayed the most significant impact, the simulation output total system ENS per Monte-Carlo year and scenario is shown in the figure below.

	ENS Base Case	ENS 10% EV flexibility	ENS 20% EV flexibility	ENS 50% EV flexibility	ENS relative change compared to base case: 10% flexibility	ENS relative change compared to base case: 20% flexibility	ENS relative change compared to base case: 50% flexibility
592	522	370	224	0	0.291187700	0.570881200	1.000000000
533	1850	1627	1437	968	0.120540500	0.223243200	0.476756800
692	219	188	158	152	0.141552500	0.278538800	0.305936100
524	3832	3666	3504	3106	0.043319420	0.085594990	0.189457200
440	1124	1089	1055	970	0.031138790	0.061387900	0.137010700
242	11794	11463	11133	10387	0.028065120	0.056045450	0.119297900
555	3579	3481	3384	3191	0.027381950	0.054484490	0.108410200
368	7313	7158	7003	6578	0.021195130	0.042390260	0.100505900
557	14783	14425	14069	13346	0.024217010	0.048298720	0.097206250
695	7883	7721	7557	7179	0.020550550	0.041354810	0.089306100

Figure 9: Monte-Carlo years where additional flexibility provides the highest impact on ENS (descending order)

The results suggest that in certain tense situations the occurrence of ENS can be mitigated or even be prevented.

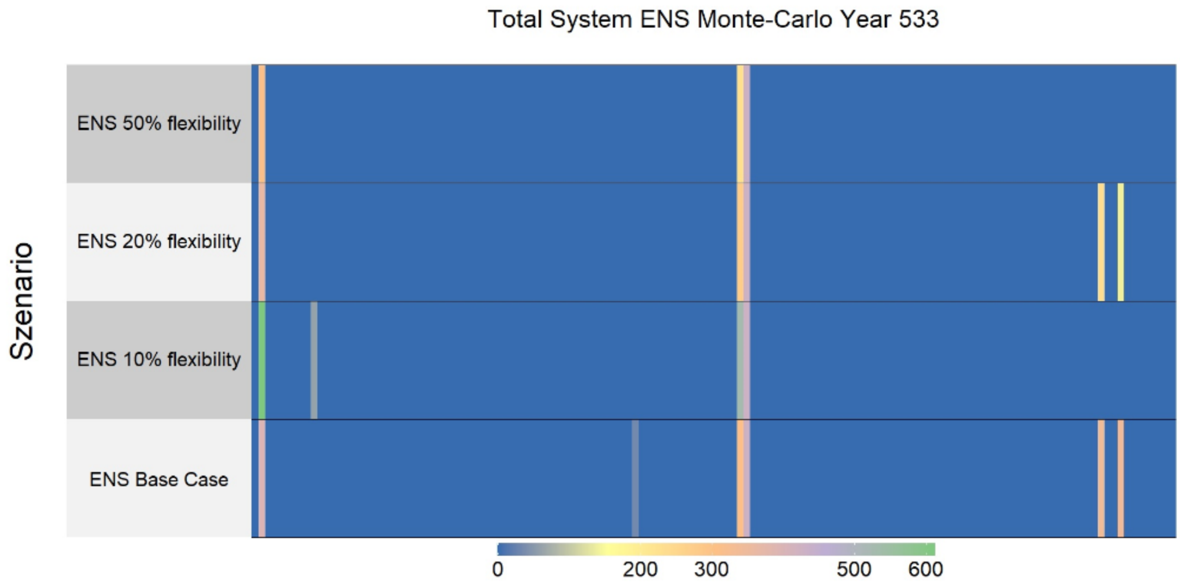

Figure 10: heatmap of ENS occurrence in Monte-Carlo year 533 (displayed are hours 680 to 820 of the target year)

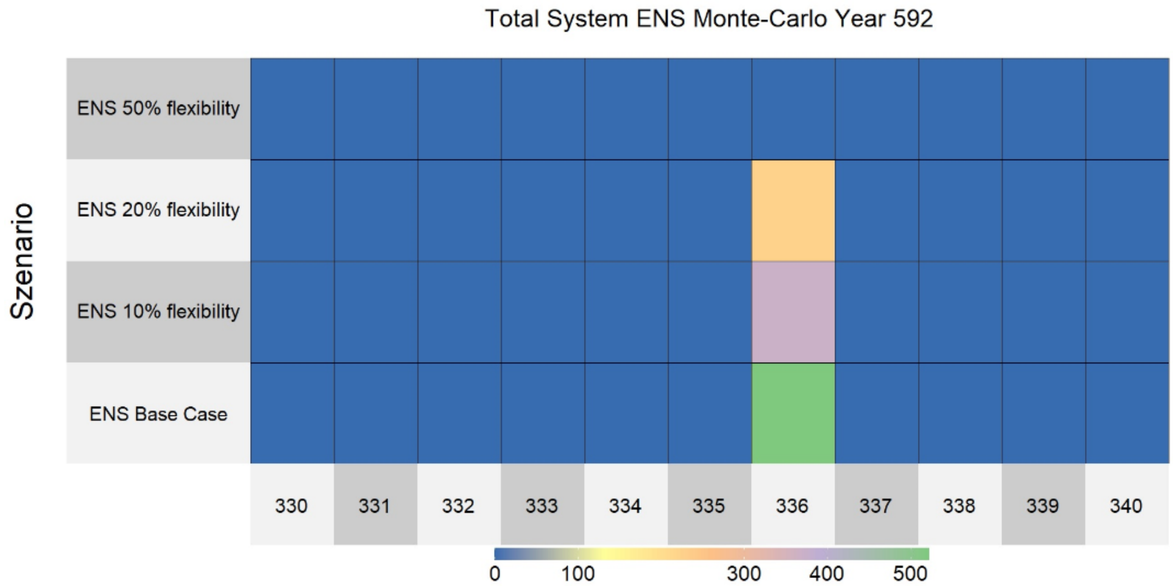

Figure 11: heatmap of ENS occurrence in Monte-Carlo year 592

In the heatmaps, the displayed time horizon was chosen such that all events of ENS occurrence throughout the target year is encompassed.

In interpreting the results above, the reader has to bear in mind that the values for ENS are only valid within the very specific framework of the test model. In particular, – due to the limited geographical scope of the model – these values **do not reflect or allow any conclusion on Austria's security of supply.** The scarcity situations in the simulations are purely artificial and completely created on purpose in order to assess the potential impact of different shares of price sensitive EVs on a stressed system.

4 Conclusions

By means of a trilateral test model, first insights on the impact of different penetration rates of price reactive EVs on security of supply could be gained. The results show that under certain circumstances, the additional flexibility can be utilized to mitigate or even prevent events of scarcity. However, since the overall system within the test model is – by its design – exposed to extended periods of scarcity which would not occur in a full ERAA model, the real “market behavior” of price reactive EVs could not be assessed adequately. Therefore, further investigations on a full European model need to follow. These investigations are part or the ongoing work within ENTSO-E and the TSOs’ experts.

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