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Electric vehicles growth until 2030: Impact on the distribution network power

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Abstract

In the coming years, we will witness a change in the current car fleet sales, from traditional fuel engines towards electrical vehicles (EVs), particularly passenger light-duty vehicles. They plug into the grid and store the electricity in rechargeable batteries; therefore, the widespread adoption of EVs will bring many challenges for the distribution network. Forecasting the impact of EVs on distribution networks is a difficult task given the uncertainty on the potential evolution of their sales.

This study forecasts the EVs sales growth for the 2020–2030 decade in 3 possible evolution scenarios, carried out for a given Portuguese regional area. The demanded energy for charging the batteries was estimated, considering one long and one short route. The analysis was applied to three EVs models: Nissan Leaf, Tesla Model 3, and Renault Zoe. Their impacts on the rated power of the distribution network are calculated for the three scenarios, and the results are presented, standing out the insufficient power at peak hours.

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Keywords: Car fleet; Charging batteries; Distribution network; Energy consumption; EVs growth; Power balance

1. Introduction

The transportation sector is one of the heaviest contributors to harmful emissions. With the global shift towards low-carbon and sustainable energy actions already underway, the electric mobility (e-mobility) strategy aims to accelerate the transition to low (and zero) emission vehicles.

In the last decade, we have witnessed the movement towards the adoption of electric vehicles (EVs), referring to vehicles that rely on plug-in electricity for their primary energy. It is about plugging into a home charging point, taking electricity from the distribution grid, and storing it in rechargeable batteries that power the electric motor. According [1] an affordable charge infrastructure is essential for the EVs widespread adoption.

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Several researchers have explored EVs charging activities and their impacts on residential and distribution networks, as [2], as well as [3]. Also, technical and scientific works have been published, disseminating strategies and methodologies for analyzing and assessing the batteries' behavior, as seen in [4] and [5]. The studies' focus can range from the maximization of the battery operation itself to the minimization of environmental impacts, presenting significant results to: minimize load peaks, flattening the load profile, and maximizing the integration of renewables, seen in [6] and [7].

At present, EVs sales growth is a reality all over the world, as reported by Kühnbach et al. [8]. However, the purchase of an EVs is not yet within everyone's financial reach, due to factors such as high initial cost, battery degradation, or inadequate charge infrastructure, according to [9].

Nevertheless, e-mobility has reached a point of no return. As more models become available and prices decrease, EVs purchases increase, reaching a broader swath of the vehicle-owning population, encompassing more than 10% of sales by 2025 and 20 to 30% of sales by 2030, stated by Hoover et al. [10].

Although the transition to EVs is inevitable, its massive penetration will, undoubtedly, impact energy system management, mainly, in distribution networks. From technical and cybersecurity concerns to economic and social impacts, many issues have been addressed by several researchers, as [11,12] and [13]. A large number of studies have already considered the consequences of a high EVs penetration into the electricity market as [14] and [15], in terms of additional electrical load, and surges in demand at peak hours and security of the distribution grids by Anastasiadis et al. [16]. Some authors present methodologies to limit the maximum power to be extracted from the grid to recharge EVs, seen in [17] and [18].

This paper aims to forecast the EVs increase over the 2020–2030 decade and their energy consumption analysis for two pattern routes (short and long-distance), applied in the top 3 EVs brands best-selling in Portugal: Nissan Leaf, Tesla Model 3, and Renault Zoe.

The impact of the growing EVs fleet on a regional Portuguese distribution network is assessed, particularly the influence of the load demand increase on the installed rated power.

In Section 2, we analyze the existing EVs fleet. According to the population evolution over the next decade, their forecast sales and percentage in global car fleet are projected in 3 developing scenarios. In Section 3 we evaluate the EVs growth impact on a regional grid and analyze the power balance, presenting results for peak and off-peak hours. We conclude in Section 4.

2. Electric vehicles in Portugal by 2030

To support this study, it was necessary first to ascertain the current EVs market situation in Portugal, and the population growth rate and the EVs sales development forecast, between 2020 and 2030. The study was applied to a regional low voltage network, the north area of Ave, Tâmega, and Sousa, and we analyze the impact of the EVs increase on the installed power at peak and off-peak hours. This LV network covers twenty municipalities, including both urban and rural areas.

For this research, we consider 100% electric vehicles, with a *wallbox* battery charging system.

2.1. Market outlook

The electric car industry is still young but overgrowing. Each year, we have seen automakers adding more EVs to their lineup and marketing new EVs brands.

In Portugal, some brands stand out in the market; among the best-selling we find Nissan Leaf, Tesla Model 3, and Renault Zoe, those getting the first three places from the top 10 list, according [19].

All the updated information and reliable databased from the automobile sector used in this study was obtained by the ACAP — Portuguese Automobile Association [20] and the UVE — Association of users of Electric Vehicles [21]. By gathering information from these entities, it was possible to analyze the development of EVs sold and the cumulated EVs fleet evolution from 2015 to the present, as seen in Fig. 1. This information is essential for this work, providing a significant basis to project the car fleet growth rate up to 2030.

In the coming decade, the Portuguese government has drawn up a forecast based on two projections published in the 'National Energy and Climate Plan' document (2019) [22]. One projection states that the number of EVs sold by 2030 will account for 1/3 of sales from the passenger car fleet. The other projection states that the EVs fleet will represent 20% of the total amount of passenger light-duty vehicles by 2030. These two projections, with a further one based on existing data, will set up the assumptions for this work conclusive analysis.

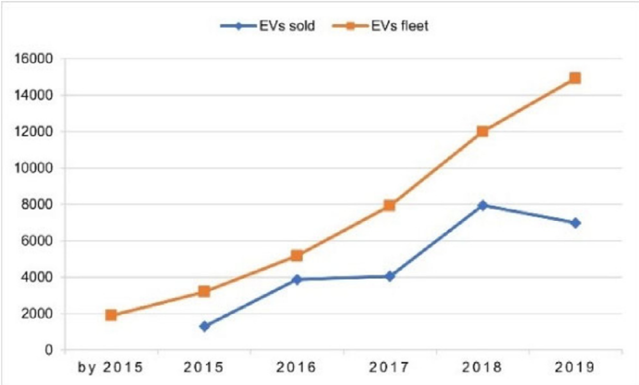

Fig. 1. EVs market in Portugal.

2.2. EVs forecast in 3 projections

To properly study the EVs impact on the distribution grid for the 2020–2030 decade, it is necessary first to analyze their expected increase in sales and their weight in the car fleet. For that, some factors should be considered, such as: population index evolution, existing vehicles, selling prices, market supply, and acquisition incentives, among others. Due to the difficulty in predicting all those factors and the way they interact, we will present the EVs evolution between 2020 and 2030 in 3 projections [23]:

Projection 1 - based on the existing EVs data projected for the evolution of the population in the described geographical region

Projection 2 – EVs account for 1/3 of total sales in 2030

Projection 3 – EVs account for 20% of the car fleet in 2030

To support those projections, we calculate the population evolution up to 2030, for the country and the described north region of Portugal. The calculation of the regional population evolution up to 2030 was based on the national standards, according to municipalities own evolution, collected from contemporary Portugal database, PORDATA official body [24].

About the car fleet development for the next decade, the data used in this work was also gathered from official bodies; it comes from the IMT — Institute of Mobility and Transport [25] and the ARAN — National Automotive Association [26]. With that reliable information based on the existing data between 2010 and 2018, the forecast for the passenger car fleet and increase in sales are calculated and presented in Table 1.

The predicted information about the population and the passenger car fleet, are the necessary inputs to calculate the EVs forecast sales up to 2030. With these previous calculations carried out, we can elaborate the three projections mentioned above for the EVs development.

For Projection 1, we use data from Fig. 1, namely, the EVs sales rate between 2016 and 2018. We took this option because we consider that EVs sales market before 2016 is not consistent data for the future, and 2019–2020 was an atypical period. About the influence COVID-19, for public charging energy dropped by 40%, but for individual charging it remains fairly constant according [27].

In this regard, the results for Projection 1, results were taken from Eq. (1).

$$PROJECTION\,1_{(n)} = CFt_{(n-1)} + \left(Sal_{(n-1)} \times \frac{\sum_{2016}^{2018} \frac{Sal_{(n)}}{Sal_{(n-1)}}}{3} \right) \tag{1}$$

For the other two projections, we use the information in Table 1 to identify the EVs growth rate in a way to match the pre-announced amounts for Projection 2 and Projection 3. From the 2018 starting point to 2030, we calculate the EVs annual growth in Portugal, as shown in Table 2. At the end of the forecast, in the table's last row, we can check the results pointing to precisely 1/3 of sales in Projection 2, and 20% from the global car fleet in Projection 3.

Table 1. Car Fleet and Sales by 2030.

Year	Sales (Sal)	Car Fleet (CFt)
2020	246 824	5 455 312
2021	255 649	5 543 580
2022	264 790	5 633 276
2023	274 258	5 724 424
2024	284 064	5 817 046
2025	294 221	5 911 167
2026	304 741	6 006 811
2027	315 637	6 104 002
2028	326 923	6 202 766
2029	338 612	6 303 128
2030	350 719	6 405 114

Table 2. EVs Evolution in 3 Projection.

Year	Projection 1 From existing data	Projection 2 1/3 Sales in 2030			Projection 3 20% from car fleet in 2030	
	EVs	EVs	Sales	EVs in sales	EVs	EVs in car fleet
2018		12 000	4 073	1,77%	12 000	0,23%
2019		22 486	10 486	4,40%	100 652	1,87%
2020	19 209	39 838	17 352	7,03%	192 170	3,52%
2021	25 469	64 534	24 696	9,66%	286 623	5,17%
2022	34 623	97 078	32 543	12,29%	384 082	6,82%
2023	48 007	137 997	40 920	14,92%	484 620	8,47%
2024	67 578	187 851	49 854	17,55%	588 311	10,11%
2025	96 194	247 225	59 374	21,18%	695 231	11,76%
2026	138 037	316 737	69 512	22,81%	805 456	13,41%
2027	199 219	397 035	80 298	25,44%	919 067	15,06%
2028	288 680	488 802	91 767	28,07%	1 036 143	16,70%
2029	419 489	592 756	103 954	30,70%	1 156 767	18,35%
2030	610 759	709 651	116 895	**33,33%**	1 281 023	**20,00%**

2.3. EVs regional profile

Regarding to the three previous projections seen in Table 2, and the population evolution, we calculate the number of EVs in the region over the next decade. For the three growth perspectives, we plot 3 scenarios for the area, each one is taken by multiplying the EVs value per capita in Portugal by the region population index; the results are plotted in Fig. 2.

Those scenarios classified as 1, 2 and 3, correspond to pessimistic, mid-range and optimistic forecasts. For each scenario, evaluate the power required to charge the EVs all over the ongoing years.

The demanded energy from the distribution network by EVs depends on the individual uses. Still, we can point to an average daily route based on two different courses: a short (city tour) and a long course (inter-city tour). The short way is about a daily 30 km round trip within the town, at an average speed of 50 km/h. The long way is a daily 94 km round trip on the highway, at an average rate of 100 km/h.

To evaluate the EVs demanded energy from the grid is important to be aware, not only of the daily route but, also of the technical characteristics of each vehicle. In this study, the analysis was applied to the top 3 EVs best-selling in Portugal: Nissan Leaf, Tesla Model 3, and Renault Zoe. The daily required energy is presented in Table 3, for the described situations.

The daily consumption was calculated for the long and short routes, and the average distance. However, each vehicle has its representativity in sales, according to the "weighting factor" variable stated in Table 3. Considering that, the "weighted energy" is calculated, achieving the value 8776 Wh for the daily EVs consumption for the region under study.

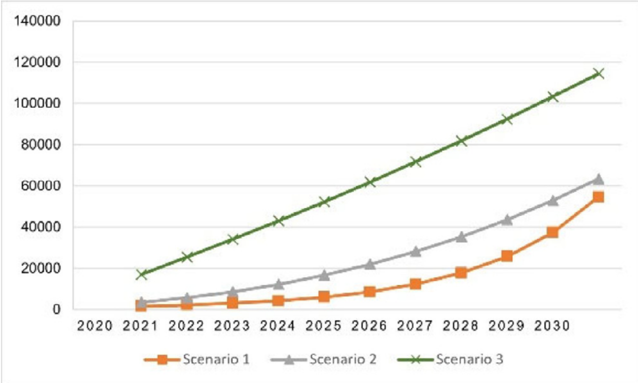

Fig. 2. EVs quantity in the region.

Table 3. Daily average energy consumption in the region.

Energy [Wh]				
	Nissan Leaf	Tesla Model 3	Renault Zoe	Total
Long route	14 974	16 088	13 908	44 970
Short route	2 376	2 595	2 261	7 232
Average trip	8 675	9 342	8 085	26 101
Weighting factor	42,2%	35,2%	22,3%	100%
Weighted energy	3 663	3 289	1 825	**8 776**
Charging: 7,4 kW – 32 A (*wallbox*)				
Total battery capacity	40 kW	74 kW	41 kW	
60% of battery capacity	24 kWh	44,4 kWh	24,6 kWh	
Usage with 8776 Wh/day	2,73 days	5,06 days	2,8 days	
Charging time (60%)	3:15 h	6:00 h	3:20 h	
Charging time (8776 Wh)	1:15 h	1:15 h	1:15 h	

That is a reference value for each we flag the charging time to compare with the other charging profiles. According to the daily route taken and the EVs features, some vehicles may, or may not, need a charge once a day.

In order to extend a battery life span, it should not discharge below 20% and charge above 80%. With this in mind, we consider the 60% charging as the net capacity [23].

For the presented results, we assume that the owner charges the battery when it has reached its minimum. Hereby, it is calculated the number of days for which it is possible to satisfy the average daily energy. Taking that into account and the daily energy values we got, we reach the time results of about 1:15 h for a minimum charging and 6 h for the maximum charging.

3. Impact on power rating

In this section, we are going to analyze the EVs charging impact on region distribution network for the three scenarios described above. For a typical day's work, we will see how the EVs charging shake on the grid-rated power, both at peak and off-peak hours.

For these calculations, it was considered that batteries charge by a *wallbox* 7,4 kW (single-phase), which implies having a home contracted (installed) power of 10,35 kVA, the standard rating to meet the required current of 32 A.

The impact on power is assessed in terms of power balance, which means it is calculated by subtracting the sum of EVs necessary installed power from the available installed capacity for charging.

3.1. Results for peak hours

This time concerns the period between 8 am and 10 pm, a time range of higher energy consumption, less available power. For the three scenarios, we can see in Fig. 3 the region's power balance from now to 2030. The results show us that, with the current grid capacity power, the EVs charging on peak hours will be possible only in scenarios 1 and 2. If the EVs growth follows the scenario 3 pattern, the grid will only last until 2026.

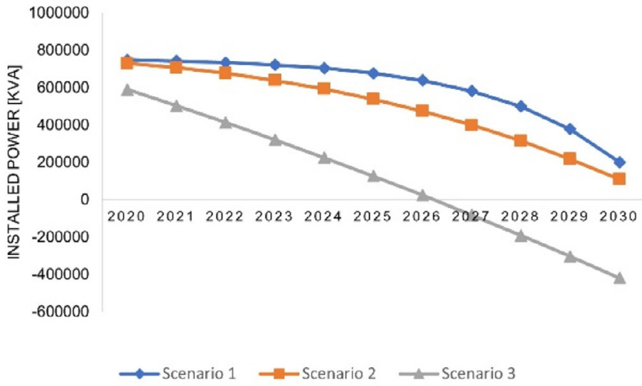

Fig. 3. Power balance at peak hours.

3.2. Results for off-peak hours

This period is set out from 10 pm to 8 am, corresponding to window time with lower energy consumption, so, more power available to charge batteries, even to guarantee the maximum charging time (6 h). By encouraging the EVs charging in off-peak hours, even though the network will withstand for two more years in scenario 3, seen in Fig. 4.

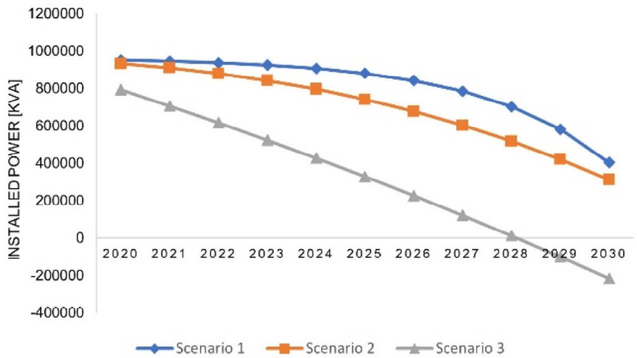

Fig. 4. Power balance at off- peak hours.

4. Conclusion

Distribution systems in Portugal face an important challenge: the oncoming mass penetration of electric vehicles for the next decade. Many questions arise about the distribution network's ability to support the increased energy consumption demanded by the growing EVs. Major congestion problems may appear, notably, if the battery charging period coincides with the higher energy demand hours.

From the study for this particular region, we conclude that the installed power on the low voltage network will not stand for the projection 3, even for the charging in off-peak hours.

That situation is replicated in many other regional networks and can become too dramatic in some urban areas. Some distribution network operators have already carried out for the strengthening network infrastructure, assembling for 95 mm^2 cross-section conductors and circuits are reconfigured to minimize network voltage drops.

This study has shown that distribution network reinforcement is urgently needed, because the EVs growth is a reality for the near future and its impact will be felt soon.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] Qu Z, Zhang S. References to literature from the business sector in patent documents: a case study of charging technologies for electric vehicles. Scientometrics 2020;124(2):867–86. http://dx.doi.org/10.1007/s11192-020-03518-1.
[2] Bastida-Molina P, Hurtado-Pérez E, Pérez-Navarro Á, Alfonso-Solar D. Light electric vehicle charging strategy for low impact on the grid. Environ Sci Pollut Res 2021;28(15):18790–806. http://dx.doi.org/10.1007/s11356-020-08901-2.
[3] Deilami S, Muyeen SM. An insight into practical solutions for electric vehicle charging in smart grid. Energies 2020;13(7):1545. http://dx.doi.org/10.3390/en13071545.
[4] Infante W, Ma J. Coordinated management and ratio assessment of electric vehicle charging facilities. IEEE Trans Ind Appl 2020;56(5):5955–62. http://dx.doi.org/10.1109/TIA.2020.2987773.
[5] Liu X, Zhao T, Yao S, Soh CB, Wang P. Distributed operation management of battery swapping-charging systems. IEEE Trans Smart Grid 2019;10(5):5320–33. http://dx.doi.org/10.1109/TSG.2018.2880449.
[6] Delgado J, Faria R, Moura P, de Almeida AT. Impacts of plug-in electric vehicles in the Portuguese electrical grid. Transp Res D: Transp Environ 2018;62:372–85. http://dx.doi.org/10.1016/j.trd.2018.03.005.
[7] Faria R, Moura P, Delgado J, de Almeida AT. Managing the charging of electrical vehicles: Impacts on the electrical grid and on the environment. IEEE Intell Transp Syst Mag 2014;6(3):54–65. http://dx.doi.org/10.1109/MITS.2014.2323437.
[8] Kühnbach M, Stute J, Gnann T, Wietschel M, Marwitz S, Klobasa M. Impact of electric vehicles: Will German households pay less for electricity? Energy Strategy Rev 2020;32:100568. http://dx.doi.org/10.1016/j.esr.2020.100568.
[9] Mohammad A, Zamora R, Lie TT. Integration of electric vehicles in the distribution network: A review of PV based electric vehicle modelling. Energies 2020;13(17):4541. http://dx.doi.org/10.3390/en13174541.
[10] Hoover Z, Nagele F, Polymeneas E, Sahdev S. How charging in buildings can power up the electric- vehicle industry. 2021, McKinsey & Co. January, https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/how-charging-in-buildings-can-power-up-the-electric-vehicle-industry?cid=eml-web.
[11] Ceballos Delgado JE, Caicedo Bravo EF, Ospina Arango S. Una propuesta metodológica para dimensionar el impacto de los vehículos eléctricos sobre la red eléctrica. Ingeniería 2016;21(2):154–75. http://dx.doi.org/10.14483/udistrital.jour.reving.2016.2.a03.
[12] Das HS, Rahman MM, Li S, Tan CW. Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review. Renew Sustain Energy Rev 2020;120:109618. http://dx.doi.org/10.1016/j.rser.2019.109618.
[13] Jiang Z, Tian H, Beshir MJ, Vohra S, Mazloomzadeh A. Analysis of electric vehicle charging impact on the electric power grid: Based on smart grid regional demonstration project — Los angeles. In: 2016 IEEE PES transmission & distribution conference and exposition-Latin America. PES T & D-la, 2016, p. 1–5. http://dx.doi.org/10.1109/TDC-LA.2016.7805675.
[14] Coban M, Tezcan SS. Analysis of impact of electric vehicles on distribution grid using survey data. In: 2019 3rd International symposium on multidisciplinary studies and innovative technologies. ISMSIT, 2019, p. 1–4. http://dx.doi.org/10.1109/ISMSIT.2019.8932933.
[15] Khan OGM, El-Saadany E, Youssef A, Shaaban M. Impact of electric vehicles botnets on the power grid. In: 2019 IEEE electrical power and energy conference. EPEC, 2019, p. 1–5. http://dx.doi.org/10.1109/EPEC47565.2019.9074822.
[16] Anastasiadis AG, Kondylis GP, Polyzakis A, Vokas G. Effects of increased electric vehicles into a distribution network. Energy Procedia 2019;157:586–93. http://dx.doi.org/10.1016/j.egypro.2018.11.223.
[17] Dixit M. Impact of optimal integration of renewable energy sources and electric vehicles in practical distribution feeder with uncertain load demand. Int Trans Electr Energy Syst 2020;30(12). http://dx.doi.org/10.1002/2050-7038.12668.
[18] Ma Z, Callaway DS, Hiskens IA. Decentralized charging control of large populations of plug-in electric vehicles. IEEE Trans Control Syst Technol 2013;21(1):67–78. http://dx.doi.org/10.1109/TCST.2011.2174059.
[19] Bacelar R. Os 10 carros elétricos mais vendidos em Portugal em 2019-4gnews. 4gnews. 2020, https://4gnews.pt/carros-eletricos-mais-vendidos-portugal/.

[20] ACAP. ACAP | Estatisticas. Associação automóvel de Portugal. 2021, https://acap.pt/pt/estatisticas.
[21] UVE. Vendas arquivos - UVE. Vendas de veículos elétricos. 2021, https://www.uve.pt/page/category/veiculo-eletrico/vendas/.
[22] https://dre.pt/dre/detalhe/resolucao-conselho-ministros/53-2020-137618093, 2019, (Accessed 24 january 2022).
[23] Nogueira T, Magano J, Sousa E, Alves GR. The impacts of battery electric vehicles on the power grid: A Monte Carlo method approach. Energies 2021;14(23):8102. http://dx.doi.org/10.3390/en14238102.
[24] PORDATA. População residente. 2021, https://www.pordata.pt/Municipios.
[25] IMT. Instituto da mobilidade e dos transportes. 2021, http://www.imt-ip.pt/sites/IMTT/Portugues/BibliotecaeArquivo/Paginas/BibliotecaeArquivo.aspx.
[26] ARAN. Associação nacional do ramo automóvel. 2021, https://aran.pt/pt/publicacoes/estatisticas.
[27] Palomino A, Parvania M, Zane R. Impact of COVID-19 on mobility and electric vehicle charging load. 2020.