

Study on the impact of electric vehicles' charging in the national load profile: an analysis on Portuguese power system

Ricardo Pastor, Ângelo Casaleiro, Gonçalo Glória,
Aleksandr Egorov
R&D NESTER
Sacavém, Portugal,
ricardo.pastor@rdnester.com

Linru Jiang
China Electric Power Research Institute
Beijing, Peoples' Republic of China

Abstract— The rapid adoption of electric vehicles (EVs) poses significant implications for national power grids, necessitating comprehensive analysis of future load impacts to guide energy planning and policy development. This study assesses the impact of EV charging on the national electricity load of Portugal using real-world datasets. EV charging behaviour is categorized into three distinct profiles: residential, workplace, and public charging. These classifications provide nuanced insights into daily and seasonal variations in energy demand.

Index Terms— Electric vehicles, Impact assessment, Load profile, Vehicle-to-Grid (V2G)

INTRODUCTION

The transition toward electric mobility is a cornerstone of global decarbonization efforts, driven by the urgent need to reduce greenhouse gas emissions and dependence on fossil fuels. Electric Vehicles (EVs) are rapidly transforming the transportation sector, with adoption rates steadily increasing due to advancements in battery technology, supportive government policies, and growing public awareness of environmental issues. However, the widespread deployment of EVs also presents significant challenges for power system operators, particularly regarding the impact of EV charging on electricity demand patterns and grid stability. As national grids were not originally designed to accommodate large-scale EV charging, understanding and mitigating these impacts is crucial for ensuring a reliable and efficient power supply [1], [2], [3]

In Portugal, the rising adoption of EVs is expected to reshape the national electricity load profile, with potential consequences for peak demand periods, energy distribution, and power quality. Unlike conventional loads, EVs introduce new variability into the system, as their charging behaviour depends on user preferences, electricity pricing, and infrastructure availability. Charging patterns can be categorized into three primary segments: residential charging, typically occurring during off-peak hours but potentially leading to increased demand at night; workplace charging, which coincides with daytime energy consumption and may interact

with solar energy generation; and public charging, which is often unpredictable and subject to user convenience and fast-charging needs. The interplay of these charging behaviours results in distinct daily and seasonal variations in electricity demand, posing challenges for grid management and necessitating the implementation of advanced demand response strategies [4], [5]. A key concern associated with EV proliferation is the potential strain on grid infrastructure. High penetration of EVs can lead to peak load intensification, increasing stress on critical components such as transformers and distribution feeders. This, in turn, may contribute to voltage instabilities, frequency fluctuations, and harmonic distortion, ultimately affecting overall power quality [6], [7]. Additionally, urban areas and commercial hubs are likely to experience localized charging demand surges, requiring targeted infrastructure enhancements to prevent congestion and supply disruptions. Without adequate planning, the increased load from EVs could necessitate costly grid reinforcements and upgrades, adding financial burdens to utilities and policymakers.

To address these challenges, smart charging solutions and Vehicle-to-Grid (V2G) technology have emerged as viable strategies for optimizing EV-grid interaction. V2G enables bidirectional energy exchange between EVs and the grid, transforming vehicles from passive consumers into active energy resources. By leveraging V2G, EVs can participate in ancillary services such as peak shaving, where stored energy is discharged to the grid during peak demand periods, thereby reducing stress on conventional power plants. Similarly, frequency regulation and voltage support can be provided by aggregating EVs into virtual power plants, enhancing grid stability and resilience [5], [8], [9], [10], [11]. Importantly, V2G also facilitates the integration of renewable energy sources (RES) by storing surplus electricity generated from solar and wind power, mitigating the intermittency of these resources and enabling a more sustainable energy ecosystem [12], [13], [14], [15].

In the Portuguese context, integrating V2G into the national grid holds significant promise for both grid management and energy sustainability. Research has demonstrated that controlled charging and discharging strategies can alleviate peak loads while enhancing the flexibility of the power system. For instance, pilot projects in the Azores and Madeira Archipelago have successfully demonstrated the feasibility of bidirectional energy flows, showcasing the potential of V2G in stabilizing islanded grids with high renewable penetration. These initiatives highlight the economic and environmental benefits of using EVs as distributed energy storage units, capable of balancing supply and demand dynamically.

This study aims to assess the impact of EV charging on Portugal’s national electricity load by analysing real-world datasets and evaluating different charging scenarios. By categorizing EV charging behaviour into residential, workplace, and public segments, this research seeks to provide a detailed understanding of how different usage patterns influence grid demand. Furthermore, the study explores the potential of demand-side management (DSM) strategies and smart charging mechanisms to mitigate adverse effects while maximizing the benefits of EV integration. The findings of this research will offer valuable insights for policymakers, grid operators, and energy planners, supporting the development of infrastructure adaptations, tariff structures, and regulatory frameworks necessary for the sustainable expansion of electric mobility in Portugal.

As the EV market continues to grow, a proactive approach to grid modernization and policy alignment will be essential to fully unlock the potential of EVs as both transport solutions and integral components of the future energy system. By implementing intelligent load management techniques, dynamic pricing schemes, and V2G-enabled solutions, Portugal can position itself as a leader in sustainable mobility, ensuring a seamless transition toward a low-carbon, resilient energy infrastructure.

METODOLOGY

The methodology in this study combines data-driven techniques and simulation-based analyses to assess the impact of EV adoption on grid performance and renewable energy integration. It consists of three key components: data cleaning, levelling and scaling of EV demand profiles, scaling of the Portuguese national demand profile, and scenario sensitivity analysis.

A. Data Cleaning, Levelling and Scaling of EV Demand Profiles

The first step involves creating standardized EV demand profiles that reflect variations in charging behaviour across residential, workplace, and public charging stations without the noise data resulting from abnormal or outliers. Historical charging data, categorized by time of day and seasonal factors, are cleaned by removing abnormal data and major outliers (e.g. charging sessions with duration greater than 24 hours). This process includes the calculation of the average power, for each dataset, per each 15-minute interval of the day (96 intervals), which corresponds to the data resolution, allowing to get a rescaling EV demand data accounting for variables such as

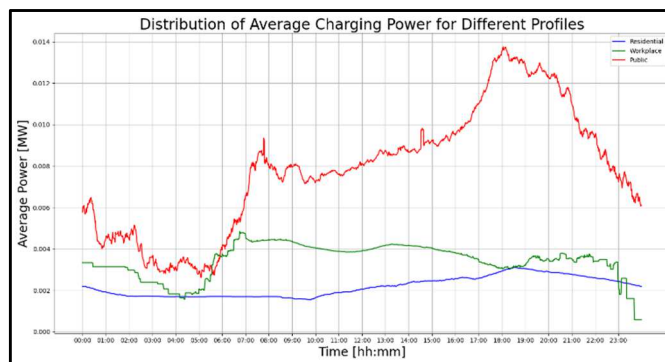


Figure 1. Distribution of Average Power Profiles for Residential, Workplace and Public Charging Stations

energy consumption per session and charging duration.

Due to the lack of data specific to Portugal, a dataset from Norway was used for the analysis of household charging stations[16]. This dataset includes information on how EV chargers behaved in residential buildings from 2018 to 2020.

While the observed charging patterns align with the expected behaviour of EV charging habits in Portugal, it is important to account for differences in peak hours between the two countries to ensure an accurate representation of Portuguese conditions. To address this, the data was adjusted with a two-hour shift, enhancing its applicability at the national level. The dataset includes information from both shared and private residential charging stations, with their charging behaviour illustrated in Figure 1. For the analysis of this charging profile, both types of residential charging stations will be considered together.

For the analysis of workplace charging stations, the "Workplace Charging Data" provided by the U.S. National Renewable Energy Laboratory (NREL) [17] will be used. This dataset includes information on all charging events at the NREL Campus up until October 2021. These data will be analysed to gain insights into charging behaviours at workplace charging stations. The average daily power consumption distribution is depicted in Figure 1.

The "Perth & Kinross UK Electric Vehicle Charging Station Usage" dataset [18] will be used to analyse public charging stations. This dataset includes statistics from 2016 to 2019 on public charging stations in Perth and Kinross, United Kingdom. The data provided by UK government aligns with European and Portuguese charging infrastructure settings.

The dataset is divided into three distinct subsets covering the periods: September 2016 to August 2017; September 2017 to August 2018; and September 2018 to August 2019. The subsets are illustrated in Figure 1. However, only data from September 2018 to August 2019 will be used, as it better reflects the current charging landscape and ensures the study remains up to date.

The presented preprocessing step ensures that the dataset accurately represents average EV behaviour while minimizing outliers. The profiles are then scaled proportionally to reflect projected EV adoption rates in Portugal, considering both low and high penetration scenarios. This approach enables a precise

estimation of the temporal and spatial distribution of charging demand.

During the analysis, two scenarios were considered regarding EV penetration, corresponding to the number of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) in the RMSA-e 2022 report [19]. These scenarios align with the EV Conservative Scenario (Table I) and the EV Ambitious Scenario (Table II), respectively.

B. Scaling of Portuguese National Demand Profile

To assess the grid-wide impact of EV charging, the processed EV demand profiles are integrated into the Portuguese national load profile. This process involves scaling the aggregated EV demand to align with population density, EV ownership projections, and infrastructure availability. Seasonal variations are also incorporated, accounting for higher electricity consumption in winter due to heating needs and in summer due to cooling loads. The resulting composite demand profile enables a comprehensive evaluation of the impact of EV penetration on peak load periods and overall energy consumption. The analysis also considers regional disparities in infrastructure development, including differences in urban and rural grid capacities.

Furthermore, according to RMSA-e 2022 estimates [19], national electricity demand is expected to increase compared to 2022 levels, following the trajectory outlined in Table III for each scenario. For the purpose of this study, two scenarios are considered: the *Conservative Central scenario* and the *Ambitious Upper scenario*, which represents an intermediate growth scenario and an upper-limit projection of demand growth, which can give us a perspective of the EV load impact according a more moderate or a more extreme national load growth scenario. For example, Figure 2 shows the evolution of the national load profiles for the *Conservative Central scenario*.

The final component of the methodology involves studying multiple scenarios to analyse the sensitivity of the power system to variations in EV penetration rates and charging behaviours. These scenarios are designed to capture diverse conditions, including seasonality (winter and summer) and charging location distribution (i.e., residential, workplace or public charging stations). Each scenario is evaluated under conservative and ambitious adoption targets, assessing the impact of EV load charging on the total national load diagram.

The sensitivity analysis provides insights into how charging behaviours and policy interventions may affect grid stability, renewable energy utilization, and infrastructure investment needs. Thus, in this study the following scenarios are considered:

- **Scenario 1:** Winter Peak load profile, Residential (75%), Workplace (15%), Public (10%)
- **Scenario 2:** Summer Peak load profile, Residential (75%), Workplace (15%), Public (10%)
- **Scenario 3:** Winter Peak load profile, Residential (40%), Workplace (30%), Public (30%)
- **Scenario 4:** Winter Peak load profile, Residential (60%), Workplace (35%), Public (5%)

TABLE I. EVOLUTION OF BEVs AND PHEVs FOR EV CONSERVATIVE SCENARIO

Year	Light Passengers				BEV light goods		Total	Percentage increase compared to 2021
	BEV		PHEV		N°	km (annual average)		
	N°	km (annual average)	N°	km (annual average in electric mode)				
2030	551000	13800	160000	5900	86000	12106	851000	812%
2035	973000	14587	210000	6000	163500	12474	1601000	1617%
2040	1158700	15130	250000	6000	231000	12702	2210200	2270%

TABLE II. EVOLUTION OF BEVs AND PHEVs FOR EV AMBITIOUS SCENARIO

Year	Light Passengers				BEV light goods		Total	Percentage increase compared to 2021
	BEV		PHEV		N°	km (annual average)		
	N°	km (annual average)	N°	km (annual average in electric mode)				
2030	937000	14456	450000	5900	313500	12106	2279500	2344%
2035	1629000	15686	400000	6000	550000	12474	3067000	3188%
2040	2109000	15892	340000	6000	728000	12702	3177000	3306%

TABLE III. NATIONAL DEMAND EVOLUTION

Year	Percentage increase in consumption compared to 2022			
	Conservative Lower Scenario	Conservative Central Scenario	Ambitious Central Scenario	Ambitious Upper Scenario
2030	18%	19%	35%	36%
2035	24%	26%	45%	47%
2040	28%	31%	52%	56%

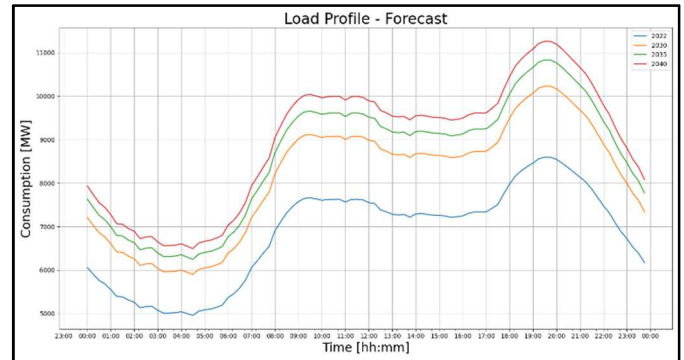


Figure 2. Portugal's National Load Profiles - Conservative Central Scenario

This methodology ensures a robust and adaptable framework for assessing the impact of EV adoption while supporting the development of strategies to enhance grid performance and promote sustainable energy transitions.

SIMULATION RESULTS

This section presents the results of the EV charging impact assessment, analysing how different charging profiles, namely residential, workplace, and public, and load evolution scenarios may impact the Portuguese power system, potentially affecting the grid's performance, peak load distribution, and renewable energy integration. The findings highlight variations in demand

patterns across different scenarios, considering seasonal influences and charging profiles' distributions.

A. Projections on Additional EV charging load at National Level

The projections presented in Table IV illustrate the substantial impact of EV adoption on Portugal's national electricity demand, with the additional EV load increasing significantly across all forecast periods. Table IV presents projections for additional EV load on the Portuguese national electricity grid under different EV penetration scenarios (*EV Conservative* and *EV Ambitious*, Table I and Table II, respectively), timeline horizons (2030, 2035, and 2040), and mixes of charging profiles (Scenario 1, Scenario 2, Scenario 3, and Scenario 4), described as follows.

Scenarios 1 and Scenario 2 emphasize residential charging (75% residential, 15% workplace, 10% public), in winter and summer season, respectively. These scenarios lead to a more gradual increase in grid demand but higher evening peak loads when people return home and charge overnight in winter and summer season, respectively.

Scenario 3 distributes charging more evenly (40% residential, 30% workplace, 30% public), resulting in the highest total load projections, especially for public charging, which adds substantial demand.

Scenario 4 balances residential (60%) and workplace (35%) charging, leading to a more moderate load increase, with lower reliance on public charging (5%).

Under the *EV Conservative scenario*, total additional EV demand in Scenarios 1 & 2 is expected to reach 1974 MW by 2040, while in the *EV Ambitious scenario*, this value rises to 2837 MW. The highest total demand is observed in Scenario 3, with the *EV Conservative scenario* reaching 4049 MW and the *EV Ambitious scenario* reaching 5821 MW by 2040. These projections highlight the necessity for robust grid planning, especially considering that public charging infrastructure contributes the most significant share of this demand in Scenario 3, exceeding 4705 MW under the *EV Ambitious* 2040 projection.

The percentage of EV charging locations plays a critical role in determining the peak load patterns and grid stress points. In Scenario 1 & 2, where 75% of charging occurs at residential locations, demand from home charging alone reaches 675 MW (*EV Conservative*) and 970 MW (*EV Ambitious*) in 2040. This concentration in evening hours could lead to grid congestion unless demand response mechanisms and smart charging strategies are implemented. Conversely, Scenario 3, which allocates 30% of charging to public stations, results in the highest public charging load of 3274 MW (*EV Conservative*) and 4706 MW (*EV Ambitious*) in 2040. This increase presents a challenge for urban grid infrastructure, as high-power fast chargers require substantial capacity, emphasizing the need for reinforced substations and energy storage solutions in key locations.

The growth of workplace charging, particularly in Scenario 4, further indicates the potential for load balancing during daylight hours. By 2040, workplace charging demand

TABLE IV. PROJECTIONS ON ADDITIONAL EV CHARGING LOAD

		Additional EV charging Load [MW]						
		EV Conservative Scenario			EV Ambitious Scenario			
		2030	2035	2040	2030	2035	2040	
Scenarios 1 & 2	Profile	% of EV						
	Residential	75%	260	489	675	696	936	970
	Work	15%	80	151	208	214	289	299
	Public	10%	420	790	1091	1125	1514	1569
All		100%	760	1430	1974	2036	2739	2838
Scenario 3	Residential	40%	139	261	360	371	499	517
	Work	30%	160	301	416	429	577	598
	Public	30%	1261	2371	3274	3376	4543	4706
	All	100%	1559	2933	4050	4177	5619	5821
Scenario 4	Residential	60%	208	391	540	557	749	776
	Work	35%	187	351	485	500	673	697
	Public	5%	210	395	546	563	757	784
	All	100%	605	1138	1571	1620	2180	2258

TABLE V. SUMMARY OF THE SIMULATION RESULTS

Scenarios	EV Load Scenario	National Load Scenario	2030 Peak Total Load [MW]	2030 Peak EV Load [MW]	2035 Peak Total Load [MW]	2035 Peak EV Load [MW]	2040 Peak Total Load [MW]	2040 Peak EV Load [MW]
Scenario 1	Conservative	Cons. Central.	10 887	684	12 069	1 288	12 970	1 777
		Ambitious Upper	12 348		13 874		15 119	
	Ambitious	Cons. Central.	11 993	1 833	13 204	2 467	13 719	2 555
		Ambitious Upper	13 454		15 009		15 868	
Scenario 2	Conservative	Cons. Central.	9 939	684	10 990	1 288	11 790	1 777
		Ambitious Upper	11 277		12 644		13 758	
	Ambitious	Cons. Central.	10 891	1 833	11 967	2 467	12 434	2 555
		Ambitious Upper	12 230		13 621		14 403	
Scenario 3	Conservative	Cons. Central.	11 336	1 157	12 914	2 177	14 137	3 005
		Ambitious Upper	12 797		14 719		16 286	
	Ambitious	Cons. Central.	13 196	3 099	14 822	4 170	15 395	4 319
		Ambitious Upper	14 657		16 627		17 544	
Scenario 4	Conservative	Cons. Central.	10 744	524	11 800	985	12 599	1 360
		Ambitious Upper	12 205		13 605		14 748	
	Ambitious	Cons. Central.	11 609	1 403	12 688	1 888	13 185	1 955
		Ambitious Upper	13 070		14 493		15 333	

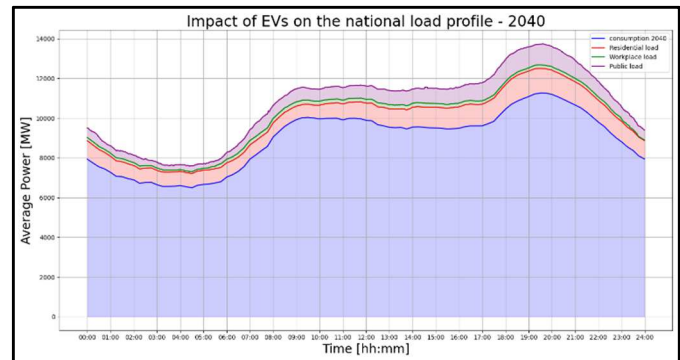


Figure 3. Total national load profile – Scenario 1 – Conservative Central Scenario – EV Ambitious – 2040

reaches 485 MW (*EV Conservative*) and 697 MW (*EV Ambitious*) in this scenario, which is beneficial for aligning EV demand with solar energy generation. However, if high public charging demand materializes as in Scenario 3, Portugal may face grid instability in high-traffic urban areas, necessitating advanced grid reinforcement, flexible tariff structures, and the integration of vehicle-to-grid (V2G) technology.

Overall, Table IV underscores the need for targeted infrastructure investments, grid modernization, and strategic energy policies to support large-scale EV adoption. The disparity between Scenario 1 & 2 moderate 2040 demand of 2837 MW and Scenario 3 peak demand of 5821 MW indicates a wide range of potential grid impacts, reinforcing the importance of scenario-based energy planning.

The increasing reliance on public and workplace charging solutions further calls for smart charging initiatives and real-time grid management tools to optimize load distribution and ensure a grid-wise safe decarbonization of transportation sector.

B. Analysis of EV Charging Impact on Peak Load

The way how different EV charging scenarios impact national peak load from 2030 to 2040 under both conservative and ambitious scenarios is presented in Table V. Additionally, Figure 3 to Figure 6 illustrate the impact on the Total National Load profile for the four EV adoption scenarios under analysis, considering the National Load Conservative Central Scenario and the EV Ambitious scenario for the year 2040, for comparison. Each scenario under analysis varies based on the distribution of residential, workplace, and public charging, affecting both peak EV load and total grid demand.

1) Scenario 1: Winter, 75% Residential, 15% Workplace, 10% Public

The EV conservative scenario, peak EV load grows from 684 MW in 2030 to 1,777 MW in 2040, while total grid demand reaches 12,970 MW. The EV ambitious scenario shows significantly higher EV penetration, with total load increasing to 15,119 MW by 2040, suggesting the need for mid-term grid reinforcements. The predominance of residential charging leads to a high evening peak load, which might stress distribution networks. We can observe already some significantly impact on the national load diagram for the EV Conservative scenario in 2030, in which EV consumption contributes with a total of 11.1 GWh per day. The simulations indicate that for the load diagram in the EV Ambitious scenario for 2040, EV contribution can go even higher reaching 41.6 GWh per day.

2) Scenario 2: Summer, 75% Residential, 15% Workplace, 10% Public

This scenario presents a lower total demand compared to Scenario 1 due to the smaller national load profile that Portugal presents in summer. Nevertheless, the peak demand still reaches 11,790 MW in the EV and National Load Conservative scenarios. The EV Ambitious scenario the national peak load reaches 14,403 MW, which is still lower than the winter case, benefiting from alignment of the EV charging and the solar energy generation.

3) Scenario 3: Winter, 40% Residential, 30% Workplace, 30% Public

This scenario is characterized by a more balanced share of charging profiles which ultimately results in a higher level of peak demand, specially in 2040, where the impact of public charging rises the peak load from 11,336 MW in the EV and National Load Conservative scenarios in 2030 to 17,544 MW in the EV and National Load Ambitious scenarios, rising the EV peak load up to 4,319 MW in the later. This highlights the potential impact on the Portuguese system and emergence need for demand-side management solutions. For the EV Conservative scenario in 2030 the EV charging contributes with a total of 17.8 GWh per day. The simulations indicate that the load diagram in the Ambitious scenario for 2040 can go even higher reaching 66.5 GWh per day.

4) Scenario 4: Winter, 60% Residential, 35% Workplace, 5% Public

This scenario is characterized by a lower component of public charging, leading to a peak EV load reaching 1,360 MW (*EV Conservative*) and 1,955 MW (*EV Ambitious*) by 2040. The total national demand remains lower than in Scenario 3, peaking at 15,333 MW in 2040 in the EV and National Load Ambitious scenarios. This seems to suggest that lower levels of public charging can contribute for the reduction of the peak load congestion.

CONCLUSIONS

The results highlight that EV charging can significantly impact Portugal's peak demand, especially under ambitious EV adoption scenarios. To mitigate grid stress and enhance renewable energy integration, a combination of technical, regulatory, and market-driven strategies should be considered.

A. Key takeaways

Scenario 3 has the highest peak loads, indicating that increased public charging can shift demand away from residential peaks. Summer scenario (Scenario 2) suggests lower stress on the grid, benefiting from solar energy availability. Ambitious EV penetration scenarios double or even triple peak EV load, requiring enhanced grid capacity and smart charging strategies.

B. Possible Mitigation strategies and recommendations

Smart Charging Infrastructure: Implementing intelligent charging systems that delay or adjust charging rates based on grid load and economical signals can help smooth out demand fluctuations and reduce demand peak load.

Vehicle-to-Grid: EVs, through V2G technology, can support renewable energy integration by offering services like reactive power compensation, congestion management or frequency regulation.

Incentivizing Workplace Charging: As seen in Scenario 2, workplace charging better aligns with solar energy availability. Policies promoting daytime charging at workplaces could help flatten peak loads minimizing grid stress while maximizing renewable utilization.

ACKNOWLEDGMENT

This work was supported by the State Grid Technology Project “China-Portugal electric vehicle charging adjustable potential mining and vehicle network interactive big data analysis technology research” (5108-202218280A-2-261-XG) from State Grid Corporation of China.

REFERENCES

[1] Till Bunsen *et al.*, “Global EV Outlook 2019 Scaling-up the transition to electric mobility,” *OECD iea.org*, p. 232, 2019, [Online]. Available: www.iea.org/publications/reports/globalevoutlook2019/

[2] ENTSO-E, “ENTSO-E Position Paper on Electric Vehicle Integration into Power Grids,” Mar. 2021.

[3] R. C. Green, L. Wang, and M. Alam, “The impact of plug-in hybrid electric vehicles on distribution networks: A review and outlook,” *Renewable and Sustainable Energy Reviews*, vol. 15, no. 1, pp. 544–553, Jan. 2011, doi: 10.1016/j.rser.2010.08.015.

[4] M. Zweistra, S. Janssen, and F. Geerts, “Large scale smart charging of electric vehicles in practice,” *Energies (Basel)*, vol. 13, no. 2, 2020, doi: 10.3390/en13020298.

[5] P. B. Andersen, S. Hashemi, C. Treholt, N. B. Arias, and R. Romero, “Distribution System Services Provided by Electric Vehicles: Recent Status, Challenges, and Future Prospects,” *IEEE Transactions on Intelligent Transportation Systems*, pp. 1–20, 2019, doi: 10.1109/tits.2018.2889439.

[6] Á. Casaleiro, R. Amaro e Silva, B. Teixeira, and J. M. Serra, “Experimental assessment and model validation of power quality parameters for vehicle-to-grid systems,” *Electric Power Systems Research*, vol. 191, p. 106891, Feb. 2021, doi: 10.1016/j.epr.2020.106891.

[7] J. C. Hernández, F. Sanchez-Sutil, P. G. Vidal, and C. Rus-Casas, “Primary frequency control and dynamic grid support for vehicle-to-grid in transmission systems,” *International Journal of Electrical Power and Energy Systems*, vol. 100, no. February, pp. 152–166, 2018, doi: 10.1016/j.ijepes.2018.02.019.

[8] N. Daina, A. Sivakumar, and J. W. Polak, “Electric vehicle charging choices: Modelling and implications for smart charging services,” *Transp Res Part C Emerg Technol*, vol. 81, pp. 36–56, 2017, doi: 10.1016/j.trc.2017.05.006.

[9] P. B. Andersen, S. Hashemi, T. Sousa, T. M. Soerensen, L. Noel, and B. Christensen, “Cross-brand validation of grid services using V2G-enabled vehicles in the Parker Project,” *Proceedings of 31st International Electric Vehicles Symposium & Exhibition & International Electric Vehicle Technology Conference IEEE*, 2018.

[10] T. Brandt, S. Wagner, and D. Neumann, “Evaluating a business model for vehicle-grid integration: Evidence from Germany,” *Transp Res D Transp Environ*, vol. 50, pp. 488–504, 2017, doi: 10.1016/j.trd.2016.11.017.

[11] S. S. Ravi and M. Aziz, “Utilization of Electric Vehicles for Vehicle-to-Grid Services: Progress and Perspectives,” *Energies (Basel)*, vol. 15, no. 2, p. 589, Jan. 2022, doi: 10.3390/en15020589.

[12] C. Ahn, C.-T. Li, and H. Peng, “Optimal decentralized charging control algorithm for electrified vehicles connected to smart grid,” *J Power Sources*, vol. 196, no. 23, pp. 10369–10379, Dec. 2011, doi: 10.1016/j.jpowsour.2011.06.093.

[13] P. Danner, W. Duschl, D. Danner, A. Alyousef, and H. de Meer, “Flexibility Reward Scheme for Grid-Friendly Electric Vehicle Charging in the Distribution Power Grid,” in *Proceedings of the Ninth International Conference on Future Energy Systems*, New York, NY, USA: ACM, Jun. 2018, pp. 564–569. doi: 10.1145/3208903.3213893.

[14] Y. Ota, H. Taniguchi, H. Suzuki, J. Baba, and A. Yokoyama, “Aggregated storage strategy of electric vehicles combining scheduled charging and V2G,” *2014 IEEE PES Innovative Smart Grid Technologies Conference, ISGT 2014*, pp. 1–5, 2014, doi: 10.1109/ISGT.2014.6816409.

[15] K. M. Tan, V. K. Ramachandaramurthy, and J. Y. Yong, “Integration of electric vehicles in smart grid: A review on vehicle to grid technologies and optimization techniques,” *Renewable and*

Sustainable Energy Reviews, vol. 53, pp. 720–732, Jan. 2016, doi: 10.1016/j.rser.2015.09.012.

[16] Å. L. Sørensen, K. B. Lindberg, I. Sartori, and I. Andresen, “Analysis of residential EV energy flexibility potential based on real-world charging reports and smart meter data,” *Energy Build*, vol. 241, p. 110923, Jun. 2021, doi: 10.1016/j.enbuild.2021.110923.

[17] C. Neuman, Andrew Meintz, and Myungsoo Jun, “Workplace Charging Data,” Dec. 2022.

[18] Perth and Kinross Council, “Electric Vehicle Charging Station Usage.,” Dec. 2021.

[19] DGEG and REN, “Relatório de Monitorização da Segurança de Abastecimento do Sistema Elétrico Nacional 2023-2040 (RMSA-E 2022),” Oct. 2022. Accessed: Jun. 11, 2024. [Online]. Available: [Relatório de Monitorização da Segurança de Abastecimento do Sistema Elétrico Nacional 2023-2040 \(RMSA-E 2022\)](https://www.dgeg.pt/pt/abastecimento/seguranca-de-abastecimento)

APPENDIX

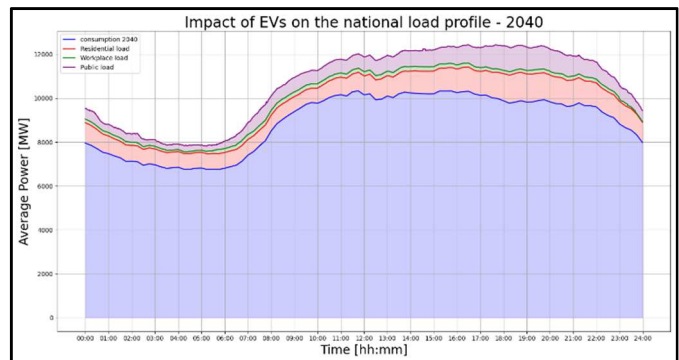


Figure 4. Total national load profile – Scenario 2 – Conservative Central – EV Ambitious – 2040

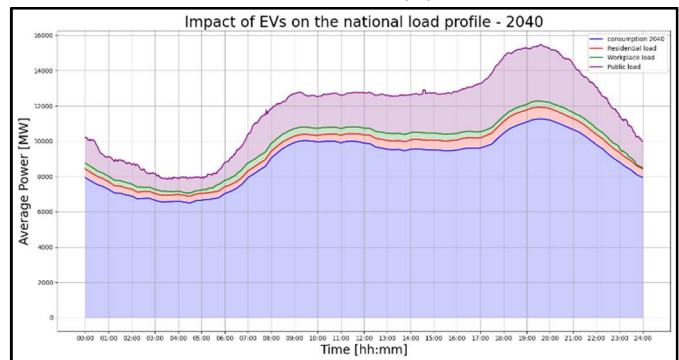


Figure 5. Total national load profile – Scenario 3 – Conservative Central – EV Ambitious – 2040

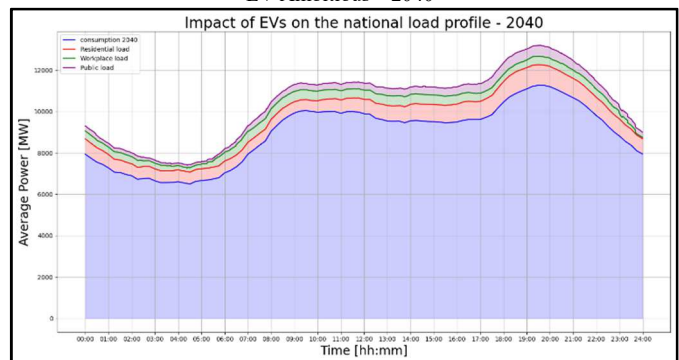


Figure 6. Total national load profile – Scenario 4 – Conservative Central – EV Ambitious – 2040