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Deliverable D1.2 Impact of V2X in energy and power systems

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Electric Vehicles Management for carbon neutrality in Europe

Deliverable D1.2
Impact of V2X in energy and power systems

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Executive Summary

The *Impact of Vehicle-to-Everything (V2X) in energy and power systems* deliverable presents a study regarding the impact of the massive penetration of electric vehicles (EVs) in the energy systems. The study is centred in the countries of the EV4EU project members (Denmark, Greece, Portugal, and Slovenia). This document presents a description of the methodology used to analyse the impact of EVs on the energy and power system considering the modelling of EV needs, and high-level power demand and generation. Moreover, several EV management strategies, considering V2X, are proposed aiming to analyse the impact of the mass adoption of EVs until 2050.

A methodology considering the evolution scenario of consumption, generation technologies and EVs has been proposed. Concerning the consumption and generation technologies, several documents were used to identify the expectations and targets in each one of the four countries. The evolution scenarios of the EVs were already studied in the deliverable D1.1 of this project. Based on the number of EVs expected in each year and country, and considering the behaviour of the users, the characteristics of the EVs and the types of charging stations, a tool for generate daily EVs profiles was implemented. This tool allows to determine the energy required to supply the need of the EVs, but mainly the daily power profile. Afterwards, several V2X management strategies were studied allowing to understand the main challenges that the EVs can introduce in the energy and power systems. Three groups of strategies were tested namely, *(i)* strategies based on price, *(ii)* strategies based in peak shaving and *(iii)* strategies based on the coordination with renewables. Finally, the effectiveness of the strategies was analysed considering *(i)* the use of the charging management and *(ii)* the availability of V2X capability.

The main achievement of the present study is that EVs will have an important impact in the energy and power system planning mainly in Portugal and Denmark, that are the countries where is expected a higher adoption of EVs until 2050. Another important conclusion of the study is a comparison between the effectiveness of the proposed strategies and the impact of V2X.

- Concerning the EVs management strategies, it was concluded that price-based strategies can be effective for the following years. However, new peaks can arrive due to the concentration of charging in periods where normally the consumption is low. This effect can be mitigated if better strategies of prices were adopted. The peak shaving strategies are interesting to mitigate the impact of EVs in peak periods. For these strategies, new peak limits should be defined to avoid the “curtailment” of EVs charging. However, these strategies do not consider the use of renewables and the power demand curtailment can arrive in periods where renewable production can be used. The strategies based on the coordination between renewables and EVS were the ones that minimize the impact of the EVs in power and energy systems mainly in countries with higher penetration of renewables (Portugal and Denmark). However, these strategies imply a continuous control of the EVs to follow the generation profiles.
- Concerning the impact of V2X strategies, it was concluded that that V2X can have a negative impact where price strategies are in place increasing the volatility of the power demand. For the strategies based on peak shaving and coordination of RES the use of V2X have clear advantages. V2X allows the reduction of the peaks or the reduction of EV charge “curtailment”. In the strategies related with the coordination with RES and EVs it is possible to verify the increased use of renewables and, mainly in Portugal and Greece (due to the high share of PV technologies), the support of the system in the periods where the RES production is low.

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Keywords, Acronym

BaU	Business as usual
CS	Charging Stations
CO_2	Carbon dioxide
EV	Electric Vehicle
GHG	Greenhouse Gas Emissions
PHEV	Plug-in Electric Vehicle
RES	Renewable Energy Resource
RTP	Real Time Pricing
SoC	State of charge
SoCa	Actual state of charge
SoCr	Requirement state of charge
ToU	Time of Use
V2X	Vehicle-to-Everything
WP	Work Package

Nomenclature

Parameters:

$\overline{E}$	Battery capacity of EV
E_r	Energy requirement for trip of EV
$\overline{P}_{ch}$	Rated power of the charging station
p^f	Penalty factor
P_t^{hp}	Historical peak load at time interval t
P_t^l	Power load at time interval t
Δt	Duration of the time interval t

Variables:

$\underline{E}_{v,t}^{socr}$	Relaxation variable for the energy state of charge of EV v at time interval t
$E_{v,t}^{Tripr}$	Relaxation variable for the trip energy requirement of EV v at time interval t
$P_{v,t}^{EV}$	EV charging consumption of EV v at time interval t
$P_{v,t}^{EVdch}$	EV discharging power of EV v at time interval t
P_t^g	Power generation at time interval t
P_t^{hpred}	Historical peak load reduced at time interval t
$\underline{P}^{aux}$	Auxiliary variable for the minimum power consumption

1 Introduction

1.1 Scope and Objectives

This document analyses the massive integration of electric vehicles (EVs), in the member countries of the EV4EU project (Denmark, Greece, Portugal and Slovenia). Based on various EV management strategies, this document assesses the positive or negative impact of EVs on the energy system for the 2030, 2040 and 2050 scenarios in the four EV4EU project countries.

The objectives of this work are twofold. First, it provides an analysis of the impact that the EVs can have in the energy and power systems, considering a time-horizon until 2050. This analysis is based on scenarios presented in the literature or defined as targets in public documents. Several EVs management strategies are analyzed considering price schemes, coordination with renewable energy sources (RES) and limits of power system (peak consumption). The second goal is to understand the advantages introduced using V2X technology in the different strategies described in the previous point.

To achieve the main objectives of this work, we carried out an extensive search of the existing literature regarding information on historical data, evolution scenarios and targets of electricity consumption, generation technologies and EVs. This information was obtained from documents published and websites of public entities and power systems stakeholders (producers, transmission system operators (TSOs), distribution system operators (DSOs), retailers, etc.). It is important to notice that the main aim of this study is not to analyze the consumption and generation scenarios but mainly the impact of the EVs on the power and energy systems. When the information was not available, some assumptions have been taken concerning consumption and generation evolution scenarios allowing to perform the analysis of the EVs in the power system.

1.2 Structure

The current document is divided into four sections. Section 2 introduces the methodology to analyse the impact of EVs in the energy and power system. The strategies simulation and impact for each country of the EV4EU are presented in section 3. Section 0 illustrates the main conclusions.

1.3 Relationship with other deliverables

The present deliverable uses information concerning the evolution scenarios of EVs studied in the deliverable D1.1. The methodologies and results obtained in this deliverable will be used mainly in the WP2 – V2X Management Strategies. The EVs profiles generation tools can be used to create synthetic data that can be used as inputs in the different tasks of WP2. In the same way the EVs management strategies can be adapted to be used in the management of houses, buildings, parking lots, etc.

2 Impact of EVs in Energy and Power Systems – Methodology

Use of EVs is increasing and, according to recent studies [1], it is expected a worldwide mass adoption of EVs. In Europe the use of EVs is following a similar trend promoted by incentives and other regulatory benefits. Recently, European Commission defined that by 2035 all the EVs sold in Europe should be zero emission vehicles [2].

EV sales in Europe have shown continuous growth since 2020, with an increase of more than 21% in 2021 [2]. Moreover, the evolution scenarios of the EVs for the four EV4EU countries studied on the D1.1 of this project confirmed the mass EV adoption for the four countries [3]. Nevertheless, even though the EV evolution has been hightailed in the last few years, the transport sector has the lowest use of renewable energy sources [4]. Based on this, it is important to develop strategies to analyse the impact of the EV mass adoption on the consumption and the energy system [5]–[8]. These strategies aim not only to execute smart management of EVs to preserve the reliability and resiliency of the power network but also to take advantage of the green energy to support the electric mobility and consequently reduce the CO_2 emission.

A simulation platform enabling the evaluation of the EVs in the power systems was developed. The core of this platform is a module where several EVs management strategies were modelled. The EVs management strategies are presented in Section 0. Several information is required to perform the evaluations. First, it is necessary to understand the daily EVs profiles, including the travels needs, the required energy and the power that will be necessary to charge the EVs. The EVs scenario generation tool is presented in Section 2.1. Afterwards, it is necessary to have information related with the consumption, production, and interconnections (Section 2.2). Finally, some strategies are defined based on the energy prices, coordination with RES, and support of the power system, among others, that are introduced in Section 0. The global methodology is presented in Figure 2.1.

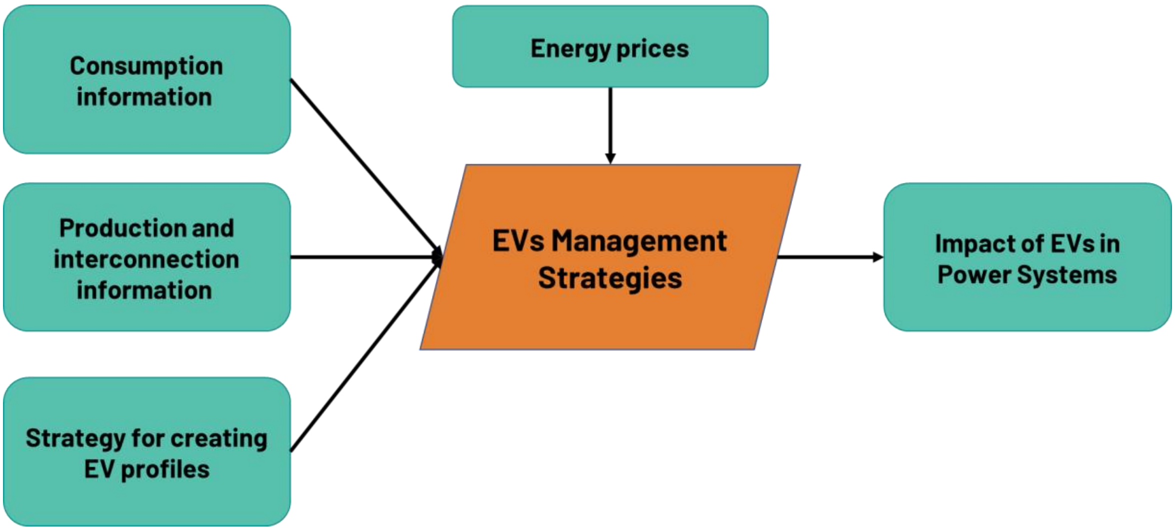


Figure 2.1 – Strategy to analyse the impact of V2X in energy and power systems

2.1 Electric Vehicles Needs Modelling

In order to achieve carbon neutrality, it is crucial to determine the EV energy demand for sustainable use of the transportation network [9]. User behaviours such as driving hours, type of recharging location (private or public), the power level of usage, type of EVs and charging stations used (slow, fast, ultrafast) make the EV charging demand an uncertain variable that can create several technical issues in the energy and power system. Hence, it is necessary to develop a tool to create EV profiles that reliably represent the EVs energy demand. Figure 2.2 illustrates the strategy implemented for creating EV profiles.

The process has the following steps:

i. Define trips: Based on the average distance of trips and on the number of cars required for the simulation, the tool will generate a set of trips during the day using a gamma distribution function.

ii. Define type of EVs: Based on the stock of EVs (type and market share) and on the number of cars, the tool will generate a set of EVs that will be used in the simulation. It is important to notice that this information have been generated based on the existing information for 2021. It is assumed that in the future, the EVs will have similar characteristics in terms of efficiency and battery capacity which is an important assumption of the simulation.

iii. Define user's profiles: A set of EV user profiles and respective percentage are inputs of the tool. The profiles include information such as the departure time, the return time, the number of trips during the day, the distance (short, medium, long), the location of charge (work, residential) and the type of charging station (private, public). The model will generate random values based in a normal distribution and on the percentage of the users in each profile. This allows that each EVs profile will be unique.

iv. Define trips for each EV/user: Based on the previous information, the trip will be linked to the EVs, considering that the EVs with higher battery capacity will be linked with longer trips. Afterwards, this information will be linked to the users' profiles.

v. Definition of trip duration and energy need: Considering the information obtained in point iv and on the average speed, it is possible to determine the duration of the trip, the energy spent in the trip and the state-of-charge (SoC) of each EV.

vi. Charging needs: A comparison of the actual SoC (SoC_a) and the requirement state of charge (SoC_r) can define whether the EV can perform a normal charge, or otherwise, whether the EV needs a faster charge. In case a faster charge is needed, the strategy defines the time to stop to charge, the CS that can be used by the EV user, sets the charging duration, and makes an update of the travel duration and SoC_a. If the EV user requires a normal charge, the strategy defines the CS type, and informs about the EV parking time, the power level of the CS used, and the EV energy consumption required.

For the implementation of this strategy in the four countries of the EV4EU project, we performed extensive research to create Denmark, Greece, Portugal, and Slovenia EV profiles. This information allowed to define the percentage of CS used, the most EVs used, and the typical EV charging user profiles (workplace, residential, public, among others) in each country to be used in the strategy [10]–[13]. The strategy also took in account the number of EVs for each country until 2050.

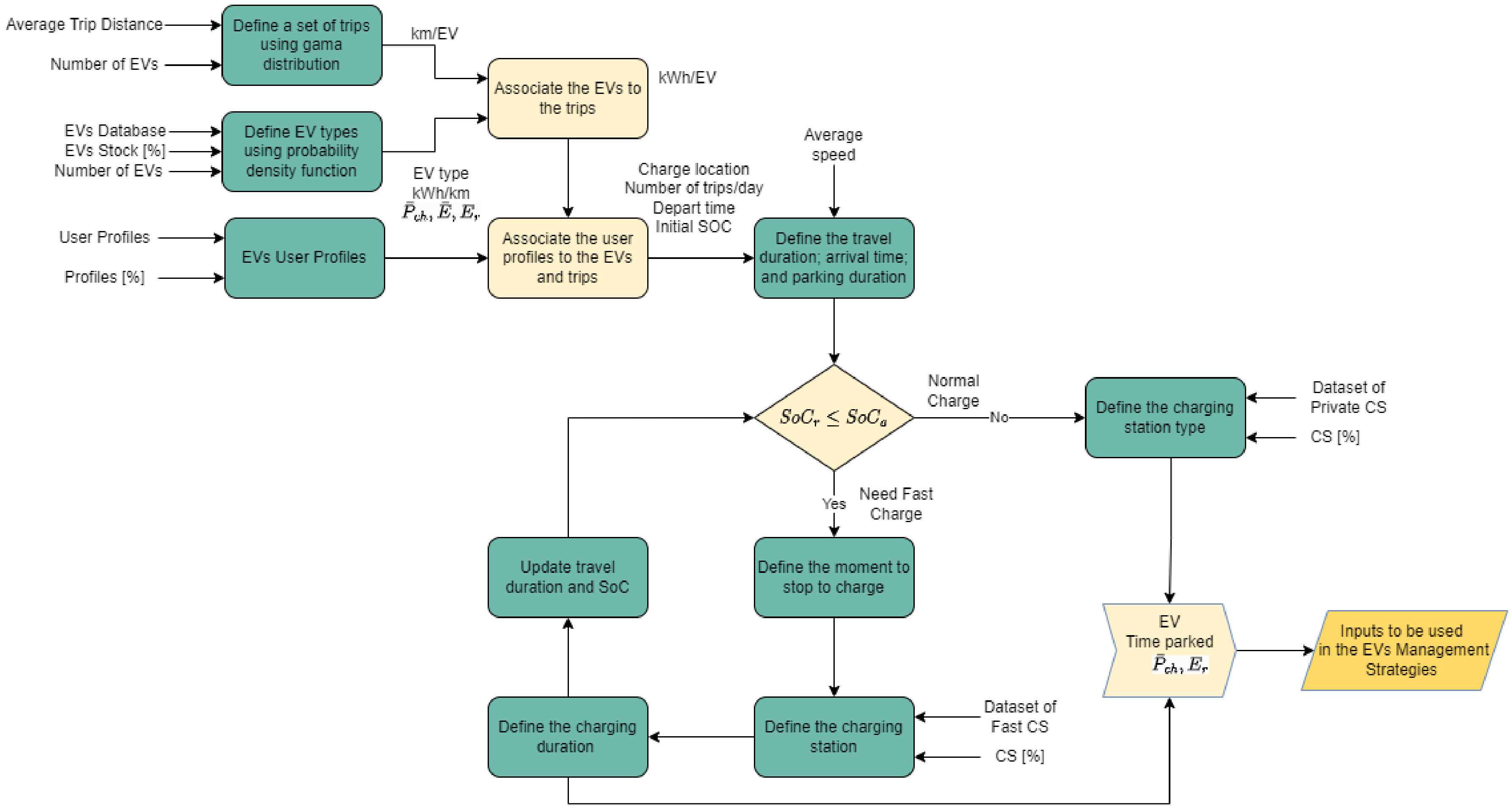


Figure 2.2 – Strategy for creating EV profiles

2.2 High-Level Power Generation and Demand Modelling

The power generation and demand were modelled based on projections and targets defined by the governments in the four countries analysed in the present document. In some few cases, when the information is not available, the values were determined based on the existing ones using an interpolation function.

The daily profiles were determined based on the day of highest consumption registered in 2021. The aim is to introduce the EVs consumption profile on the top of the existing consumption. Because of that the use of the day with highest consumption should lead, in principle, to a worst-case scenario. Nevertheless, we are neglecting the impact of renewable technologies in the definition of this worst-case scenario. Thus, 2021 is considered the reference year and the expected percentage increase/decrease for each technology generation can be estimated, as well as the consumption. Accordingly, through this percentage increase and considering that the generation and consumption profile will remain the same until 2050, it is possible to estimate the increase in the values of the generation and consumption profiles. In the Danish case was used information from [14]–[16]. For the Greece case, the information used were obtain from [17]–[20]. In the case of Portugal, the sources used were [21]–[23]. Finally, for Slovenia, the data used was obtained from [13], [19], [24]–[26].

Another important aspect is the interconnection capacity in each one of the countries. In this matter, an assessment of the existing interconnections was performed. However, it is important to notice that the interconnection capacity can be different day by day depending on the operating conditions. For the following years, no information is available in the literature. Only Portugal has an estimation of the interconnection capacity with Spain [22]. In the other countries, some projects have been already announced but, in most cases, exact information is not available [27]–[29]. The values of interconnection capacity used for scenarios of 2030 but mainly 2040 and 2050 are indicative. Figure 2.3 shows the evolution of power generation, interconnection, and consumption until 2050 for the 4 countries of the EV4EU project. Hence, as can be observed, it is expected an increase in renewable capacity generation and a reduction in non-renewable capacity installation for the four countries. Regarding the consumption, for the four countries there is a gradual increase.

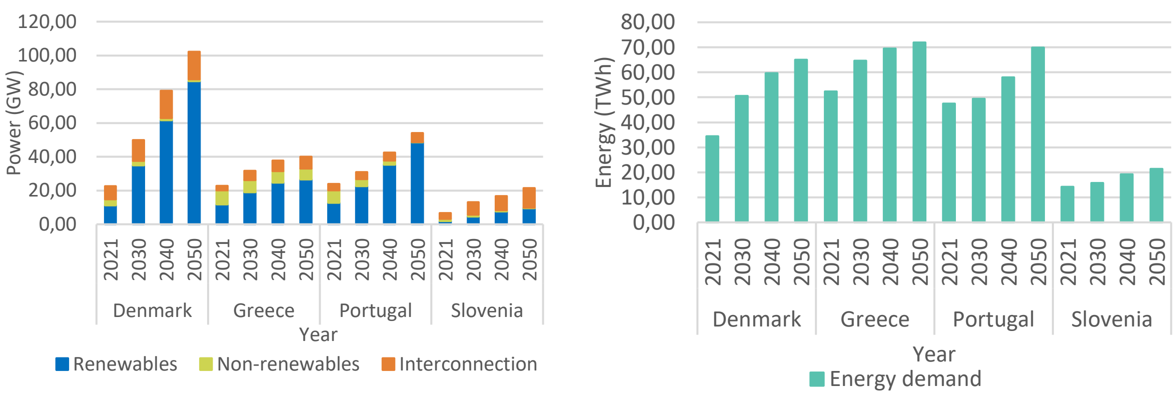


Figure 2.3 – Power generation, interconnection, and consumption evolution until 2050 for the countries of EV4EU project

2.3 Electric Vehicles Management Strategies

As mentioned, the EV mass adoption requires enormous energy consumption. The increase of consumption can lead to several issues in the power system, such as congestion in the lines and power transformers, voltage, and frequency instability among others [30], [31]. Therefore, the development of EV management strategies becomes necessary to avoid technical issues. In this section, several EV management strategies are presented, namely:

- **Business As usual (EVs charge without control):** The Business as Usual (BaU) is a scenario related to the EV charging without control. Hence, in this case, the users will charge EVs, when possible, without any limitation until achieving the maximum capacity of their EVs batteries. V2X is not considered in BaU strategy.
- **Time-of-Use (ToU) Tariffs:** ToU is one of the most used and simple type demand response [32]. The program consists in the definition of different energy prices during the day. The most popular ToU tariffs consider bi-hourly and tri-hourly tariffs. In the ToU strategy, the users are encouraged to charge their EV batteries in time intervals with lower prices tariff [33]. When V2X is available EV users can also take advantage of the higher price to discharge their EV batteries [33]. In the present simulation, prices have been defined considering that the difference between the higher price and the lower price is higher than the battery degradation cost. This means that in the V2X program, the users will take advantage on discharging their batteries.
- **Real Time Pricing (RTP):** The real time pricing strategy is similar to ToU, but the prices can change daily, depending on the electricity market clearing price and other factors [34]. Hence, the EV users are encouraged to charge the batteries when the market price is low and resulting in an opportunity for them [34]. When V2X is considered, the possibility of users discharging their EV batteries is promoted by taking advantage of the opportunity cost, i.e., high prices, for discharging. The main difference between ToU and RTP strategies is that the users can charge more energy that the quantity required, to take advantage of low energy prices.
- **Support renewable energy resource, alternative a (RES-a):** The strategy supports Renewable Energy Source (RES), alternative a, incentives the green energy resource through the minimization of the conventional generation usage (non-renewable generation), collaborating with the minimization of the CO_2 emission [35]. When V2X is available, the EV discharging is considered in the energy balance in the system.
- **Support renewable energy resource, alternative b (RES-b):** like the former strategy, the support RES, alternative b, is focused on the minimization of conventional resource usage, moreover, this strategy also encourages the EVs to charge during periods with low load consumption, this guarantee that even in case of poor RES availability, the EV charging power does not represent a technical issue for the power system, as illustrated by (1) and (2). When V2X is available, the EV discharging is considered in the energy balance in the system. Where $\underline{P}^{aux}$ is an auxiliary variable for the minimum power consumption, P_t^g is the power generation from non-renewable sources, $E_{v,t}^{Tripr}$ is a relaxation variable for the trip energy requirement, $\underline{E}_{v,t}^{socr}$ is a relaxation variable for the energy state of charge, p^f is a penalty factor, and, P_t^l is the power demand.

$$\min f = \sum_{t\in T} P_t^g - \underline{P}^{aux}\xi + \sum_{v\in V}\sum_{t\in T}(E_{v,t}^{Tripr}p^f + \underline{E}_{v,t}^{socr}p^f) \tag{1}$$

Subject to:

$$\underline{P}^{aux} \leq P_t^l + \sum_{v\in V} P_{v,t}^{EV}, \qquad \forall t \tag{2}$$

- **Minimize the global peak of consumption (Min Peak):** in this EV management strategy the main goal is to minimize the peak consumption in the system. Thus, EV charging is managed with the aim to avoid the peak of consumption considering the natural load demand in the system, as illustrated by expressions (3) and (4). Moreover, when the V2X is implemented, the EV discharging power is considering in the objective function, as shown by expression (3). Where P_t^{hpred} is the historical peak load reduced, $P_{v,t}^{EV}$ is the EV charging consumption, and $P_{v,t}^{EVdch}$ is the EV discharging power.

$$\min f = \sum_{t \in T} P_t^{hpred} + \sum_{v \in V} P_{v,t}^{EVdch} \zeta + \sum_{v \in V} \sum_{t \in T} (E_{v,t}^{Tripr} p^f + \underline{E}_{v,t}^{socr} p^f) \tag{3}$$

Subject to:

$$P_t^{hpred} \geq P_t^l + \sum_{v \in V} P_{v,t}^{EV}, \qquad \forall t \tag{4}$$

- **Peak-Shaving Signals, alternative a (Peak-a):** this is an EV management strategy with the aim of control the EV charging to limit the peak demand to a defined threshold. The value of the threshold should be defined based on the historical maximum demand. In that strategy, the threshold is considered a hard limit and no EVs can be charged when the threshold is overtaken. Hence, EV charging power curtailment can be needed as indicated by expressions (5) and (6) [36]. When V2X is available, the possibility of the EV batteries executing discharging to avoid peak consumption is considered, where P_t^{hp} is the historical peak load.

$$P_{v,t}^{EV} = 0, \ \forall v, t: P_t^l \geq P_t^{hp} \tag{5}$$

$$P_t^l + \sum_{v \in V} P_{v,t}^{EV} \leq P_t^{hp}, \qquad \forall t \tag{6}$$

- **Peak-Shaving Signals, alternative b (Peak-b):** The main objective of the peak-shaving signal, alternative b strategy is focused on the minimization of the quadratic value of a reduction of the historical peak of load consumption, as indicated by the expressions (7) and (8). When V2X is available, the possibility of the EV batteries executing discharging to avoid peak consumption is considered.

$$\min f = \sum_{t \in T} (P_t^{hpred})^2 + \sum_{v \in V} \sum_{t \in T} (E_{v,t}^{Tripr} p^f + \underline{E}_{v,t}^{socr} p^f) \tag{7}$$

Subject to:

$$P_t^l + \sum_{v \in T} P_{v,t}^{EV} - P_t^{hpred} \leq P_t^{hp}, \qquad \forall t \tag{8}$$

3 Strategies Simulation and Impact

The aim of this chapter is to present the impact of the strategies described in subsection 0 in the power systems of Denmark, Greece, Portugal, and Slovenia. The analysis has been performed considering the day with highest electricity consumption (winter day) in 2021, in the different countries. This consumption and generation were then updated for 2030, 2040 and 2050, considering the percentual evolution of the consumption in each country as described in subsection 2.2. Importantly, it is assumed that the daily profiles will remain the same as the ones registered in 2021. In addition, the consumption due to EVs charging will be analysed on the top of the load profiles.

To estimate the impact of EVs, the first step should be the generation of the electric mobility scenarios. The main assumptions adopted in the present study are the following ones:

- Based on [37], in Europe, in 2030 54% of the EVs will be charged at homes at private charging stations and 46% of the EVs will be charged at the workplace at private charging stations. This assumption is maintained for 2040 and 2050 scenarios.
- The daily profiles of the use of EVs have been defined following the profiles presented in [38]. Moreover, several driver profiles scenarios were defined considering different types of trips (short, medium, and long).
- The average travel distance in km/day, the average speed in km/h, the most usage CS power, the numbers of EVs for scenario, and the types of EVs were defined based on the singular characteristics of each country.
- For the analyses of ToU strategy, in the four countries, was considered the tri-hourly tariff commonly used in Portugal based on [39], thus, this type of tariff can be used as a based reference to analyse the other countries of the EV4EU project.

The main results for the Denmark case are presented in subsection 3.1, for the Greece Case in subsection 3.2, for the Portugal case, the main results are presented in subsection 3.3, and for the Slovenia case, the main results are discussed in subsection 3.4.

3.1 Denmark Case

This Section presents the results obtained for Denmark, considering the scenarios between 2021 and 2050. Table 3.1 shows the information regarding the total number of Danish EVs for each scenario. The Support to RES strategy considered all the renewable energy resources in Denmark according to [40]. In Denmark, power-to-x (PtX) is an emerging technology [40], and some projections predict a corresponding large increase of electricity demand. However, there is large uncertainty related to the development of PtX, and its influence was disregarded so that future scenarios among all 4 countries of the EV4EU project were more comparable. The average travel distance was defined as 36.6 km/day [10]. The average speed was defined as 50 km/h [41]. The percentage of usage of charging stations was obtained from [42], where the most used (86%) is the 22 kW public charging station.

Table 3.1: Total EVs considered in each scenario in the Denmark case (Source: [43]**)**

Year	Total EVs
2021	145,000
2030	3,000,000
2040	3,100,000
2050	3,200,000

To understand how EVs can impact the Danish power system it is necessary to study how consumption is nowadays and how it is expected to change in the future. Figure 3.1 shows the power generation and demand for Denmark on February 8th, 2021, [14].

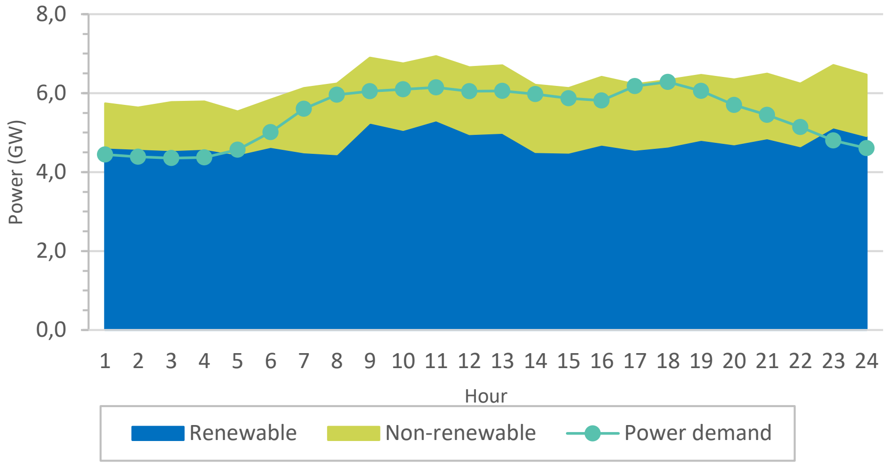


Figure 3.1 – Power generation and demand curve from Denmark, scenario 2021

As observed in Figure 3.1, the peak consumption was 6.28 GW (18h). However, it is also possible to observe that the generation based on RES was 4.65 GW (18h), representing 74% of the total demand. This is a clear example of the high RES capacity installed in Denmark.

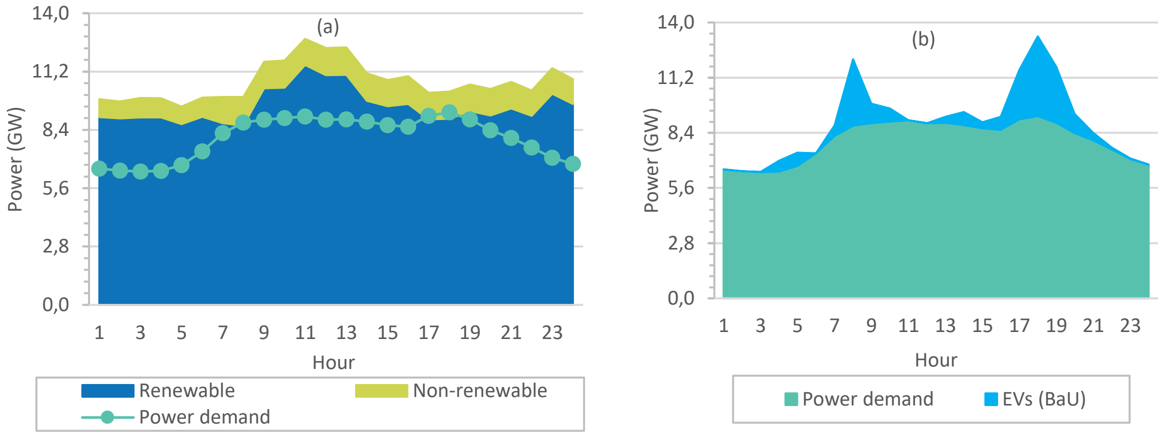


Figure 3.2 – Power generation and demand curve from Denmark (a) vs EV charging without management (b), scenario 2030

Based on the production and consumption registered in 2021, scenarios for 2030 until 2050 were defined. In Figure 3.2 (a), it is possible to see the expected evolution of consumption and production for 2030 since 2021 (Figure 3.1). In Figure 3.2 (a) is possible to observe that, compared with 2021, for 2030 the peak consumption will increase to 9.24 GW (18h), but an increase on renewable generation is also expected, to 11.51 GW at 11h. The impact of EVs can be observed in Figure 3.2 (b). In that case, two new peak consumption periods can be identified due to the vehicles that are charged in residential charging stations in the evening and the ones that are charged at work in the morning. In that case, the peak can amount to 8.1 GW around 18h. Considering the average power of the residential charging stations, this value represents around 800 thousand EVs charging at the same time corresponding to 25% of the total number of EVs. This value represents an extreme scenario for the system with low probability to occur. However, as stated on [37], it is expected that 54% of the EVs will be charged in residential charging stations.

Considering the impact of EVs in Danish system, some strategies have been tested. First, it is analysed the use of ToU tariffs to change the behaviour of the EVs' users. The results are presented in the Figure 3.3 considering the management of the EVs charging (a) and V2X (b).

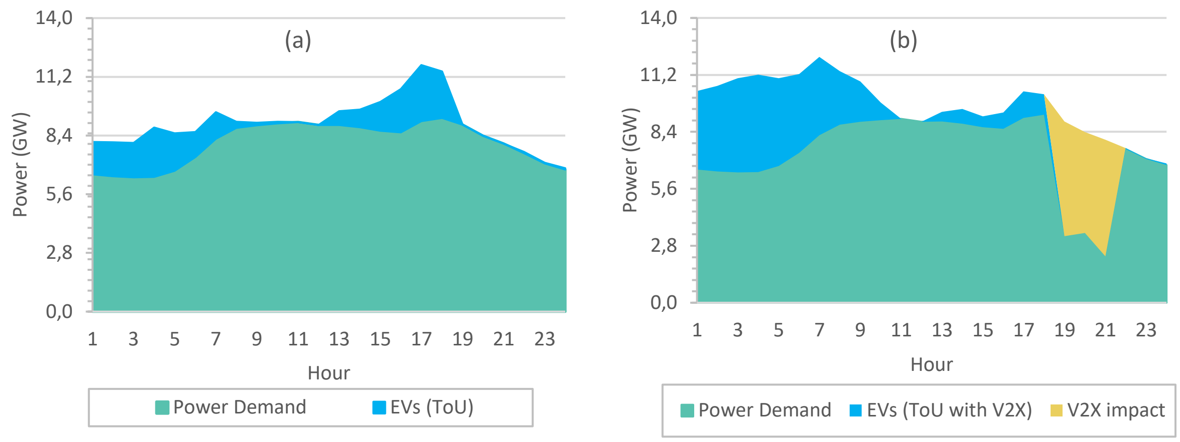


Figure 3.3 – Power demand curve and EVs management with ToU without V2X (a) and ToU with V2X (b), Denmark, Scenario 2030

In Figure 3.3, it is possible to see that the use of ToU has a positive impact in the system, reducing the peak demand to 11.76 GW at 17h. In that case, the peak is achieved during a middle-peak period mainly because of the EVs that are charged during work hours. When V2X technology is considered, the system presents higher variations in the global peak demand during the day. In fact, the EVs will take advantage of higher prices in peak-hours to discharge power, reducing the global consumption in the traditional peak hours. However, new peaks are created in off-peak hours (6h). Aiming to clarify the V2X implementation, Figure 3.4 shows the EV power consumption/discharging for Denmark, scenario 2030. Thus, it is possible to observe that during the hours with higher prices (18h-22h), the EV users, in fact, take advantage of this tariff to discharge their batteries. In summary, the use of ToU tariffs can introduce benefits in the system but, mainly when V2X capability is available, can introduce higher volatility in the system demand.

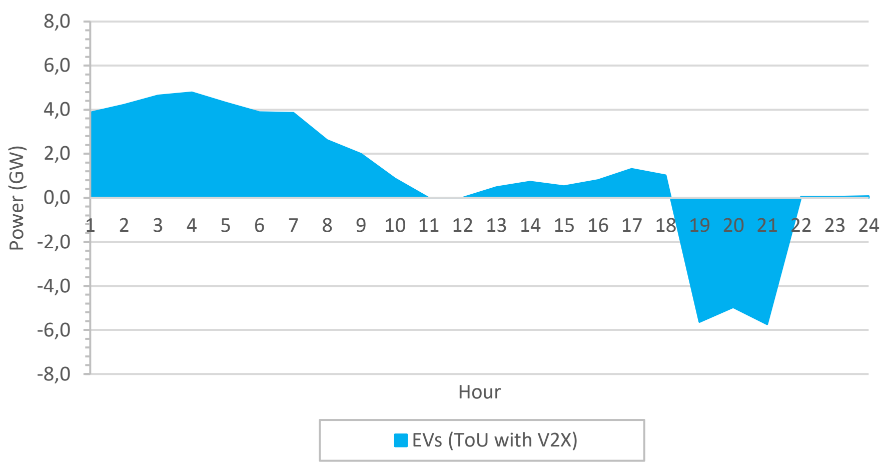


Figure 3.4 – EVs management with considering with V2X, Denmark, Scenario 2030

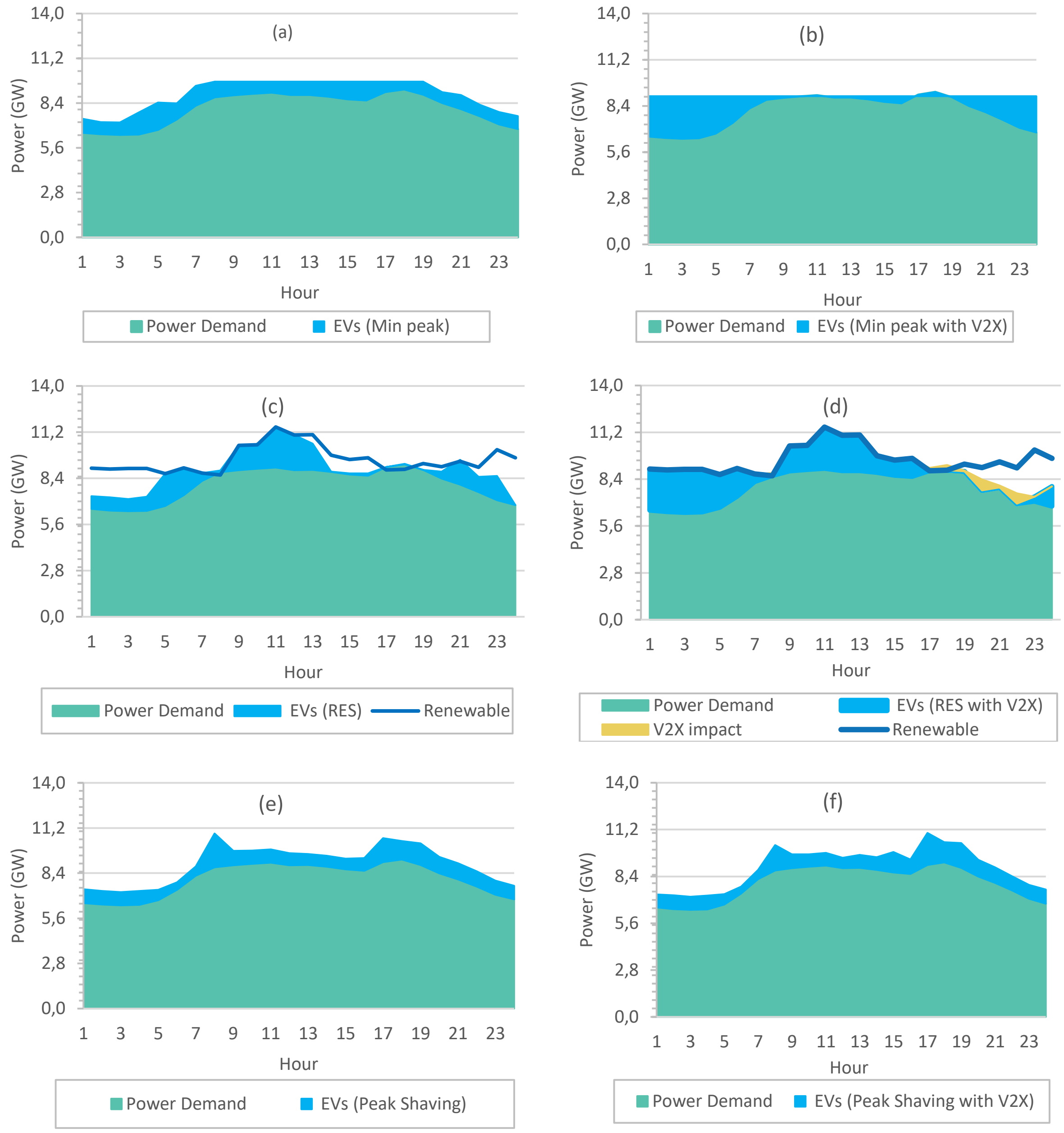


Figure 3.5 – Summary results for Denmark, Scenario 2030. (a) Min peak without V2X, (b) Min peak with V2X. (c) RES without V2X, (d) RES with V2X, (e) Peak Shaving without V2X, (f) Peak Shaving with V2X

A summary of the other strategies tested for Denmark is presented in Figure 3.6. The ideal one is the reduction of global peak demand (a) without V2X and (b) with V2X, in which the peak will be maintained around 9.7 GW. However, this strategy can only be achieved when direct control of the EVs is available. Coordination with renewables, and peak shaving signals are the other strategies that can provide good results in the management of the Danish System. In the RES strategy (alternative b) with and without V2X, the EVs take advantage to charge in the hours with more availability of RES generation. For instance, in Figure 3.6 (c and d) is visible that the peak consumption (11.51 GW) at 11h coincides with the peak of RES generation. Moreover, when V2X is available (Figure 3.6 (d)), the EV consumption is higher than in the case without V2X, this the discharging of the EVs cannot affect the requirement of transportation, hence the EVs increase their power demand, but it visible that the EV consumption follows the RES generation curve, additionally, the V2X impact maintains the power demand curve without variations. In the peak shaving signal ((e) and (f)), the peak of consumptions is

11 GW for both with and without V2X, it is important to highlight that when the EVs are managed the peak of consumption is less than 10 GW. The evolution of EVs from 2030 until 2050 for Denmark is 100,000 more EVs for 2050, hence, it is expected similar results for 2040 and 2050.

3.2 Greece Case

For the Greek case, the EV evolution is presented in Table 3.2. The average travel distance is 37 km/day [44]. The Support to RES strategy considered all the renewable energy resources in Greece according to [11]. The information on the most used Greek EVs was obtained from [45]. The percentage of usage of charging stations was obtained from [46], where the most used (94%) is the 7.2 kW public charging station. The average speed was defined as 50 km/h [47]. In Greece, the day of highs consumption was on February 19th of 2021. The demand diagram of this day is presented in Figure 3.6 [17].

Table 3.2: Total EVs considered in each scenario in the Greece case (source [48])

Year	Total EVs
2021	10,300
2030	428,076
2040	892,271
2050	1,356,466

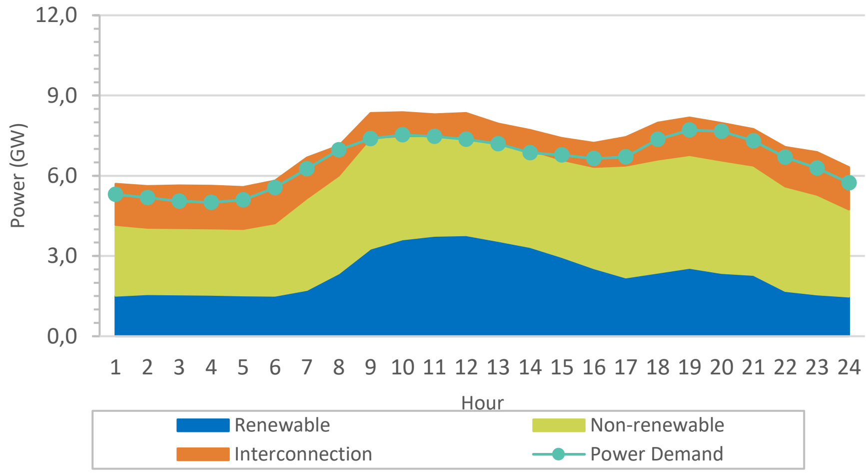


Figure 3.6 – Power generation and demand curve from Greece, Scenario 2021

As observed, the peak consumption was at 19h, with a total of 7.7 GW. However, due to the capacity of interconnection, the Greek system was able to attend this peak of demand. Moreover, at this time, the RES generation represented 35% of the total power demand.

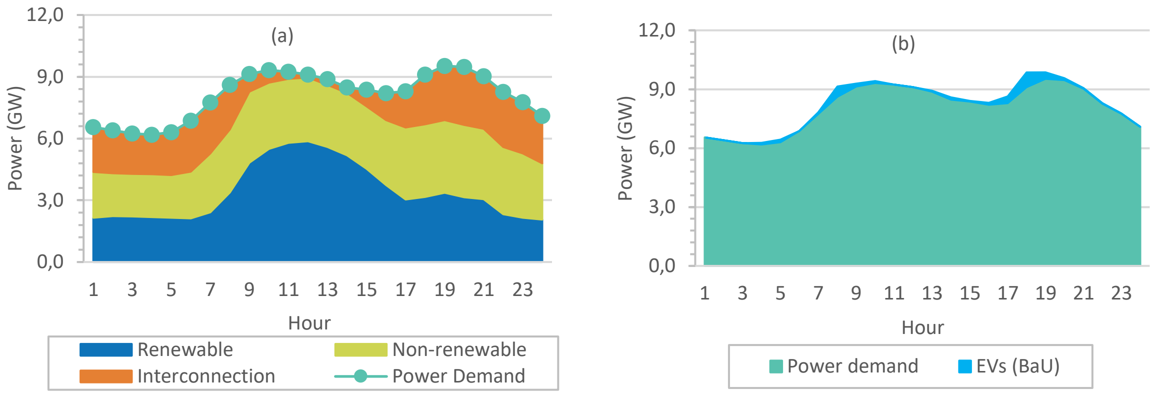


Figure 3.7 – Power generation and demand curve from Greece (a) vs EV charging without management (b), Scenario 2030

Taking as references the production and consumption registered in 2021, it was defined the scenarios of 2030 until 2050 for Greece. In Figure 3.7 (a), it is possible to see the expected evolution of consumption and production for 2030 compared with 2021. The peak consumption will increase to 9.52 GW but is also expected an increase on the maximum renewable generation, 5.86 GW for 2030, incrementing 2.09 GW since 2021. The impact of EVs can be observed in Figure 3.7 (b). In that case, at hours 8h and 18h, two new peak consumption can be identified, 9.13 GW and 9.85 GW, respectively. These peaks are produced due to the vehicles that are charged in residential charging stations in the evening and the ones that are charged at work in the morning, particularly, at 18h, it is expected that almost 54% of the EVs will be charged in residential charging stations for 2030 [37]. Due to the number of EVs in Greece for 2030 (428,076), its impact on the power system is not significant, moreover, from 2030 until 2040, in Greece the EVs will increase by 464,195 EVs, hence, they are expected similar results for 2030.

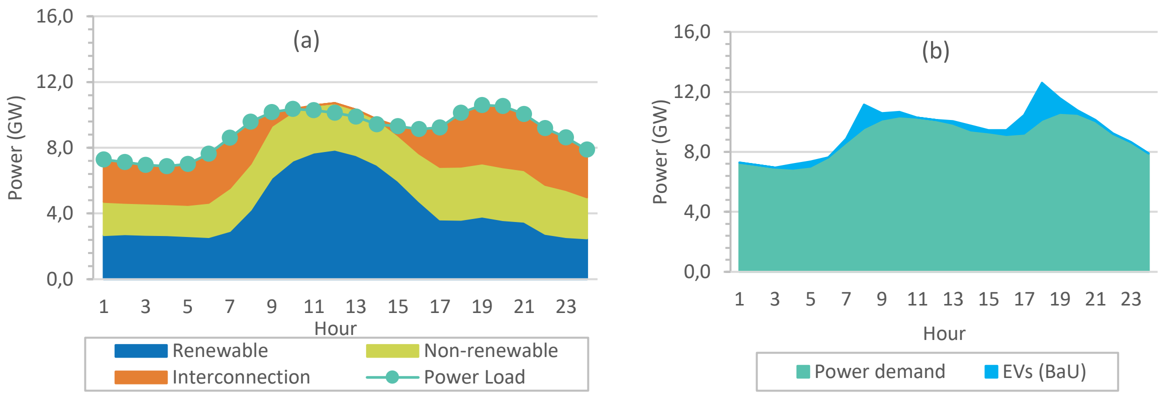


Figure 3.8 – Power generation and demand curve from Greece (a) vs EV charging without management (b), Scenario 2050

For 2050, it is expected the most EV mass adoption in Greece. In Figure 3.8 (a), it is possible to see the expected evolution of consumption and production for 2050 since 2030. Hence, the peak consumption will increase to 10.59 GW at 19h. Importantly, the RES generation will achieve a maximum of 7.8 GW at 12h. The impact of EVs can be observed in Figure 3.8 (b). For this scenario, the EVs without management will be created a peak consumption of 12.61 GW at 18h, and 11.15 GW at 8h. Hence, for 2050, due to the EV mass adoption in Greece, it will become necessary the management of EV charging.

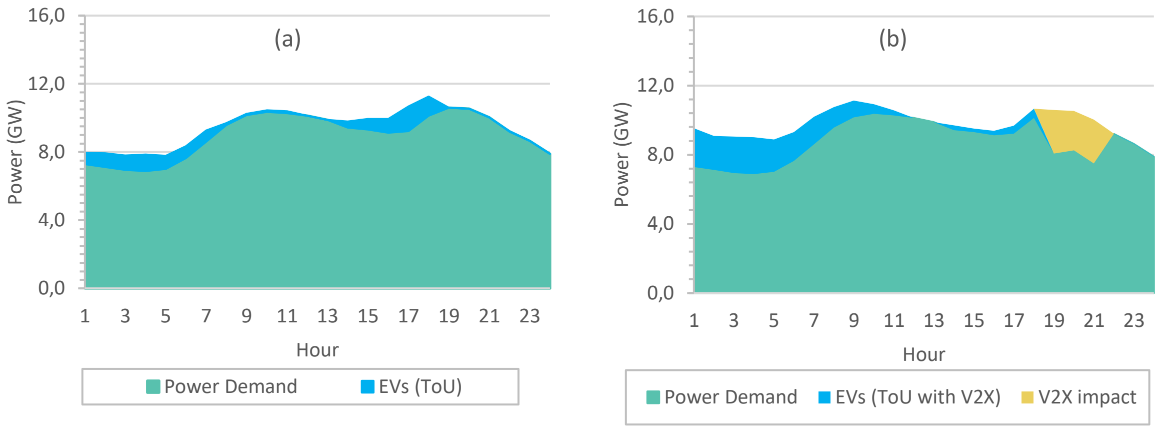
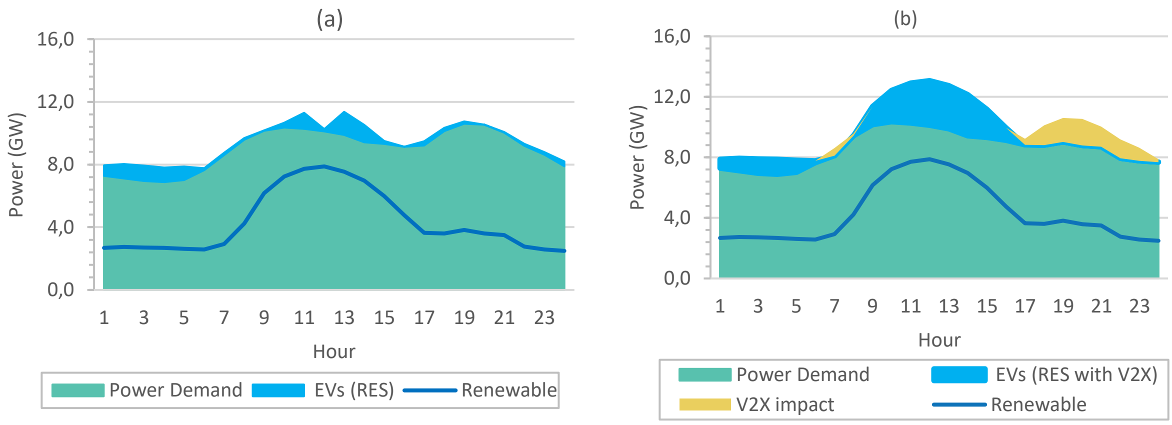
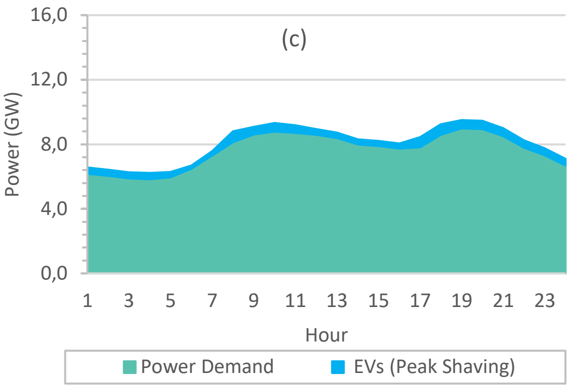


Figure 3.9 – Power demand curve and EVs management with ToU without V2X (a) and ToU with V2X (b), Greece, Scenario 2050

In Figure 3.9, it is possible to observe that the use of ToU have a positive impact in the Greek system, reducing the global Peak demand to 11.25 GW. When V2X is available, a new peak of consumption will be created in off-peak hours (9h), 11.13 GW, that confirms the higher variations that the V2X technology can introduce in the power system. On the other hand, the EVs will take advantage of higher prices in the peak-hours to discharge power, reducing the global consumption in the traditional peak hours. The V2X implementation, in the Greek case, is like the one presented in Figure 3.4, in which the EV discharging power has negative values, nevertheless, due to the main focus of this study is to analyse the impact of the V2X implementation on top of the power demand, the Figure 3.4 can be used as an example to clarify the discharging process of the EVs for all the cases analysed. In summary, like in the Denmark case, the use of ToU tariffs can introduce benefits in the Greek power system, but, when V2X capability is implemented, can introduce higher volatility in the system demand. Figure 3.10 shows a summary of the other strategies tested for the Greek case.





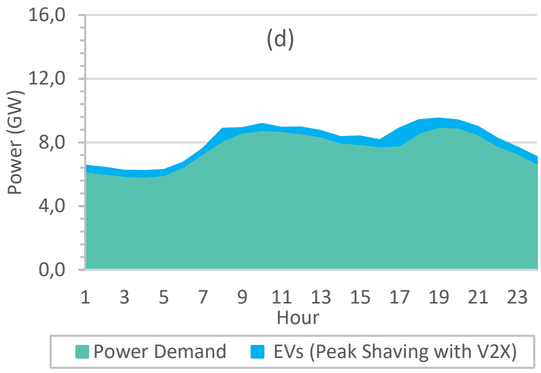


Figure 3.10 – Summary results for Greece, Scenario 2050. (a) RES without V2X, (b) RES with V2X, (c) Peak Shaving without V2X, (e) Peak Shaving with V2X

Coordination with renewables and peak shaving signals are the two strategies that can provide good results in the management of the Greek System. In the RES strategy without V2X, the EVs take advantage to charge in the hours with more availability of RES generation, and with a peak consumption of 10.26 GW at 12h (Figure 3.10 (a)). When V2X is available, the peak consumption will be will maintain in 12.91 GW, and even with higher consumption than without V2X, the EV power demand follows the RES generation curve, moreover, the V2X impact maintains the power demand curve without alterations. In the peak shaving signals ((Figure 3.10 (c) and (d)), the peak of consumption is 9.5 GW at 19h for both without and with V2X. For the Greek case, in summary, the best indicated EV management is the peak shaving signals, due to the stability that will maintain even when V2X will be considered.

3.3 Portugal Case

For Portugal, Scenarios (2021, 2030, 2040, 2050) were simulated considering the EV evolution shown in Table 3.3. The average travel distance was considered in 46 km/day [12]. The Support to RES strategy considered all the renewable energy resources in Portugal [23]. The information on the Portuguese most popular EVs used was obtained from [49]. The percentage of usage of charging stations was obtained from [12], where the most used, was 22 KW for public area, at 44% and 7.2 KW at 96% for private area. The average speed for Portugal was defined as 80 km/h [50]. Figure 3.11 shows the power generation and curve demand for Portugal on the worst day, on January 12th, 2021, [22].

Table 3.3: Total EVs considered in each scenario in the Portugal case (Source [23]**)**

Year	Total EVs
2021	86,604
2030	2,350,000
2040	6,000,000
2050	6,330,000

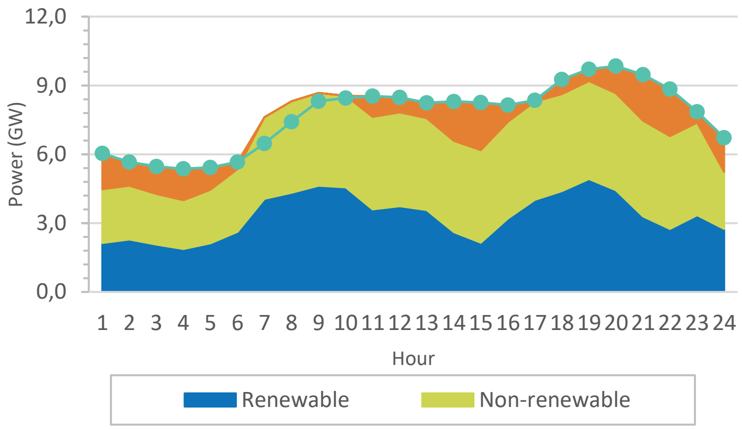


Figure 3.11 – Power generation and demand curve from Portugal, Scenario 2021

At 20h, due to the capacity of interconnection, Portugal was able to attend the peak consumption in the worst scenario (9.84 GW), through an energy importation of 1.18 GW. On the other hand, at 20h, 51% of the Portuguese power generation was from RES.

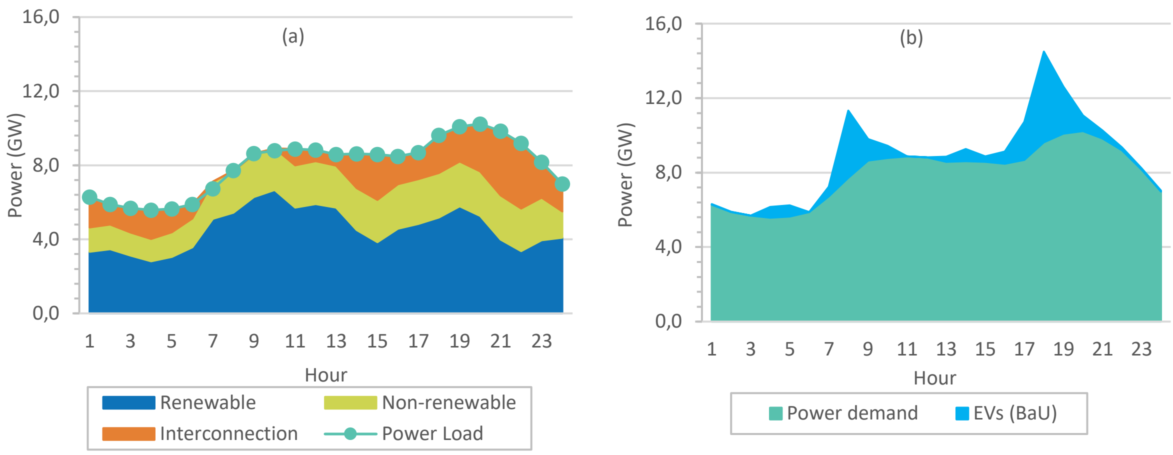


Figure 3.12 – Power generation and demand curve from Portugal (a) vs EV charging without management (b), scenario 2030

Taking as references the production and consumption registered in 2021, it was defined the scenarios of 2030 until 2050 for Portugal. In Figure 3.12 (a), it is possible to see the expected evolution of production and consumption for 2030 since 2021. The peak consumption will increase by 10.2 GW, moreover, it is expected an increase on the peak renewable generation of 6.65 GW for 2030, incrementing 2.26 GW since 2021. The impact of EVs can be observed in Figure 3.12 (b). In that case, at hours 8h and 18h, two new peak consumption can be identified, 11.32 GW and 14.5 GW, respectively. These peaks are produced due to the vehicles that are charged in residential charging stations in the evening and the ones that are charged at work in the morning, particularly, at 18h, it is expected that almost 54% of the EVs will be charged in residential charging stations for 2030 in Europe [37].

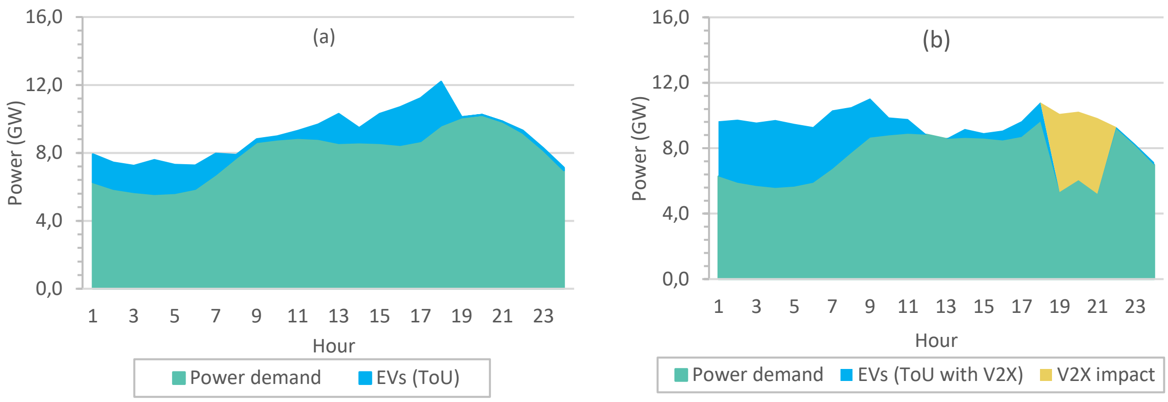


Figure 3.13 – Power demand curve and EVs management with ToU without V2X (a) and ToU with V2X (b), Portugal, scenario 2030

In Figure 3.13, it is possible to observe that, like in Denmark and Greece, the use of ToU strategy also has a positive impact in the Portuguese system, reducing the global Peak demand to 11.2 GW. Nevertheless, when V2X is available, new peaks will be created in off-peak hours, 11.04 GW at 9h, that confirms the higher variations that the V2X technology can introduce in the power system. On the other hand, the EVs will take advantage of higher prices in the peak-hours to discharge power, reducing the global consumption in the traditional peak hours.

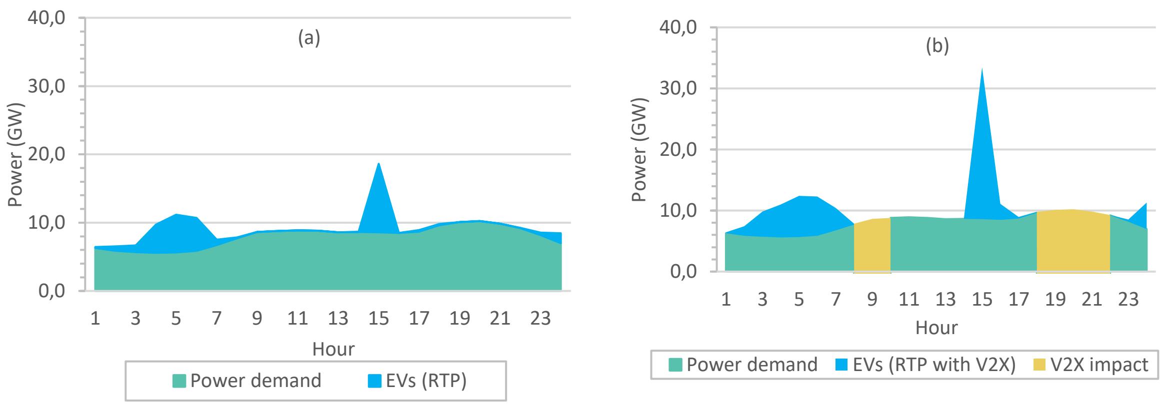


Figure 3.14 – Power demand curve and EVs management with RTP without V2X (a) and RTP with V2X (b), Portugal, Scenario 2030

The RTP strategy is shown in Figure 3.15, for the implementation of this strategy was used the typical energy prices for a day of winter season in Portugal [51]. Hence, in Figure 3.15 (a and b) is possible to observe the high variability that this strategy will introduce in the Portuguese system, creating a new peak of consumption at 15h, 18.6 GW without V2X Figure 3.15 (a) and 33.4 GW with V2X Figure 3.15 (b).

In summary, the use of ToU tariffs can introduce benefits in the power system, but, when V2X capability is implemented, can introduce higher volatility in the system demand. Related to RTP, this strategy is not recommended to be considered in scenarios with high EV adoption, hence, for Portugal in 2030, this strategy is not efficient. Since Portugal has de higher EV mass adoption of the four EV4EU countries, in this document, RTP strategy is analysed only for this scenario, Figure 3.16 shows a summary of the other strategies tested for the Portuguese case.

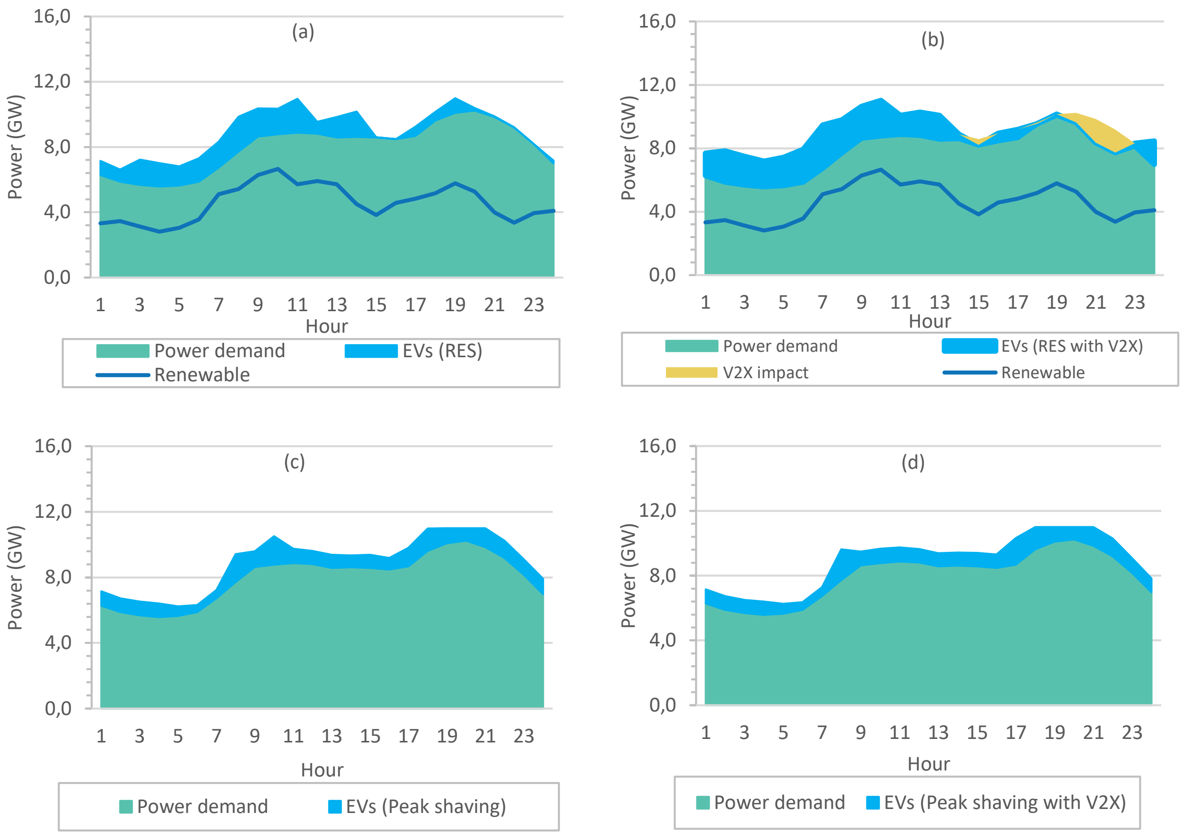


Figure 3.15 – Summary results for Portugal, Scenario 2030. (a) RES without V2X, (b) RES with V2X, (c) Peak Shaving without V2X, (e) Peak Shaving with V2X

For 2030, the strategies RES and peak shaving are the most adequate to manage the EVs mass adoption in Portugal, both without and with V2X. In the case of RES, the peak consumption will be 10.14 GW without V2X and 11.1 GW with V2X, and even with an EV demand higher than without V2X, the EV consumption follows the RES generation curve. Furthermore, the V2X impact maintains the power demand curve without alterations. For the peak shaving, the peak consumption will be 11 GW, increasing by 0.9 GW the total power demand.

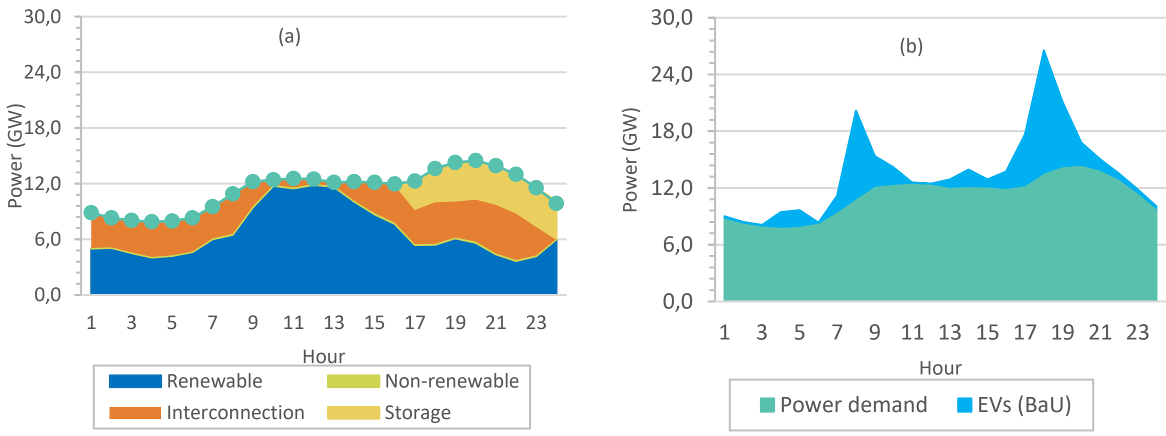


Figure 3.16 – Power generation and demand curve from Portugal (a) vs EV charging without management (b), Scenario 2050

Portugal has the most expected mass EV adoption for 2050 (6,330,000), Figure 3.16 shows the expected evolution of production as well as the EV charging demand impact in the power system without management for 2050. The peak consumption will increase to 14.47 GW but is also expected an increase of RES generation, with a peak production of 11.8 GW. Moreover, it is possible to observe that Portugal will have storage capacity available, and, consequently, through storage management, the Portuguese system will be able to take advantage of the solar production (11h – 16h) and then, when necessary (between 17h – 24h), will be able to attend the peak consumption. The impact of EVs can be observed in Figure 3.16 (b). In that case, two new peak consumption can be identified due to the vehicles that are charged without management in residential charging stations in the evening and the ones that are charged at work in the morning. In that case, the peak can arrive to 26.5 GW around 18:00, more than twice that of the energy consumption in the system.

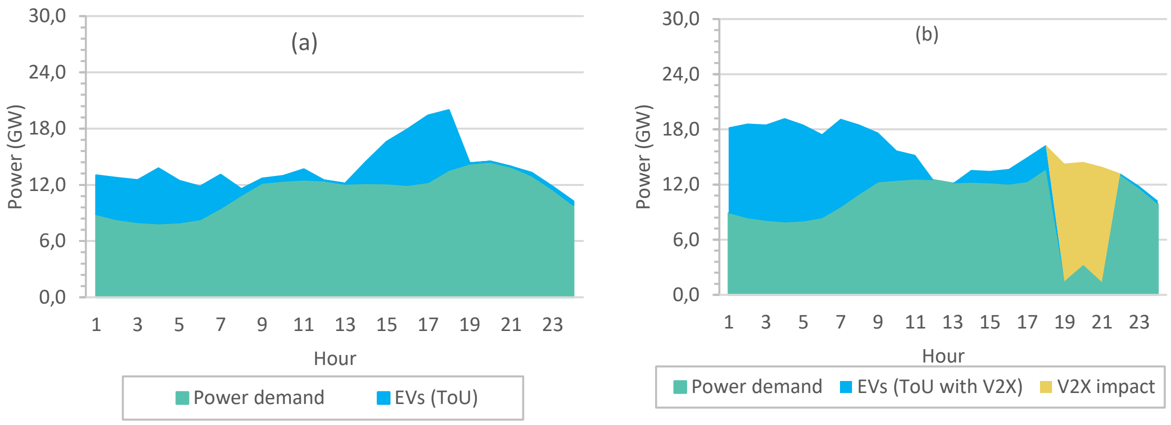
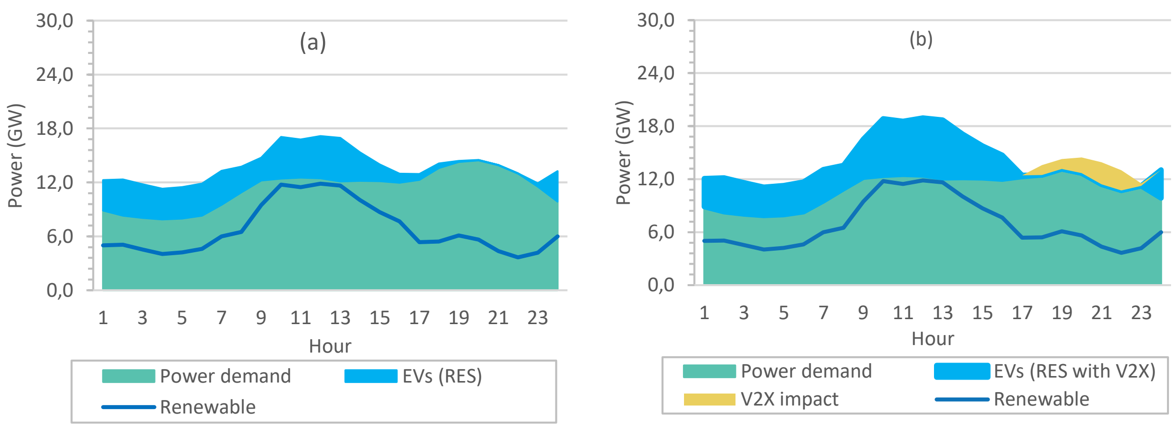


Figure 3.17 – Power demand curve and EVs management with ToU without V2X (a) and ToU with V2X (b), Portugal, Scenario 2050

In Figure 3.17, it is possible to observe that, like for scenario 2030, the use of ToU will reduce the global Peak demand to 19.9 GW, but, even with this reduction, this strategy will require an increase of 6.3 GW to attend the EV charging demand. Moreover, when V2X is available, a new peak of 19.3 GW will be created in off-peak hours (7h), which confirms the high variations that the V2X technology can introduce in the power system. Figure 3.18 shows a summary of the other strategies tested for the Portuguese case, scenario 2050.



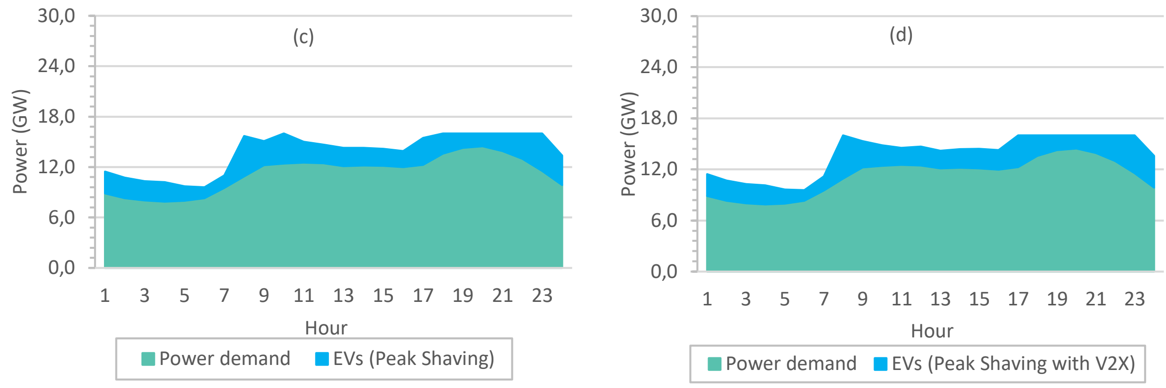


Figure 3.18 – Summary results for Portugal, Scenario 2050. (a) RES without V2X, (b) RES with V2X, (c) Peak Shaving without V2X, (d) Peak Shaving with V2X

For 2050, the strategy peak shaving is the most adequate to manage the EVs mass adoption in Portugal, both without and with V2X, in which the peak consumption will be 16 GW, increasing to 5.08 GW the total demand for the power system. In the case of RES, the peak consumption (without V2X, Figure 3.18 (c)) will be 17.05 GW, increasing to 4.6 GW the total demand for the power system. When V2X is considered in the RES coordination Figure 3.18 (d), the peak consumption will be 18.8 GW, increasing by 6.41 GW the total demand for the power system, but the EVs consumption follows the RES generation curve, moreover, the V2X impact maintains the power demand curve without modifications. In the peak shaving signals, the peak consumption will be maintained in 16 GW for both without and with V2X.

3.4 Slovenia Case

For the Slovenia case, it was simulated four scenarios (2021, 2030, 2040, 2050) considering the EV evolution shown in Table 3.4. The average travel distance was considered 32.3 km/day [52]. The Support to RES strategy considered all the renewable energy resources in Slovenia [53]. The information on the Slovenian most popular EVs used was obtained from [54]. The percentage of usage of charging stations was obtained from [55], where the most used (93%) is the 22 kW public charging station. The average speed for Slovenia was defined as 70 km/h [56]. Figure 3.19 shows the power generation and curve demand for Slovenia on the worst day (the based scenario), on January 19th, 2021, [53].

Table 3.4: Total EVs considered in each scenario in the Slovenia case (Source [57]**)**

Year	Total EVs
2021	21,574
2030	217,993
2040	701,061
2050	1,427,729

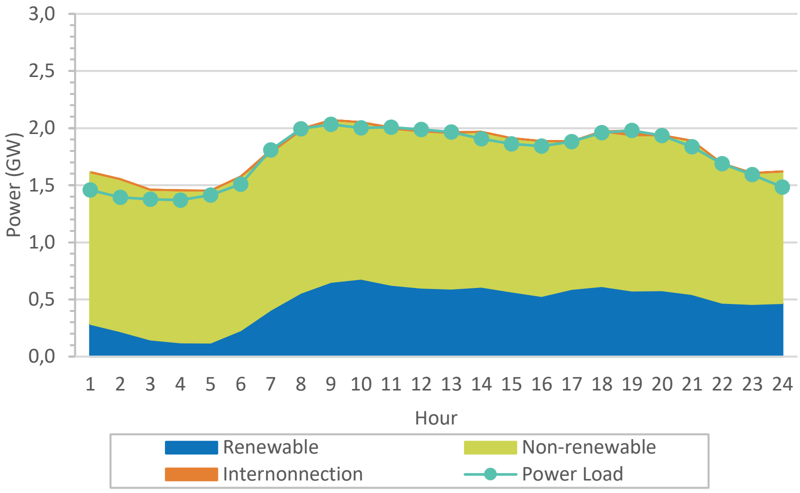


Figure 3.19 – Power generation and demand curve from Slovenia, Scenario 2021

At 9h, due to the high non-renewable generation and with an energy importation of 0.2 GW, Slovenia was able to attend the peak consumption in the worst scenario (2.03 GW).

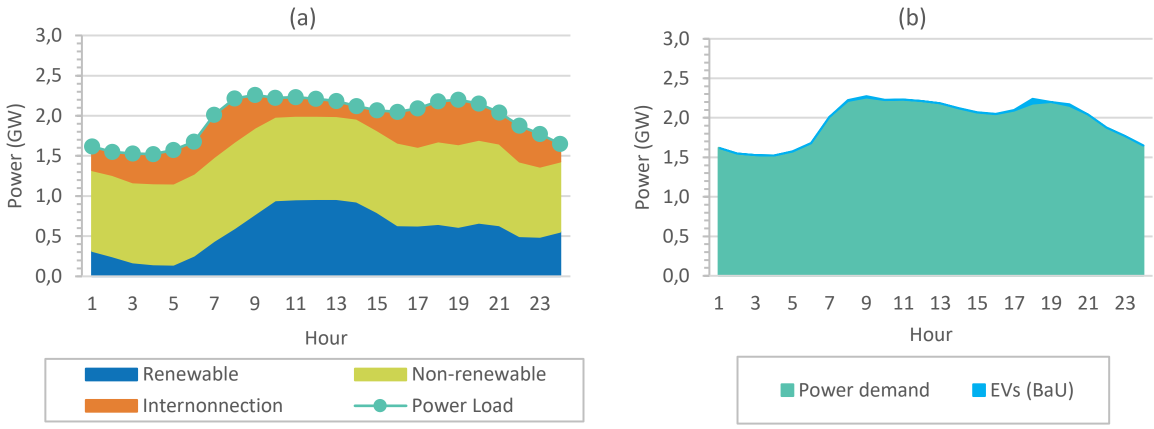


Figure 3.20 – Power generation and demand curve from Slovenia (a) vs EV charging without management (b), Scenario 2030

Based on the production and consumption registered in 2021, it was defined the scenarios of 2030 until 2050 for Slovenia. In Figure 3.20 (a), it is possible to see the expected evolution of consumption and production for 2030 since 2021. The peak consumption will increase to 2.25 GW but is also expected reduce on the maximum non-renewable generation, 1.07 GW for 2030, reducing 0.35 GW since 2021, another important fact is the need of interconnection for the Slovenia system will be able to attend to its demand consumption. The impact of EVs can be observed in Figure 3.20 (b). In that case, at 17h, a new peak consumption can be identified, 2.1 GW. These peaks are produced due to the vehicles that are charged in residential charging stations in the evening and the ones that are charged at work in the morning. Due to the number of EVs in Slovenia for 2030 (217,993), its impact on the power system is not significant, moreover, from 2030 until 2040, in Slovenia the EVs will increase by 701,061 EVs, hence, they are expected similar results for 2040.

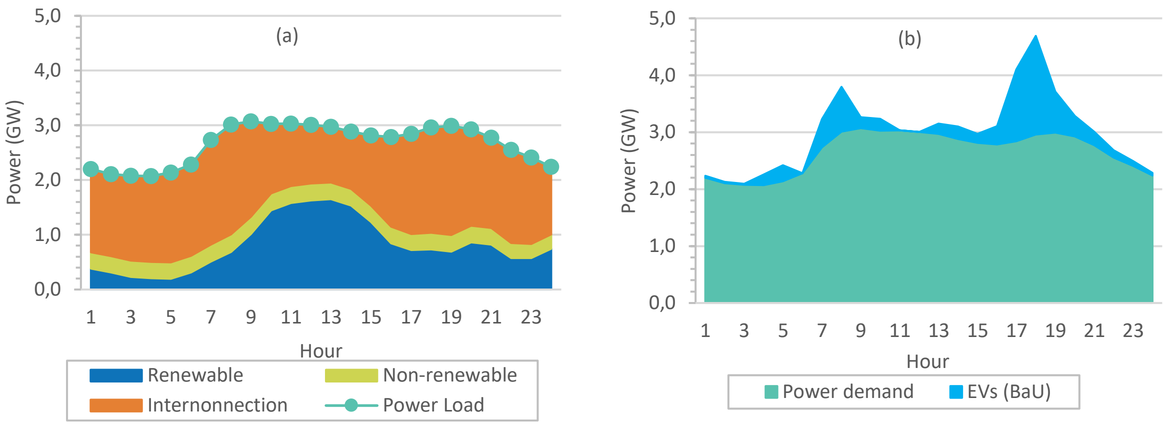


Figure 3.21 – Power generation and demand curve from Slovenia (a) vs EV charging without management (b), Scenario 2050

For 2050, it is expected the most EV mass adoption in Slovenia (1,427,729). In Figure 3.21 (a), it is possible to see the expected evolution of consumption and production for 2050. For scenario 2050, it is necessary a high capacity of interconnection (1.7 GW at 9h) for the Slovenia system will be able to attend to its demand consumption. The peak consumption will increase to 3.07 GW. The impact of EVs can be observed in Figure 3.21 (b). For this scenario, the EVs without management will be created a peak consumption of 4.7 GW at 18h. Hence, for 2050, the management of the EV charging will be necessary.

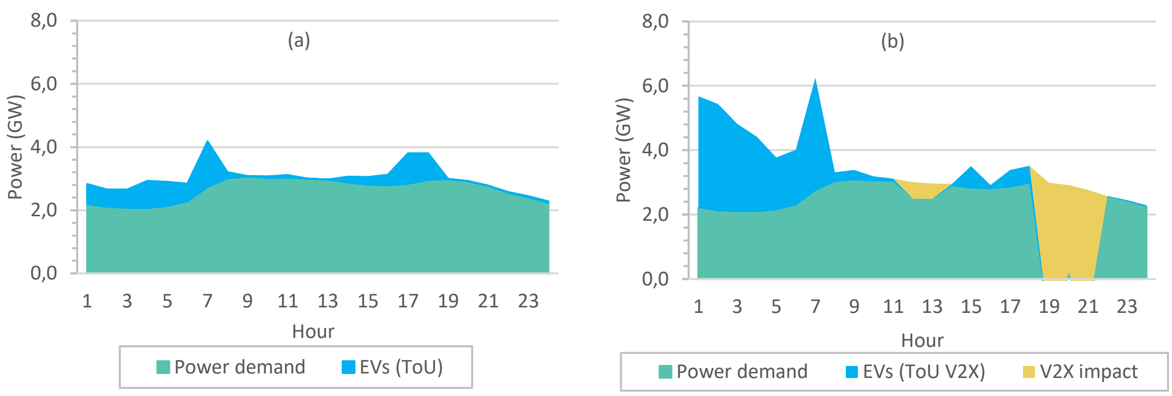


Figure 3.22 – Power demand curve and EVs management with ToU without V2X (a) and ToU with V2X (b), Slovenia, Scenario 2050

In Figure 3.22, it is possible to observe that the use of ToU will have a positive impact in the Slovenia system, reducing the peak demand by 4.18 GW at 7h. When V2X is available, new peaks will be created, 6.25 GW in off-peak hours (7h), that confirms the higher variations that the V2X technology can introduce in the power system. On the other hand, the EVs will take advantage of higher prices in the peak-hours to discharge power, reducing the global consumption in the traditional peak hours. In summary, the use of ToU tariffs can introduce benefits in the power system, but, when V2X capability is implemented, can introduce higher volatility in Slovenian power system. Figure 3.23 shows a summary of the other strategies tested for the Slovenian case.

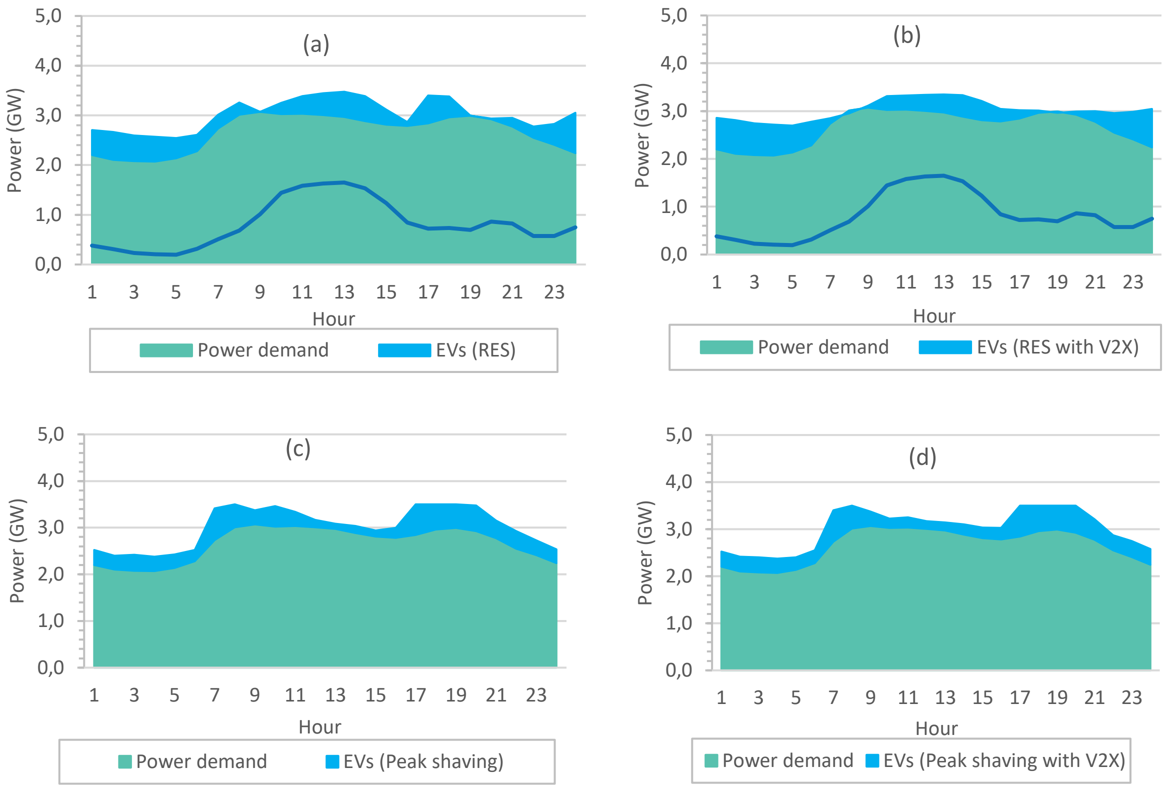


Figure 3.23 – Summary results for Slovenia, Scenario 2050. (a) RES without V2X, (b) RES with V2X, (c) Peak Shaving without V2X, (d) Peak Shaving with V2X

For the Slovenian power system, coordination with renewables and peak shaving signals are the two strategies that can provide good results. In the RES strategy without V2X, the peak consumption will be 3.47 GW at 13h (Figure 3.23 (a)), this is due to the EV users take advantage RES generation to charge their batteries. When V2X is available, the peak consumption will be 3.33 GW at 12h. In the peak shaving signals ((Figure 3.23 (c) and (d)), the peak of consumption is 3.5 GW for both without and with V2X. For the Slovenian case, in summary, the best indicated EV management is the peak shaving signals, due to the stability that will maintain even when V2X will be considered.

3.5 Results Discussion (Comparison between Countries)

The EV management strategies simulation allows to analyse the impact of EVs through their evolution until 2050 in each country of the EV4EU project. Denmark and Portugal have de most increasing of EVs mass adoption until 2050, in which, 100% of total cars will be EVs in Denmark, and 98% in Portugal. Related to the energy demand, EV consumption will represent 12% of the total consumption for Denmark in 2050 and 18% for Portugal. In both cases, due to the volatility of EVs power demand, it is concluded that price-based strategies (ToU and RTP) will not be efficient to be considered to manage de EVs mainly when the V2X capability is available. On the other hand, until 2050 Denmark will have 89% of its power capacity from renewable energy resources (RES), allowing attend its power demand with security and in a sustainable way, even with the EV mass adoption for 2050. In the case of Portugal, the capacity of interconnection will allow the power system to attend the increase of consumption due to the EV mass adoption for 2030, nevertheless, for 2040 and 2050 will be necessary to implement energy storage systems management to take advantage of the solar production and, therefore, to serve the power demand in the hour with peak consumption. Moreover, Portugal will have an important increase of generation of 11.76 GW by 2050, representing an increase of 268%

compared with 2021 (4.39GW), allowing the Portuguese power system will take advantage of the RES generation to implement storage management to serve its massive adoption of electric mobility. Considering this scenario, the management of V2X can have an important role in the global energy system management. Hence, for both countries, the support to RES and peak shaving strategies are the most efficient to be implemented in the scenarios with higher mass EV adoption considering V2X (2040 and 2050). However, coordination with RES leads to a better usage of the renewable generation and consequently to the reduction of GHG emissions.

In Greece and Slovenia it is expected a lower adoption of EVs until 2050. In Greece, it is expected an important development of the use of RES mainly based on PV technology and important investments in the interconnection capacity. Considering these aspects, is concluded that Greek system will accommodate the increase power and energy needs, due to the EVs, in a sustainable and efficient way. In the case of Slovenia, it is concluded that the interconnection capacity evolution will play a major role in the power system stability considering the evolution of EVs and their impact on the system.

For the four EV4EU countries, V2X will be advantageous when considered in the minimization of the peak and peak shaving signals, since under these management strategies, the EV discharging will not introduce high variability, even will be able to collaborate to support the power system (reduce the peak of consumption). Related to RES strategy, for Denmark, Greece and, Portugal, it is highly recommended for 2050 to take advantage of RES coordination integrated with the EV management, since for these countries a considerable increment in RES generation is expected. Therefore, the RES strategy will guarantee not only to manage the EV charging to preserve the power system but also to reduce the CO_2 emissions.

The need to implement EV management was confirmed for all four countries, because when the EVs are not controlled, in all the cases considered for each country and scenario, new consumption peaks will be negatively affecting the power system of each country. Finally, a considerable reduction in the non-renewable production is expected for the four countries, so that the future mass adoption of EVs will be integrated with the RES coordination to ensure the decarbonisation goal.

4 Conclusions

This deliverable presents an analyse of the impact of mass electric vehicle (EVs) adoption, considering *vehicle-to-everything* (V2X), in the countries of the EV4EU project members (Denmark, Greece, Portugal, and Slovenia). The first conclusion is that since the EV adoption is different for the four countries, the impact of EV mass adoption in the power system is also different.

One of the main conclusions of the present study is that the increased use of the EVs will have an important impact in the power system management both in terms of energy and power. The impact will be different in each country depending on the adoption of the EVs. In the study it was realized that these scenarios are more demanding in Portugal and Denmark when compared with Greece and Slovenia, where the EVs can represent around 100% of the total vehicles until 2050. This impact is illustrated by the increase of peak consumption to 32% in Denmark and 49% in Portugal compared with the 19% and 37% in Greece and Slovenia, respectively.

Related to the EVs management strategies, it is possible to conclude that price-based strategies can be effective for the following years. However, for 2050, new peaks can arrive due to the concentration of charging in periods where normally the consumption is low, for Denmark, the peak will achieve 9 GW at 7h, representing an increase of 13% of the consumption for this period. For Portugal, 13.7 GW at 4h with an increase of 43% of the peak consumption. For Greece, 7.63 GW at 17h with an increase of 20% of the peak consumption. Finally for Slovenia 4.18 GW at 7h, representing an increase of 34% of the total consumption in this hour. Related to the coordination with RES, this strategy is extremely recommended to be implemented in 2050 for the four countries, since the peak of consumption will take advantage of renewable generation. For Denmark, the peak consumption will achieve 11.51 GW at 11h, with 100% of this power demand will be attended by RES generation. For Greece, the peak consumption will be 11.2 GW at 11h, in which, the RES generation will represent 68% of this power demand. In the case of Portugal, the peak consumption will arrive 17.14 GW at 11h, in which, the RES generation will represent 70% of this power demand. Finally, in Slovenia, the peak will achieve 3.44 GW, with 47% of this power demand will be served by RES generation. Strategies based in peak shaving are also recommended to be implemented in 2050 for the four countries, since the peak consumption will be maintained in a secure way. For Denmark, the peak consumption will be 11 GW at 18h, in which the EVs will increase the total consumption to 10%; for Greece, the peak consumption will arrive 9.5 GW, in which the EVs will represent an increase of 5% of the total consumption at 18h; for Portugal, the peak consumption will be 16 GW at 18h in which the EVs will increase the total consumption to 11%; and for Slovenia, the peak consumption will amount 3.5 GW at 18h, in which the EVs will represent an increase of 15% of the total consumption.

Regarding the impact of V2X strategies, it is possible to conclude that V2X will have a negative impact when considering price strategies in 2050, since will introduce volatility in the power demand and will create peaks of consumption at off-peak periods, for Denmark, at 8h will create a peak consumption of 12.07 GW, for Greece 11.13 GW at 9h, for Portugal 19.17 GW at 7h, and for Slovenia, 6.25 GW at 7h. On the other hand, for the strategies based on peak shaving and coordination of RES the use of V2X will be advantageous since will allow the reduction of the peaks or the reduction of EV charge "curtailment". The strategies related to the coordination with RES and EVs will increase the use of renewables and, mainly in Portugal and Greece (due to the high share of PV technologies), the support of the system in the periods where the RES production is low maintaining the power demand consumption stable.

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