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Energy Transition and Electromobility in Spain

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Master’s Thesis

Energy Transition and Electromobility in Spain

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Madrid

July 2021

Madrid

TRANSICIÓN ENERGÉTICA Y ELECTROMOVILIDAD EN ESPAÑA

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Director: Barquín Gil, Julián.
Entidad Colaboradora: ENDESA

RESUMEN DEL PROYECTO

En este proyecto se ha evaluado la proyección de penetración del vehículo eléctrico en España en el año 2030 para estimar la carga adicional que supondrá esta nueva demanda en el sistema eléctrico español.

Palabras clave: Descarbonización, Electrificación del Transporte, Vehículo Eléctrico (EV), Curva de Demanda Eléctrica, PNIEC 2021-2030.

1. Introducción

El objetivo de este proyecto es evaluar la penetración a gran escala del vehículo eléctrico en el Sistema Eléctrico en 2030. El PNIEC prevee una contribución muy importante de la electrificación del transporte para reducir las emisiones de gases de efecto invernadero y sustituir los derivados del petróleo. Se trata de estimar tanto el incremento de la demanda en términos anuales como la modificación de la curva de carga cronológica debido a esta importante demanda, actualmente casi inexistente.

La incorporación del Vehículo eléctrico puede ser la medida que a lo largo de esta década suponga un mayor incremento de la demanda eléctrica.

2. Definición del Proyecto

En primer lugar, se hace una estimación del parque de vehículos eléctricos que podría estar en servicio en 2030. Para ello se han utilizado las referencias disponibles en el PNIEC (Plan Nacional Integrado de Energía y Clima 2021-30) para el turismo eléctrico y se han hecho estimaciones coherentes con esas referencias para otros vehículos, furgonetas, ciclomotores y motocicletas y autobuses. En el caso de autobuses se ha tomado como referencia la flota de autobuses de transporte público de las áreas metropolitanas más habitadas de España que albergan el 55% de la población.

Una vez definido el parque eléctrico se estima la cuantía de la demanda eléctrica asociada y su distribución horaria para conocer el posible impacto en la curva de demanda.

3. Descripción del modelo/sistema/herramienta

En este proyecto se han modelado todos los parámetros y variables que ha sido necesario para determinar la curva de demanda anual del vehículo eléctrico a 2030. Se ha seguido la siguiente metodología:

- Se han hecho proyecciones a 2030 del parque de vehículos eléctricos, tanto sobre sus características técnicas (Batería, autonomía, consumo específico,) como sobre su distribución por segmentos.

- También se han hecho estimaciones sobre el kilometraje medio anual de ese parque de vehículos eléctricos para 2030, teniendo en cuenta que serán vehículos con poca antigüedad y que el vehículo eléctrico penetrará antes en usuarios y segmentos de vehículos con kilometraje superior a la media debido a los menores costes por kilómetro.
- Se ha analizado el consumo específico eléctrico de los distintos vehículos en función de sus prestaciones y las características de la carga (potencia de carga, energía por carga unitaria, tiempo de recarga). Para turismos y furgonetas se ha contemplado el caso de carga lenta, en general nocturna, y en cargador rápido público. Para motocicletas sólo se ha contemplado la carga lenta con potencias domésticas de baja tensión. En autobuses se ha contemplado la carga lenta en cocheras, y la carga rápida con pantógrafo.
- Se han estudiado las pérdidas del proceso de carga de la batería para calcular el consumo en cargador
- Se han evaluado las pérdidas de transporte y distribución en la red eléctrica, para calcular la demanda a nivel de central (demanda en barras de central)
- También ha sido necesario estimar un perfil de carga de los distintos tipos de vehículos eléctricos en los distintos tipos de carga. Para ello, previamente fue necesario analizar las nuevas tarifas de acceso y los cargos vigentes desde junio de 2021. La diferencia de precios eléctricos entre los distintos períodos de consumo (punta, llano y valle) pueden condicionar en gran medida los horarios de recarga, especialmente en carga doméstica.
- Con todo lo anterior se ha definido un perfil de carga horario para los distintos tipos de vehículos considerados.
- Mediante la agregación de esos perfiles se ha definido una curva de carga cronológica de la demanda en central de la carga del vehículo eléctrico para todas las horas del año.

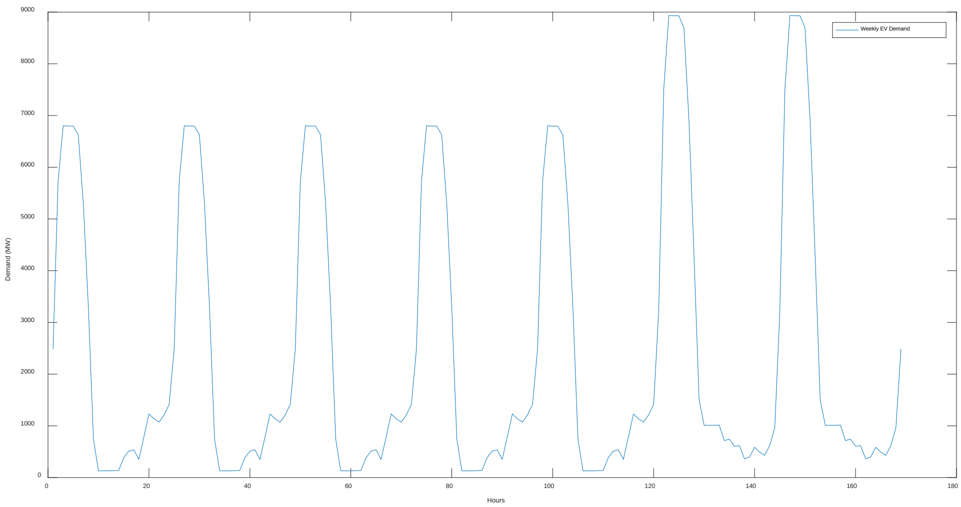
4. Resultados

- La incorporación del parque de vehículos calculado para 2030 supondría una demanda de 21.000 GWh al año, equivalente al 8% de la demanda de 2019.

	Cars&Vans		**Motorcycles**	**Buses**			
	Home	**Fast**		**Depot**	**Opportunity**	**Total**	
Vehicles in 2030	3.417.274		691.687	10.983		4.119.944	Units
Total distance travelled	67.359	5.468	3.740	467	200	77.236	Million Km/Year
Charges/Year	350	23	66	4	-	444	Million Charges
Net charge in batteries	12.897	1.070	177	707	303	15.154	GWh
Gross consumption in charger	15.363	1.132	210	744	319	17.769	GWh
Electric demand in Power Plant	18.703	1.210	254	783	336	21.286	GWh
Annual mileage of the EV type	19.711	1.600	5.408	42.537	18.230	18.747	Km/veh/year
Charges per year	103	7	96	358	-	107,7	Charges/veh
Energy consumption at the batteries	3.774	313	256	64.376	27.590	4.434,6	KWh/veh
Specific consumption	0,19	0,19	0,05	1,51	1,51	0,20	KWh/Km
Specific consumption at Power Plant	0,23	0,23	0,07	1,68	1,68	0,23	KWh/Km
% Total Losses	31,0%	11,6%	30,3%	9,8%	9,8%	28,8%	% Demand at Power Plant

Tabla resumen de los resultados obtenidos en este estudio.

- En el supuesto de que la recarga se hiciese mayoritariamente en las horas valle que se definen en la nueva estructura de tarifas de acceso y cargos, los incrementos de la demanda en esas horas serían del orden de 7-9.000 MW y en torno al 1.000 MW el resto de las horas.



Demanda semanal del Vehículo Eléctrico en 2030.

5. Conclusiones

El vehículo eléctrico podría suponer el mayor incremento de la demanda en esta década. Por tanto, la correcta asignación horaria de esta nueva demanda, así como la implementación de mecanismos que incentiven la carga del vehículo eléctrico en horas de bajos precios y baja demanda resultarán cruciales para optimizar el funcionamiento del sistema eléctrico.

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ENERGY TRANSITION & ELECTROMOBILITY IN SPAIN

Autor: de Marcos López-Baissón, José María**.**
Director: Barquín Gil, Julián.
Entidad Colaboradora: ENDESA

ABSTRACT

This project aims to evaluate the penetration of electric vehicles in Spain for the year 2030 to estimate the additional load that this new demand will place on the Spanish electricity system.

Keywords: Decarbonization, Transport Electrification, Electric Vehicle (EV), Electric Demand Curve. PNIEC 2021-2030.

1. Introduction

The objective of this project is to evaluate the impact of the large-scale penetration of electric vehicles in the Spanish peninsular electricity system in 2030. The aim is to estimate the increase in annual demand and the changes on the chronological load curve due to this important demand.

The incorporation of the electric vehicle may be the most important increase in demand on this decade.

2. Project Definition

Firstly, an estimation of the electric vehicle fleet that could be in service in 2030 is made. For this purpose, the references available in the PNIEC (National Integrated Energy and Climate Plan 2021-30) have been used for electric tourism and estimates consistent with these references have been made for other vehicles, vans, mopeds, motorcycles, and buses. In the case of buses, the fleet of public transport buses in the most populated metropolitan areas of Spain, home to 55% of the population, has been taken as a reference.

Once the electric fleet has been defined, the associated electric demand and its hourly distribution is estimated to evaluate the possible impact on the demand curve.

3. Description of the model

In this project we have modeled all the parameters and variables that have been necessary to calculate the expected hourly demand of the fleet for the year 2030. The following methodology has been followed:

- Projections to 2030 of the electric vehicle fleet have been made, both on its technical characteristics (Battery, autonomy, specific consumption,) and on its distribution by segments.
- Estimates have also been made on the average annual mileage of this electric vehicle fleet for 2030, considering that they will mostly be vehicles under 4 years

of age, and that the electric vehicle will penetrate earlier in users and vehicle segments with higher mileage than the average.

- The specific electric consumption of the different vehicles has been analyzed according to their performance and charging characteristics (input power level, energy consumed per charge, charging time…). For cars and vans, slow charging (normally at night) and fast charging at public stations were considered. For motorcycles, only slow charging with domestic power has been considered. For buses, slow charging at the depot and fast charging with pantograph have been considered.
- The losses of the battery charging process have been studied to calculate the consumption in the charger.
- Transmission and distribution losses in the electrical network have been evaluated to calculate the demand at the power plant level (demand at power plant busbars).
- It was also necessary to estimate the charging profile of the different types of electric vehicles for the different power inputs. To do this, it was previously necessary to analyze the new access tariffs and charges that came into place in June 2021, and how the difference in electricity prices between the different consumption periods (peak, flat and valley) can largely condition the charging schedules, especially in domestic charging.
- Based on these times to complete a charging cycle, an hourly charging profile has been defined for weekdays and weekends in the case of cars and vans.
- The hourly profile for mopeds, motorcycles and buses experiments a high seasonal variability, so it was examined for the different months of the year. Also, the bus hourly profile is examined for the different cities.
- By aggregating these profiles, a chronological load curve of the electric vehicle demand at a power plant level is defined.

4. Results

- The addition the expected fleet of Electric Vehicles for the year 2030 would result in a demand of 21,000 GWh per year, equivalent to 8% of 2019 demand.

	Cars&Vans		**Motorcycles**	**Buses**			
	Home	**Fast**		**Depot**	**Opportunity**	**Total**	
Vehicles in 2030	3.417.274		691.687	10.983		4.119.944	Units
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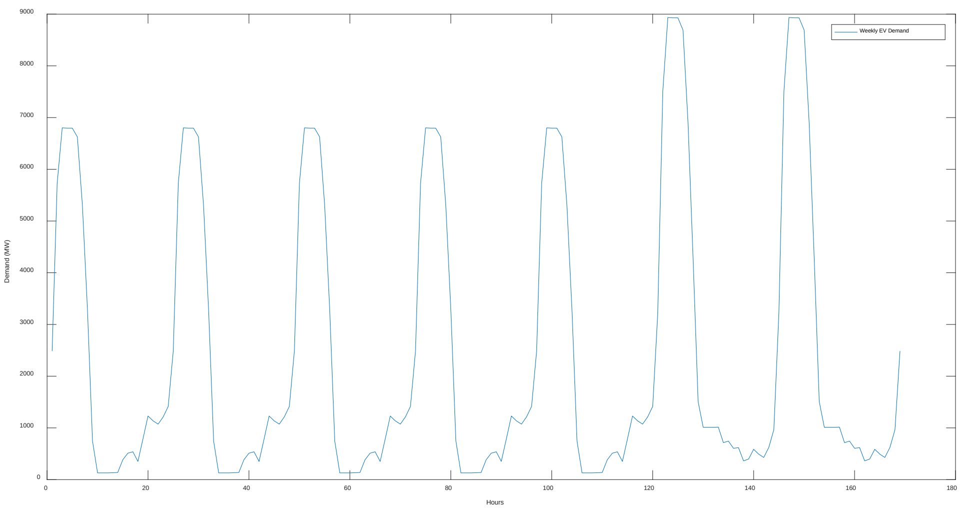
Specific consumption at Power Plant	0,23	0,23	0,07	1,68	1,68	0,23	KWh/Km
% Total Losses	31,0%	11,6%	30,3%	9,8%	9,8%	28,8%	% Demand at Power Plant

Summary of the obtained results.

- If vehicles charged their batteries in the off-peak hours defined in the new access tariff structure, the increase in demand in those hours would be in the order of 7.000 MW in the weekdays and around 9,000 MW in the weekend nights, and 1.000 in the peak hours.



Weekly demand of EVs in 2030

5. Conclusions

The electric vehicle could represent the largest increase in demand in this decade. Therefore, the correct hourly allocation of this new demand, as well as the implementation of mechanisms that encourage electric vehicle charging at times of low prices and low demand will be crucial to achieve the optimal performance of the electric power system.

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Table of Contents

Chapter 1. ***Description of the project*** ***8***

1.1 Introduction 8

1.2 Methodology 8

Chapter 2. ***Electric Cars & Vans*** ***11***

2.1 Current situation 11

2.2 Forecasting of the Spanish EV fleet in 2030. 15

2.2.1 Characteristics of the Electric cars & vans fleet in 2030 .... *15*

2.2.2 Estimation of the number of electric cars & vans in 2030 .... *16*

2.2.3 Forecasting of the annual mileage of cars & vans *18*

2.3 Losses 21

2.3.1 Charging losses *21*

2.3.2 Battery self-discharge losses *23*

2.3.3 Transmissions and distribution network losses *23*

2.4 Estimation of the electric energy consumed per charge 25

2.4.1 Home charge *26*

2.4.2 Fast Charge *28*

2.5 Annual energy load of the batteries for the fleet and mileage considered 32

2.5.1 Home charge *32*

2.5.2 Fast charge *34*

2.5.3 Home and Fast charge aggregated demand *35*

2.6 Demand at the power plant and load curve of the electric fleet 36

2.6.1 Effect of the cost of energy *36*

2.6.2 Home Charge load curve *38*

2.6.3 Fast Charge load curve *42*

2.6.4 Total consumption (home and fast) without shifting load to the weekends *44*

2.6.5 Total consumption (home and fast) shifting load to the weekends *44*

Chapter 3. ***Motorbikes*** ***47***

3.1 Current situation 47

3.2 Forecasting of the motorcycle fleet in 2030 49

3.2.1 Characteristics of the motorcycles fleet in 2030 .... *49*

3.2.2 Number of vehicles ... 50
3.2.3 Forecasting of the annual mileage of motorcycles ... 50
3.3 Losses ... 52
3.4 Unitary consumption of the motorcycles for the different categories ... 53
3.4.1 Unitary net charge for the different categories ... 53
3.4.2 Unitary gross charge for the different categories ... 53
3.4.3 Charge time of the different categories for selected power inputs ... 54
3.5 Annual consumption of the fleet ... 55
3.5.1 Number of charges per year ... 55
3.5.2 Annual consumption calculation ... 56
3.6 Daily schedule and load curve ... 58
3.6.1 Seasonal component of the electric motorcycle demand ... 61

Chapter 4. ***Buses ... 63***
4.1 Annual distance travelled by public buses ... 64
4.2 Specific consumption of public buses in metropolitan areas per km ... 66
4.2.1 Specific consumption as a function of temperature ... 66
4.2.2 Annual temperature distribution across areas ... 68
4.3 Losses ... 70
4.4 Hourly distribution of the electric load ... 71

Chapter 5. ***Summary and conclusions ... 73***
5.1 Summary of the main results ... 73
5.2 Expected load curve of the ev fleet in spain in 2030 ... 73
5.3 Conclusions ... 75
5.4 Integration of the EV load curve in Endesa's energy transition model ... 78

Chapter 6. ***Bibliography ... 80***

List of Figures

Figure 1 Real word range vs rated range as a function of temperature.[4] 14
Figure 2 Expected increase of EVs 2017/2030. [5].. 16
Figure 3 Annual mileage for selected types of vehicles [14] 19
Figure 4 Charging losses for selected input powers [2] 22
Figure 5 Lineal charge zone. [6]... 25
Figure 6 Fast charge curve for Tesla model 3 and Hyundai 29
Figure 7 Daily load without shifting load to the weekends... 40
Figure 8 Daily load on the weekdays shifting load to the weekends. 41
Figure 9 Daily load on the weekends shifting load to the weekends. 41
Figure 10 Expected load curve of fast charge in Norway. [3]... 42
Figure 11 Daily load curve in fast charge... 43
Figure 12 Total demand (home+fast) without load shifting.. 44
Figure 13 Total demand (home+fast) on the weekdays. 45
Figure 14 Total demand (home+fast) on the weekends. 45
Figure 15 Load curve of different categories for different input powers 59
Figure 16 Hourly demand profile of electric motorcycles accounting for distribution & Transmission Losses.. 60
Figure 17 Seasonal variability factor for motorcycle use. Source: England's department for transport. [7] 61
Figure 18 Hourly dispersion range for all months.. 62
Figure 19 Bus consumption as a function of external temperature 67
Figure 20 Monthly average temperatures for the main metropolitan areas........................ 68
Figure 21 Specific consumption of buses by month for the main metropolitan areas. 69
Figure 22 Daily bus fleet consumption for the fleets of the different metropolitan areas in different months.. 70
Figure 23 Expected hourly load curve for the electric bus fleets of the main metropolitan areas in 2030.. 72
Figure 24 Hourly Demand VE at Power Plant in weekdays 74

Figure 25 Hourly Demand of VE at power plant level in Weekends 74

Figure 26 Capacity of Energy valley-filling. Spain 2019 demand (GWh).......................... 75

Figure 27 Flattening of the load curve thanks to EV charging in a week 76

Figure 28 Overall increase on load, and curve flattening.. 77

Figure 29 Comparison of monotonous demand curves with and without EVs. High Electrification Scenario 79

Figure 30 Aggregated curves of all consumptions not aimed at storage. High electrification Scenario 79

List of tables

Table 2-1 Segments - Example of representative vehicles 12
Table 2-2 Market share per segment in Spain 2019 12
Table 2-3 Average characteristics of EVs in each segment in 2021 13
Table 2-4 Expected characteristics of the Spanish Electric Vehicle fleet in 2030. 16
Table 2-5 Fleet structure 2030 17
Table 2-6 Expected increase on market share of electric vans respect to total vans sold. .. 18
Table 2-7 Average mileage of the Spanish car fleet by engine capacity [14] 19
Table 2-8 Mileage by age of the cars 19
Table 2-9 Mileage of the Spanish car fleet by age of the vehicles 20
Table 2-10 Annual Mileage of the segments and total mileage of the Electric car and van fleet in 2030 20
Table 2-11 Average charging depending on input power for home charging. 21
Table 2-12 Average charging depending on input power for fast charging. 22
Table 2-13 Expected losses depending on input power [1] 22
Table 2-14 Transmission & distribution losses by period and tariff. [12] 23
Table 2-15 Home charge. Unitary Net charge per cycle (KWh) 26
Table 2-16 Home charge. Unitary Gross Charge per cycle (KWh) 27
Table 2-17 Home charge. Time to charge a vehicle of each segment with different input powers. 27
Table 2-18 Fast charge. Unitary Net charge per cycle (KWh) 28
Table 2-19 Fast Charge. Unitary Gross Charge per cycle (KWh). 28
Table 2-20 Fast Charge. Average power charge for each nominal input power (KW) 30
Table 2-21 Time to charge every segment in fast charge. 30
Table 2-22 Expected annual charges per year for every segment and associated mileage. 31
Table 2-23 Distribution of electric cars & vans by charging power and segment expressed as percentages 32
Table 2-24 Distribution of the electric cars and vans by charging power and segments by 2030 32

Table 2-25 Annual Power consumption by segment and charge power for home charge (GWh/year) 34
Table 2-26 Annual Power consumption by segment and charge power for fast charge 34
Table 2-27 Expected annual consumption of Spain's Electric Car fleet in 2030 (Home+Fast) 35
Table 2-28 Values of access tariffs and charges to transmission and distribution network applicable starting June 1, 2021 (€/KWh) [12] 37
Table 2-29 Total variable Cost of Energy for Home charging (€/KWh) 38
Table 2-30 Hourly home charging schedule........ 39
Table 3-1 Number of motorcycles. [14] 48
Table 3-2 Motorcycle categories. 48
Table 3-3 Characteristics of the fleet in 2030........ 49
Table 3-4 Increase in sales forecast and total electric motorcycle fleet for the year 2030.. 50
Table 3-5 Average mileage........ 51
Table 3-6 Estimated total mileage for all motorcycles in a category 51
Table 3-7 Estimated total mileage for all motorcycles in a category 51
Table 3-8 Losses in the charger. 52
Table 3-9 Transmission and distribution losses. [12]........ 52
Table 3-10 Battery Net charge........ 53
Table 3-11 Battey gross charge. 54
Table 3-12 Time to charge........ 54
Table 3-13 Specific consumption. 55
Table 3-14 Number of charges per year 56
Table 3-15 Number of motorcycles per category and selected power inputs 57
Table 3-16 Net aggregated charge of the fleet (GWh) 58
Table 3-17 Gross aggregated charge of the fleet (GWh)........ 58
Table 3-18 Number of vehicles charging daily. 59
Table 3-19 Hourly demand for an average day in every month........ 62
Table 4-1 Total annual distance travelled (in km) by buses in the main metropolitan areas of Spain 65

Table 4-2: Specific consumption of buses under different occupation and weather conditions [10] 67

Table 5-1 Main inputs & results 73

Chapter 1. DESCRIPTION OF THE PROJECT

1.1 INTRODUCTION

The main objectives of this project are:

- To define the expected **load increase** due to **the widespread adoption of Electric Vehicles (EV) in Spain by 2030**.

- To analyze the relevant **modifications in the generation balance** at an hourly, daily and annual levels using **Endesa's Energy transition model**. These modifications would come not only by the adoption of EVs, but also from the higher penetration of non-dispatchable renewable energy sources in the Spanish electricity mix following the decarbonization objectives that Spain has set.

The **EV may represent the greatest increase in demand in the 2020-30** period, even more than the massive incorporation of heat pumps for heating and cooling. Moreover, this new demand **may change the shape of the daily load curve** as EV charging is concentrated in off-peak hours.

1.2 METHODOLOGY

Every **type of vehicle will be studied separately** (electric cars, vans, motorcycles, and buses) to correctly estimate the degree of electrification of each type of vehicle and the expected annual consumption of each type.

According to the National Integrated Energy and Climate Plan (PNIEC) 2021-2030, in Spain in 2030 there will be **five million Electric Vehicles**. Out of this five million, **three million are expected to be electric cars**. The other two million vehicles would be buses, vans, motorcycles and plug in electric hybrids, but it does not address how many of each type there will be.

First, some **assumptions** will be made about the **expected recharge schedules** of the batteries of the fleet to estimate their impact on the chronological curve of electric charging.

Second, once the aggregate chronological load curve of the electric vehicle is available, it will be **added to the demand curve contemplated by Endesa's Energy Transition Model**.

Finally, we will **evaluate the impact** on the Spanish electric system.

The methodology that will be followed in this report is the next one:

1. The electric vehicles (cars, vans, and motorcycles) models currently in the market will be analyzed to correctly assess the characteristics of the fleet, and databases for every type of vehicle will be made. Said database will **group the models** with similar technical parameters together, to create segments or categories that correctly display the main characteristics of the vehicles.

2. Using the characteristics of the vehicles currently on the market as a starting point, the **characteristics of the vehicles in the year 2030 will be estimated**. Some factors will be considered, like the increase in battery capacities, which will also result in increased range.

3. With the current fleet classified by segments, the shape of the fleet and the **number of vehicles in the year 2030 will be modelled** by means of the expected increase in sales of each year respect to the previous one, and the expected market share of EVs.

   In addition, based on the mileage of the current fleet, the mileage of electric vehicles to 2030 is also projected, considering that, the most modern vehicles of any segment run more km per year than the average of the segment and electric vehicles will do more mileage than conventional ones.

4. All the expected potential losses in the charging process have been analyzed. These losses include the **losses in the charger and the losses in the distribution and transmission networks**.
5. Then, for every family or segment, **the energy consumption for a charging cycle** will be calculated. There will also be an estimation of the percentage of vehicles that will use each type of charger. With both, the capacity of the batteries and the input power of the chargers, the **time to complete a charging cycle will be calculated for every segment and input power.**
6. With the unitary consumption of the charging cycles and the number of charges needed to cover the expected annual mileage of each segment, **the net consumption of the EV will be calculated**. Adding to this net demand the expected losses in the charging cycle, the **gross energy consumption in charger will be obtained**.
7. To evaluate the impact of EV on the Spanish Electric system, it is necessary to **estimate the shape of the load curve attributable to the EVs**. For this reason, some **hypotheses have been made on the expected behavior of the users**. The prices of the new access tariffs have been taken into consideration. These tariffs are intended to incentivize the charging on the valley hours (0-8h) and the weekends.
8. Lastly, with all the calculations done previously, the load curve of the electric vehicle is defined, and the losses in the distribution and transmission networks are added to said curve, and the final demand at a power plant level is obtained.
9. For electric buses, the methodology is slightly different, and it will be explained further in its own section. (Chapter 4. Buses)

Chapter 2. ELECTRIC CARS & VANS

In this chapter, the impact of widespread use of electric cars and vans in the year 2030 will be studied. The increase in electric energy consumption caused by shifting from internal combustion engine cars and vans to electric ones will be studied. This process will be gradual, and thus, it is necessary to study its evolution for the whole decade (2020-2030), and the end results are expected to be of the same order that the goal set by the PNIEC

2.1 CURRENT SITUATION

In this section, the main characteristics of the Spanish car fleet are analyzed (including cars, vans, and trucks weighing less than 3,500kg) to estimate its evolution towards 2030.

The car fleet has been classified into different "segments" (Euro Car segments, see table below). Each segment includes vehicles with similar size, similar technical characteristics of the engine and similar functionalities.

To characterize the Electric Car fleet in Spain in 2030, data from the database "Electric Vehicle Database"[1] was extracted. Such database includes important parameters such as battery capacity, the range per charge expressed in km, the specific consumption expressed in kWh/100km, and finally, the Euro Car segment to which the vehicles belong. A brief description of the different Euro Car segments is shown in the table down below:

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

Segment	Description	Example vehicles
A	Mini cars	Smart ForTwo, Renault Twingo
B	Small cars	Volkswagen Polo
C	Medium cars	Volkswagen Golf, BMW 1-Series
D	Large cars	Mercedes C-Class, Audi A4
E	Executive cars	Mercedes E-Class, BMW 5-Series
F	Luxury cars	Mercedes S-Class, BMW 7-Series
J	Sport utility vehicles /SUV	Ford Kuga, VW Tiguan
M	Multi purpose cars /MPV	Mercedes B-Class, Opel Zafira
S	Sports Cars	Audi TT, Porsche 911

Table 2-1 Segments - Example of representative vehicles

This classification by segments will allow to better estimate the mean parameters of the EVs as well as the expected market share of each segment.

Segment	Car	Mini-Van	SUV	Total	Percentage
A	52.309			52.309	4,1%
B	273.145		207.442	480.587	37,5%
C	260.47	53.491	294.771	608.731	47,5%
D	55.381	7.113	59.038	121.531	9,5%
E	8.202		8.501	16.703	1,3%
F	2.427			2.427	0,2%
Cars				1.282.288	100,0%
N Vans			214.567	214.567	

Table 2-2 Market share per segment in Spain 2019

Data from the database "Electric Vehicle Database" [2] will be used. Said data includes important parameters such as battery capacity, range per charge expressed in km, specific consumption expressed in kWh/100km and Euro Car segment to which the cars belong.

[2] https://ev-database.org/

We have first classified the database by segment in order to calculate the average characteristics for each of them.

Segment	Models	Bat (KWh)	Range (km)	Consum(KWh/100km)
A	6	22	133	16,6
B	27	44	260	16,8
C	54	64	341	18,5
D	17	73	396	18,4
E	15	84	361	23,2
F	24	88	489	18,4
N	24	67	267	24,8
S	1	200	970	20,6
Total	**168**	**67**	**342**	**19,5**

Table 2-3 Average characteristics of EVs in each segment in 2021[3]

Some considerations about the data provided:

- Battery Capacity refers to net or useful capacity, which is approximately 5-10% lower than the nameplate capacity.

- Range is a systematic range that responds to extreme conditions. This means vehicle use in cities in worst case scenario conditions (-10ºC and using heating). At first sight, these conditions do not look very representative of Spain, but, at an annual level, it can be assumed that the increase in consumption due to heating in winter would be compensated by the increase in cooling consumption in summer.

  As shown in Figure 1, the vehicle range is symmetric respect to the 22ºC axis, so the conditions in Spain would be the same as in the Netherlands, Germany the UK. These countries are where the testing was carried out for the reference database. In those countries, the reduction of the real-world range because heating in temperatures

[3] https://ev-database.org/

below 22ºC would be the same as the reduction on range because of cooling above 22ºC in Spain. [4]

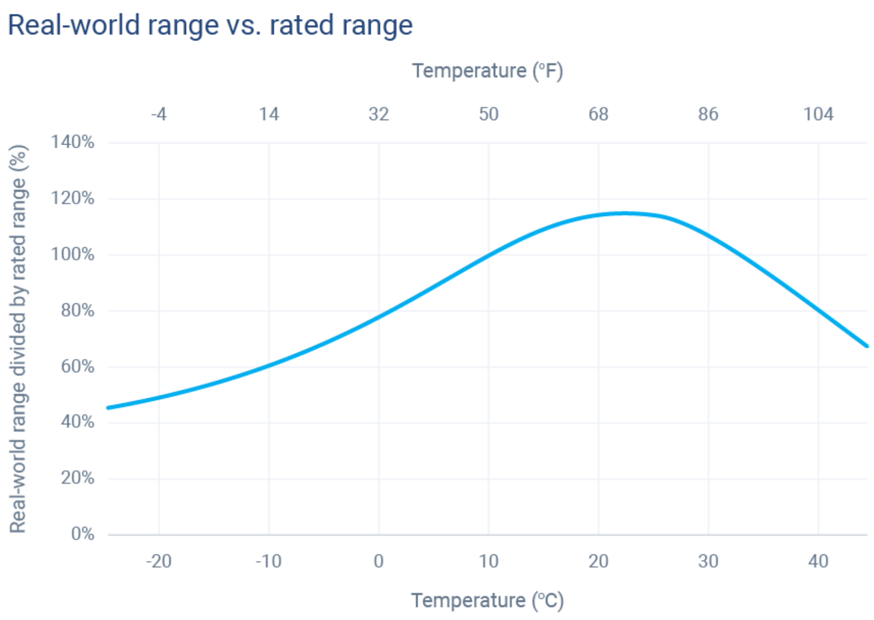

Figure 1 Real word range vs rated range as a function of temperature.[4]

- Therefore, the efficiency or specific consumption is consequently higher than that usually published by the manufacturers, which corresponds to the WLTP[5] test conditions.

[4] See also Figure 20

[5] "The old lab test – called the New European Driving Cycle (NEDC) – was designed in the 1980s. Due to evolutions in technology and driving conditions, it became outdated. The European Union has therefore developed a new test, called the Worldwide Harmonised Light Vehicle Test Procedure (WLTP). The EU automobile industry welcomes the shift to WLTP and has actively contributed to the development of this new test cycle.
While the old NEDC test determined test values based on a theoretical driving profile, the WLTP cycle was developed using real-driving data, gathered from around the world. WLTP therefore better represents everyday driving profiles.
The WLTP driving cycle is divided into four parts with different average speeds: low, medium, high and extra high. Each part contains a variety of driving phases, stops, acceleration and braking phases. For a certain

For the estimation of electric energy consumption in the 2030 horizon, the main references for passenger cars are the B and C segments (representing 83% of the market share).

- Segment B, with 27 models from 12 manufacturers, has an average battery of 44 kWh (range 23.8-64 kWh) with a range of 260 km (range 145-370 km) and an efficiency of 16.8 kWh/100 km (range 15.6-19.3 kWh/100 km).

- Segment C, with 54 models from 17 manufacturers has an average battery of 64 kWh (range 30-87 kWh) with a range of 341 km (range 170-450 km) and an efficiency of 18.5 kWh/100 km (range 15.6-22.6 kWh/100 km).

The N Commercial segment with 24 models from 8 manufacturers, has an average battery of 67 KWh (range 31-90 KWh) with a range of 267 Km (range 160-320 Km) and an efficiency of 24.8 Kwh/100Km (range 19.4-281 KWh/100Km).

2.2 FORECASTING OF THE SPANISH EV FLEET IN 2030.

2.2.1 CHARACTERISTICS OF THE ELECTRIC CARS & VANS FLEET IN 2030

Because the database includes all electric vehicles currently in circulation in Europe, and vehicles to be released in 2021 and 2022, an increase of 10% in battery capacity and range has been applied to account for the technical improvements that will be made until 2030. This estimation could be rather conservative, but it could be adjusted later. Specific

car type, each powertrain configuration is tested with WLTP for the car's lightest (most economical) and heaviest (least economical) version.
WLTP was developed with the aim of being used as a global test cycle across different world regions, so pollutant and CO2 emissions as well as fuel consumption values would be comparable worldwide. However, while the WLTP has a common global 'core', the European Union and other regions will apply the test in different ways depending on their road tra c laws and needs." https://www.wltpfacts.eu/what-is-wltp-how-will-it-work/

consumption has been kept the same because it is expected that the improvements in efficiency will be compensated with more energy demanding features.

	Battery (KWh)	Range Km	Consum (KWh/100 Km)	Top Speed Km/h
A Mini	24	146	16.4	130
B Small	48	286	16.8	150
C Medium	70	375	18.6	171
D Large	80	435	18.4	200
E Executive	92	397	23.2	198
F Luxury	97	538	18.1	250
N Commercial	74	294	25.3	133
Average	73	376	19.5	178

Table 2-4 Expected characteristics of the Spanish Electric Vehicle fleet in 2030.

2.2.2 ESTIMATION OF THE NUMBER OF ELECTRIC CARS & VANS IN 2030

For the forecasting of the size and shape of the Spanish electric car fleet in 2030 the goal value of 3 million electric cars set by the PNIEC has been used as a reference. [13]

ANFAC has determined the needed increase in sales of electric vehicles expressed as a share of the total number of vehicles sold per year. It can be observed that the market share of electric vehicles for the year 2030 should be 40% of all vehicles sold to reach the goal of 3 million EVs in that year. Most of the sales of EVs should occur in the period 2025-2030. [5]

Figure 2 Expected increase of EVs 2017/2030. [5]

Regarding the distribution of those 3 million vehicles by segments, the hypothesis is that the distribution should remain the same as in the past few years. The structure data for the year 2019 and its projection to 2030 is shown below:

	Fleet structure as a percentage of total.	Units
A Mini	4,1%	122.381
B Small	37,5%	1.124.366
C Medium	47,5%	1.424.168
D Large	9,5%	284.330
E Executive	1,3%	39.077
F Luxury	0,2%	5.678
Total		3.000.000

Table 2-5 Fleet structure 2030

For the estimation of the van fleet in 2030 a projection of increase of sales has been made using the data for the 2018-2019 period. An annual increase on sales of 0,1% has been used. The market share of electric vans respect to total vans is the same every year as in cars, but with a delay of one year.

Expected increase on market share of electric vans respect to total vans sold.			
	Projection	Market share (%) Electric Vans	Accumulated number of electric Vans
2018-19	214.567		
2020	-	4,8%	6.069
2021	214.782	4,8%	16.379
2022	214.996	7,0%	31.428
2023	215.211	9,8%	52.519
2024	215.427	12,5%	79.447
2025	215.642	16,1%	114.166
2026	215.858	20,0%	157.337
2027	216.073	24,1%	209.411
2028	216.290	28,0%	269.972
2029	216.506	32,0%	339.254
2030	216.722	36,0%	417.274

Table 2-6 Expected increase on market share of electric vans respect to total vans sold.

2.2.3 FORECASTING OF THE ANNUAL MILEAGE OF CARS & VANS

To define the annual mileage of the different vehicles considered, the information available from the Directorate General of Traffic (DGT) of the Ministry of internal affairs has been used. The report "Anuario Estadístico General" (General statistical yearbook) [14] collects information on the annual mileage of the different vehicles subjected to periodically pass the Technical Vehicle Inspection (26.4 million inspections). Although the data is referred to 2019, it is considered that it is still valid and representative of the current and even expected mileage for 2030.

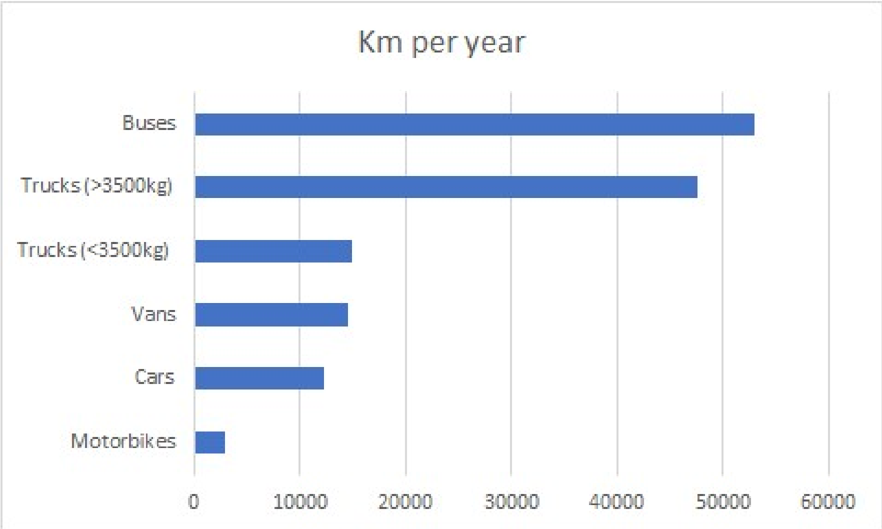

Figure 3 Annual mileage for selected types of vehicles [14]

Regarding cars, the document breaks down mileage by engine capacity of the cars and their age

Engine Capacity (cm^3)	Average yearly mileage (km)
<1200	8.861
1200-1599	11.482
1600-1999	13.142
>2000	13.240

Table 2-7 Average mileage of the Spanish car fleet by engine capacity [14]

The mileage is also classified by vehicle age:

Age(years)	Km/year	Ratio/Avg
0-4	19.689	1,61
5 a 9	15.301	1,25
10 a 14	12.399	1,01
15 a 19	10.532	0,86
20 o more	8.472	0,69
Average fleet	12.266	1

Table 2-8 Mileage by age of the cars

It is observed that the passenger car fleet averages 12.266 km per year. Vehicles less than four years old make an average of 61% more km per year. Based on the available information, the annual mileage of vehicles of different engine capacities has been estimated and associated with the classification by segments.

Segment	0-4 Years	0-9 years
A	14.223	12.638
B	16.327	14.508
C	18.431	16.377
D	19.763	17.561
E	21.095	18.744
F	21.252	18.884

Table 2-9 Mileage of the Spanish car fleet by age of the vehicles

To project the annual mileage of the electric vehicle in 2030 from the data, it has been considered that a significant part of the electric fleet will be less than five years old in 2030. In addition, it has been assumed that the vehicles with the highest annual mileage will be electrified first. Therefore, it has been assumed that the average mileage of EVs in 2030 will be the same as the mileage of internal combustion engine vehicles under five years currently in circulation, increased by 15%.

	Units	Mileage Km/unit-year	Millions Km-year
A Mini	122.381	16.357	2.002
B Small	1.124.366	18.776	21.111
C Medium	1.424.168	21.195	30.186
D Large	284.330	22.727	6.462
E Executive	39.077	24.260	948
F Luxury	5.678	24.440	139
N Vans	417.274	28.712	11.981
Total Car+Vans	3.417.274	21.312	72.828

Table 2-10 Annual Mileage of the segments and total mileage of the Electric car and van fleet in 2030

The total EV fleet would cover some 73.000 million km per year and the average mileage per vehicle would amount to 21.300 km/year. This high average mileage of EVs in 2030 is justified by the fact that they are new vehicles, that, as mentioned above, have a more intense use, and because the low variable cost of EVs makes them more economically interesting for users who make more use of them.

2.3 LOSSES

Additionally, to better estimate the increase of load in the Spanish System due to EVs, up to three additional concepts of losses due to electricity consumption must be considered: charging losses, battery self-discharge losses, and transmission and distribution network losses.

2.3.1 CHARGING LOSSES

Charging losses are losses that occur during the charging process due to the power electronics used for AC-DC conversion, as well as the energy required to maintain the batteries at an adequate temperature during the charging process (either by heating them or cooling them). In addition, some of the energy is lost as heat and not stored in the battery.

The databases below show estimates of losses depending on the input power for both Home Charge (slow charge at low power, less than 15 KW) and Fast Charge (high power, more than 50 KW)

Input Power (KW)	2,3	3,7	7,4	11
Power Loss (%)	15,5%	15,8%	16,1%	16,6%
Power Loss (KW)	0,36	0,58	1,19	1,83

Table 2-11 Average charging depending on input power for home charging. [6]

[6] Calculated with the data from: https://ev-database.org/

Input Power (KW)	50	100	175	350
Power Loss (%)	5,9%	5,8%	5,2%	5,2%
Power Loss (KW)	3,0	5,8	9,1	18,2

Table 2-12 Average charging depending on input power for fast charging. [7]

Different sources were cross-checked to ensure reliability. Additional studies show similar numbers and conclusions: the losses are reduced the higher the charging power and are estimated at 15-17% of the energy charged.

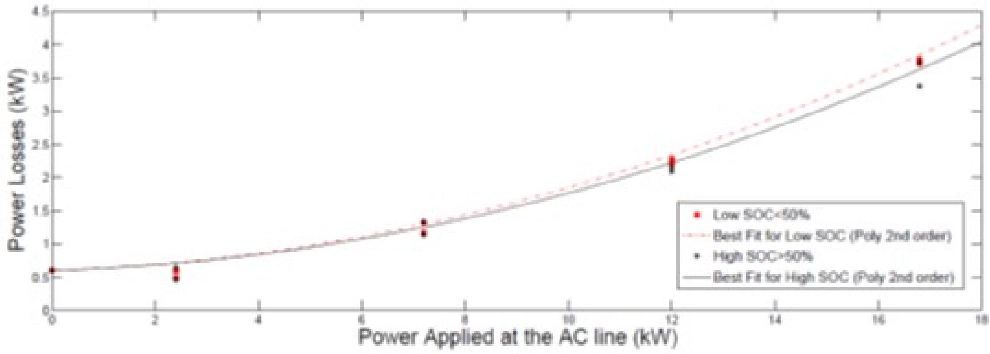

Figure 4 Charging losses for selected input powers [2]

Battery: Overall Charging Efficiency					
P(KW)	<u>3</u>	<u>16</u>	<u>22</u>	<u>43</u>	<u>50</u>
Efficiency Chargin Battey	97,2%	97,1%	97,0%	91,8%	94,2%
Efficiency Charger	86,0%	91,6%	92,2%	92,6%	92,6%
Overall Charging Efficiency	83,6%	88,5%	89,5%	85%	87,2%

Table 2-13 Expected losses depending on input power [1]

[7]Calculated with the data from: https://ev-database.org/

2.3.2 BATTERY SELF-DISCHARGE LOSSES

Battery self-discharge losses are losses due to storage inefficiency of the batteries while the vehicle is not being used. They have not been considered in this project, as they can be considered negligible. (Tesla evaluates them at 0.5% per month [8])

2.3.3 TRANSMISSIONS AND DISTRIBUTION NETWORK LOSSES

Transmission and distribution network losses are losses in the grid from the power plant to the charger. They are estimated from the loss coefficients.

Tariff	Hourly Periods							
	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Note	Mean
2.0 TD	16,70%	16,30%	18,00%	–	–	–	P< 15 KW	17,00%
3.0 TD	16,60%	17,50%	16,50%	16,50%	13,80%	18,00%	U<1KV P>15 KW	16,48%
6.1 TD	6,70%	6,80%	6,50%	6,50%	4,30%	7,70%	P=<450KW	6,42%
6.2 TD	5,20%	5,40%	4,90%	5,00%	3,50%	5,40%		4,90%
6.3 TD	4,20%	4,30%	4,00%	4,00%	3,00%	4,40%		3,98%
6.4 TD	1,60%	1,60%	1,60%	1,60%	1,50%	1,70%		1,60%

Table 2-14 Transmission & distribution losses by period and tariff. [12]

Some additional considerations [12]:

- The values correspond to the new access tariffs (June 2021).
- In the case of low voltage recharges with a contracted power lower than 15 KW, the coefficients are applied at an hourly level (peak, P1 from 10 am to 2 pm and from 6 pm to 10 pm; flat, from 8 am to 10 am, from 2 pm to 6 pm and from 10 pm to 12 am; valley, P3 from 12 am to 8 am and the whole day on Saturdays and Sundays).

[8] 08.03.02 Self-discharge information: The self-discharge rate of the High Voltage battery is likely to be less than 0.5% per month. https://iaspub.epa.gov/otaqpub/display*file.jsp*?*docid* = 51237*flag* = 1

- In the case of charges in the upper segments (15KW<P<450KW), it would be necessary to consider the type of day (holidays or not), electric consumption seasonality, peninsular or island systems, etc. We used the average annual coefficient will be used for simplicity.

2.4 ESTIMATION OF THE ELECTRIC ENERGY CONSUMED PER CHARGE

For the estimation of the charge schedule at home, an average increase of 60% in State of Charge (SoC) has been considered for every charge, going from 30% SoC to 90%. This is done to account for both the range anxiety and the inertia of the battery, because the rate of charge is lower the higher the SoC.

On the other hand, for the fast charge an increase of 70% in SoC has been considered, charging from 10% to 80%, because fast charging would be used for emergencies, and as it will most likely be a pay to use service, so charging on the lineal zone would be advisable, avoiding the non-lineal zone, which is less efficient. As seen on Figure 5, for the expected charging cycle (30% to 90% SoC), the relation between the state of charge of the battery and the time is lineal from 0% to 90% SoC, so the increase of SoC per unit of time remains the same. In the range from 90% SoC to 100% SoC, an increase of one percentage point in SoC takes much more time.

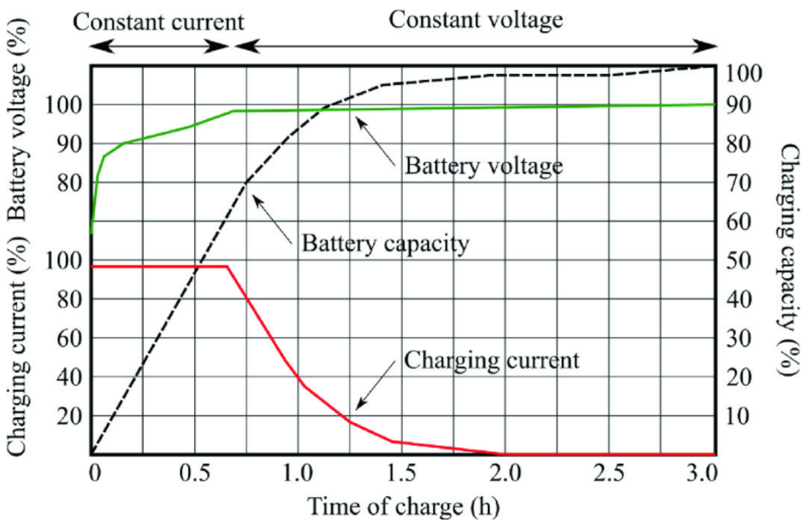

Figure 5 Lineal charge zone. [6]

An hypothesis has also been made about the plug power that these vehicles will most likely use. For this hypothesis on the charging power, the necessary time to charge the batteries for the different segments was considered, so that the charging power results on a reasonable time to charge.

2.4.1 HOME CHARGE

2.4.1.1 Energy incorporated to the battery.

The net energy stored in the battery for every charging cycle is the product of the useful capacity times the increase in State of Charge (SoC). For the charge at lower input power, defined as home charge, the expected increase in the state of charge on a normal charging cycle is 60% (from 30% to 90% of the battery capacity)

Input Power (KW)	Energy storaged in the batteries (KWh)
A	14,4
B	28,9
C	41,9
D	48,0
E	55,2
F	58,4
N	44,5

Table 2-15 Home charge. Unitary Net charge per cycle (KWh)

The difference between gross and net energy correspond to the charging losses expressed in KWh. The gross charge can be calculated as:

$$Gross\ Charge\ (KW) = \frac{Net\ Charge\ (KW)}{100\% - Charging\ losses\ (\%)}$$

The resulting gross charge has been calculated using the Charging losses from Table 2-11.

Input Power(KW)	2,3	3,7	7,4	11
A	17,0	17,0	17,1	17,2
B	34,1	34,3	34,4	34,6
C	49,6	49,8	50,0	50,3
D	56,8	57,0	57,2	57,5
E	65,3	65,6	65,8	66,2
F	69,0	69,3	69,6	70,0
N	52,6	52,8	53,0	53,4

Table 2-16 Home charge. Unitary Gross Charge per cycle (KWh)

2.4.1.2 Time required to charge the batteries

For home recharge (Lower than 15KW) the rate of charge is constant, and thus, the load curve of the battery is flat and equal to the input power minus the charging losses.

$$Time\ to\ charge\ (h) = \frac{Gross\ Charge\ (KWh)}{Input\ Power\ (KW)}$$

The resulting mean times to charge for every segment are shown in the table down below:

	Time to charge (h)			
Input Power (KW)	2,3	3,7	7,4	11
A Mini	7,4	4,6	2,3	1,6
B Small	14,8	9,3	4,6	3,1
C Medium	21,6	13,5	6,8	4,6
D Large	24,7	15,4	7,7	5,2
E Executive	28,4	17,7	8,9	6,0
F Luxury	30,0	18,7	9,4	6,4
N Commercial	22,9	14,3	7,2	4,9

Table 2-17 Home charge. Time to charge a vehicle of each segment with different input powers.

Cells colored in gray are deemed unfeasible due to the excessive time to charge.

2.4.2 FAST CHARGE

2.4.2.1 Energy incorporated to the battery.

The same analysis of the net and gross charge stored in the battery per cycle was conducted for the fast charge situation. In this type of charge, input powers are much higher than on home charge (Input powers higher than 50KW), and the increase in SoC is higher, from 10% to 80%.

Input Charge(KW)	Energy storaged in the batteries (KWh)
A	16.7
B	33.7
C	48.9
D	56.0
E	64.4
F	68.1
N	51.9

Table 2-18 Fast charge. Unitary Net charge per cycle (KWh)

The gross power is calculated adding the charging losses from Table 2-12.

Input Power (KW)	50	100	175	350
A	17.8	17.8	17.7	17.7
B	35.8	35.8	35.5	35.5
C	52.0	52.0	51.6	51.6
D	59.5	59.5	59.1	59.1
E	68.5	68.4	67.9	67.9
F	72.4	72.3	71.8	71.8
N	55.2	55.1	54.8	54.8

Table 2-19 Fast Charge. Unitary Gross Charge per cycle (KWh)

2.4.2.2 Time required to charge the batteries in fast charge.

For input power levels above 50-100KW, batteries are not prepared to charge at the nominal rate for the whole duration of the charge. For that reason, once a threshold of SoC is reached, the input power is reduced, either lineally or by steps.

The input power curve is not flat, that is, the input power is not always the nominal one. Instead, the higher the SoC, the lower the input power. This is done due to technical constraints of the batteries.

The Input Power/SoC curve of the Tesla Model 3 and Hyundai is shown down below:

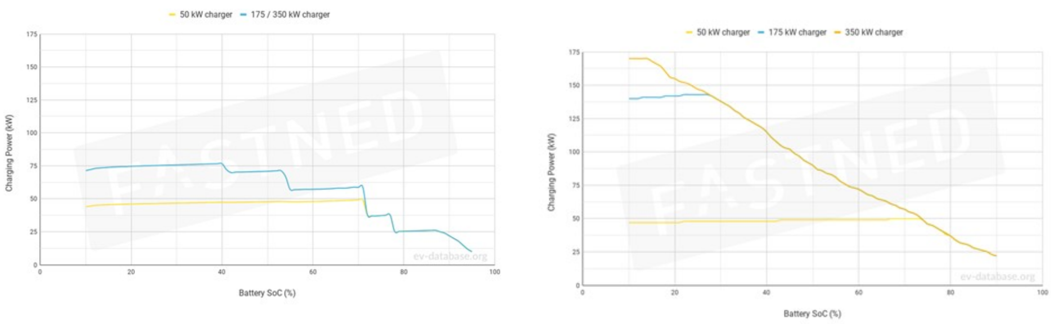

Figure 6 Fast charge curve for Tesla model 3 and Hyundai [9]

In this study, instead of using these curves, the average power of charge that allows for the same increase of SoC in the same time has been used. The table down below shows the average power values representative of each segment:

[9] Curves extracted from: https://ev-database.org/

Input Power (KW)	50	100	175	350
A	30.0	30.0	30.0	30.0
B	48.0	45.0	65.0	65.0
C	50.0	60.0	100.0	100.0
D	50.0	75.0	100.0	105.0
E	50.0	85.0	115.0	125.0
F	50.0	90.0	135.0	150.0
N	50.0	60.0	100.0	100.0

Table 2-20 Fast Charge. Average power charge for each nominal input power (KW)

From the table of energy needed to increase the SoC 70% and the Average power in fast charge, the time to charge for the different segments and nominal input powers are obtained.

	Time to Charge (h)			
Input Power (KW)	50	100	175	350
A	0,59	0,59	0,59	0,59
B	0,75	0,79	0,55	0,55
C	1,04	0,87	0,52	0,52
D	1,19	0,79	0,59	0,56
E	1,37	0,80	0,59	0,54
F	1,45	0,80	0,53	0,48
N	1,10	0,92	0,55	0,55

Table 2-21 Time to charge every segment in fast charge.

The values obtained are summarized in the following table. This table also shows the number of annual charges per vehicle that each vehicle segment will have to perform depending on its useful battery capacity and the increase of SoC adopted in slow charge and fast charge. As a general criterion, it has been assumed that the vehicles have a regular recharging point, either at their home/garage, workplace, or depot where the vehicle stays overnight. Fast charging has been considered as a non-regular charging that is used on long trips or in certain emergency situations.

	Home Charge		Fast Charge		Total
Segment	km	Charges/Year	Km	Charges/Year	km/year
A	15.949	182	408	4	16.357
B	17.775	104	1.001	5	18.776
C	19.621	87	1.574	6	21.195
D	19.681	75	3.046	10	22.727
E	20.924	88	3.336	12	24.260
F	19.918	62	4.522	12	24.440
N	26.246	149	2.466	12	28.712

Table 2-22 Expected annual charges per year for every segment and associated mileage.

As a reference figure, as stated on Table 2-10 the total EV fleet would cover some 73,000 million km per year and the average mileage per vehicle would amount to 24,330 km/year. This high average mileage of EVs in 2030 is justified by the fact that they are new vehicles, which, as mentioned above, are more widely used, and because the low variable cost of EVs makes them more economically interesting for users who make more use of them, provided that such use is compatible with the limited autonomy. With the recharging hypotheses considered, about 349 million slow recharges would be made annually (955,000 per day). In Fast Charge, 23.3 million recharges would be made per year, which is 63,600 per day. The reduced number of fast charges has been estimated considering that according to the study by Saele and Petersen, in Norway, public charging stations and fast charging stations are used on a monthly basis or even less often, by 52.1% and 64.0% of households (family house or row house) and housing cooperatives. [3]

2.5 ANNUAL ENERGY LOAD OF THE BATTERIES FOR THE FLEET AND MILEAGE CONSIDERED

2.5.1 HOME CHARGE

With the charging times calculated in Table 2-16, the hypothesis of the percentage of vehicles that are usually charged at each power level was constructed. The results are shown in the following table:

	Vehicles per segment over total	Percentage inside the segment			
Input Power (KW)		2.3	3.7	7.4	11
A Mini	4.1%	60%	30%	7%	3%
B Small	37.5%	30%	40%	25%	5%
C Medium	47.5%		30%	60%	10%
D Large	9.5%			90%	10%
E Executive	1.3%			60%	40%
F Luxury	0.2%			50%	50%
N Commercial	-		5%	50%	45%

Table 2-23 Distribution of electric cars & vans by charging power and segment expressed as percentages

	Units in the different segments and input power				
Input Power (KW)	2,3	3,7	7,4	11	Total
A Mini	73,428	36,714	8,567	3,671	122,381
B Small	337,310	449,747	281,092	56,218	1,124,366
C Medium		427,250	854,501	142,417	1,424,168
D Large			255,897	28,433	284,330
E Executive			23,446	15,631	39,077
F Luxury			2,839	2,839	5,678
N Commercial		20,864	208,637	187,773	417,274
Total Car+ Vans	410.738	934,575	1.634.978	436.983	3.417.274

Table 2-24 Distribution of the electric cars and vans by charging power and segments by 2030

Based on the fleet considered, its consumption (KWh/100Km) and its mileage, the necessary energy to be stored in the different charges throughout the year is calculated. The following table shows the gross energy (including charging losses) and net energy (stored in the battery) in the usual recharge at home or slow charge, in the hypotheses that have been assumed.

	Gross Charge (GWh/year)					Net Charge (GWh/year)				
Input Power(KW)	2,3	3,7	7,4	11	Total	2,3	3,7	7,4	11	Total
A	227	114	27	12	380	192	96	22	10	320
B	1.193	1.596	1.002	201	3.992	1.008	1.344	840	168	3.361
C		1.856	3.727	625	6.208		1.563	3.127	521	5.211
D			1.103	123	1.227			926	103	1.028
E			136	91	226			114	76	189
F			12	12	24			10	10	20
N		164	1.649	1.493	3.306		138	1.383	1.245	2.767
Total Cars & Vans					15.363					12.897

Table 2-25 Annual Power consumption by segment and charge power for home charge (GWh/year)

2.5.2 FAST CHARGE

Similarly to home charge, taking into account the next inputs:

- Number of fast charges per vehicle per year
- Number of vehicles inside of each segment that use the different input powers of fast charging.
- The increase in SoC per charging cycle (70% for fast charging)

The energy consumption of cars and vans that use fast charging in a year can be calculated:

	Gross Charge (GWh/year)					Net Charge (GWh/year)				
Input Power (KW)	50	100	175	350	Total	50	100	175	350	Total
A	2	3	3	2	9	2	2	2	2	8
B	40	60	60	40	200	38	57	57	38	189
C	89	133	132	88	443	84	125	125	84	418
D	34	51	50	34	169	32	48	48	32	159
E	6	10	10	6	32	6	9	9	6	30
F	1	1	1	1	5	1	1	1	1	5
N	55	83	82	55	275	52	78	78	52	260
Total Cars & Vans					1.132					1.070

Table 2-26 Annual Power consumption by segment and charge power for fast charge

2.5.3 HOME AND FAST CHARGE AGGREGATED DEMAND

With the considered hypotheses, the annual charging of 3,42 million passenger cars and vans would require 14.000 GWh per year of battery charging for an average mileage of 21,300 km/year and 73,000 million km per year. This means an average consumption of the fleet of 19,18 kWh/100 km. Customer consumption associated with recharging the fleet, considering charging losses, would rise to 16.500 GWh at the charger level.

Segment	Gross Charge (GWh/year)	Net Charge (GWh/year)
A	388	329
B	4.192	3.55
C	6.651	5.629
D	1.395	1.188
E	258	220
F	29	25
N	3.581	3.027
Total Cars & Vans	16.495	13.967

Table 2-27 Expected annual consumption of Spain's Electric Car fleet in 2030 (Home+Fast)

As stated earlier, net charge is referred to energy stored in the batteries, and gross charge is referred to energy stored in the battery plus the energy lost in the charging process at the charger level. Because the aim of this study is to estimate the impact of EVs at a generation level, it is necessary to incorporate transmission and distribution network losses. This will be done on the next section.

2.6 DEMAND AT THE POWER PLANT AND LOAD CURVE OF THE ELECTRIC FLEET

Once the energy per charge, time of charge, annual mileage, and number of charges per year have been calculated, to estimate the daily load curve of electric cars is important to assess the most likely schedule of the charge.

2.6.1 EFFECT OF THE COST OF ENERGY

To estimate the load curve, it is important to consider the structure of the electricity prices in low voltage. In Spain, the variable terms of the electricity cost are:

- Access term, which charges the customer for the costs of the electricity transmission and distribution network necessary to carry out the supply. The calculation of the cost of the access term is carried out by the National Commission for Markets and Competition (CNMC) and corresponds to the costs recognized for transmission and distribution activities.
- Charges, which pass on certain energy policy costs to the customer. They are set by the Ministry for Ecological Transition and the Demographic Challenge. They consist of three basic parts:
  - The cost of the special regime for renewable energies, cogeneration, and generation with waste (Recore)
  - The coverage of the deficit of previous years.
  - The compensation of 50% of the excess cost of generation in non-peninsular territories.
- Cost of energy, increased by transmission and distribution losses.

- Other small contributions, such as the adjustment service, financing of System operator and Market operator, variable marketing cost, etc. They total in 0,01€/KWh.
- The tax on electricity of 5.11% which affects the above items.
- VAT which is calculated on the above items including the electricity tax. The current rate is 21%

After a long period in which the tariff structure has remained without changes, on June 1st, 2021, there has been an important modification. For customers with less than 15 KW of contracted power, a three-period structure has been created throughout the 24 hours of the day. This structure affects access tariffs and charges.

The amounts are shown in the following table:

	Period 1	Period 2	Period 3
Tariff Group	10-14h & 18-22h	8-10 & 14-18 & 22-24	0-8h & Weekends
2.0 TD Access Transmission & distribution	0,027378	0,020624	0,000714
Segment 1 Charges	0,105740	0,021148	0,005287
Total Access + Cargos	0,133118	0,041772	0,006001

Table 2-28 Values of access tariffs and charges to transmission and distribution network applicable starting June 1, 2021 (€/KWh) [12]

These variable costs for the use of the networks and for energy policy costs present a very important variation between peak and off-peak hours and are a very important incentive to shift electric vehicle charging to nighttime and weekends. The variable cost of the peak charge and access tariff (0,13 €/Kwh) can be twice the cost of energy (0.06€/KWh). If this charge structure is maintained in 2030, the user will be forced to charge the electric vehicle at night and on weekends for economic reasons.

The following table shows an estimate of the total variable cost per KWh for the electric vehicle user considering that the price of energy in the wholesale market is around 0,06 €/KWh and is practically flat throughout the 24 hours of the day.

Cost of energy:		0,06	€/KWh
	Period 1	Period 2	Period 3
Total Access tariffs	0,133	0,042	0,006
Cost of energy (loss included)	0,069	0,069	0,069
Total Energy	0,202	0,111	0,075
Electricity Tax+ IVA	0,074	0,049	0,039
Total Cost (€/KWh)	**0,276**	**0,160**	**0,114**

Table 2-29 Total variable Cost of Energy for Home charging (€/KWh)

As seen on Table 2-29, the cost of a KWh in peak hours is nearly 2,5 times higher than in valley hours. For the average owner of a C segment vehicle, it would mean the difference between paying 1.200€/year, to just 500€/year.

2.6.2 HOME CHARGE LOAD CURVE

2.6.2.1 Home charge without shifting load to the weekends.

This study assumes that slow charging is carried out at night whenever possible because of the cost structure currently in place. Only charging in the flat midday period is considered in some segments of vehicles with relatively small batteries (segments A and B) that charge at high input powers (7 & 11KW). Charging in the afternoon-evening is also contemplated for vehicles that need many hours of charging (13-14 h) because they use a low charging power (2.3 KW or 3.7 KW) and need to start charging earlier to be ready in the morning.

With all these assumptions, the expected charging schedule of the Spanish car fleet in home charge is crafted:

				Indicator of charge																							
Segment	KW input	H to charge	EVs Charging/day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
A	2.3	7.4	36,690	1	1	1	1	1	1	1	0.4																
A	3.7	4.6	18,345		1	1	1	1	0.6																		
A	7.4	2.3	4,280															1	1	0.3							
A	11	1.6	1,834																1	0.6							
B	2.3	14.8	95,726	1	1	1	1	1	1	1	1	1										0.8	1	1	1	1	1
B	3.7	9.3	127,634	1	1	1	1	1	1	1	1															0.3	1
B	7.4	4.6	79,771			1	1	1	1	0.6																	
B	11	3.1	15,954															1	1	1	0.1						
C	2.3		0																								
C	3.7	13.5	102,128	1	1	1	1	1	1	1	1											0.5	1	1	1	1	1
C	7.4	6.8	204,255		1	1	1	1	1	1	0.8																
C	11	4.6	34,043			1	1	1	1	0.6																	
D	2.3		0																								
D	3.7		0																								
D	7.4	7.7	52,848		1	1	1	1	1	1	1	0.7															
D	11	5.2	5,872	0.2	1	1	1	1	1																		
E	2.3		0																								
E	3.7		0																								
E	7.4	8.9	5,641	1	1	1	1	1	1	1	1	0.9															
E	11	6.0	3,761	0.0	1	1	1	1	1	1																	
F	2.3		0																								
F	3.7		0																								
F	7.4	9.4	480	1	1	1	1	1	1	1	1	1															0.4
F	11	6.4	480		1	1	1	1	1	1	0.4																
N	2.3		0																								
N	3.7	14.3	8,517	1	1	1	1	1	1	1	1	1										0.3	1	1	1	1	1
N	7.4	7.2	85,175	1	1	1	1	1	1	1	0.2																
N	11	4.9	76,657		1	1	1	1	0.9																		
Power demand in charger (MW)				1,877	4,787	5,751	5,751	5,751	5,598	4,407	2,821	578	0	0	0	0	0	207	227	197	25	367	630	630	630	752	1,103
Distribution & Transmission Losses				18%	18%	18%	18%	18%	18%	18%	18%	16%	16%	17%	17%	17%	17%	16%	16%	16%	16%	17%	17%	17%	17%	16%	16%
Power demand in Power plant(MW)				2,290	5,837	7,014	7,014	7,014	6,827	5,375	3,440	691	0	0	0	0	0	248	272	235	30	441	756	756	756	899	1,318

Table 2-30 Hourly home charging schedule

In this scenario, the average daily energy supplied to the chargers is 42.091 MWh, which is 15.363 GWh/year. Considering the losses in Transmission and Distribution (17.8%), the energy demand at power plant level is 18.692 GWh/year.

With the charging profile crafted in Table 2-30, the resulting load curve would be the following:

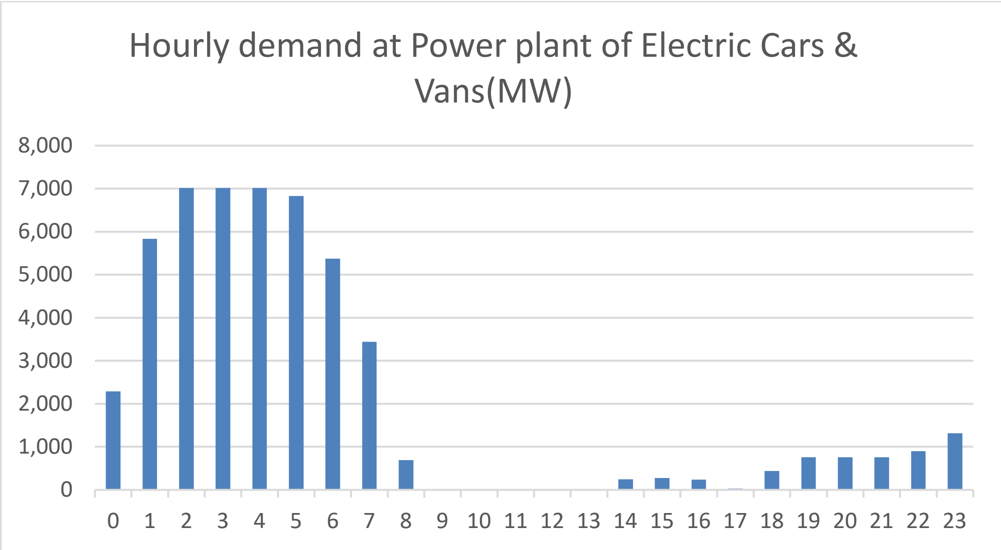

Figure 7 Daily load without shifting load to the weekends.

2.6.2.2 Charge shifted to weekends for home charge.

The scenario where charges made on weekdays are shifted to weekends has also been studied. This shift would be justified to allow a greater use of the vehicle on weekdays and weekends enjoy 24 h off-peak network tariffs when energy is, in addition, usually cheaper. It has been assumed that 5 to 10% of the daily recharges from Monday to Friday can be shifted to Saturday or Sunday. It is also assumed that the 12-15 h weekend charges do not start in the evening of the previous day and end at 8h but start at 0 h and end at 13-15h. With these assumptions, the following chronological demand curves are obtained in the power plant from Monday to Friday and from Saturday to Sunday.

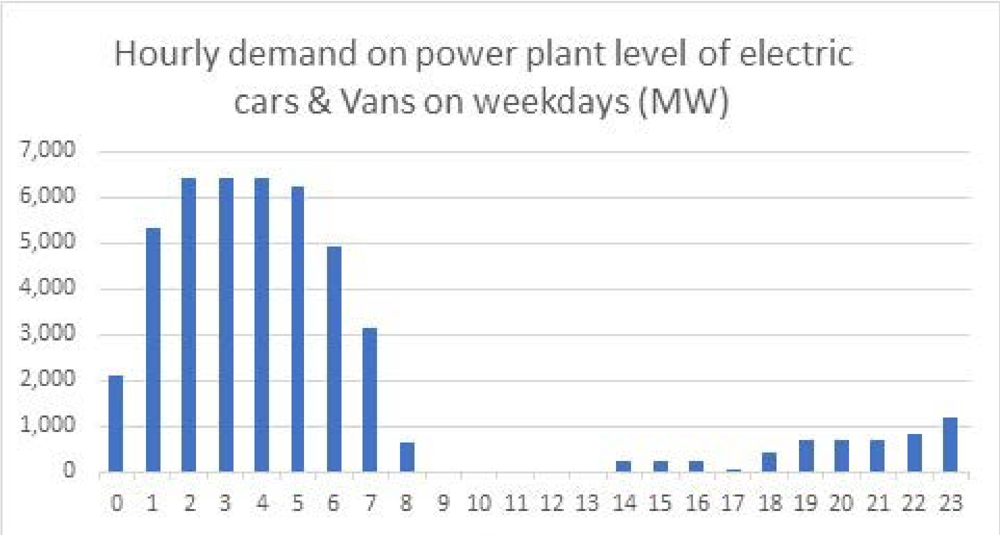

Figure 8 Daily load on the weekdays shifting load to the weekends.

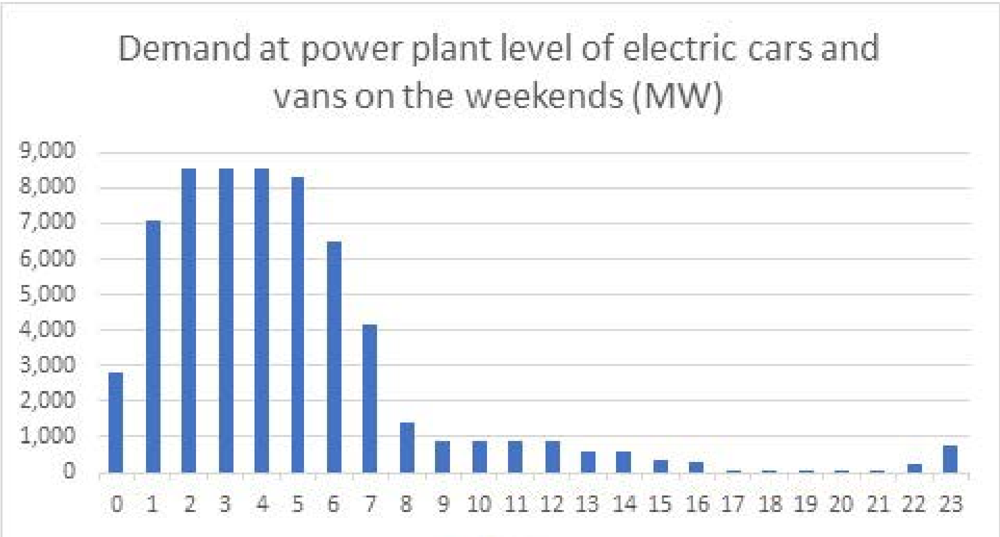

Figure 9 Daily load on the weekends shifting load to the weekends.

2.6.3 FAST CHARGE LOAD CURVE

Because of the lack of a widespread network of public chargers worldwide, it is difficult to establish the load curve of public chargers. One of the studies found" Electric vehicles in Norway and the potential for demand response", by Hanne Saele and Idar Petersen [3], made a poll to EV users to estimate the fast-charging pattern in Norway. The results of said poll are shown below:

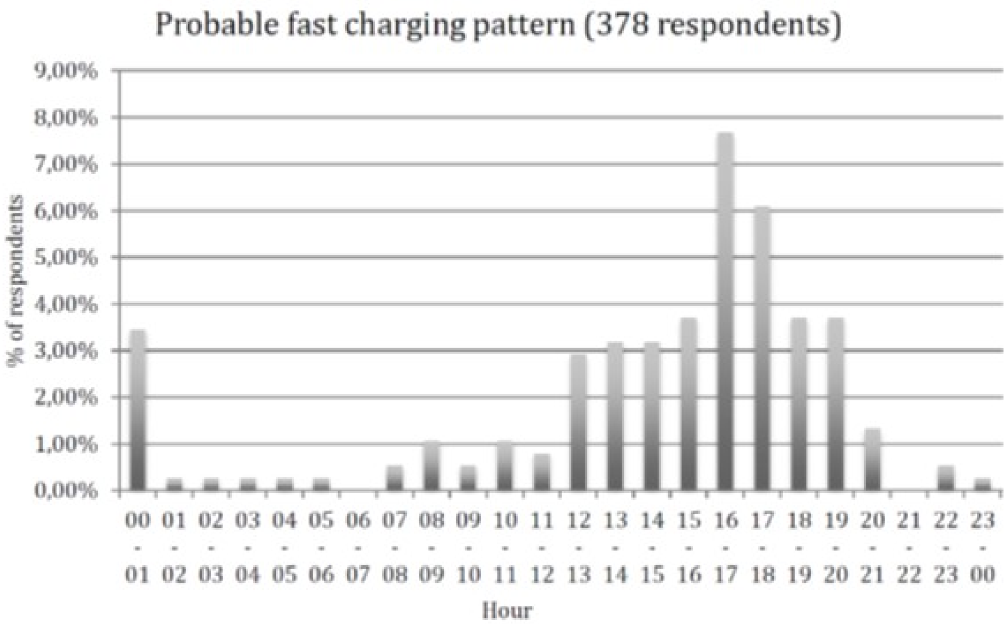

Figure 10 Expected load curve of fast charge in Norway. [3]

Based on this study, and considering that in Norway the valley period is from 21h to 5h, and extrapolating this curve to the Spanish case, where the valley time is 3 hours later, the resulting curves are the following:

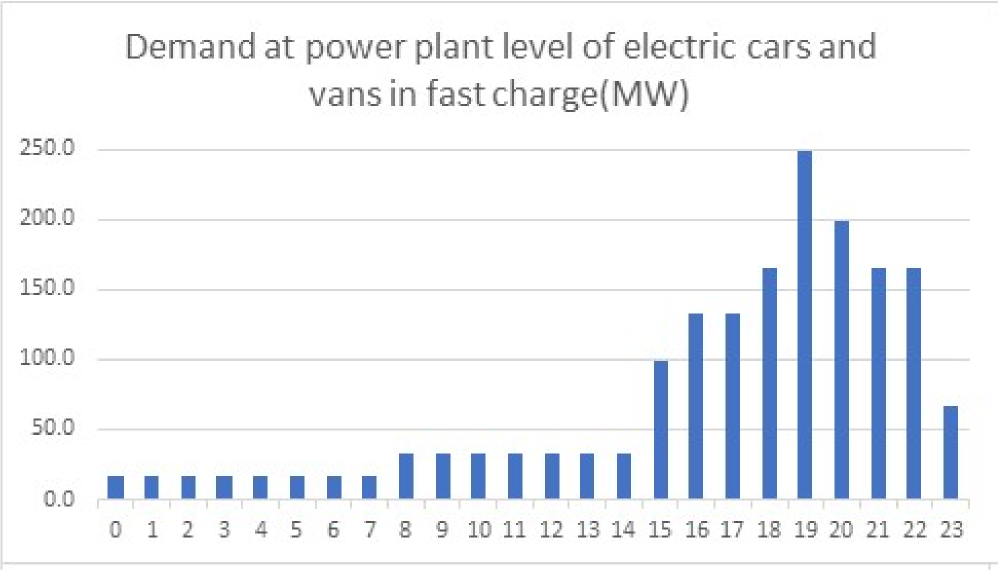

Figure 11 Daily load curve in fast charge

2.6.4 TOTAL CONSUMPTION (HOME AND FAST) WITHOUT SHIFTING LOAD TO THE WEEKENDS

Adding up the load curve for home charging without shifting power to the weekends and the fast charge curve, the following charge profile for cars & vans is obtained:

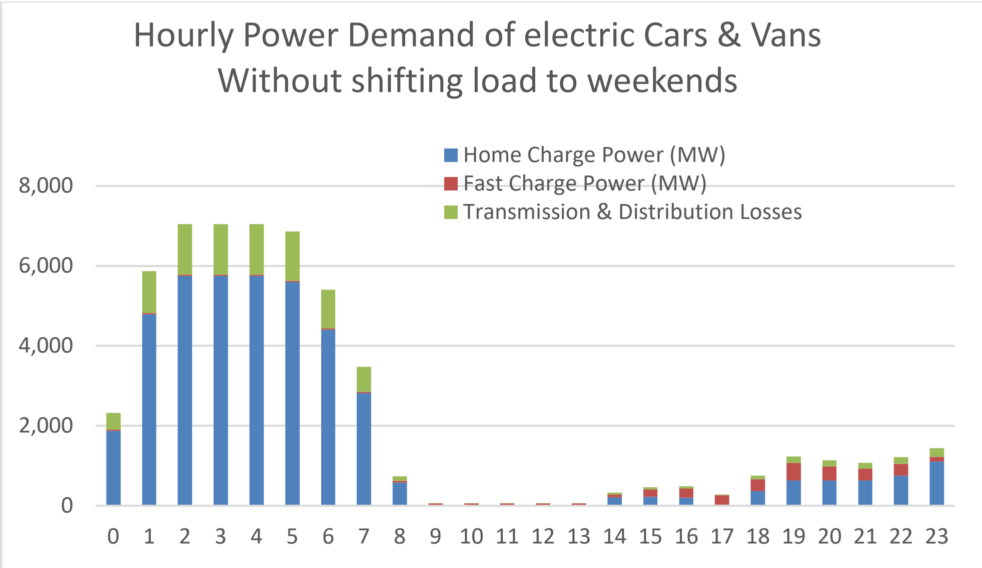

Figure 12 Total demand (home+fast) without load shifting.

2.6.5 TOTAL CONSUMPTION (HOME AND FAST) SHIFTING LOAD TO THE WEEKENDS

By adding up the curves for home charging on weekdays and fast charging, the following charging profile is obtained:

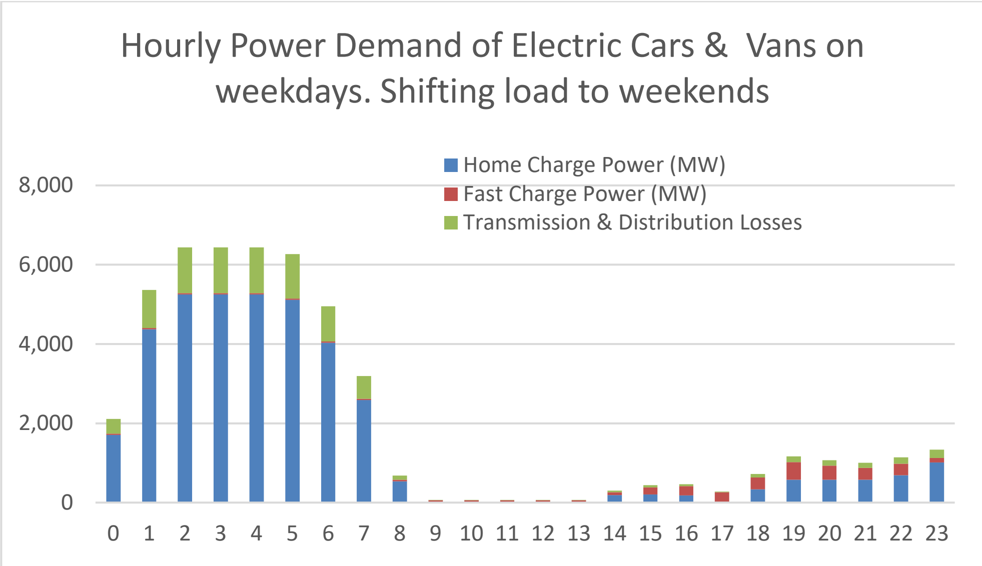

Figure 13 Total demand (home+fast) on the weekdays.

By adding up the curves for home charging on weekends and fast charging, the following charging profile is obtained

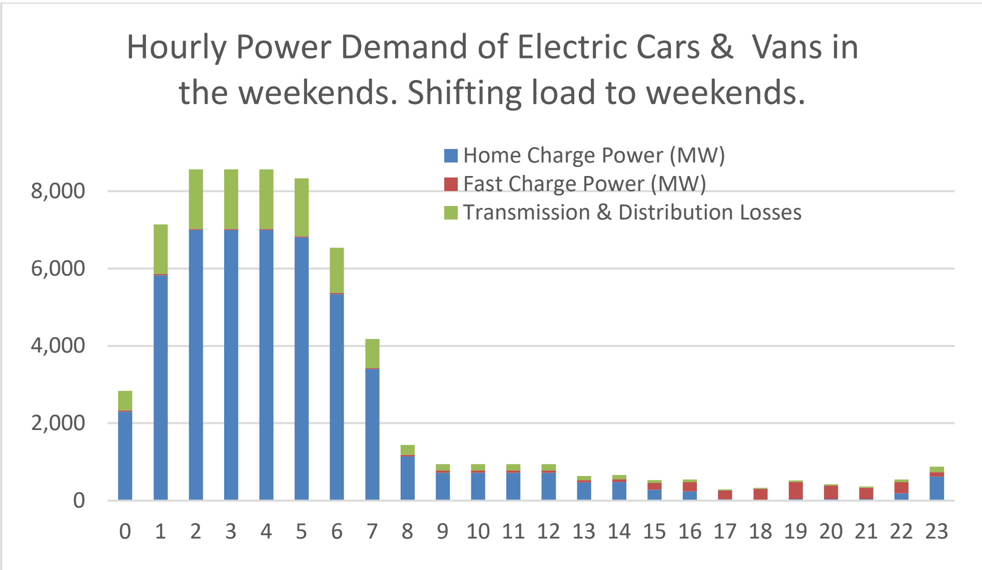

Figure 14 Total demand (home+fast) on the weekends.

These profiles will be integrated with the motorcycle and bus profiles later to obtain the load curve of all the potential EVs in Spain for the year 2030.

Chapter 3. MOTORBIKES

On this chapter, the different current models of electric mopeds, motorbikes, scooters, and motorcycles are analyzed, to forecast the characteristics of the fleet in the year 2030, as well as the potential number of motorcycles, to finally assess the annual consumption associated to the fleet and the daily load profile.

Motorcycles are considered very important for the electrification of transport because of their use as a mean of personal urban transportation. The PNIEC specifies that in the next few years, restrictions will be imposed on the use of combustion engine vehicles on the main urban centers in Spain. Motorcycles are also regarded in PNIEC as a mean of transport exclusive for short distance commute. For all these reasons, motorcycles, especially electric ones, are expected to experience an increase in sales in the next few years.

3.1 CURRENT SITUATION

For the potential number of motorcycles in 2030, the data of sales in the last five years is extracted from the annual report from the Spanish "Dirección general de trafico" (DGT) [10]

[10] Includes sales for motosharing, companies and private individuals.

	Moped and motorbikes	Motorcycles & Scooters				
	< 50 cc	< 125 cc	126-250 cc	251-500 cc	Total <500 cc	Total Moped+ Motorcycle <500cc
2016	19.650	91.970	5.707	23.021	120.698	140.348
2017	23.876	75.194	3.616	23.129	101.939	125.815
2018	19.490	86.481	3.811	27.926	118.218	137.708
2019	22.399	95.100	3.485	32.515	131.100	153.499
Average	21.354	87.186	4.155	26.648	117.989	139.343

Table 3-1 Number of motorcycles. [14]

The market of motorcycles experiences big changes every year in the number of units sold, as seen on the table.

To characterize the Electric Motorcycle fleet in Spain, the current market has been analyzed, the same way the car market was. The main reference is the database created by IDAE to grant subsidies for the purchase of electric motorcycles, as well as the website Motofichas.com[11].

IDAE defines four categories of motorcycles: L1e-B, L3e-1, L3e-2 and L3e-3, out of which L3e-3 is the only one not electable for a subsidy on purchase. With all this information the next table is created:

	# Models	Battery KWh	Range Km	Consum KWh/100 Km	Top Speed Km/h
L1e-B Moped &Motorbikes	6	1,4	59	2,4	45
L3e-1 Scooter 125	27	3,0	82	3,7	80
L3e-2 Medium end 125	54	5,0	109	4,6	95
L3e-3 High end		14,0	145	9,6	140

Table 3-2 Motorcycle categories.

[11] www.motofichas.com/marcas/electrica

3.2 FORECASTING OF THE MOTORCYCLE FLEET IN 2030

3.2.1 CHARACTERISTICS OF THE MOTORCYCLES FLEET IN 2030

With the current fleet as a starting point, the characteristics of the fleet for the year 2030 are estimated by increasing the battery capacity and range by 10%. This is the same increase as the electric car fleet for the year 2030.

	Avg characteristics of the fleet in 2030 (+10%)			
	Battery KWh	Range Km	Consum KWh/100 Km	Top Speed Km/h
L1e-B Moped &Motorbikes	1,6	65	2,4	45
L3e-1 Scooter 125	3,3	90	3,7	80
L3e-2 Medium end 125	5,5	120	4,6	95
L3e-3 High end	15,4	160	9,6	70

Table 3-3 Characteristics of the fleet in 2030.

3.2.2 NUMBER OF VEHICLES

With this data, with an expected yearly increase in sales of motorbikes of a 10% and using the same annual market share of electric vehicles as in the cars section, the total amount of electric motorcycles for the year 2030 is obtained:

Yearly motorcycle sales increase = 10% (respect to the prior year)

	Electric motorcycle market share	Moped< 50 cc	motorcycle < 125 cc	Motor cycle 126-250 cc	motorcycle 251-500 cc	Total motorcycle <500 cc	Total Moped+Motorcycle <500 cc
2020	4,8%	1.127	4.603	219	1.407	6.230	7.357
2021	7,0%	2.936	11.988	571	3.664	16.223	19.160
2022	9,8%	5.721	23.361	1.113	7.140	31.614	37.335
2023	12,5%	9.629	39.317	1.874	12.017	53.207	62.837
2024	16,1%	15.166	61.923	2.951	18.926	83.801	98.967
2025	20,0%	22.732	92.815	4.423	28.368	125.605	148.338
2026	24,1%	32.761	133.761	6.374	40.883	181.018	213.779
2027	28,0%	45.577	186.090	8.868	56.877	251.835	297.413
2028	32,0%	61.690	251.876	12.003	76.984	340.863	402.553
2029	36,0%	81.629	333.286	15.882	101.866	451.035	532.663
2030	40,0%	105.999	432.787	20.624	132.278	585.689	691.687

Table 3-4 Increase in sales forecast and total electric motorcycle fleet for the year 2030.

With these hypotheses of growth in the number of motorcycles sold, and the increase of the market share of electric motorcycles, it is expected that in the year 2030 there will be nearly 700.000 electric motorcycles in circulation. That year, the number of electric motorcycles sold will be roughly 40% of all motorcycles.

3.2.3 FORECASTING OF THE ANNUAL MILEAGE OF MOTORCYCLES

The average mileage is extracted from the DGT annual report, increasing said mileages by 10-25% because new and electric motorcycles tend to travel more kilometers than regular ones on average. So, motorcycles that are both new and electric are expected to travel more miles than average.

	Factor	Average Km/year
Reference Value		4.560
L1e-B Moped &Motorbikes	1,1	5.115
L3e-1 Scooter 125	1,15	5.347
L3e-2 Medium end 125	1,2	5.580
L3e-3 High end	1,25	5.812

Table 3-5 Average mileage

As adittional information, the mileages of al the motorcycles within a category in a year are gathered:

	Millions of kilometers travelled
L1e-B Moped &Motorbikes	542
L3e-1 Scooter 125	2314
L3e-2 Medium end 125	115
L3e-3 High end	769
Total	3.740

Table 3-6 Estimated total mileage for all motorcycles in a category

As adittional information, the mileages of al the motorcycles within a category in a year are gathered:

	Millions of kilometers travelled
L1e-B Moped &Motorbikes	542
L3e-1 Scooter 125	2314
L3e-2 Medium end 125	115
L3e-3 High end	769
Total	3.740

Table 3-7 Estimated total mileage for all motorcycles in a category

3.3 LOSSES

The losses when charging motorcycles are the same kind as in cars, but due to the lower input power in the charging process, which depends directly on the smaller battery capacity.

For the losses in the charging power, the highest input power considered for motorcycles is 3.7KW. Because the losses in the charging process are inversely proportional to the input power (the higher the input power, the lower the losses), the losses in the recharge of motorcycles are on average, higher than in cars.

	Losses in the charger			
Input Power (KW)	0,77	1,3	2,3	3,7
Losses (%)	15,5%	15,5%	15,5%	15,8%
Losses (KW)	0,12	0,20	0,36	0,58

Table 3-8 Losses in the charger.

For the transmission and distribution losses, only the 2.0TD tariff is considered, as all the input powers are below 15kW.

Tension Level	Hourly periods							
	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6		Average
2.0 TD	16,70%	16,30%	18,00%	–	–	–	P< 15 KW	17,00%

Table 3-9 Transmission and distribution losses. [12]

The self-discharge losses are also deemed negligible.

3.4 UNITARY CONSUMPTION OF THE MOTORCYCLES FOR THE DIFFERENT CATEGORIES

3.4.1 UNITARY NET CHARGE FOR THE DIFFERENT CATEGORIES

Once all the losses have been defined for, the net and gross energy consumed per recharge for all categories are calculated, using the same formulas as in cars:

$$Net\ Charge\ (KW) = Battery\ Capacity\ (KW) \cdot \Delta SoC(\%)$$

The selected increase in the state of charge (SoC) for a normal charging cycle is 60%, as a mean to account for the range anxiety.

ΔSoC=60% (30 >> 90%)	Battery net charge (KWh/veh)
L1e-B Moped &Motorbikes	0,95
L3e-1 Scooter 125	1,98
L3e-2 Medium end 125	3,30
L3e-3 High end	9,24

Table 3-10 Battery Net charge

3.4.2 UNITARY GROSS CHARGE FOR THE DIFFERENT CATEGORIES

To obtain the gross charge, it is necessary to add the charging losses described in the description of the charging process:

$$Gross\ Charge\ (KW) = \frac{Net\ Charge\ (KW)}{100\% - Charging\ losses\ (\%)}$$

ΔSoC=60% (30 >> 90%)	Gross charge (KWh/veh)
L1e-B Moped &Motorbikes	1,12
L3e-1 Scooter 125	2,34
L3e-2 Medium end 125	3,90
L3e-3 High end	10,93

Table 3-11 Battey gross charge.

3.4.3 CHARGE TIME OF THE DIFFERENT CATEGORIES FOR SELECTED POWER INPUTS

Once the Gross energy consumption in the charging process is calculated, the time per charge for each category for every input power is calculated dividing the gross energy by the input power.

$$Time\ to\ charge\ (h) = \frac{Gross\ Charge\ (KW)}{Input\ Power\ (KW)}$$

	Hours to complete the charge (h)			
Input Power (KW)	0,77	1,3	2,3	3,7
L1e-B Moped &Motorbikes	1,5	0,9	0,5	0,3
L3e-1 Scooter 125	3,0	1,8	1,0	0,6
L3e-2 Medium end 125	5,1	3,0	1,7	1,1
L3e-3 High end	14,2	8,3	4,8	3,0

Table 3-12 Time to charge.

The main difference when charging motorcycles respect to cars & vans is that the average time to complete a charging cycle for motorcycles is lower, due to the smaller battery capacity of this type of vehicle. The average time for a charging cycle of motorbikes is 2-3h.

3.5 *ANNUAL CONSUMPTION OF THE FLEET*

To calculate the annual consumption of all the vehicles of a category, three things are needed:

- The number of charges per year, which also depends on three factors:
  1. The average specific consumption of each category expressed in KWh/100km.
  2. The average annual mileage of all the vehicles of each category.
  3. The net energy stored in the battery in a normal charging cycle
- The number of vehicles within each category.
- The time needed to complete a charging cycle for each category and input power.

3.5.1 NUMBER OF CHARGES PER YEAR

As stated earlier, the number of charges per year for the vehicles within a category depends on the specific consumption and the annual mileage.

The specific consumption is extracted from Table 3-3:

	Consum KWh/100 Km
L1e-B Moped &Motorbikes	2,4
L3e-1 Scooter 125	3,7
L3e-2 Medium end 125	4,6
L3e-3 High end	9,6

Table 3-13 Specific consumption.

The net energy stored in the batteries is the same as Table 3-10.

With both tables, dividing the annual mileage between the specific consumption, the number of charges in a year is obtained:

$$Number\ of\ charges\ a\ year\ = \frac{Net\ Energy\ per\ charge\ (KW)}{Specific\ Consumption\ (\frac{KWh}{100km})} \cdot Mileage(km) \cdot 100$$

The resulting number of charges per year is the following:

	Range (Km) with 60% SoC	Average Mileage Km/year	Charges/year	Days between charges
L1e-B Moped &Motorbikes	39,0	5.115	131,2	2,78
L3e-1 Scooter 125	54,0	5.347	99,0	3,69
L3e-2 Medium end 125	72,0	5.580	77,5	4,71
L3e-3 High end	96,0	5.812	60,5	6,03

Table 3-14 Number of charges per year

3.5.2 ANNUAL CONSUMPTION CALCULATION

With the number of charges per year for each category, the unitary charge, and the total number of motorcycles within each category, it is possible to calculate the total consumption of all electric motorcycles.

The following table shows the percentage of motorcycles in each category out of the total number of motorcycles, and the percentage of motorcycles that use the selected input power inside each category.

Electric Motorcycles	691,687					
	%s/total	% Inside each category				
Input Power(KW)		0,77	1,3	2,3	3,7	Units
L1e-B Moped &Motorbikes	15,3%	55%	35%	8%	2%	105.999
L3e-1 Scooter 125	62,6%	30%	40%	25%	5%	432.787
L3e-2 Medium end 125	3,0%	2%	30%	60%	8%	20.624
L3e-3 High end	19,1%			30%	70%	132.278
	100,0%					691.687

Table 3-15 Number of motorcycles per category and selected power inputs

With the three parameters obtained earlier (Unitary Net Charge per charge cycle, number of charges in a year for one motorcycle, and the number of vehicles of each category that use a determined power input) the net aggregated demand of the fleet can be calculated.

	Net aggregated charge of the fleet(GWh/year)				
Input power (KW)	0,77	1,32	2,3	3,68	Total
L1e-B Moped &Motorbikes	7	5	1	0	13
L3e-1 Scooter 125	25	34	21	4	85
L3e-2 Medium end 125	0	2	3	0	5
L3e-3 High end	0	0	22	52	74
Total					177

Table 3-16 Net aggregated charge of the fleet (GWh)

Adding the charging losses, the gross annual demand (in charger) can be calculated as well.

	Gross anual charge for the fleet (GWh/year)				
Input power(KW)	0,77	1,3	2,3	3,7	Total
L1e-B Moped &Motorbikes	9	5	1	0	16
L3e-1 Scooter 125	30	40	25	5	100
L3e-2 Medium end 125	0	2	4	1	6
L3e-3 High end	0	0	26	62	88
Total					210

Table 3-17 Gross aggregated charge of the fleet (GWh)

3.6 DAILY SCHEDULE AND LOAD CURVE

The first step to define the load curve is to estimate the number of vehicles of each category charging any given day. To obtain said number, it has been supposed that the number of vehicles charging daily is evenly distributed:

To calculate this figure, the following formula is used:

$$Vehicles\ charging\ any\ given\ day = \frac{Total\ number\ of\ vehicles}{365\ days} \cdot \frac{Charges}{year}$$

	Number of vehicles charging any given day				
Input Power (KW)	0,77	1,3	2,3	3,7	Total
L1e-B Moped &Motorbikes	20.948	13.331	3.047	762	38.088
L3e-1 Scooter 125	35.226	46.968	29.355	5.871	117.419
L3e-2 Medium end 125	88	1.314	2.627	350	4.379
L3e-3 High end	0	0	6.583	15.360	21.942
Total	56.262	61.612	41.612	22.343	181.829

Table 3-18 Number of vehicles charging daily.

To estimate the charging hours for all the categories of motorcycles using different plugs at different nominal powers, some hypotheses were made. As stated on the cars section, the new access tariffs and charges that came into place in June 2021 encourage consumers to displace their consumption to the night hours (0-8h)

The next figure shows the percentage of motorcycles that start a charging cycle at any given hour at any given charge rate in a day:

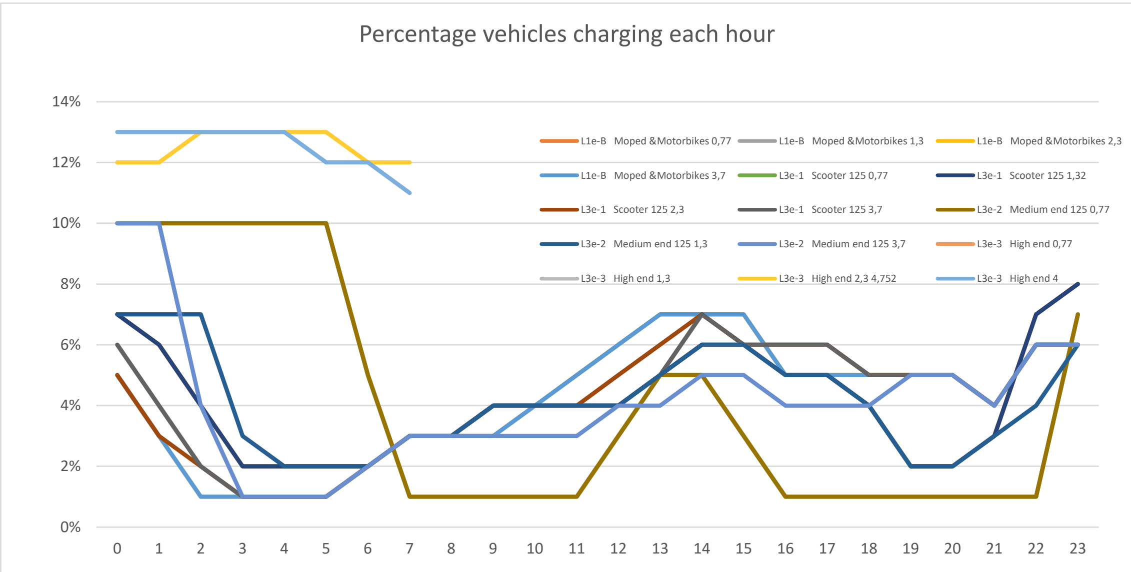

Figure 15 Load curve of different categories for different input powers

Most of the demand is concentrated on the early night hours and starts declining as the charging cycles end. By 7 am, there is virtually none, as all the charging cycles have already ended, and many users start their daily commute. There is also a second charge intensive period at noon.

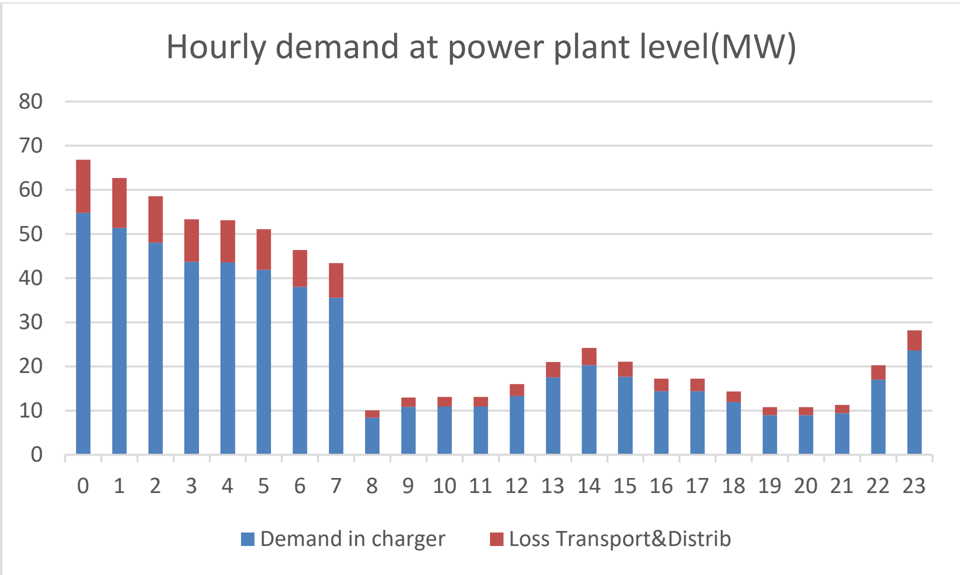

Figure 16 Hourly demand profile of electric motorcycles accounting for distribution & Transmission Losses

3.6.1 SEASONAL COMPONENT OF THE ELECTRIC MOTORCYCLE DEMAND

Motorcycle use as a mean of transportation depends greatly on the weather, mainly because of the dangers that rain and wind pose on the safety of the users. For this reason, the expected monthly demand varies significantly with the seasons, with higher demand on the warmer seasons, and lower demand in the cold ones.

To account for this seasonality, the results from a poll made by the Department for Transport of England were used [7]. The results of this poll create a distribution of motorcycle use during the year:

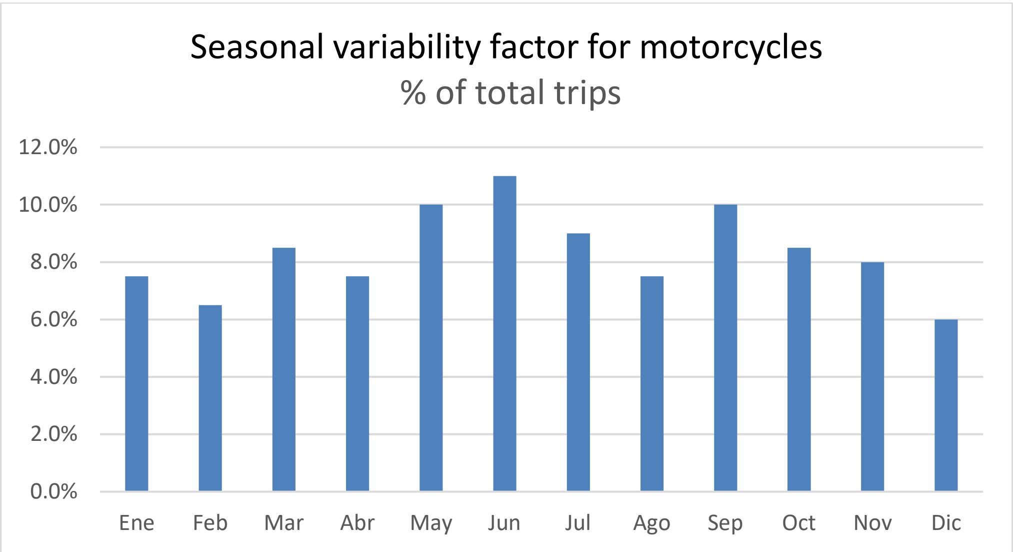

Figure 17 Seasonal variability factor for motorcycle use. Source: England's department for transport. [7]

By applying this distribution to the base hourly load curve shown in Figure 16, the hourly demand for the electric motorcycle fleet each month is obtained:

				Hourly demand (MW)																							
Seasonal use of motorcy	Percentage/	Days	GWh/Day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Ene	7.5%	31	0.62	59	55	52	47	47	45	41	38	9	11	12	12	14	19	21	19	15	15	13	10	10	10	18	25
Feb	6.5%	28	0.59	57	53	50	45	45	43	39	37	8	11	11	11	14	18	21	18	15	15	12	9	9	10	17	24
Mar	8.5%	31	0.70	67	63	59	53	53	51	46	43	10	13	13	13	16	21	24	21	17	17	14	11	11	11	20	28
Abr	7.5%	30	0.64	61	57	53	49	48	47	42	40	9	12	12	12	15	19	22	19	16	16	13	10	10	10	19	26
May	10.0%	31	0.82	79	74	69	63	63	60	55	51	12	15	15	15	19	25	29	25	20	20	17	13	13	13	24	33
Jun	11.0%	30	0.93	89	84	78	71	71	68	62	58	13	17	18	18	21	28	32	28	23	23	19	14	14	15	27	38
Jul	9.0%	31	0.74	71	66	62	56	56	54	49	46	11	14	14	14	17	22	26	22	18	18	15	11	11	12	22	30
Ago	7.5%	31	0.62	59	55	52	47	47	45	41	38	9	11	12	12	14	19	21	19	15	15	13	10	10	10	18	25
Sep	10.0%	30	0.85	81	76	71	65	65	62	56	53	12	16	16	16	19	26	29	26	21	21	17	13	13	14	25	34
Oct	8.5%	31	0.70	67	63	59	53	53	51	46	43	10	13	13	13	16	21	24	21	17	17	14	11	11	11	20	28
Nov	8.0%	30	0.68	65	61	57	52	52	50	45	42	10	13	13	13	16	20	24	21	17	17	14	10	10	11	20	27
Dic	6.0%	31	0.49	47	44	41	38	38	36	33	31	7	9	9	9	11	15	17	15	12	12	10	8	8	8	14	20
Annual total (GWh)	100%	365	254.4	24	23	21	19	19	19	17	16	4	5	5	5	6	8	9	8	6	6	5	4	4	4	7	10
			Hourly dispersion range for the different months (MW)																								
			Max	89	84	78	71	71	68	62	58	13	17	18	18	21	28	32	28	23	23	19	14	14	15	27	38
			Mean	67	63	59	53	53	51	46	43	10	13	13	13	16	21	24	21	17	17	14	11	11	11	20	28
			Min	47	44	41	38	38	36	33	31	7	9	9	9	11	15	17	15	12	12	10	8	8	8	14	20

Table 3-19 Hourly demand for an average day in every month

The dispersion on the demand hour by hour for all the months is shown down below:

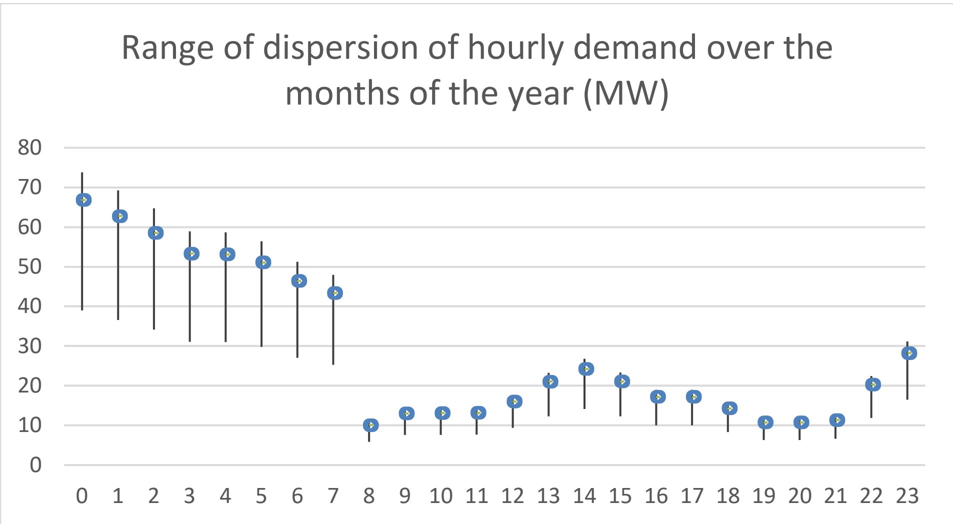

Figure 18 Hourly dispersion range for all months.

Chapter 4. BUSES

In this chapter, the electric demand resulting from electrifying a significant part of the national bus fleet in 2030 will be analyzed. The methodology followed in this section is slightly different to the previous ones and is described down below:

The buses most likely to be electrified are **public buses in urban and metropolitan areas**. This part of the bus fleet has been selected because, on top of its relevance in number, the characteristics would make them easier to electrify. Public buses in urban and metropolitan areas:

- Follow almost the same route every day for 10-14 hours and travel an average of 166 km daily.
- Stay in overnight bus garages where the electric charge can be readily provided
- Belong to local organizations with the economic capacity to afford investing in electric vehicles and charge infrastructure, reducing operational costs.

Methodology: below there is an overview of the methodology followed for the estimation of the impact on the load curve of the electrification of the public buses in urban and metropolitan areas

- Quantify the annual distance travelled (in km) by the public buses in urban and metropolitan areas. Given the homogeneity of the fleet, considered the whole fleet has been considered as a single segment without any differentiation.
- Estimate the specific consumption (per km) to be able to calculate the total annual electric consumption (net of losses). It has been assumed that the specific consumption depends on external temperature. Therefore, the course of action will be:

4..1 Define the relationship (curve) between temperature and specific consumption

4..2 Characterize the annual temperature variation across the different urban and metropolitan areas**.**

At this point, it will be possible to estimate the **total annual consumption** of the selected segment of the bus fleet (**net of losses**)

- Account for losses to estimate the total (gross) consumption and the effect on the load curve. Charging losses and transport and distribution losses will be considered, and battery self-discharge losses will be ignored.
- Estimate the hourly distribution of the battery charging process. Two strategies will be contemplated: slow charge and opportunity charge. It will be assumed that approximately 70% of the energy is charged overnight at the depot (slow-charge) and the remaining 30% at the terminal and selected bus stops (opportunity charge).

4.1 Annual distance travelled by public buses

In 2019, the Spanish national bus fleet had 65.470 vehicles. During 2020, 2.780 buses were retired, and 3.650 buses were incorporated, leading to an annual net increase of around 1.000 vehicles (1,5%).

In this study, the focus is set on public buses in urban and metropolitan areas, and data from the 23 metropolitan areas in Spain that constitute the Metropolitan Mobility Observatory has been analyzed. There are around 11.000 buses in this segment (about a sixth of the national bus fleet).

Table 4-1 summarizes the main parameters of the urban buses in the Metropolitan Mobility Observatory [11]. Some observations:

- There **is high variation** in the **average daily distance** traveled depending on the type of bus lines: 127 km/day for lines operating inside the main city, 163 km/day for lines operating inside smaller, satellite cities and 223 km/day for lines connecting cities inside of metropolitan areas.

The **total annual distance in km travelled by buses in each area** has been calculated.

	Fleets of buses (# vehicles).				Vehicles-km per year (millions). Year 2018				Km/day-veh			
	Urban bus	Other Urban Buses	Metrop Bus	Total buses	Urban bus	Other Urban Buses	Metrop Bus	Total buses	Urban bus	Other Urban Buses	Metrop Bus	Total buses
Madrid	2.049		1.886	3.935	92		177	270	123		258	188
Barcelona	1.085	875	633	2.593	43	52	51	146	109	164	220	155
Valencia	492		117	609	21		7	28	115		169	126
Sevilla	400	18	144	562	19	1	11	31	130	167	209	151
Bizkaia			338	338			28	28			225	225
Asturias	67	82		149	4	5		9	176	164		169
Málaga	254		100	354	12		8	19	127		205	149
Mallorca1	176		209	385	13		12	25	196		159	176
B. Cádiz			71	71			6	6			212	212
Zaragoza	337		53	390	18		5	23	149		248	162
Gipuzkoa	132		0	132	7			7	141			141
C. Tarragona	68	15	161	244	3	1	13	17	129	146	226	194
Granada	184	3	112	299	7		8	15	101	0	191	134
Almería	0		75	75			3	3			106	106
Alicante	92		47	139	5		2	7	140		128	136
Valladolid	150		0	150	7			7	124			124
Lleida	47		98	145	2		4	6	117		103	106
Pamplona	143		0	143	8			8	153			153
C. Gibraltar	0		24	24			2	2			194	194
A Coruña	93		0	93	6			6	165			165
Jaén	0		85	85			3	3			87	87
León	31		0	31	2			2	150			150
Cáceres	37		0	37	2			2	155			155
Total	**5.837**	**993**	**4.153**	**10.983**	**270**	**59**	**338**	**667**	**127**	**163**	**223**	**166**

Table 4-1 Total annual distance travelled (in km) by buses in the main metropolitan areas of Spain

4.2 SPECIFIC CONSUMPTION OF PUBLIC BUSES IN METROPOLITAN AREAS PER KM

The specific consumption of electric buses varies greatly with the external temperature. This is not because the external temperature affects the performance of the motor, but because the power source for the air conditioning and heating of the cabin is electric, and it feeds from the batteries.

The following model estimates the electric consumption of the bus fleet for different external temperatures.

4.2.1 SPECIFIC CONSUMPTION AS A FUNCTION OF TEMPERATURE

We have developed a model to estimate specific consumption as a function of external temperature (using data provided from an existing analysis) and cross-checked for consistency with additional sources.

The model is based on Algin's "S*tudy of electric buses E433 of BKM Holding and average power consumption of 15 electric buses on the same route, as well as the average temperature in Minsk depending on the month*" [9]. We have interpolated a parabolic function of specific consumption as a function of temperature from the data provided by the analysis. The results are show on Figure 19.

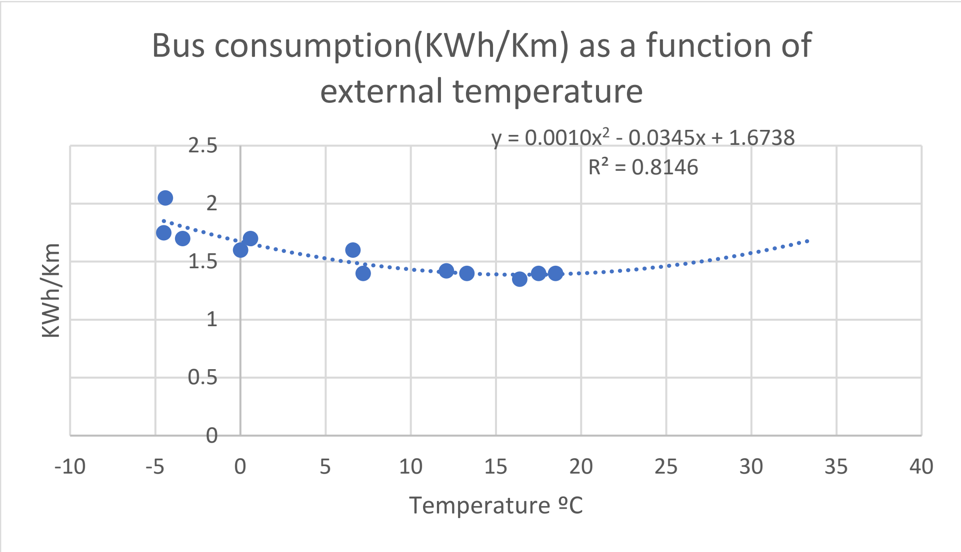

Figure 19 Bus consumption as a function of external temperature

The following study [10] illustrates that the average consumption is in line with the results provided by the model.

Battery Electric Buses Smart Deployment Zero Emission Bus Conference November 30, 2016.	KWh/100 Km	Range Using a 500kWh Battery (Km)
Route A (summer, no passengers)	107	375
Route A (summer, avg. passengers)	131	306
Route A (summer, max passengers)	153	262
Route A (winter, no passengers)	119	336
Route A (winter, avg. passengers)	164	245
Route A (winter, max passengers)	193	208
Route B (fall, no passengers)	104	383
Route B (fall, avg. passengers)	128	312
Route B (fall, max passengers)	137	306

Table 4-2: Specific consumption of buses under different occupation and weather conditions [10]

4.2.2 ANNUAL TEMPERATURE DISTRIBUTION ACROSS AREAS

The next step to calculate the specific consumption from the model, is to characterize the annual temperature distribution of each area.

Data from the weather observatories of the 23 biggest metropolitan areas has been used. These areas integrate 25,7 million people, which accounts for 55% of the Spanish population.

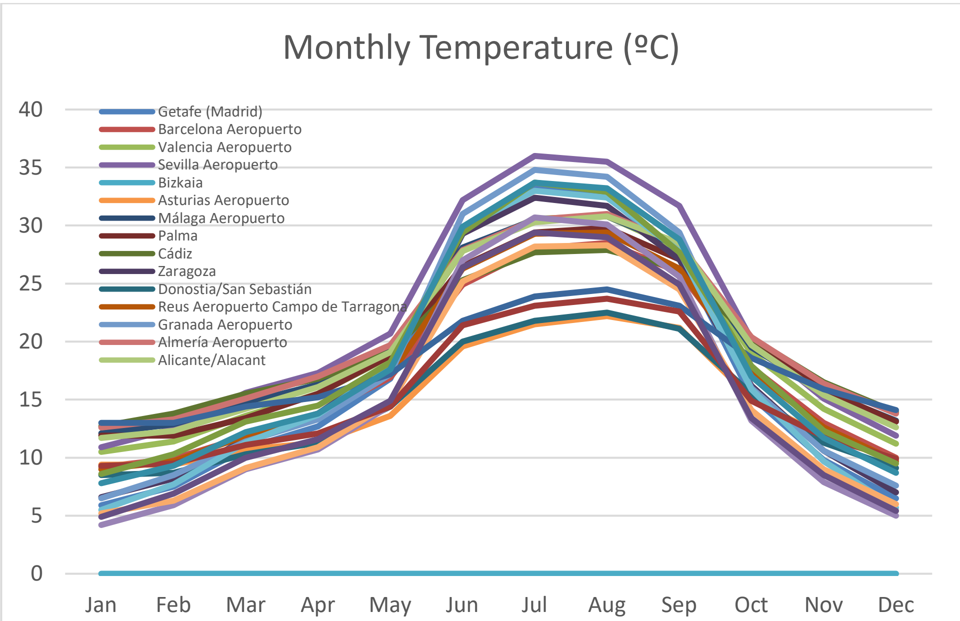

Figure 20 Monthly average temperatures for the main metropolitan areas

With this, the specific consumption per month and per area has been estimated.

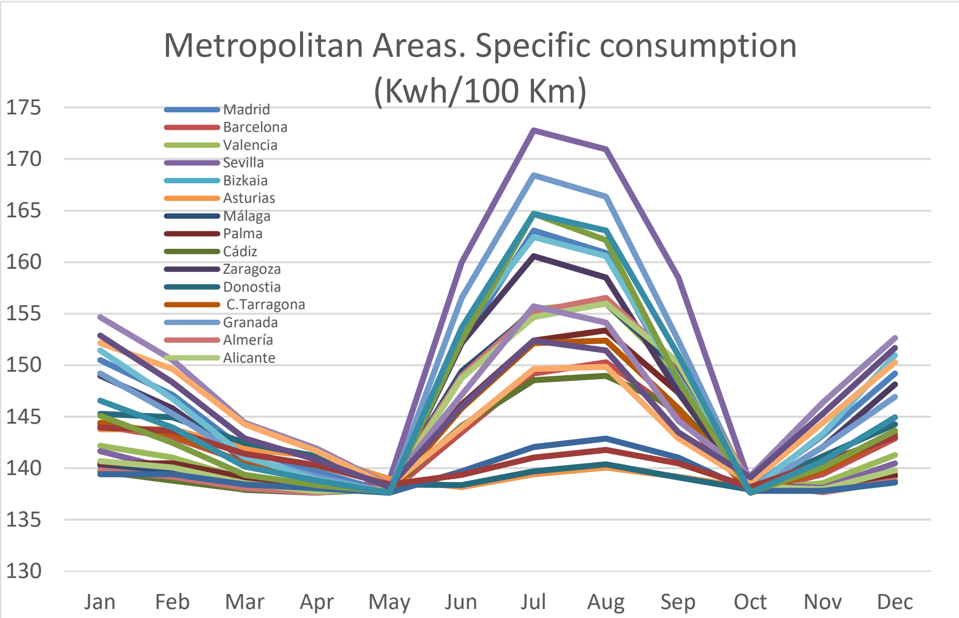

Figure 21 Specific consumption of buses by month for the main metropolitan areas.

Finally, using the results from sections 4.1 (average monthly distance travelled per region) and 4.2 (specific consumption per month based on average temperature per region) the average daily load needs for every month can be estimated (see Figure 21).

The total estimation results in approximately 1.010 GWh per year.

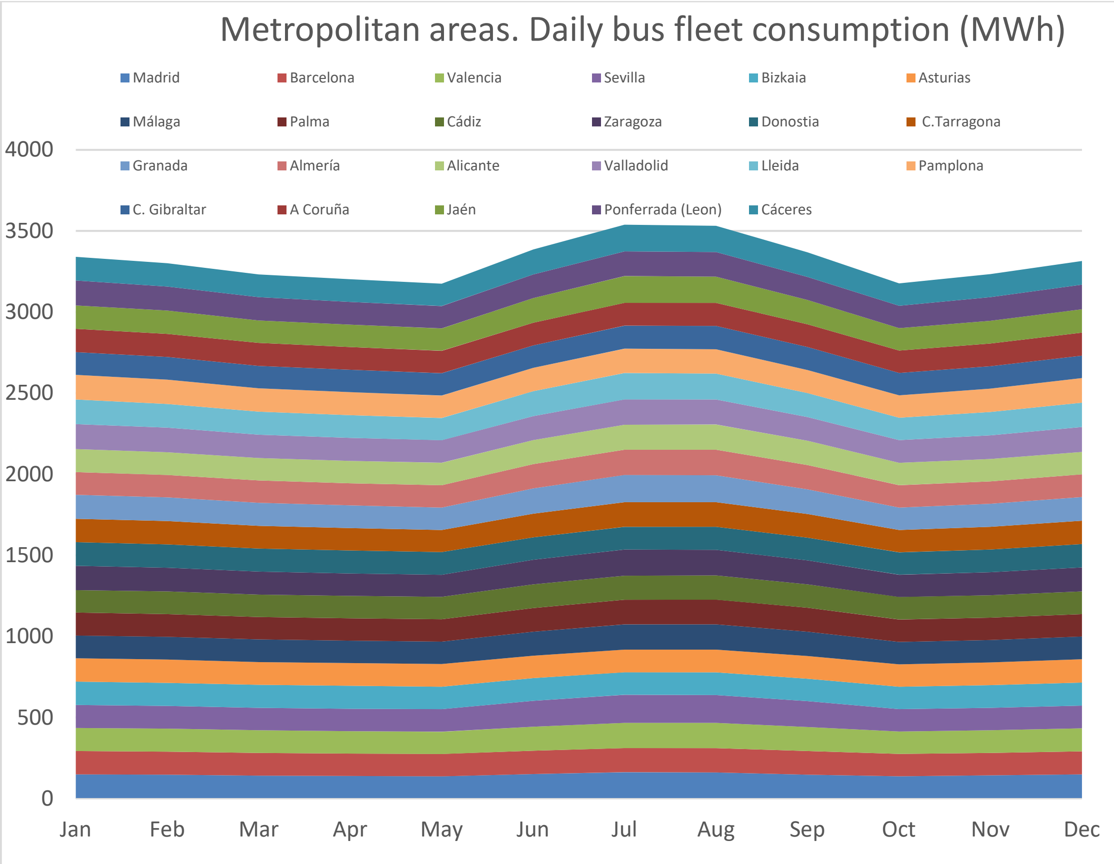

Figure 22 Daily bus fleet consumption for the fleets of the different metropolitan areas in different months

4.3 LOSSES

Electric buses use batteries with big storage capacities, so they also charge at high input powers to keep the charging times short. For these input powers, the charging losses are estimated to be 5%. The total annual consumption in the charger would be then:

$$Total\ consumption\ in\ charger\ = \frac{1.010}{(1-5\%)} = 1.063\ GWh/year$$

Transmission **and distribution losses** at the power levels used by electric buses (Access Tariffs 6 TD) are estimated to be around **5%** as well.

$$Total\ consumption\ at\ Power\ Plant\ = \frac{1.063}{(1-5\%)} = 1.120\ GWh/year$$

Total consumption in Power Plant to electrify the public buses of the 23 urban and metropolitan areas considered will be estimated at **1.120 GWh/year by 2030**.

4.4 HOURLY DISTRIBUTION OF THE ELECTRIC LOAD

Nowadays, there are two strategies for the charging process of public buses:

- **Slow charging**: at the depot, generally overnight charge, with approximate durations of 3-8 hours. Can be performed via plug but also via roof mounted pantograph.
- **Opportunity charging** or fast-**charging**: at the terminal and at selected bus stops, via pantograph with a descending arm.

According to the ZeEus Report 2017-2018 [8], for pure electric buses, around 44% of batteries are charged exclusively via depot charging and 56% via opportunity charge.

For this study, it is considered that 70% of the charging of electric buses batteries is done via slow charging at the depot for 7 hours (overnight) and the rest is done via opportunity charging at the terminal and selected bus stops through the 15 hours of service.

With the previous assumptions, the daily power demand from the central in an average day is shown in the graph below.

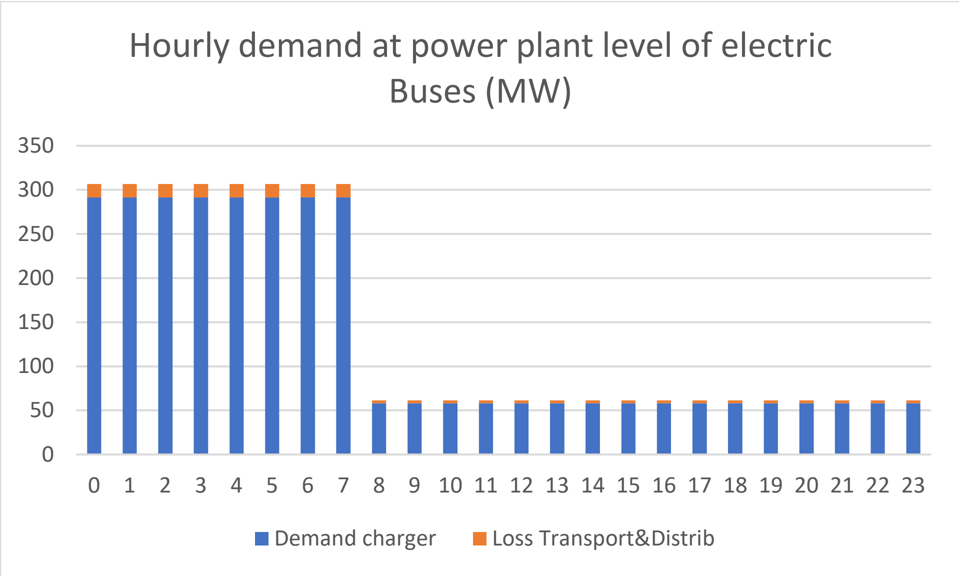

Figure 23 Expected hourly load curve for the electric bus fleets of the main metropolitan areas in 2030

Chapter 5. SUMMARY AND CONCLUSIONS

5.1 *SUMMARY OF THE MAIN RESULTS*

The following table shows the most relevant data used in this study, and the results derived from it:

	Cars&Vans		**Motorcycles**	**Buses**			
	Home	**Fast**		**Depot**	**Opportunity**	**Total**	
Vehicles in 2030	3.417.274		691.687	10.983		4.119.944	Units
Total distance travelled	67.359	5.468	3.740	467	200	77.236	Million Km/Year
Charges/Year	350	23	66	4	-	444	Million Charges
Net charge in batteries	12.897	1.070	177	707	303	15.154	GWh
Gross consumption in charger	15.363	1.132	210	744	319	17.769	GWh
Electric demand in Power Plant	18.703	1.210	254	783	336	21.286	GWh
Annual mileage of the EV type	19.711	1.600	5.408	42.537	18.230	18.747	Km/veh/year
Charges per year	103	7	96	358	-	107,7	Charges/veh
Energy consumption at the batteries	3.774	313	256	64.376	27.590	4.434,6	KWh/veh
Specific consumption	0,19	0,19	0,05	1,51	1,51	0,20	KWh/Km
Specific consumption at Power Plant	0,23	0,23	0,07	1,68	1,68	0,23	KWh/Km
% Total Losses	31,0%	11,6%	30,3%	9,8%	9,8%	28,8%	% Demand at Power Plant

Table 5-1 Main inputs & results

5.2 *EXPECTED LOAD CURVE OF THE EV FLEET IN SPAIN IN 2030*

Figure 24 represents the average hourly demand resulting from this study for the weekdays. The demand is concentrated on the valley period, from 12 am to 8am. It decays during the working hours, and it starts to grow back in the period from 2pm to 12am. The concentration of load on the valley hours is mainly due to the new access tariffs that heavily incentivize night charging.

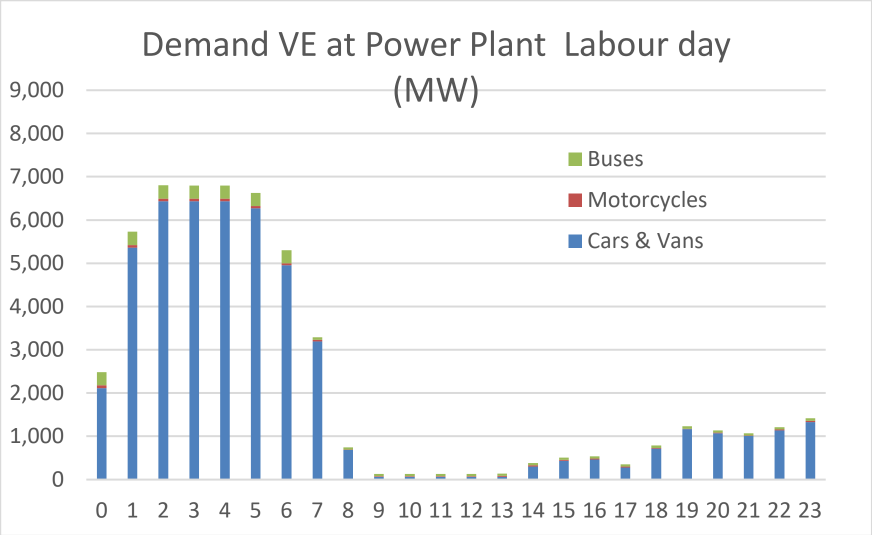

Figure 24 Hourly Demand VE at Power Plant in weekdays

Figure 25 represents the average hourly demand resulting from this study for the weekends. The demand is still concentrated on the valley hours, but it is not reduced as much during the morning hours. Shifting load to the weekends makes sense because all the hours in a weekend are considered valley period under the new access tariffs.

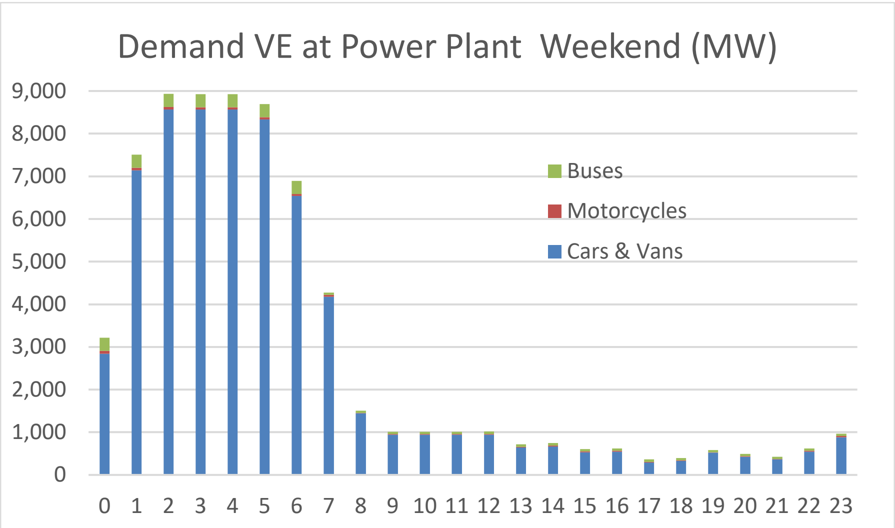

Figure 25 Hourly Demand of VE at power plant level in Weekends

5.3 CONCLUSIONS

- The energy consumed on the night hours is on the same magnitude order that the one that would be needed to fill the valley period gap.

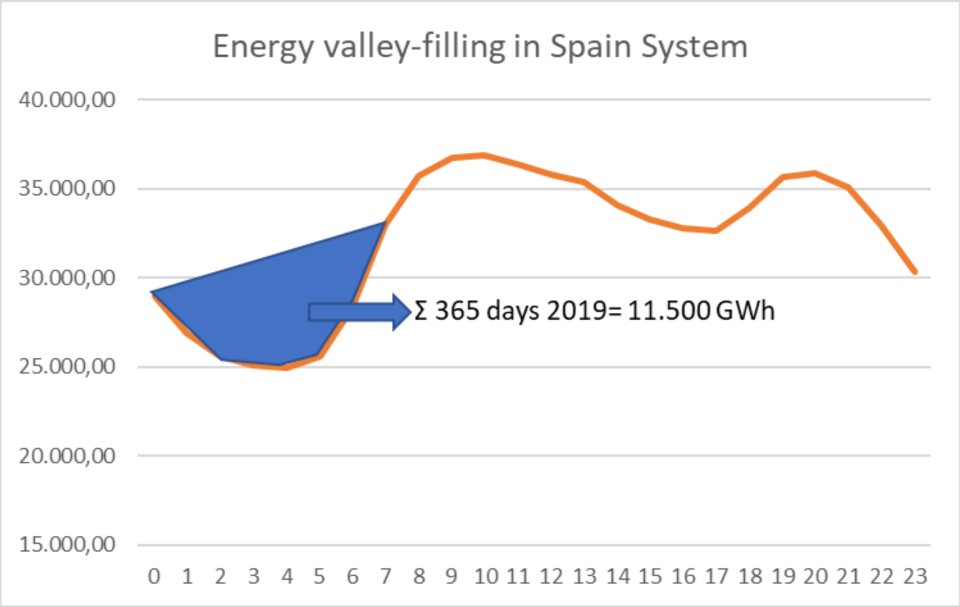

Figure 26 Capacity of Energy valley-filling. Spain 2019 demand (GWh)

- The total demand of 4,12 million EVs would be equal to 21,3 TWh at power plant level in the year 2030.

  This increase on the demand due to the charging of EVs would be 8,5% of the total Spanish demand for the year 2019. This demand would be equivalent to a uniform yearly growth of 0,8% during the 2020-2030 decade.
- There is a lot of uncertainty regarding the charging schedules of EVs at an hourly and weekly level. For company fleets, vehicle sharing services, buses, and particulars using slow charging, it seems like most charges will occur outside of working hours.
- The access tariff policies in use also seem like a determinant factor when allocating the EV charging hours, and the load shifting to the weekends.

- The new 2.0 TD tariffs, night charging and weekend charging appear to be heavily incentivized, and EV users would be very sensitive to price signals (under the assumption of a constant marginal price on the wholesale market).
- With these hypotheses, half of the EV demand would be concentrated from 12am to 8am, and a third of the EV demand would be concentrated on the weekends.
- The nightly consumption would be 7.000 MW on the weekday nights, and 9.000MW on the weekend nights. This would help a lot to flatten the demand curve.
- Figure 27 shows the resulting curve with the addition of EVs, compared to the 2019 demand. It is noticeable that the gap in demand between the peak and valley hours is reduced.

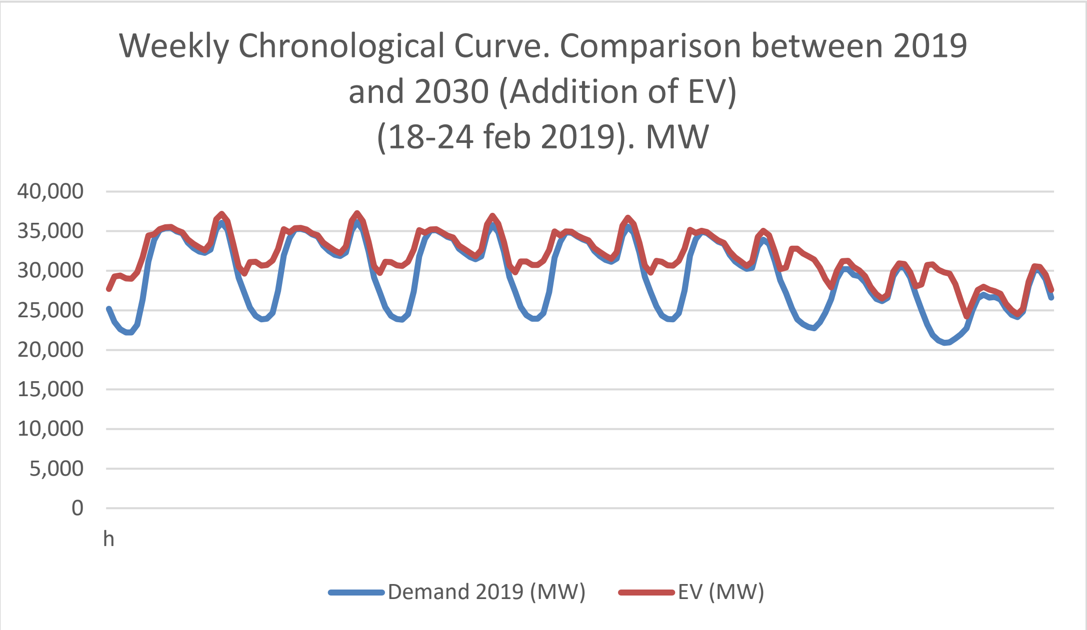

Figure 27 Flattening of the load curve thanks to EV charging in a week

- The result would be a flatter chronological demand curve caused by an overall increase on energy consumption. As stated earlier, this increase in consumption would be concentrated on the night hours.

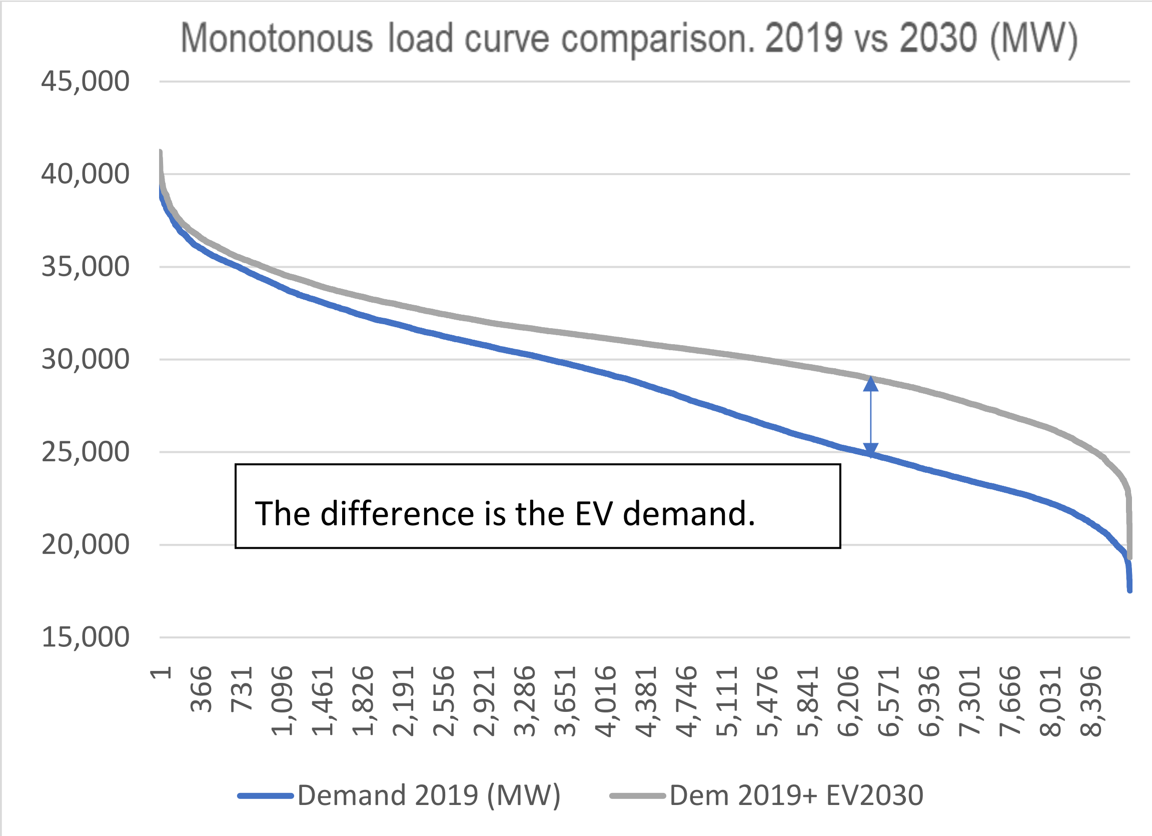

Figure 28 Overall increase on load, and curve flattening.

5.4 INTEGRATION OF THE EV LOAD CURVE IN ENDESA'S ENERGY TRANSITION MODEL

The chronological curve of the EVs was introduced in the ENDESA´s Energy Transition Model. The main objective of this model is to analyze the capacity of the Spanish electric system to satisfy the increased demand in the future in a scenario of high decarbonization of the sector. The model contemplates diverse scenarios with several degrees of decarbonization and electrification in the final consumption of energy.

The cornerstone of the model is a cost optimization function that considers the annualized fixed costs (investment costs), and the variable costs of each generation technology. It also considers the expected costs of non-served energy and spillages.

With this data and the expected demand, the model calculates the optimal capacity of each technology that needs to be installed to satisfy the expected demand. Regarding this expected demand, it will most likely be much higher than the current demand for several factors:

- The addition of the EV load, modelled in this project.
- The electrification of traditional nonelectric demands such as residential and industrial heating, via heat pumps, heat accumulators, and resistors.

The model also incorporates storage elements that can work both as a load or a generation unit (hydro pumping, battery storage, hydrogen production with electrolyzers/hydrogen CCGTs). This feature allows the system to avoid spillages and non-served energy in a renewable energy source-based system.

After running the model with the time series of the EV demand resulting from this project, the following monotonous and chronological load curves were obtained for the scenario of high decarbonization and electrification of the economy, where there is not fossil fuel generation, nor nuclear.

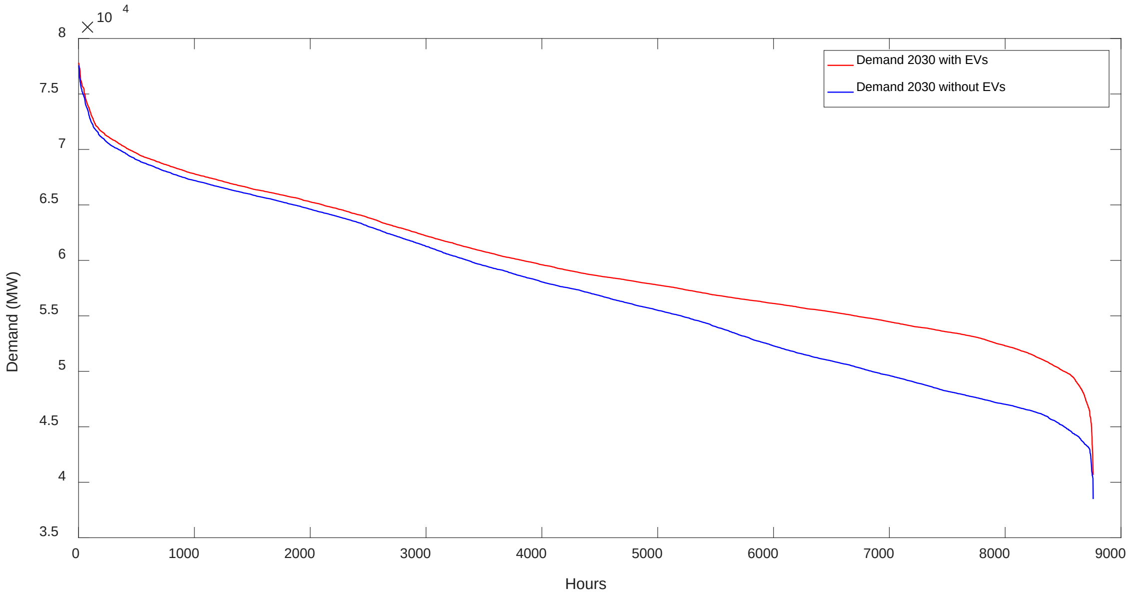

Figure 29 Comparison of monotonous demand curves with and without EVs. High Electrification Scenario

Figure 30 shows the load curve of the total demand not dedicated to storage in each week (Traditional demand, heating demands, and EVs)

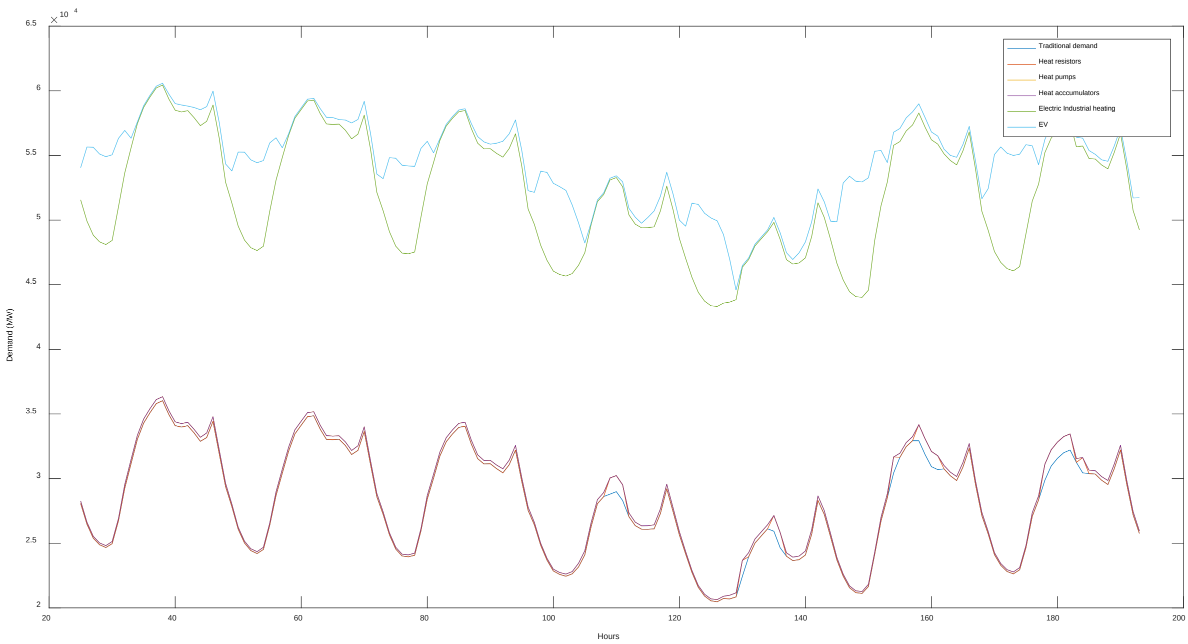

Figure 30 Aggregated curves of all consumptions not aimed at storage. High electrification Scenario

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