MOBILE ENERGY RESOURCES

IN GRIDS OF ELECTRICITY

ACRONYM: MERGE

GRANT AGREEMENT: 241399

WP 3
TASK 3.2 (PART II)
TO BE INCLUDED IN DELIVERABLE D3.2

Evaluation of the impact that a progressive deployment of EV will provoke on electricity demand, steady state operation, market issues, generation schedules and on the volume of carbon emissions

JUNE 2011

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AUTHORS

Fernando Báñez Chicharro	Fernando.Banez@iit.upcomillas.es
Kristin Dietrich	Kristin.Dietrich@iit.upcomillas.es
Andrés Ramos	andres.ramos@iit.icai.upcomillas.es
Jesús Latorre	jesus.latorre@iit.upcomillas.es

CONTRIBUTORS

APPROVAL			DATE
Project Coordinator	PPC	N. Hatziargyriou	../../2010
Technical Coordinator	INESC Porto	J. Pecas Lopez	../../2010
Work Package Leader			../../2010

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EXECUTIVE SUMMARY

The objective of the present task is to evaluate the technical, economic and environmental impacts of the introduction of EVs into the power system. More precisely, an estimation of the drawbacks and benefits of the introduction of EVs into the system, and the changes that would arise in its operation are presented. The power systems under study are the Spanish, Portuguese and Greek systems for the year 2020. Three different penetration levels and charging strategies for the EVs are considered to cover possible future scenarios.

The introduction of EVs means an increase of the total demand, no matter what charging strategy is adopted, and therefore the following drawbacks result from the deployment of EVs:

- Increase in the specific cost of the power system.
- Increase in CO_2 emissions produced by the power system.

However, the introduction of EVs has significant potential benefits:

- Reduction in wind spillage.
- Reduction in the net CO_2 emissions of the country. The introduction of EVs would come with a reduction of internal combustion vehicles, resulting in a total net reduction of CO_2 emissions. When applying a charging profile adapted to the power system, EVs may have an equivalent CO_2 emissions in a range of 24-70 gCO_2/km, while currently in internal combustion engines it is about 130 gCO_2/km.

Since the demand is increased, the operation must be adapted to the new situation. The necessary changes in generation are mainly absorbed by CCGTs and coal plants. The specific modification of operation, that is the increment in the share of CCGT and coal, as well as the associated drawbacks and benefits that result, are strongly related to the generation mix of the country and the charging strategy adopted by the EVs. If the EVs are charged without taking into account the situation and characteristics of the power system, a reduction of the benefits and an increase of the drawbacks will occur, and even, the CO_2 net emissions will not be reduced.

Several recommendations are derived from these results:

- To avoid negative impacts of EVs deployment, it is important that they are charged using an “intelligent” charging profile that takes into account the power system.
- The “intelligent” charging profile is highly dependent on the system: generation mix, wind and demand profiles. For some systems it would be smart to charge at night and for others at midday.

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6 EVALUATION OF THE ECONOMIC AND ENVIRONMENTAL IMPACTS OF EV DEPLOYMENT

The changes introduced into the generation schedules due to the future deployment of higher volumes of EVs into the system and their resulting impacts in the economic and environmental aspects have to be evaluated.

The amount of energy, as well as its hourly profile, required by EVs depends on the mobility needs of the consumers, including their grid-connection profile and the technical characteristics of the EVs. Another important aspect to obtain the energy consumption profile of the EVs is the charging strategy employed by the consumers and/or by the system.

This section evaluates the economic and environmental impacts of the future deployment of EVs in mainland Spain, Portugal and Greece system for the year 2020. For this purpose, different EV penetration levels [1] and charging strategies are studied using the ROM Model [6].

6.1 Mainland Spain

6.1.1 Input Data

Input data for the model include thermal and hydro generation data, demand profiles and profiles for renewable energy sources (RES) such as wind, solar, biomass and cogeneration as well as data about EVs.

Table 6.1. Input data for mainland Spain 2020.

2020 case study		
Energy	[TWh]	374
Winter Peak	[MW]	58000
Summer Peak	[MW]	53000
Min Load	[MW]	28450
Peak/OffPeak Ratio	[p.u.]	2.0
Max Upward Reserve	[MW]	5530
Max Downward Reserve	[MW]	1160
Nuclear	[MW]	7000
Coal	[MW]	7113
CCGT	[MW]	29000
Gas/Oil	[MW]	301
Max Hydro Output	[MW]	16692
Pure Pumped Storage Hydro	[MW]	5185
Combined Pumped Storage Hydro	[MW]	2884
Wind Generation	[MW]	34820
Solar PV	[MW]	6250
CSP	[MW]	3810
Cogeneration	[MW]	10310
Other RES	[MW]	4460

Natural Hydro Inflows	[TWh]	28
Nuclear Price	[€/Mcal]	0.002
Coal Price	[$/short tons]	125
Natural Gas Price	[$/MMBTU]	11
CO2 Price	[€/t CO2]	15
# of Electric Vehicles	[units]	0-575000

✓ **Generation data**

Data about thermal generators have been provided by the Spanish System Operator (Red Eléctrica de España). These data include minimum and maximum power output, ramp rates, Scheduled Outage Rate (SOR) and Equivalent Forced Outage Rate (EFOR). Furthermore data about costs (variable, fixed and start-up costs) have been provided as well fuel consumption, specific emissions and start-up consumption (see Table 6.2 for more information).

Total installed generation capacities can be found in Table 6.1~~Table 6.1~~. The share of each technology can be found in Figure 6.1~~Figure 6.1~~.

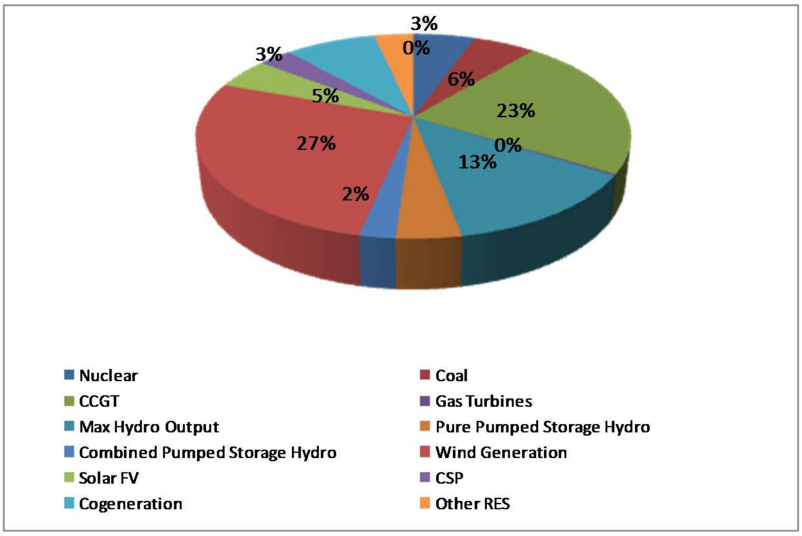

Figure 6.1 Share of installed capacities for mainland Spain 2020

Table 6.2 Average characteristics of thermal units for mainland Spain 2020.

		Nuclear	Coal	CCGT single axis	CCGT multiple axis	Gas	Oil
SOR	[p.u.]	0.0	0.07	0.03	0.03	0.03	0.03
EFOR	[p.u.]	0.0	0.05	0.06	0.06	0.10	0.10
Min Out	[MW]	908	146	191	199	61	85
Max Out	[MW]	908	316	391	805	204	116
Ramp Up	[MW/h]		173	200	581	240	31
Ramp Down	[MW/h]		173	200	581	240	31

Var Heat Rate	[Mcal/MWh]	2500	2528	ix 1A 1581	ix 1B 1555	1C 2453	1D 2611
1E No Load Heat	ix 1F [Mcal/h]	1G	1H 64304	1I 315480	1J 544671	1K 121507	1L 18169
1M Fuel Cost	ix 1N [€/Mcal]	1O 0.002	x 1P 0.018	1Q 0.032	ix 1R 0.032	x 1S 0.032	1T 0.035
1U CO2 Cost	x 1V [€/t CO2]		15	15	15	15	15
Specific Emiss	[t CO2/MWh]		1.025	0.371	0.365	0.575	0.843
O&M Var Cost	[€/MWh]	0.060	0.042	0.055	0.055	0.025	0.025
Startup Cons	[Mcal/str]		1440400	380000	760000	488000	488000

Data about hydro generators include maximum output in MW and maximum reserves in GWh. Hydro Inflows are given on a daily basis for the whole year.

Wind generation profiles were provided from the same source. Other generation profiles were obtained from [8] and scaled to the installed generation capacity provided in [7].

✓ Operation reserve data

The operation reserve data were obtained as it is stated in (1) and (2), where α is the factor to account for wind forecast error, β is the factor to account for demand forecast error and γ is the largest generation unit.

$$Res_{UP} = \alpha \cdot WG + \beta \cdot Dem + \gamma \qquad \textbf{(1)}$$

$$Res_{DOWN} = \beta \cdot Dem \qquad \textbf{(2)}$$

✓ Demand data

Demand profiles were provided by the Spanish System Operator as well. Total electricity demand for 2020 of 374 TWh has been published in [7]. Peak demands for winter and summer are 58 GW and 53 GW, respectively.

✓ Electric Vehicles

Three different charging profiles for the Spanish case were provided by REE, the Spanish System Operator, depending on their benefits for system operation. These profiles can be seen in Figure 6.2~~Figure 6.2~~:

- Dumb profile: it is the plug and charge connection of EVs into the grid, without taking into account the system situation.
- Multi-tariff profile: EV charging depends on different tariffs in order to promote energy demand in off-peak hours.

- Smart profile: there are a lot of possible smart charging profiles, depending on the objective pursued. In this case, the smart profile allocates the EV charge demand in order to fill the off-peak hours (valley) of system demand.

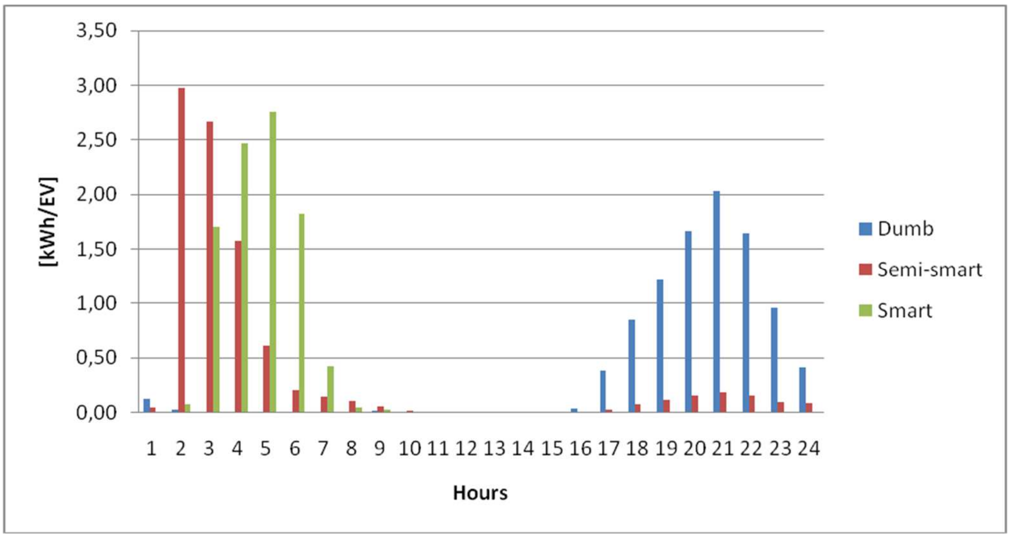

Figure 6.2 Charging profiles considered.

Assuming a mix of EVs with an average energy specific consumption of 0.14 kWh/km, a battery capacity of 28 kWh and 95 % efficiencies in grid-to-battery and battery-to-grid processes, the approximately average distance travelled by a car is 63 km/day.

6.1.2 Different EV penetration scenarios

For the year 2020 four different EV penetration levels have been considered [1]: a base case which does not have EVs, and then, scenarios with 138000, 281000 and 575000 EVs, which represent approximately a 0.5%, a 1% and a 2% of the total fleet of vehicles, respectively.

The analysis carried out in this section compares the results of the different penetration levels using the smart charging profile, when it is possible. All the results presented take into account only weekdays, because the EV charging profiles provided were adjusted only for these days. For this reason, taking into account the whole week would produce questionable results.

✓ **Annual wind spillage**

Figure 6.3~~Figure 6.3~~ shows the sum of wind spillage throughout the year 2020 for mainland Spain. These results take into account the daily operation planning (unit commitment) including the optimal dispatch of all units and the uncertainties such as the failure of thermal units or the demand and wind forecast errors in real-time. Annual wind spillage will decrease the higher the penetration of EVs is, except for the scenario with less EV penetration. The scenario with 138000 EVs increases wind spillage a 0.8% compared to the 0 EVs scenario, while the 281000 and 575000 EVs reduce wind spillage by 1.9% and 4.1%, respectively. These results are based on the smart charging profile.

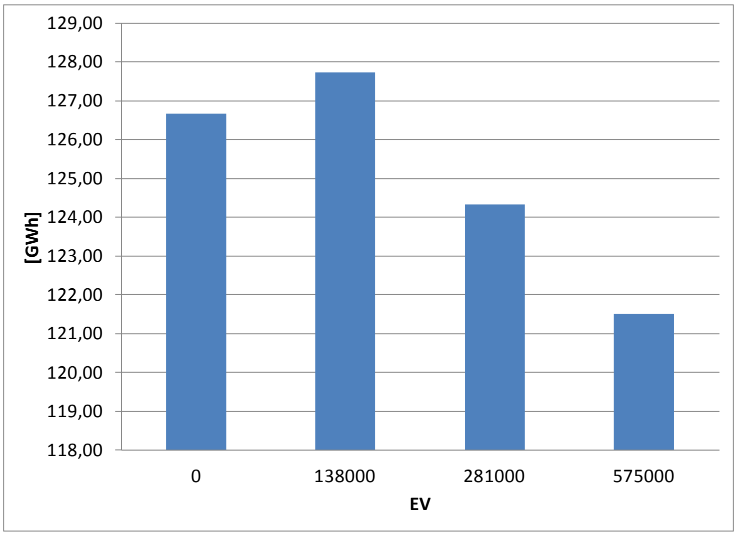

Figure 6.3 Annual wind spillage for different EV penetration scenarios mainland Spain 2020 (smart charging scenario)

✓ **Annual specific cost**

The specific cost (€ per MWh of demand) is presented in Figure 6.4~~Figure 6.4~~. This cost has an increase of a 0.5%, a 0.6% and a 1.1% for the scenarios with 138000, 281000 and 575000 EVs. These penetration levels show that the change in the specific cost due to the introduction of the EVs is not linear.

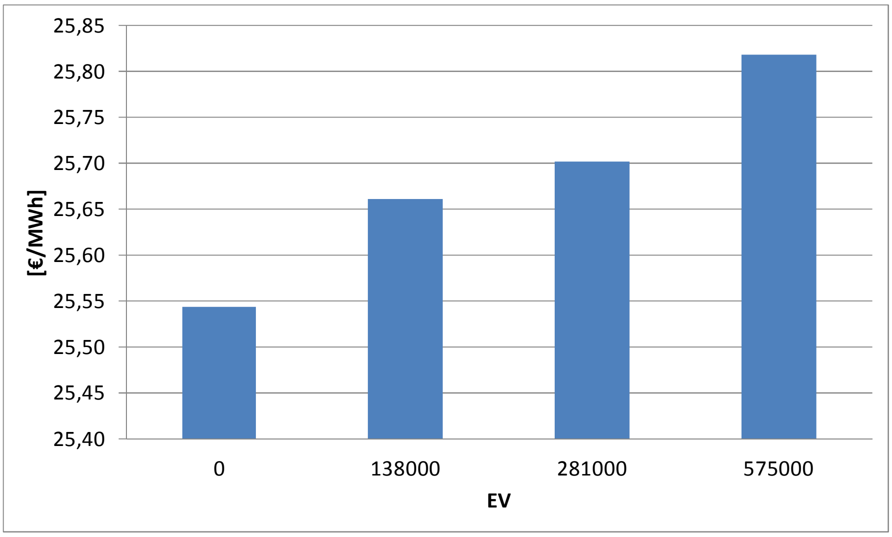

Figure 6.4 Specific cost for different EV penetration scenarios for mainland Spain 2020 (smart charging scenario)

✓ **Annual CO_2 emissions**

The annual CO_2 emissions for Spain during the year 2020 considering different EV penetrations levels are displayed in Figure 6.5~~Figure 6.5~~. This figure shows that the introduction of more EVs into the system increases the production of CO_2 emissions in an almost linear way (the increment in percentage of the CO_2 emissions is a 0.4%, a 0.8% and a 1.4% for the different penetration levels). This situation occurs because the introduction of a higher quantity of EVs produces an increase in the demand and then, more energy production is required.

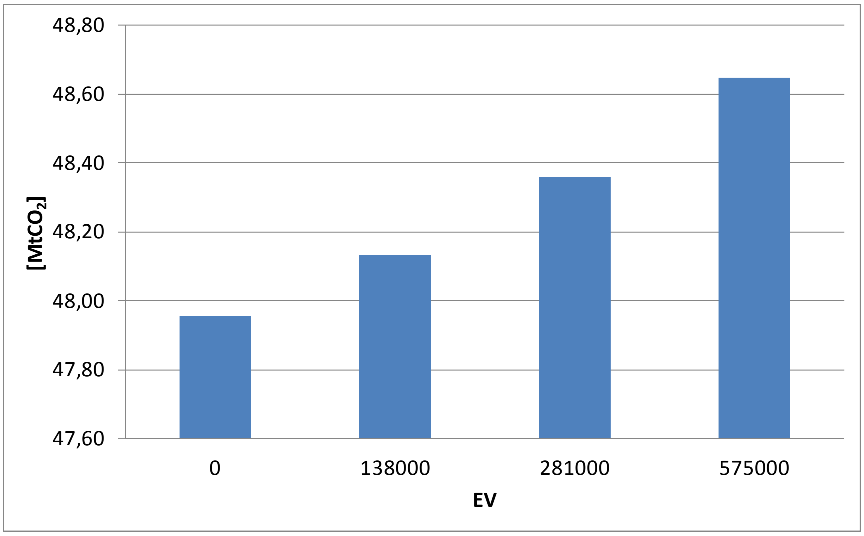

Figure 6.5 CO_2 emissions for different EV penetration scenarios for the year 2020 in mainland Spain (smart charging scenario)

It is interesting to remark that introducing EVs into the system results in a further decrease in the CO_2 emissions, because these vehicles have no CO_2 emissions and substitute other vehicles that would emit CO_2 while running. Table 6.3 presents the comparison of emissions that would be produced if instead of EVs there were more internal combustion vehicles, and the equivalent CO_2 emissions for the EVs. The EV data presented in section 6.1.1, and the limit fixed by the European Union for fleet average CO_2 emissions, which is 130 gCO_2/km, are used to calculate these values.

Table 6.3. Increase in CO_2 emissions with internal combustion vehicles

Number of EVs introduced	Increase in CO_2 emissions	Equivalent EV CO_2 emissions (gCO_2/km)
138000	45%	72
281000	37%	80
575000	46%	70

- ✓ **Daily wind spillage profile**

The daily wind spillage profile for weekdays is shown in Figure 6.6~~Figure 6.6~~. This profile shows that the introduction of EVs into the system reduces wind spillage over the night, but there is also a raise during some moments of the day (the most important moment is around hour 15). For the scenarios with a higher number of EVs (281000 and 575000 EVs), the increase of wind spillage is compensated with the decrease over the night, producing a net reduction of wind spillage (as can be seen in Figure 6.3~~Figure 6.3~~). However, for the 138000 EVs scenario, the reduction of wind spillage over the night does not compensate the increase during the day, resulting in a net increase of wind spillage (as can be seen in Figure 6.3~~Figure 6.3~~).

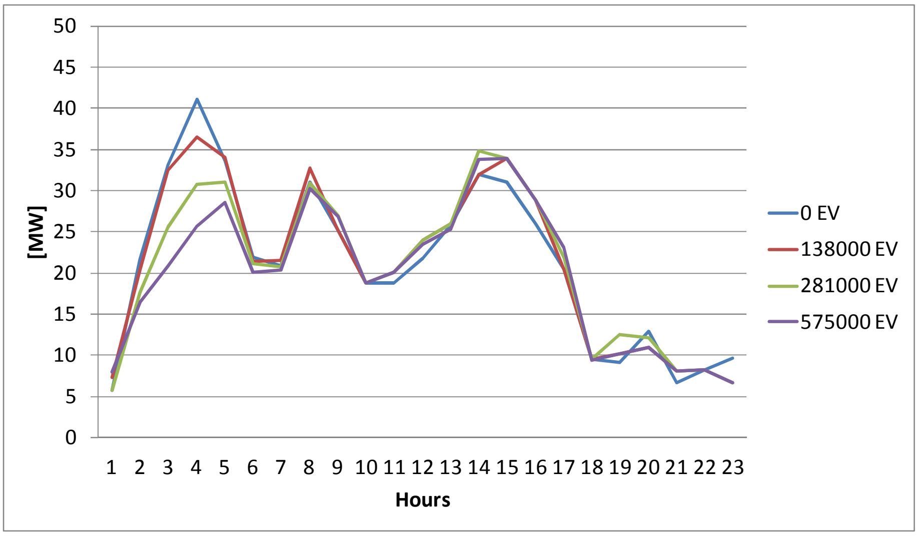

Figure 6.6 Average wind spillage profile for weekdays for different EV penetration scenarios for mainland Spain 2020 (smart charging scenario)

✓ Annual productions by technologies

The charging of EVs is mainly absorbed by CCGTs as can be seen in Figure 6.7~~Figure 6.7~~. To a lower extent hydro production and electricity from coal is increasing too. Higher hydro production is mainly due to the fact that with an increasing EV fleet less hydro energy has to be spilled.

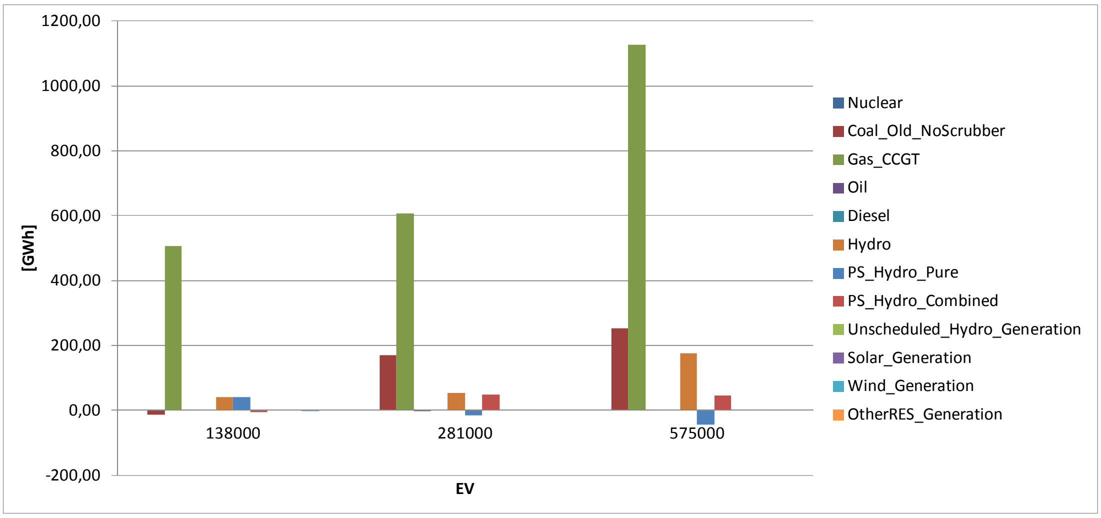

Figure 6.7 Difference of production by technologies wrt 0 EV scenario mainland Spain 2020 (smart charging scenario)

6.1.3 Changing the charging behaviour of EVs

Three different scenarios for the charging behaviour have been considered. In all the three the charging profile is predefined. See Section 6.1.1 for the description of these different charging scenarios. It has to be reminded that the results presented take into account only weekdays, without considering weekends.

✓ Annual specific cost

Section 6.1.2 shows that the increase of EVs produces an increment in the specific cost of the system, and Figure 6.8~~Figure 6.8~~ shows that this increase happens independently of the charging strategy adopted.

The multi-tariff profile is the one with better specific costs for all the EV penetration scenarios. In the 138000 EVs scenario, the smart profile is a little bit costly than the dumb profile but, when the number of EVs increases, the dumb profile has higher costs than the smart one.

The different charging profiles are based on different charging hours, as can be seen in Figure 6.2~~Figure 6.2~~. The smart charging strategy implies charging during valley hours, the dumb strategy would mean charging during peak hours, and for the multi-tariff strategy the charging is performed during both peak and valley hours. For this reason, the generation technologies used for each charging profile will differ, which results in different generation costs. It is important to remember that the optimal unit commitment obtained by the ROM model minimizes the total cost (including fuel variable cost and CO_2 emission cost). A more detailed analysis of the generation technologies used for the profiles is in the annual CO_2 emissions section.

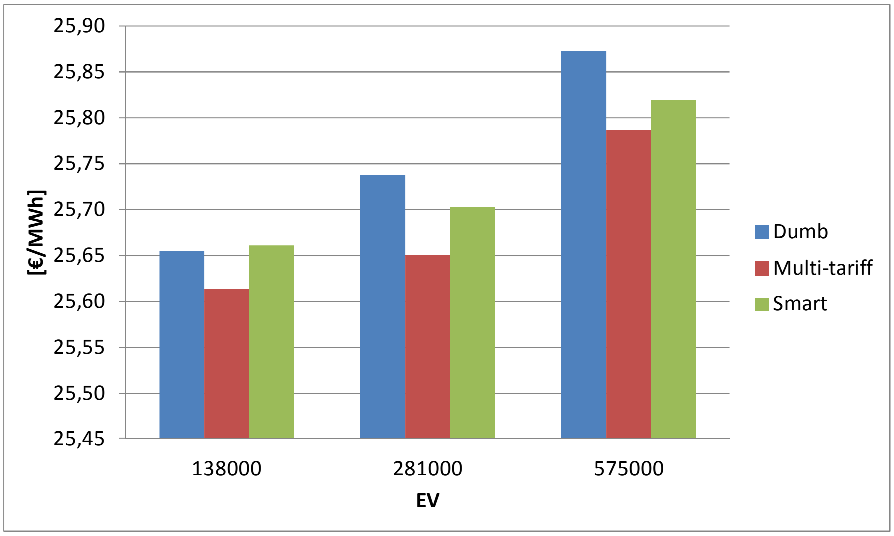

Figure 6.8 Annual specific cost for different charging scenarios for mainland Spain 2020

In the last case, the difference between the multi-tariff and the smart strategy is about 0.1%. This small difference exists as a result of the multi-tariff strategy having, due to the random nature of maintenance and outages, more hydro production than in the smart strategy. However, this difference is not related to the different charging strategies adopted by the EVs.

✓ Annual CO_2 emissions

Section 6.1.2 shows that the deployment of a higher amount of EVs into the system would increase the CO_2 emissions. The growth in the demand, as seen in Figure 6.7~~Figure 6.7~~ is mainly supplied by CCGT units. Figure 6.9~~Figure 6.9~~ presents the behaviour of CO_2 emissions when comparing different charging strategies for the EVs. It is interesting to see that the multi-tariff strategy has the best CO_2 emissions.

This situation occurs because in this case, the demand is supplied with lower volumes of production with coal and CCGT units, as can be seen in Figure 6.10~~Figure 6.10~~, Figure 6.11, Figure 6.12 and Figure 6.13, and higher volumes of wind and hydro production.

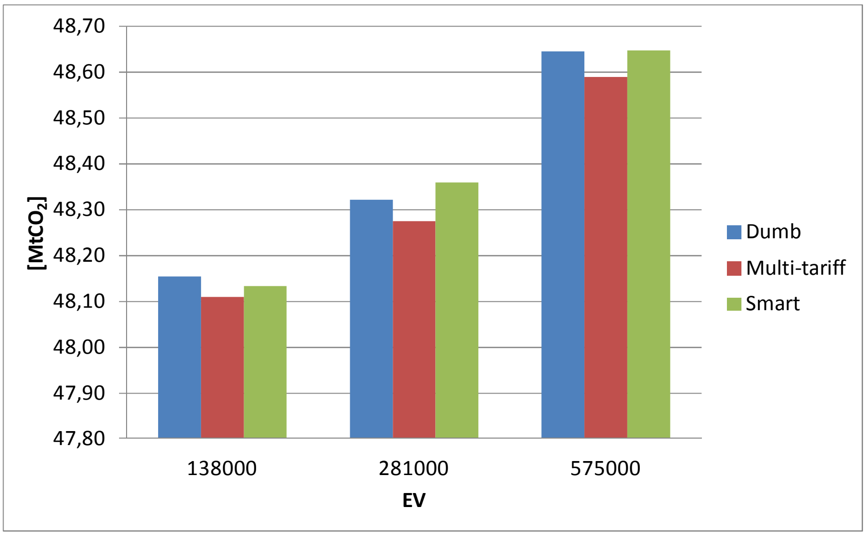

Figure 6.9 CO_2 emissions for different EV penetration levels and charging strategies for mainland Spain 2020.

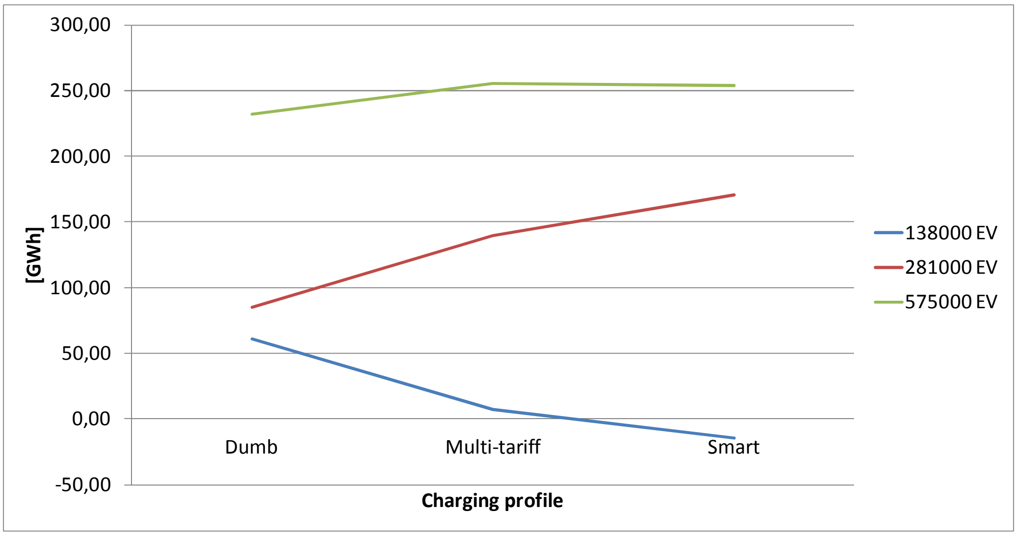

Figure 6.10 Differences of coal production compared with the 0 EV scenario for mainland Spain 2020.

The differences in coal and CCGT production with the different charging profiles for the three EV penetration levels are displayed in Figure 6.11, Figure 6.12 and Figure 6.13. In these figures it can be noticed that, except for the scenario with less EVs, the multi-tariff profile has always the lowest production with both technologies, having then lower CO_2 emissions.

In the 138000 EVs scenario, despite the multi-tariff profile has a higher production of coal units than the smart profile, the CCGT production is much lower.

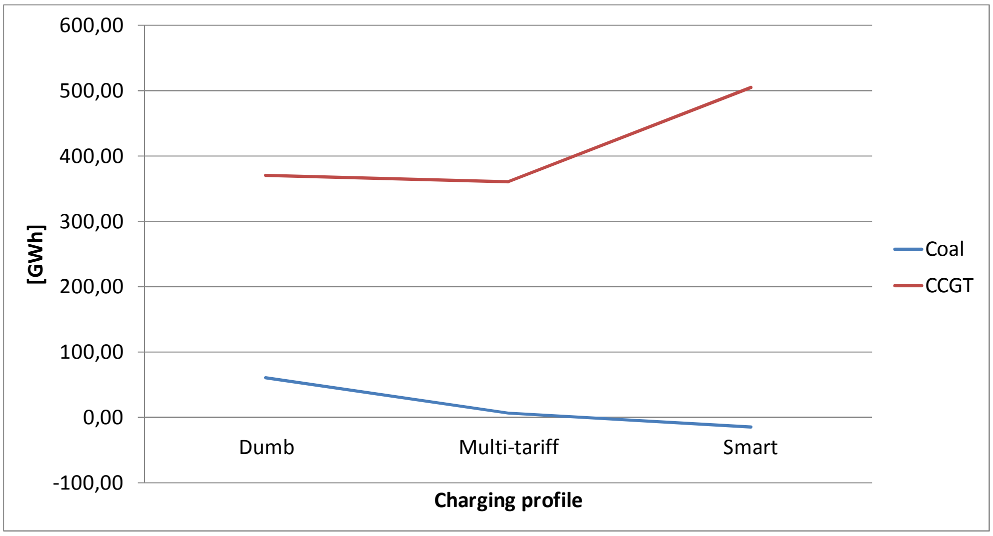

Figure 6.11 Differences of coal and CCGT production between the 138000 EVs and 0 EVs scenarios for mainland Spain 2020

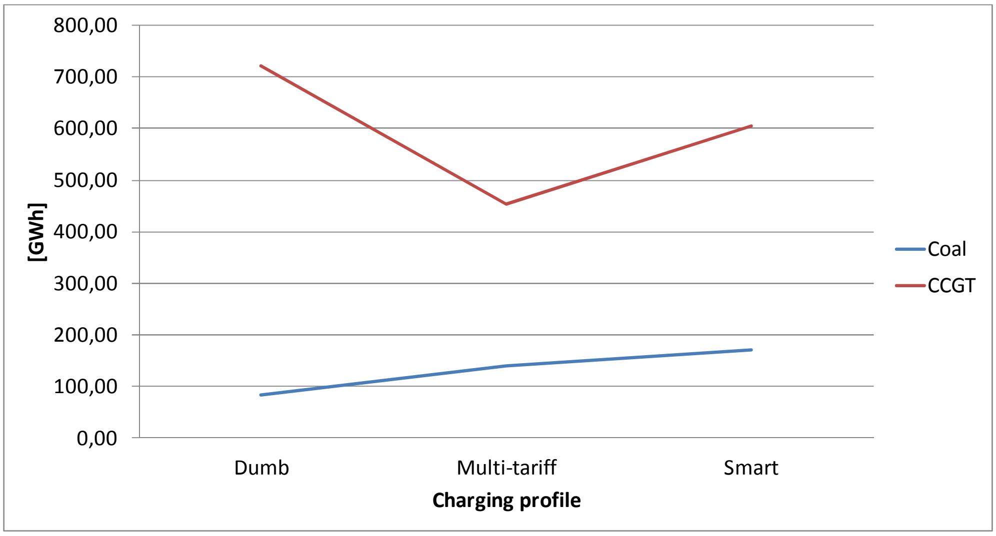

Figure 6.12 Differences of coal and CCGT production between the 281000 EVs and 0 EVs scenarios for mainland Spain 2020

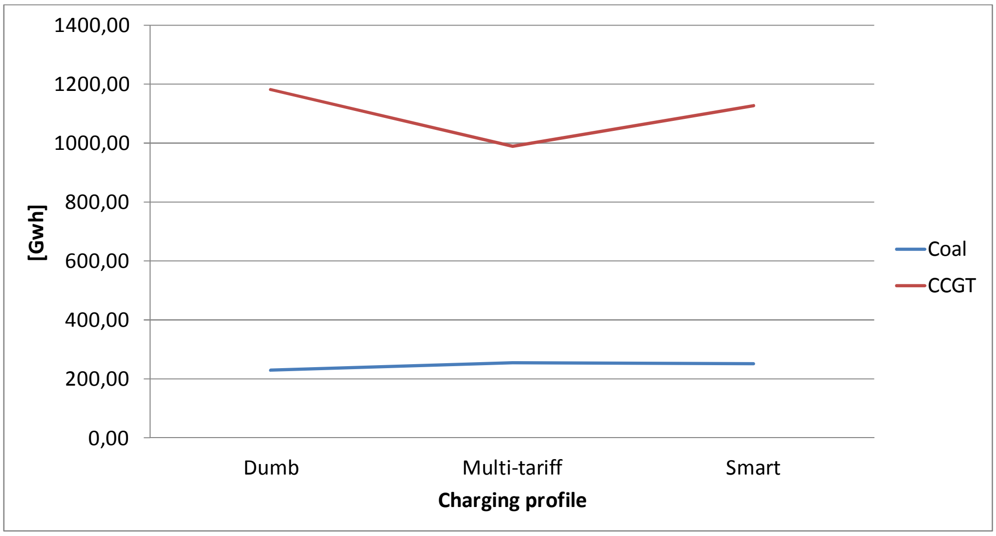

Figure 6.13 Differences of coal and CCGT production between the 575000 EVs and 0 EVs scenarios for mainland Spain 2020

As said in the specific cost analysis, the production of hydro plants is higher in the multi-tariff profile than in the smart profile (due to the random nature of maintenance and outages), resulting in about 0.1% difference in CO_2 emissions. Nonetheless, this difference, which is not a consequence of the different charging profiles used, is irrelevant taking the whole results into account.

✓ **Daily wind spillage profile**

Section 6.1.2 shows that spillage reduction of wind generation increases when the number of EVs in the system does, except for the scenario with less EVs. This section studies this variation using different charging profiles. This analysis is carried out for the different EV penetration levels independently.

Figure 6.14~~Figure 6.14~~ displays the average wind spillage profile for weekdays in the scenario with less EV fleets. With 138000 EVs in the system it can be observed that the reduction in the wind spillage is produced mostly during the night and the first hours at morning. It is interesting that the multi-tariff profile has less wind spillage reduction, particularly in the night hours that the dumb profile.

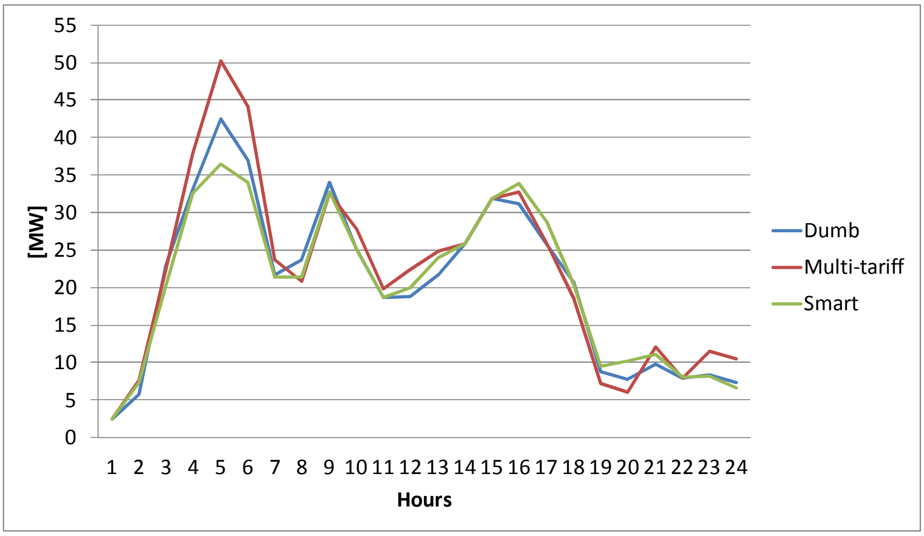

Figure 6.14 Average wind spillage profile for weekdays for different charging scenarios for 138000 EVs mainland Spain 2020

In Figure 6.15~~Figure 6.15~~ the average wind spillage profile for weekdays in the scenario of 281000 EVs in the system is presented. In this scenario, the wind spillage reduction is also produced during the night and the first hours of the morning for the multi-tariff and, especially, the smart charging profile. The dumb profile, however, increases the wind spillage during the night hours. There is also a little reduction in the wind spillage around the hour 11 with the multi-tariff and smart profiles. This figure shows that, with this EV penetration, the multi-tariff and smart profile have a much better behaviour than the dumb profile. It is also interesting to see that, with this EV fleet, the wind spillage peak for the smart profile has changed from the night hours to afternoon (around hours 15-16).

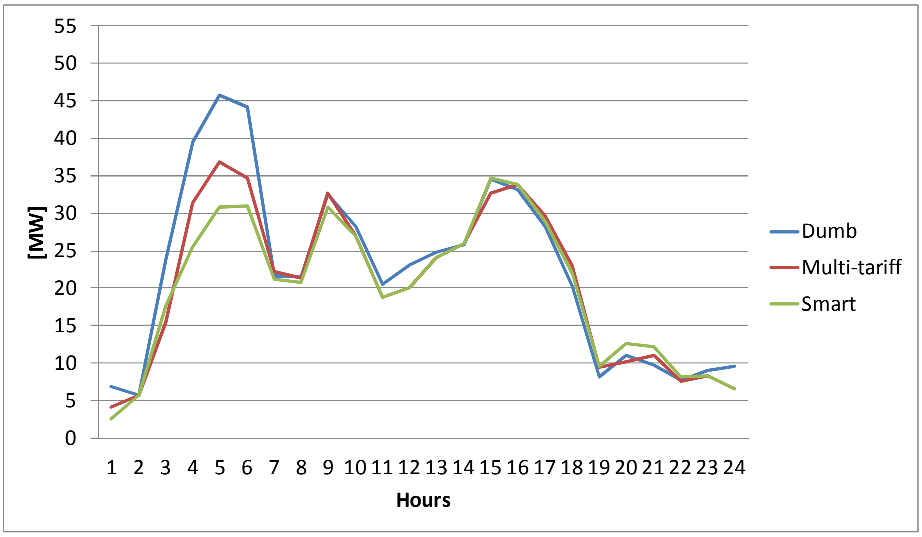

Figure 6.15 Average wind spillage profile for weekdays for different charging scenarios for 281000 EVs mainland Spain 2020

Figure 6.16~~Figure 6.16~~ shows the average wind spillage profile for weekdays in the 575000 EVs scenario. In this situation, the wind spillage decrease is, as in the other scenarios, produced mostly during the night and at first hours of the morning for the multi-tariff and, specially, the smart charging profiles. The dumb profile increases again the wind spillage during these hours.

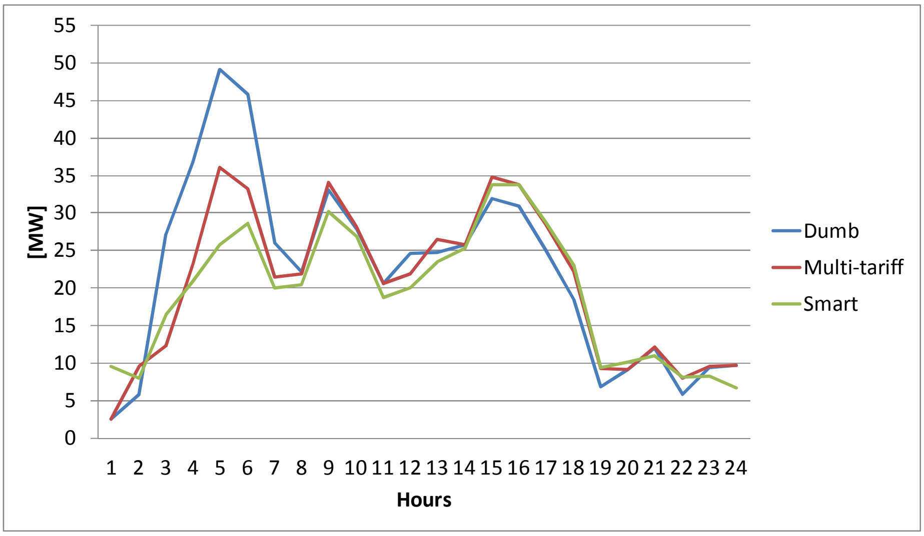

Figure 6.16 Average wind spillage profile for weekdays for different charging scenarios for 575000 EVs mainland Spain 2020

6.2 Portugal

6.2.1 Input Data

The input data for the model, including thermal and hydro generation data, demand and renewable energy sources (wind, solar, biomass and cogeneration) profiles and electric vehicles data are summarized in Table 6.6~~Table 6.6~~. The installed capacities data were obtained from [9].

Table 6.4. Input data for Portugal 2020.

2020 case study		
Energy	[TWh]	63
Winter Peak	[MW]	11900
Summer Peak	[MW]	9500
Min Load	[MW]	5837
Peak/OffPeak Ratio	[p.u.]	2.0
Max Upward Reserve	[MW]	992
Max Downward Reserve	[MW]	238
Nuclear	[MW]	0
Coal	[MW]	1756
CCGT	[MW]	5489
Gas/Fuel	[MW]	0
Max Hydro Output	[MW]	5734

Pure Pumped Storage Hydro	[MW]	3936
Combined Pumped Storage Hydro	[MW]	0
Wind Generation	[MW]	3854
Solar PV	[MW]	1500
CSP	[MW]	0
Cogeneration	[MW]	2250
Biomass	[MW]	250
Small Hydro	[MW]	0
Natural Hydro Inflows	[TWh]	14
Coal Price	[$/short tons]	125
Natural Gas Price	[$/MMBTU]	11
CO2 Price	[€/t CO2]	15
# of Electric Vehicles	[units]	0-100000

[*] Pure Pumped Storage Hydro plants may also serve as hydro generation plants and then, the total Max Hydro Output would be 9670 MW.

✓ Generation data

Data about thermal generators have been obtained from [10] and have been adapted by comparison with the thermal units of the mainland Spanish system for 2020. The maximum power output was obtained from [9] and the minimum power output, ramp rates, costs (variable, fixed and start-up costs), fuel consumption, specific emissions and start-up consumption were adapted by comparison with the characteristics of thermal units for mainland Spain 2020 (Table 6.3) considering the type of technology of each unit and using power output as the scaling variable.

Data about hydro plants have been obtained from [9] and have been extrapolated using the operation data of Portugal in year 2010 as a reference. REN provided the maximum output data of the units, as well as the information on pumping capability of each unit, i.e., whether they are able to pump or not and to which extent. The efficiency of the pumping units was assumed to be 70%. The maximum reserve was re-scaled by comparison with the hydro units of the Spanish system for 2020. Hydro inflows for the year were assumed to be proportional to the hydro production of an average year [10] using Portugal 2010 installed capacities as reference. The Spanish daily inflow series (that can be considered similar) were used as the reference to allocate the hydro inflows to each month.

Wind generation installed capacities were provided in [9] and wind generation profiles were assumed proportional to the Spanish profiles. The wind generation forecast error was supposed to be equal, in percentage, to the error occurred in mainland Spain for the year 2009 (e-sios, http://www.esios.ree.es/web-publica/).

Solar, cogeneration and biomass installed capacities were provided in [9]. Their generation profiles were assumed to be equal to the mainland Spanish 2009 profile (REE and e-sios) and were scaled down using the installed capacity provided by REN [9].

Total installed generation capacities can be found in Table 6.4, and the share of the installed capacities by technologies is displayed in Figure 6.17.

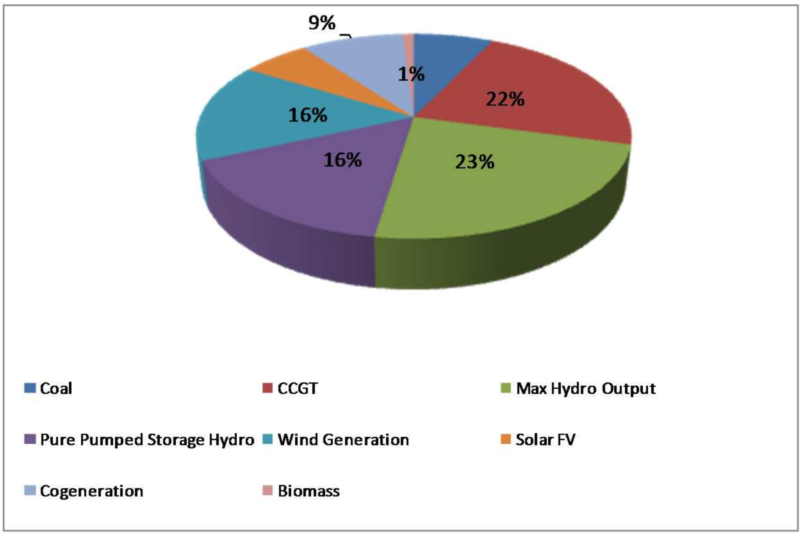

Figure 6.17. Share of installed capacities for Portugal 2020

✓ Operation reserve data

The operation reserve data were obtained in the same manner as for the Spanish system as it is stated in (1) and (2), where *α* is the factor to account for wind forecast error, *β* is the factor to account for demand forecast error and *γ* is the largest generation unit.

$$Res_{UP} = \alpha \cdot WG + \beta \cdot Dem + \gamma \qquad \textbf{(3)}$$

$$Res_{DOWN} = \beta \cdot Dem \qquad \textbf{(4)}$$

✓ Demand data

The total electricity forecasted consumption for 2020 is 63 TWh [9], with peak demands for winter and summer of 11.9 GW and 9.5 GW, respectively. Demand profiles were re-scaled using the mainland Spanish system for 2009 as reference.

✓ Electric vehicles

Three different charging profiles for the Spanish case were provided by REE, depending on their benefits for system operation. These profiles were re-scaled for the Portugal system and can be seen in Figure 6.18:

- Dumb profile: it is the plug and charge connection of EVs into the grid, without taking into account the system situation.
- Multi-tariff profile: EV charging depends on different tariffs in order to promote energy demand in off-peak hours.
- Smart profile: there are a lot of possible smart charging profiles, depending on the objective pursued. In this case, the smart profile allocates the EV charge demand in order to fill the off-peak hours of system demand.

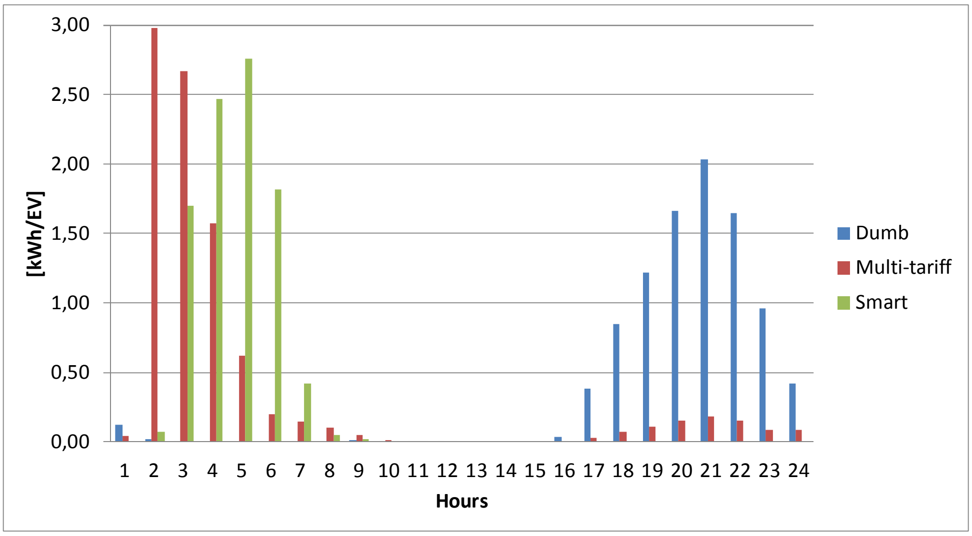

Figure 6.18. Charging profiles considered

Assuming a mix of EVs with an average energy specific consumption of 0.14 kWh/km, a battery capacity of 28 kWh and 95 % efficiencies in grid-to-battery and battery-to-grid processes, the approximately average distance travelled by a car is 63 km/day.

6.2.2 Different EV penetration scenarios

For the year 2020 four different EV penetration levels have been considered [1]: a base case which does not have EVs, and then, scenarios with 24000, 50000 and 100000 EVs, which represent 0.5%, 0.9% and 1.8% of the total fleet of vehicles, respectively.

The analysis carried out in this section compares the results of the different penetration levels using the smart charging profile, when it is possible. All the results presented take into account only weekdays, because the EVs charging profiles provided were adjusted only for these days. For this reason, taking into account also weekends would produce questionable results.

✓ Annual wind spillage

The annual wind spillage for the different scenarios is shown in Figure 6.19. These results take into account the daily operation planning (unit commitment) including the optimal dispatch of all the units and the uncertainties such as the failure of thermal units or the demand and wind forecast errors in real-time.

Figure 6.19 shows how the introduction of a higher quantity of EVs helps to integrate the wind, resulting in lower spillages. The 24000, 50000 and 100000 EVs scenarios have 10.4%, 19.1% and 20.0% reduction of wind spillage, respectively.

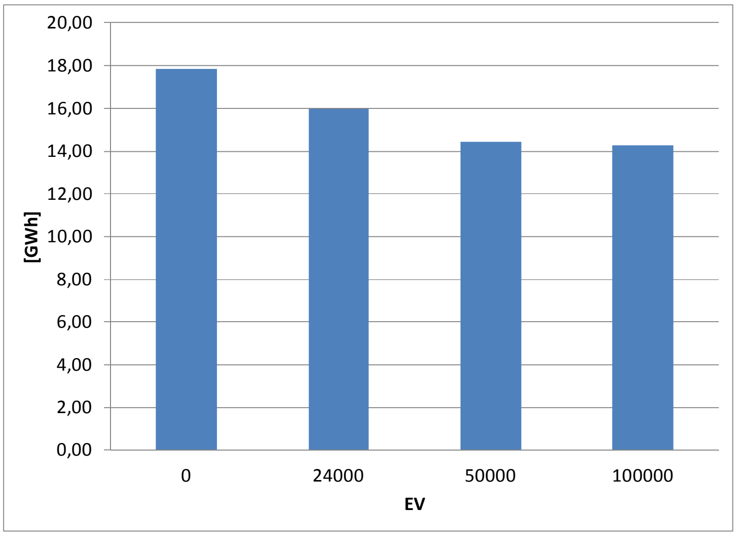

Figure 6.19. Annual wind spillage for different EV penetration scenarios for Portugal 2020 (smart charging scenario)

✓ Annual specific cost

The specific cost (€ per MWh of demand) variation for the different EV penetration scenarios is shown in Figure 6.20. The additional energy consumption that is required to charge the EVs produces a rise in the specific cost of the system of 0.1%, 0.2% and 0.6% for the different EV penetration levels (24000, 50000 and 10000 EVs).

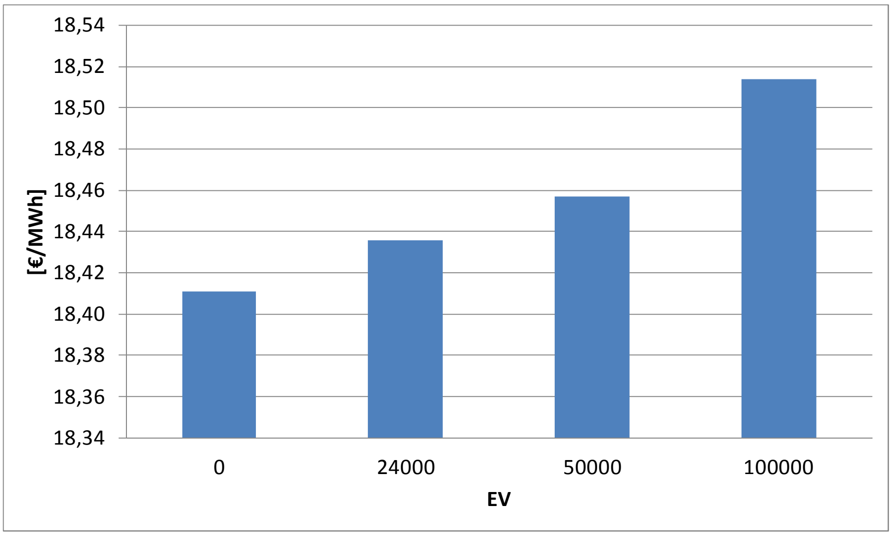

Figure 6.20. Specific cost for different EV penetration scenarios for Portugal 2020 (smart charging scenario)

✓ Annual CO_2 emissions

The annual CO_2 emissions for Portugal during the year 2020 considering different EV penetration levels, and with the smart charging profile, are displayed in Figure 6.21. This figure shows that the introduction of EVs into the system produces an increase in the CO_2 emissions (0.3%, 0.4% and 0.7% of increase in comparison with the 0 EV situation for the scenarios with 24000, 50000 and 100000 EVs). This increase in the emissions occurs because the introduction of a higher quantity of EVs produces an increase in the demand and then, more energy production is required.

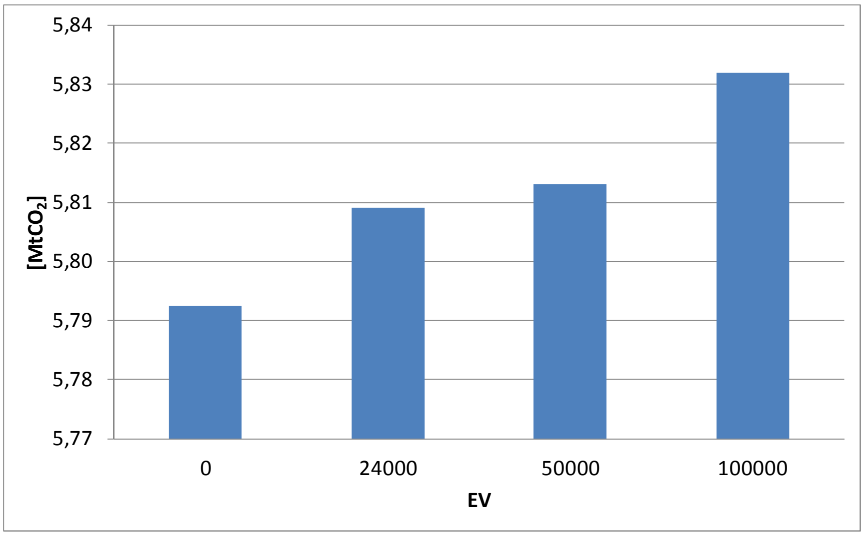

Figure 6.21. CO_2 emissions for different EV penetration scenarios for the year 2020 in Portugal (smart charging scenario)

It is interesting to remark that introducing EVs into the system results in a further decrease in the CO_2 emissions, because these vehicles have no CO_2 emissions and substitute other vehicles that would emit CO_2 while running. Table 6.5 presents the comparison of emissions that would be produced if instead of EVs there were more internal combustion vehicles, and the equivalent CO_2 emissions for the EVs. The EVs data presented in section 6.2.1, and the limit fixed by the European Union for fleet average CO_2 emissions, which is 130 gCO_2/km, are used to calculate these values.

Table 6.5. Increase in CO_2 emissions with internal combustion vehicles

Number of EVs introduced	Increase in CO_2 emissions	Equivalent EV CO_2 emissions (gCO_2/km)
24000	67%	43
50000	81%	25
100000	81%	24

✓ **Daily wind spillage profile**

The daily wind spillage profile for weekdays is displayed in Figure 6.22. As displayed in this figure, for the initial case (0 EVs in the system), almost all the wind spillage is produced over the night hours (from hour 23 up to hour 10).

Figure 6.22 explains how the wind spillage reduction is produced over the day. It shows that the introduction of EVs into the system produces a wind spillage reduction during night hours (which are the problematic ones), reducing the wind spillage peak. Moreover, the introduction of the EVs does not produce any increment of the wind spillage during the remaining hours of the day. This situation explains the annual total results that have been displayed in Figure 6.19.

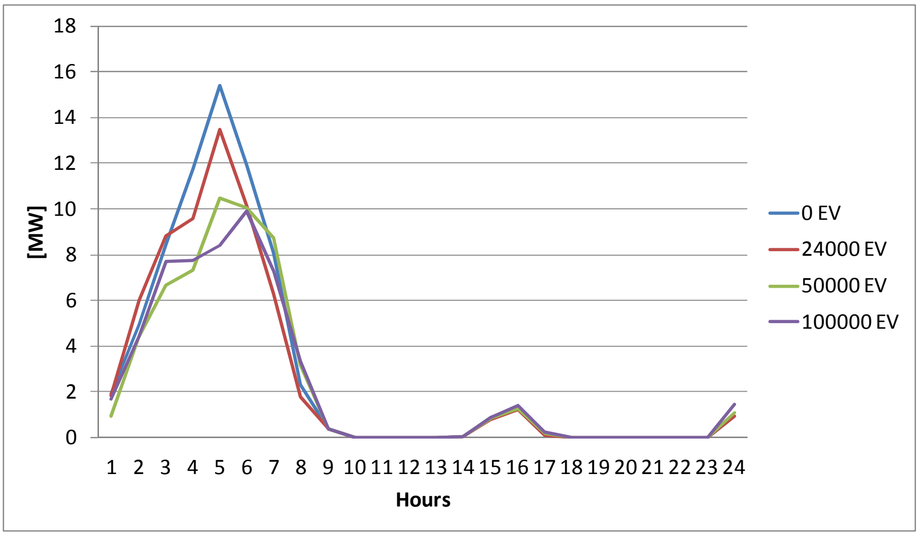

Figure 6.22. Average wind spillage profile for weekdays for different EV penetration scenarios for Portugal 2020 (smart charging scenario)

✓ Annual productions by technologies

The increment of the demand produced by the introduction of EVs into the system is mainly absorbed by CCGTs as can be seen in Figure 6.23. Coal units also have a raise in their production, although this increase is not constant. Furthermore, wind generation produced more as a result of having less wind spillage. It is interesting to see that the hydro production, in contrast with other sources, has a small decrease in its generation done during the year by keeping some water in the reservoirs.

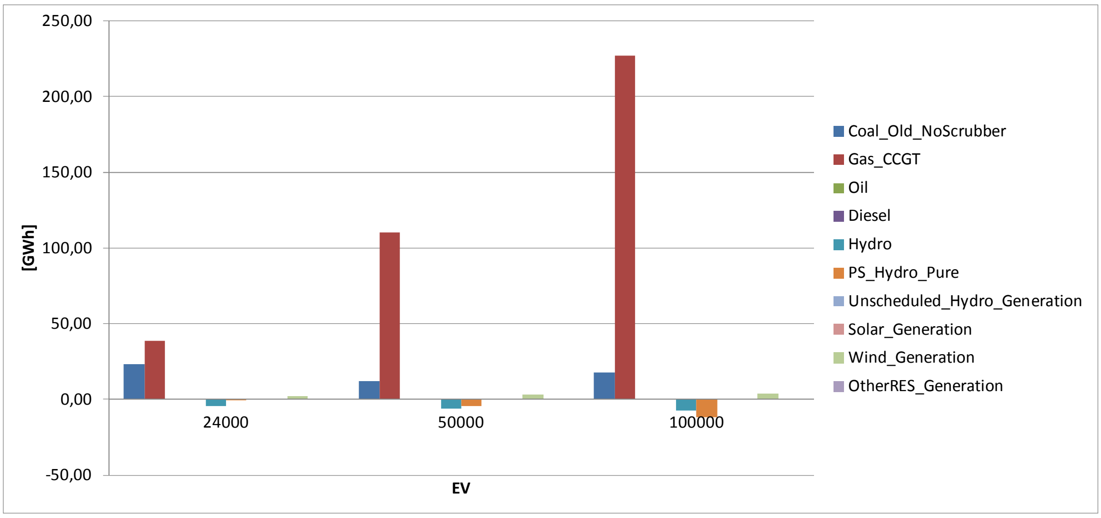

Figure 6.23. Difference to production by technologies in 0 EV scenario for Portugal 2020 (smart charging scenario)

6.2.3 Changing the charging behaviour of electric vehicles

Three different scenarios for the charging behaviour have been considered. In all the three the charging profile is predefined. See Section 6.2.1 for the description of these different charging scenarios. It has to be reminded that the results presented take into account only weekdays, without considering weekends.

✓ Annual specific cost

Section 6.2.2 shows that the increase of EVs produces an increment in the specific cost of the system, and Figure 6.24 shows that this increase happens independently of the charging strategy adopted.

Although the increase is different depending on the charging profile adopted, the results do not show a great difference between the different strategies. Nevertheless, the results also show that as the number of EVs in the system increases, the difference in the specific cost between the strategies is bigger. The specific cost when there are 24000 EVs in the system is almost equal for the three charging strategies (about 0.1% difference with respect to the 0 EV case). When the system has 50000 EVs, the increase is about 0.3% for the dumb and multi-tariff strategies and 0.2% for the smart strategy with respect to the 0 EV case. Finally, when 100000 EVs are introduced in the system, the differences are higher, with increases of 0.7%, 0.6% and 0.5% with respect to the 0 EV case for the dumb, multi-tariff and smart strategy, respectively.

The different charging profiles are based on different charging hours, as can be seen in Figure 6.18. The smart charging strategy implies charging during valley hours, the dumb strategy would mean charging during peak hours, and for the multi-tariff strategy the charging is performed during both peak and valley hours. For this reason, the generation technologies used for each charging profile will differ, which results in different generation costs. A more detailed analysis of the generation technologies used for the profiles is in the annual CO_2 emissions section.

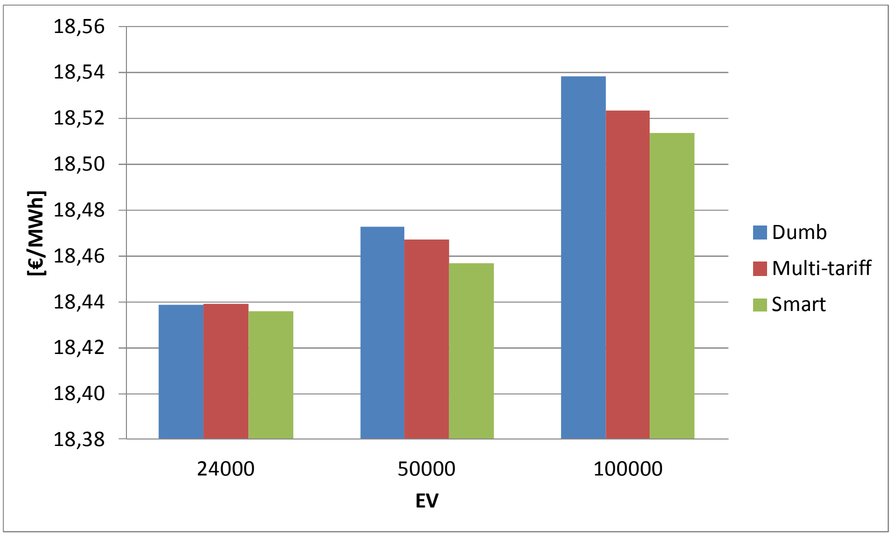

Figure 6.24. Annual specific cost for different charging scenarios for Portugal 2020

✓ Annual CO_2 emissions

In Section 6.3.2 it has been seen that the deployment of a higher amount of EVs into the system will increase the CO_2 emissions in a slightly manner. Figure 6.25 presents the behaviour of CO_2 emissions when comparing different charging strategies for the EVs.

It is interesting to notice that the behaviour of the dumb and multi-tariff profiles is not constant. For the lowest EV penetration level, the dumb and multi-tariff profiles have nearly the same emissions, while the smart profile having the highest level (the increase in emissions compared with the 0 EVs case is 0.3% for the smart and 0.1% for the remaining two). For the case of 50000 EVs in the system, the increases are 0.4% for the smart and dumb charging and 0.3% for the multi-tariff profile. Finally, with 100000 EVs in the system, the increases are 0.5%, 0.6% and 0.7% for the dumb, multi-tariff and smart profiles, respectively.

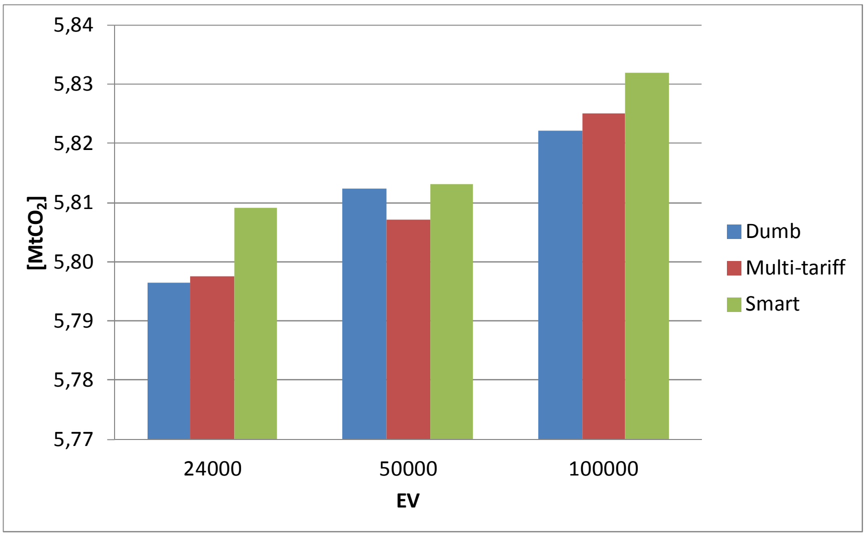

Figure 6.25. CO_2 emissions for different EV penetrations levels and charging strategies for Portugal 2020

As it has been seen in Figure 6.23, the growth in the demand is mainly covered by coal and CCGT units. Therefore, the differences in the CO_2 emission behaviours are related with their production, taking into account that CO_2 emissions are higher for the coal units than CCGT units. Figure 6.26, Figure 6.27 and Figure 6.28 display the production of the coal and CCGT units for the different EV penetration levels and charging strategies. It is interesting to notice that the smart profile is the one which has a bigger increase of generation with coal units (and therefore lowest increase of generation with CCGTs) for all the EV penetration scenarios, explaining why the smart profile is the one with higher CO_2 emissions. The dumb and multi-tariff profiles have almost the same behaviour with both types of units for the scenarios with 24000 and 100000 EVs (the multi-tariff has a little more production in both cases, having then more emissions too). For the case with 50000 EVs, the multi-tariff profile reduces the production with coal units and produces more with the CCGTs, resulting in fewer emissions than the dumb profile.

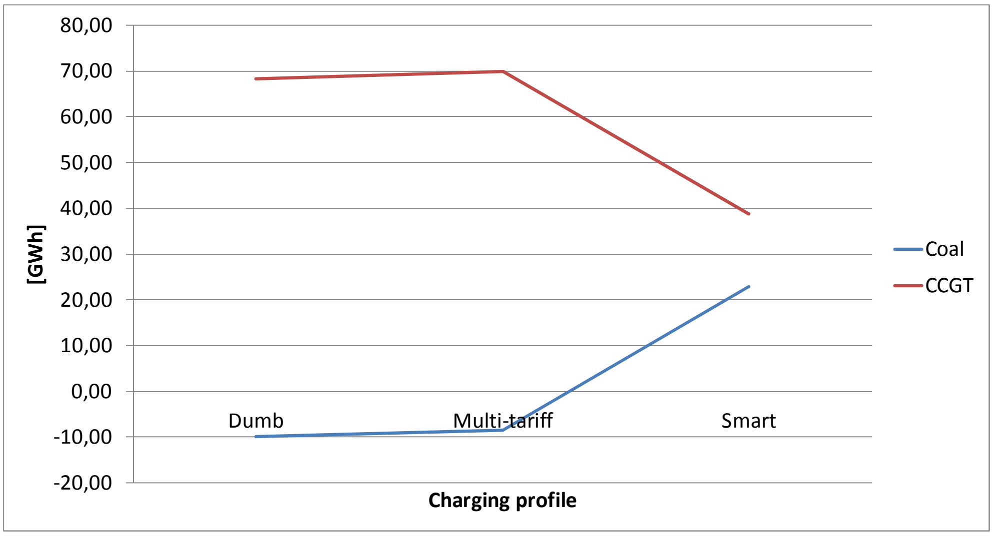

Figure 6.26. Differences of coal and CCGT production between the 24000 EVs and 0 EVs scenarios for Portugal 2020

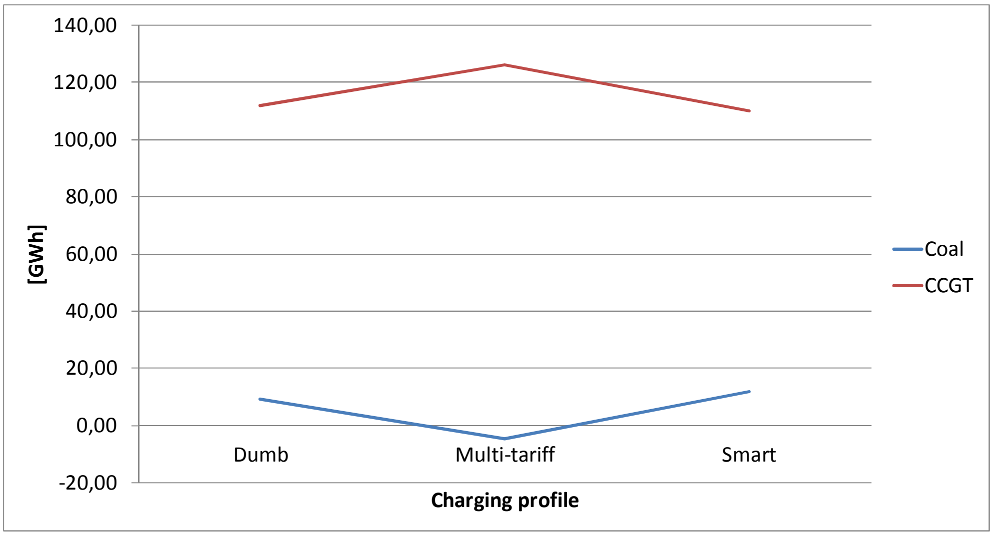

Figure 6.27. Differences of coal and CCGT production between the 50000 EVs and 0 EVs scenarios for Portugal 2020

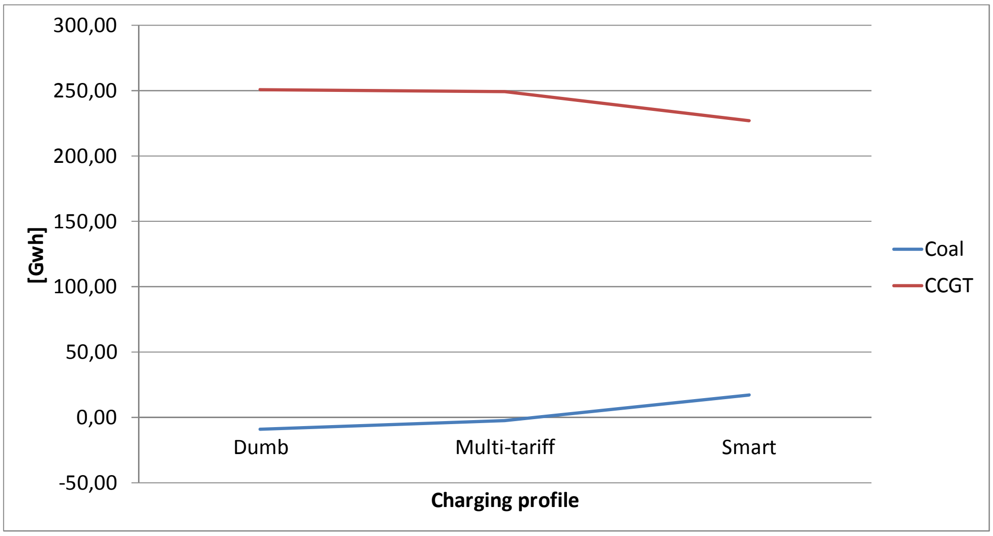

Figure 6.28. Differences of coal and CCGT production between the 100000 EVs and 0 EVs scenarios for Portugal 2020

The “smarter” strategies, e.g. multi-tariff and smart strategies, involve charging EVs mainly at night and during the first hours of the morning, while the dumb strategy tends to charge the EVs over the evening, as displayed in Figure 6.18. The energy production over night hours is essentially provided by coal and CCGT units in a ratio of 40-60% approximately. When the electricity demanded by the EVs is only during the night (these are the hours with less demand), the system produces with coal units rather than CCGTs (smart profile situation). When the system has electricity demanded by the EVs also during the first hours of the morning (when currently exists one peak of demand), the system produces with CCGTs rather than with coal units (multi-tariff situation). The same situation occurs when the electricity demanded by the charge of the EVs is at evening hours (dumb situation).

✓ Daily wind spillage profile

Section 6.2.2 shows that spillage reduction of wind generation increases when the number of EVs in the system does. This section studies this variation using different charging profiles. The analysis is carried out for the different EV penetration levels independently.

Figure 6.29 displays the average wind spillage profile for weekdays in the scenario with less EVs. With 24000 EVs in the system the reduction in the wind spillage is produced during the night and the first hours in the morning. It is interesting that the multi-tariff profile has better results than the smart profile, because the multi-tariff profile produce more with CCGTs (and less with coal), which are more flexible units and, therefore more adequate to accommodate wind generation. Another interesting point is that there is no increase of wind spillage at any other hour of the day.

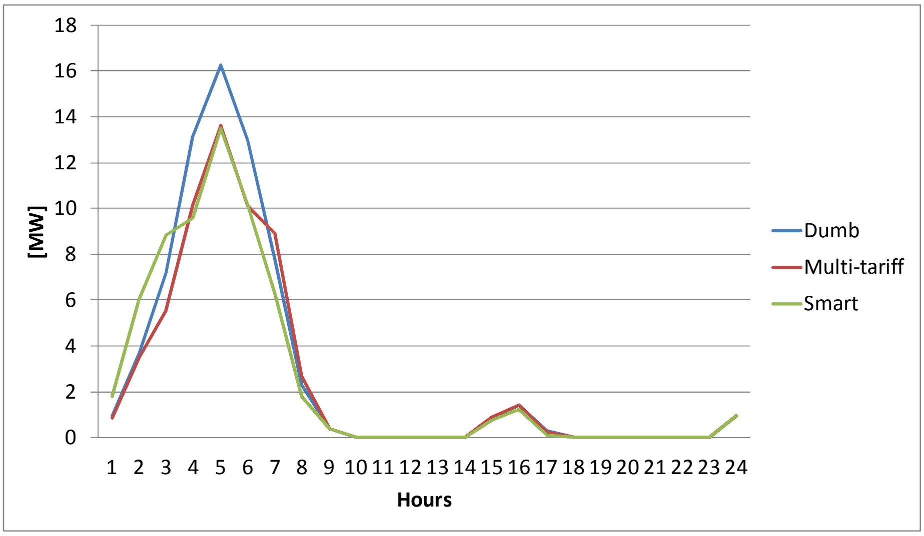

Figure 6.29. Average wind spillage profile for weekdays for different charging scenarios with 24000 EVs in Portugal 2020

Figure 6.30 presents the average wind spillage profile for weekdays in the scenario of 50000 EVs in the system. For the second time, the wind spillage is reduced during the night, and no increase is produced at any other hour. In this situation, the smart profile has the best results and it is interesting that the multi-tariff profile has a similar peak spillage than the dumb profile.

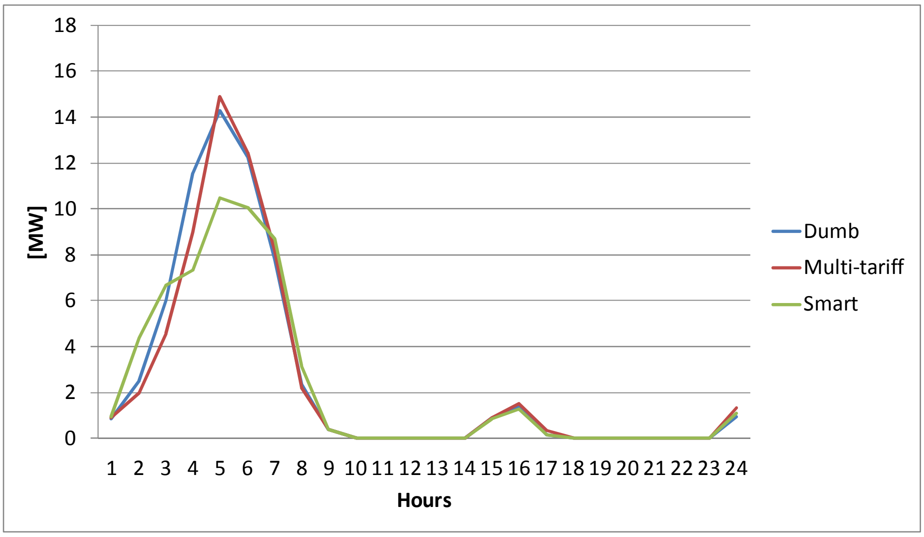

Figure 6.30. Average wind spillage profile for weekdays for different charging scenarios with 50000 EVs in Portugal 2020

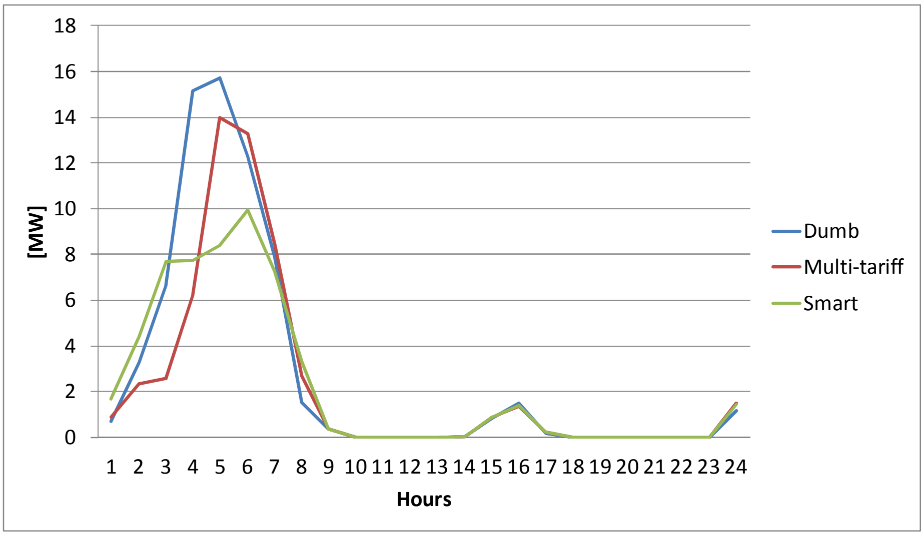

Figure 6.31. Average wind spillage profile for weekdays for different charging scenarios with 100000 EVs in Portugal 2020

Figure 6.31 shows the average wind spillage profile for weekdays in the 100000 EVs scenario. In this situation, the wind spillage decrease is, as in the other scenarios, produced during the night.

6.3 Greece

6.3.1 Input Data

The input data for the model, including thermal and hydro generation data, demand and renewable energy sources (wind, solar, biomass and cogeneration) profiles and EV data are summarized in Table 6.6~~Table 6.6~~. These data do not include the Crete island.

Table 6.6. Input data for Greece 2020.

2020 case study		
Energy	[TWh]	61
Summer Peak	[MW]	11449
Min Load	[MW]	3762
Peak/OffPeak Ratio	[p.u.]	3.0
Max Upward Reserve	[MW]	1359
Max Downward Reserve	[MW]	229
Coal	[MW]	3764
CCGT	[MW]	4374
Gas/Oil	[MW]	264
Max Hydro Output	[MW]	2327
Combined Pumped Storage Hydro*	[MW]	699

Wind Generation	[MW]	7900
Solar PV	[MW]	2250
CSP	[MW]	185
Cogeneration	[MW]	56
Biomass	[MW]	282
Small Hydro	[MW]	253
Natural Hydro Inflows	[TWh]	5
Coal Price	[$/short tons]	125
Natural Gas Price	[$/MMBTU]	11
CO2 Price	[€/t CO2]	15
# of Electric Vehicles	[units]	0-140000

[*] Combined Pumped Storage Hydro units may also serve as hydro output units and then, the total Max Hydro Output would be 3026 MW.

✓ Generation data

Data about thermal generators have been provided by NTUA and have been translated by comparison with the thermal units of the mainland Spanish system for 2020. The maximum power output, EFOR, SOR and maintenance duration and schedule were provided by NTUA. The minimum power output, ramp rates, costs (variable, fixed and start-up costs), fuel consumption, specific emissions and start-up consumption were translated by comparison with the characteristics of thermal units for mainland Spain 2020 (Table 6.7) considering the type of technology of each unit and using power output as the scaling variable.

Data about hydro generators has been provided by NTUA and have been extrapolated using the year 2009 of Greece as a reference. NTUA provided the maximum output data of the units, as well as the information on pumping capability of each unit, i.e., whether they are able to pump or not and to which extent. The efficiency of the pumping units was assumed to be 70%. The maximum reserve was re-scaled by comparison with the hydro units of the Spanish system for 2020. Hydro inflows for each month were assumed to be equal to the respective monthly production of the reference year (HTSO Monthly Balance Reports 2009). The monthly inflows were shared equally between the days of each month.

Wind generation profiles and installed capacities were provided by the same source. The wind generation forecast error was supposed to be equal, in percentage, to the error occurred in Spain for the year 2009 (e-sios, http://www.esios.ree.es/web-publica/).

Photovoltaic and small hydro production profiles and installed capacity were provided by NTUA. Biomass, cogeneration and CSP generation profiles were assumed to be equal to the Spanish 2009 profile (REE and e-sios) and were scaled using the installed capacity provided by NTUA.

Total installed generation capacities can be found in Table 6.6~~Table 6.6~~, and the share of the installed capacities by technologies is displayed in Figure 6.32~~Figure 6.32~~.

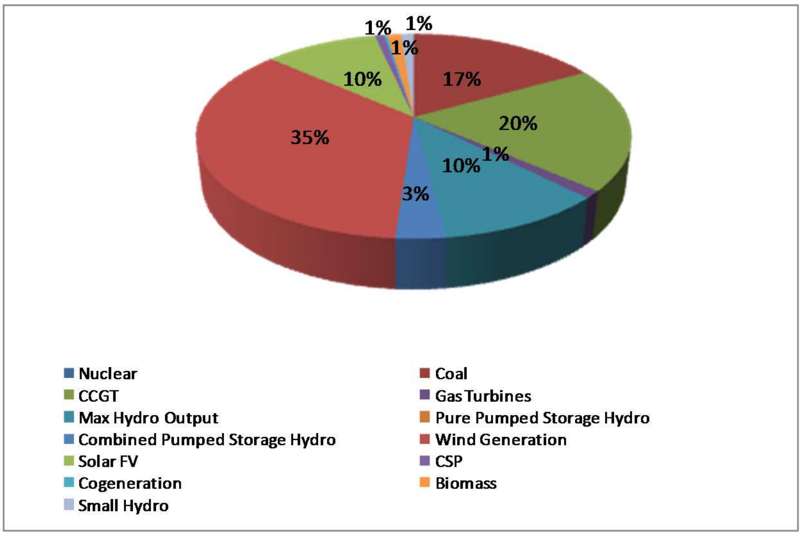

Figure 6.32. Share of installed capacities for Greece 2020.

✓ Operation reserve data

The operation reserve data were obtained in the same manner as for the Spanish system as it is stated in (1) and (2), where *α* is the factor to account for wind forecast error, *β* is the factor to account for demand forecast error and *γ* is the largest generation unit.

$$Res_{UP} = \alpha \cdot WG + \beta \cdot Dem + \gamma \qquad \textbf{(5)}$$

$$Res_{DOWN} = \beta \cdot Dem \qquad \textbf{(6)}$$

✓ Demand data

Demand profiles for the year 2020 were provided by NTUA, as well as the interconnection profiles for 2009. The net demand was obtained by adding the demand with the net exports and imports (export – import).

Total electricity for 2020 is of 61 TWh, with a peak demand of 11 GW.

✓ Electric Vehicles

Three different charging profiles for the Spanish case were provided by REE, depending on their benefits for system operation. These profiles were re-scaled for the Greece system and can be seen in Figure 6.33~~Figure 6.33~~:

- Dumb profile: it is the plug and charge connection of EVs into the grid, without taking into account the system situation.
- Multi-tariff profile: EVs charging depends on different tariffs in order to promote energy demand in off-peak hours.
- Smart profile: there are a lot of possible smart charging profiles, depending on the objective pursued. In this case, the smart profile allocates the EV charge demand in order to fill the off-peak hours of system demand.

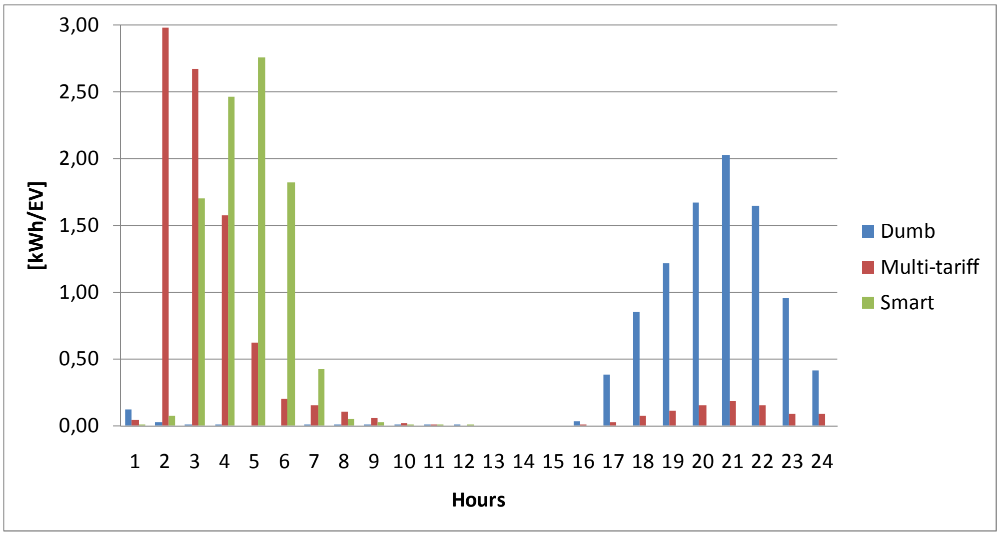

Figure 6.33 Charging profiles considered.

Assuming a mix of EVs with an average energy specific consumption of 0.14 kWh/km, a battery capacity of 28 kWh and 95 % efficiencies in grid-to-battery and battery-to-grid processes, the approximately average distance travelled by a car is 63 km/day.

6.3.2 Different EV penetration scenarios

For the year 2020 four different EV penetration levels has been considered [1]: a base case which does not have EVs, and then, scenarios with 34000, 70000 and 142000 EVs, which represent a 0.5%, a 1% and a 2% of the total fleet of vehicles, respectively.

The analysis carried out in this section compares the results of the different penetration levels using the smart charging profile, when it is possible. All the results presented take into account only weekdays, because the EVs charging profiles provided were adjusted only for these days. For this reason, taking into account also weekends would produce questionable results.

✓ Annual wind spillage

The annual wind spillage behaviour for the different scenarios is shown in Figure 6.34~~Figure 6.34~~. These results take into account the daily planning of the operation (unit commitment) including the optimal dispatch of all units and the uncertainties such as the failure of thermal units or the errors in demand and wind forecast in real-time.

Figure 6.34~~Figure 6.34~~ shows how the introduction of a higher quantity of EVs, except in the case with a lower EV penetration level, helps to integrate the wind, resulting in lower spillages. The 34000 EVs scenarios has an increase in the wind spillage of 0.4%, while with the 70000 EVs and 142000 EVs scenarios has 1.0% and 1.6% of wind spillage reduction.

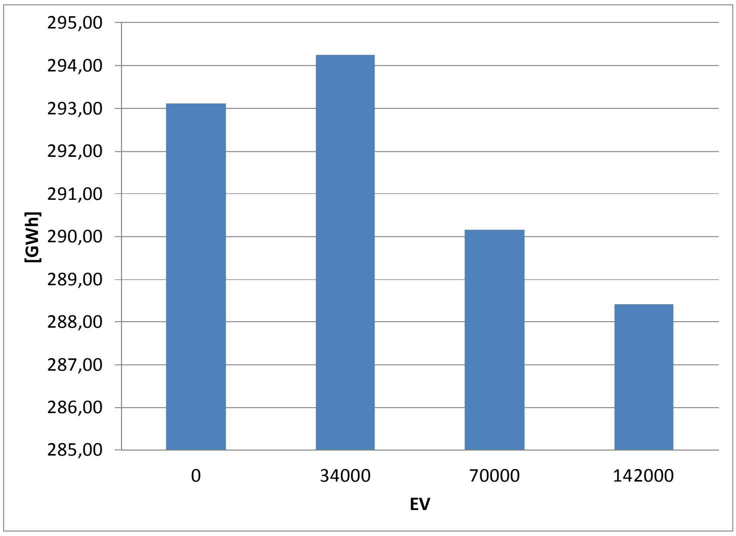

Figure 6.34 Annual wind spillage for different EV penetration scenarios for Greece 2020 (smart charging scenario)

✓ Annual specific cost

The specific cost (€ per MWh of demand) variation for the different EV penetration scenarios is shown in Figure 6.35~~Figure 6.35~~. The increment for the 34000, 70000 and 142000 EVs scenarios is 0.06%, 0.14% and 0.4%, respectively. The additional energy consumption that is required for the EVs is the main reason of this increase.

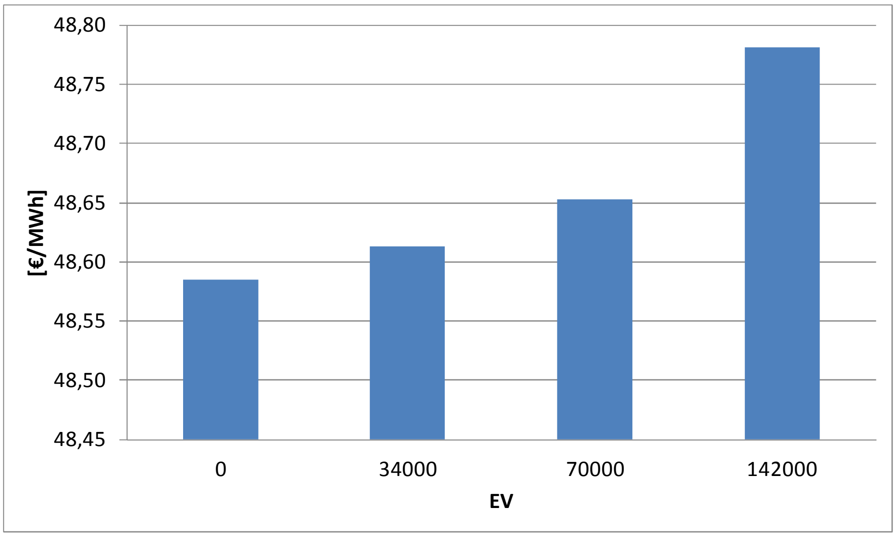

Figure 6.35 Specific cost for different EV penetration scenarios for Greece 2020 (smart charging scenario)

✓ Annual CO_2 emissions

The annual CO_2 emissions for Greece during the year 2020 considering different EV penetrations levels are displayed in Figure 6.36~~Figure 6.36~~. This figure shows that the introduction of more EVs into the system increases the production of CO_2 emissions. There is an increment, when compared to the 0 EVs scenario, of 0.3%, 0.5% and 1.1% of CO_2 emissions for the scenarios with 34000, 70000 and 142000

EVs, respectively. This situation occurs because the introduction of a higher quantity of EVs produces an increase in the demand and then, more energy production is required.

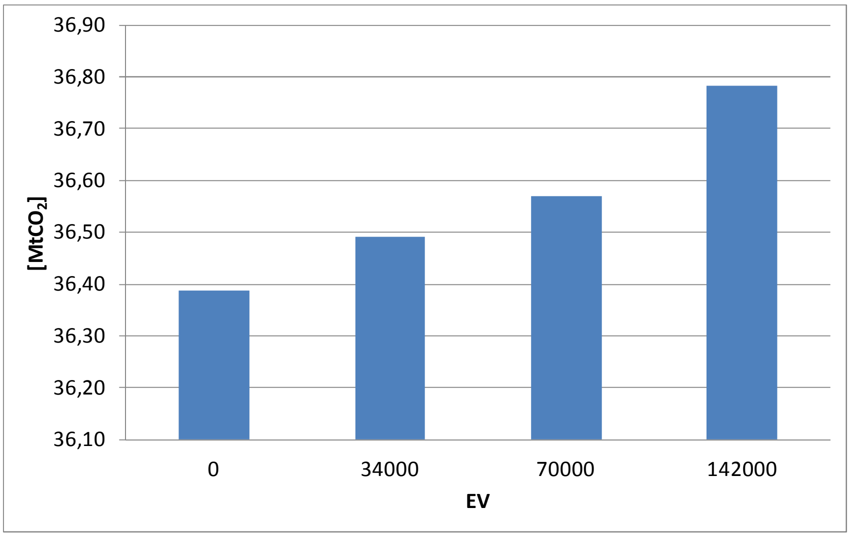

Figure 6.36 CO_2 emissions for different EV penetration scenarios for the year 2020 in Greece (smart charging scenario)

It is interesting to remark that introducing EVs into the system results in a further decrease in the CO_2 emissions, because these vehicles have no CO_2 emissions and substitute other vehicles that would emit CO_2 while running. Table 6.8 presents the comparison of emissions that would be produced if instead of EVs there were more internal combustion vehicles, and the equivalent CO_2 emissions for the EVs. The EV data presented in section 6.3.1, and the limit fixed by the European Union for fleet average CO_2 emissions, which is 130 gCO_2/km, are used to calculate these values. In this case, the charging of the EVs introduced into the system produces more CO_2 emissions than when internal combustion vehicles are used. This situation can be explained by the use of a charging profile that was adjusted for Spain, not for Greece and also because of the use of a large share of coal generation in the Greek system.

Table 6.8. Increase in CO_2 emissions with internal combustion vehicles

Number of EVs introduced	Increase in CO_2 emissions	Equivalent EV CO_2 emissions (gCO_2/km)
34000	-44%	187
70000	-22%	159
142000	-32%	172

- ✓ **Daily wind spillage profile**

The daily wind spillage profile for weekdays is displayed in Figure 6.37~~Figure 6.37~~. As displayed in this figure, wind spillage reduction is produced mostly over the night, and this reduction increases when the number of EVs into the system does. However, there are also some differences in the wind spillage during the rest of the day, especially in the peaks and valley hours. These differences, comparing scenarios with EVs and without them, are usually worst for the scenarios with EVs but, excluding the scenario with 34000 EVs, the wind spillage reduction over the night hours compensate these increases during the day hours (as displayed Figure 6.34~~Figure 6.34~~).

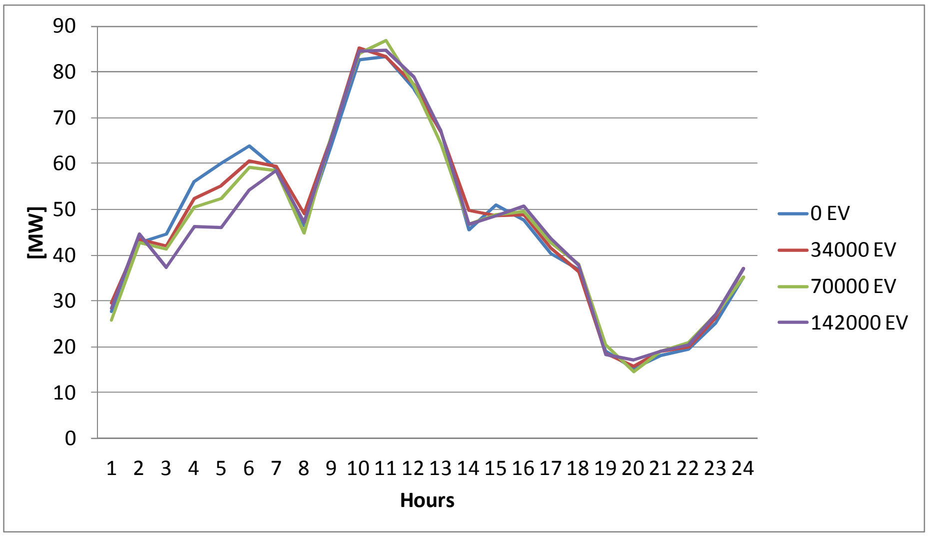

Figure 6.37 Average wind spillage profile for weekdays for Greece 2020 (smart charging scenario)

✓ Annual productions by technologies

Figure 6.38~~Figure 6.38~~ shows the production differences by technologies between the 0 EV scenario and the others. The CCGT and the coal units are the mainly responsible of providing energy to the charge of the EV and there is also a less production with hydro units. It is interesting to notice that the increase in the production with coal is more important than the CCGT increase for the scenarios with 34000 and 70000 EVs, while for the scenario with 142000 EVs is the other way round.

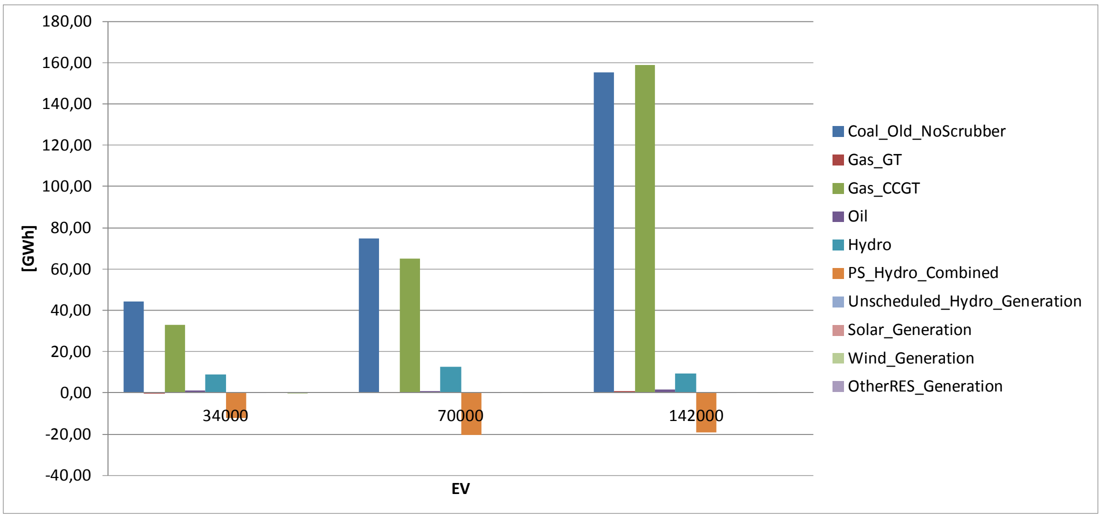

Figure 6.38 Differences of production by technology with the 0 EV scenario for Greece 2020

6.3.3 Changing the charging behaviour of electric vehicles

This section analyses with more detail the differences in the results obtained by applying the different charging profiles presented in Section 6.3.1 to the scenarios analysed in Section 6.3.2. It has to be reminded that the results presented take into account only weekdays, without considering weekends.

✓ **Annual specific cost**

Section 6.3.2 shows that the increase of EV produces an increase of the specific cost of the system. Figure 6.39~~Figure 6.39~~ shows that the application of smarter charging profiles produces the lowest specific cost in the system, followed by the multi-tariff profile. The difference in the cost between the smart and multi-tariff profile with the dumb profile increases as the number of EVs in the system does (0.02% and 0.06% less cost for the multi-tariff and smart strategies with the 34000 EVs scenario and 0.26% and 0.28% less cost for the multi-tariff and smart strategies with the 142000 EVs scenario).

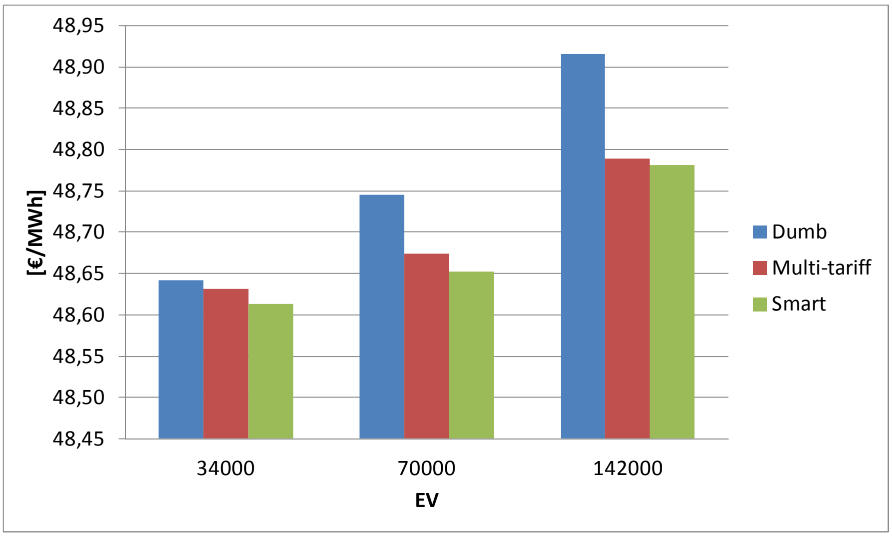

Figure 6.39 Annual specific cost for different charging scenarios for Greece 2020

The different charging profiles are based on different charging hours, as can be seen in Figure 6.33~~Figure 6.33~~. The smart charging strategy implies charging during valley hours, the dumb strategy would mean charging during peak hours, and for the multi-tariff strategy the charging is performed during both peak and valley hours. For this reason, the generation technologies used for each charging profile will differ, which results in different generation costs. A more detailed analysis of the generation technologies used for the profiles is in the annual CO_2 emissions section.

✓ **Annual CO_2 emissions**

In Section 6.3.2 it has been seen that the deployment of a higher amount of EVs into the system will increase the CO_2 emissions. The growth in the demand, as has been seen in Figure 6.38~~Figure 6.38~~, is mainly covered by coal and CCGT units. Figure 6.40~~Figure 6.40~~ presents the behaviour of CO_2 emissions when comparing different charging strategies for the EVs. It is interesting to see that the multi-tariff and smart strategies produce more CO_2 emissions that the dumb strategy. In addition, the smart and multi-tariff profiles produce almost the same emissions for the 34000 and

70000 EVs scenarios. In the scenario with 142000 EVs, the smart profile is the one with most emissions.

This happens because “smarter” strategies, e.g. multi-tariff and smart strategies, involve charging EVs mainly at night and during the first hours of the morning, while the dumb strategy tends to charge the EVs over the evening, as displayed in Figure 6.33~~Figure 6.33~~. The energy production over night hours is essentially provided by coal units, which are not at their maximum. Meanwhile, the energy production over the peak hours is provided by CCGT units, since coal units are already at their maximum. As a result, the smarter the profile is the more production with coal units (and therefore, less production with CCGT units). CO_2 emissions are higher for the coal units than CCGT units, which explain the increase in CO_2 emissions for “smarter” charging profiles. Figure 6.41~~Figure 6.41~~ and Figure 6.42~~Figure 6.42~~ display the variation of coal and CCGT production for the different EV penetration levels and charging profiles considered. As explained, coal production increases for smarter charging strategies and CCGT production decreases, because more energy is generated over the night. It is interesting to notice that this increase/decrease relationship between the production of the coal and CCGT units is almost inverse.

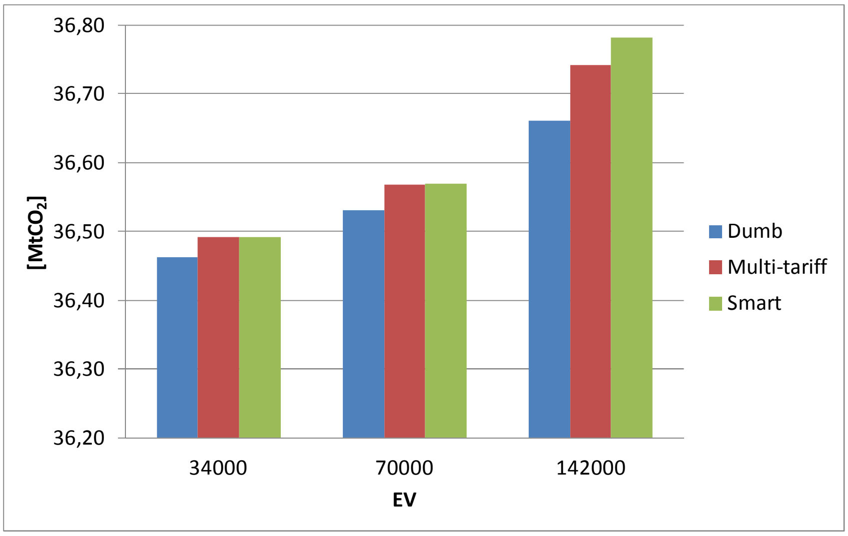

Figure 6.40 CO_2 emissions for different EV penetration levels and charging strategies for Greece 2020

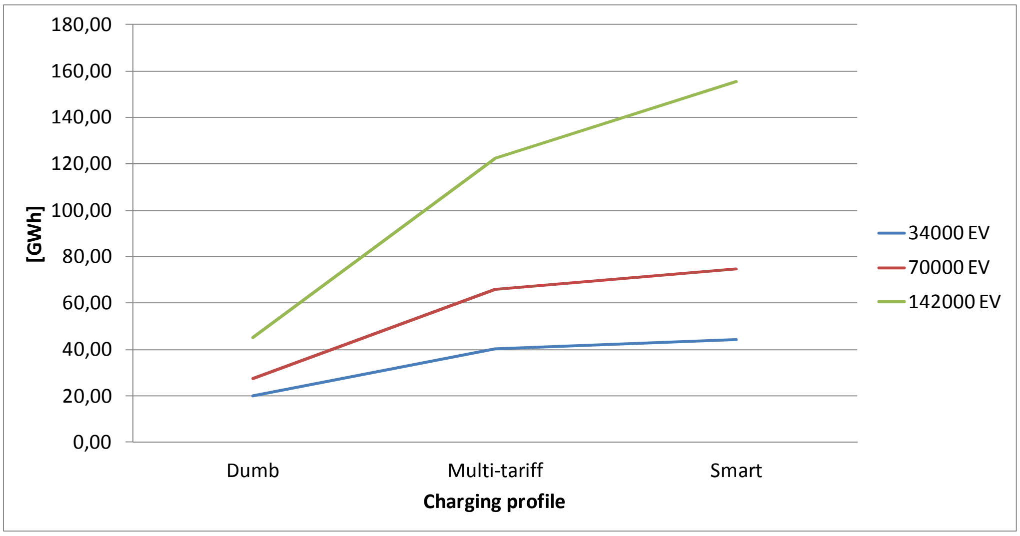

Figure 6.41 Differences of coal production compared with the 0 EV scenario for Greece 2020.

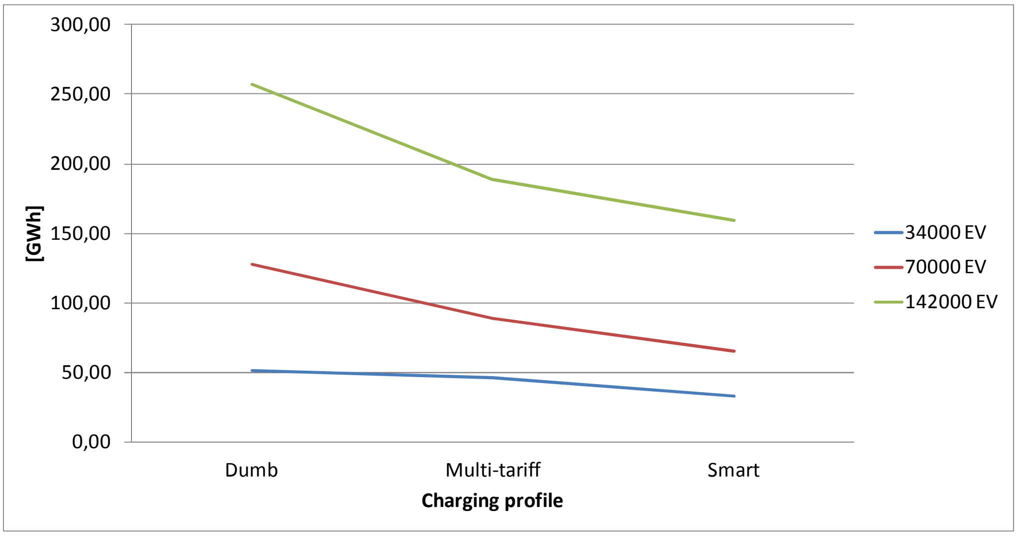

Figure 6.42 Differences of CCGT production compared with the 0 EV scenario for Greece 2020.

✓ **Daily wind spillage profile**

Section 6.3.2 shows that spillage reduction of wind generation increases when the number of EVs in the system does, except for the scenario with less EVs. This section analyses this variation using different charging profiles. This analysis is carried out for the different EV penetration levels independently.

Figure 6.43~~Figure 6.43~~ displays the average wind spillage profile for weekdays in the scenario of 34000 EVs in the system. It can be observed that the smart charging profile has better wind spillage results in the night and the peak hours. However, the multi-tariff and dumb profiles have better results during the rest of the day, resulting in better results than the smart profile.

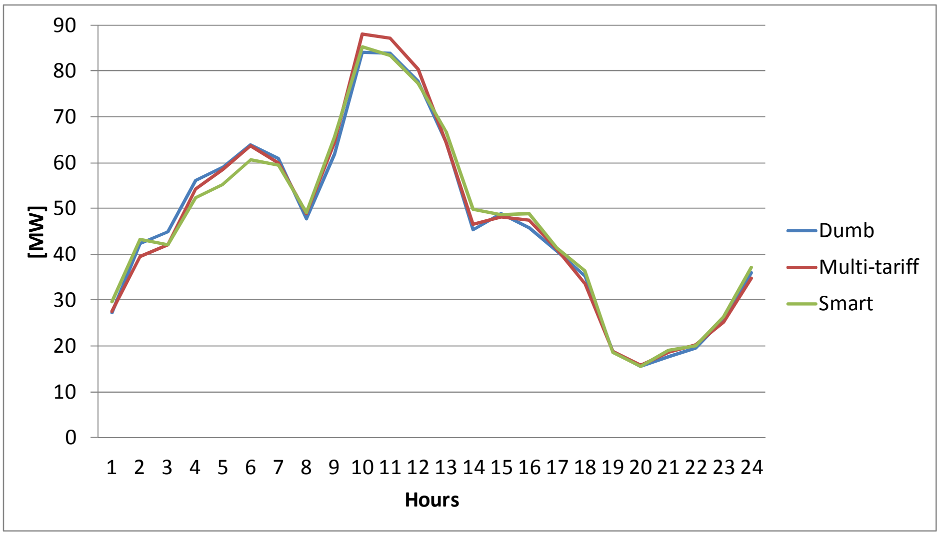

Figure 6.43 Average wind spillage profile for weekdays for different charging profiles with 34000 EVs in Greece 2020.

Figure 6.44~~Figure 6.44~~ presents the average wind spillage profile for weekdays in the scenario of 70000 EVs in the system. In this scenario, the wind spillage reduction is also produced during the night and the first hours of the morning with the multi-tariff and, especially with the smart charging profile. The dumb profile increases again the wind spillage during these hours. As a consequence of the wind spillage reduction in the night for the smart profile, this strategy achieves the best overall wind spillages results.

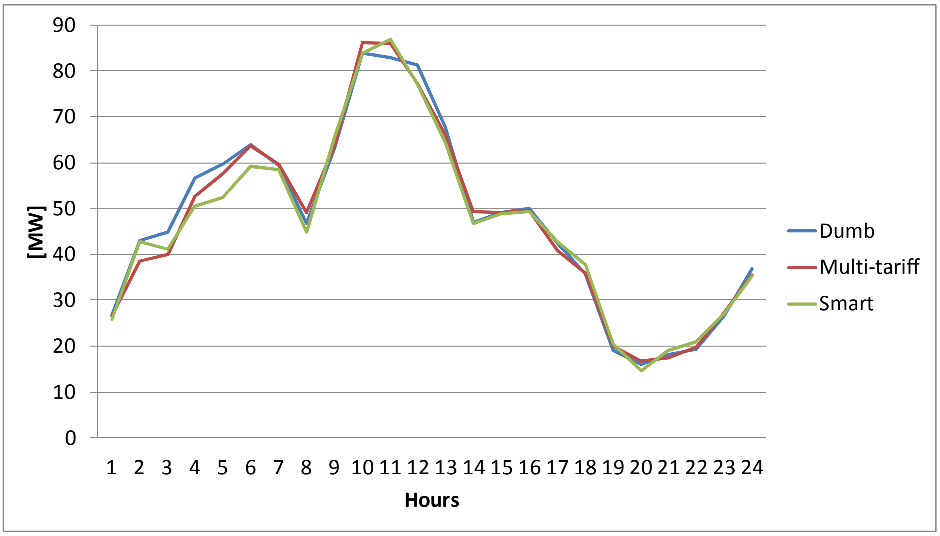

Figure 6.44 Average wind spillage profile for weekdays for different charging profiles with 70000 EVs in Greece 2020.

Figure 6.45~~Figure 6.45~~ shows the average wind spillage profile for weekdays in the 142000 EVs scenario. In this situation, the wind spillage decrease is, as in the other scenarios, produced mostly during the night and in the first hours of the morning for the multi-tariff and, specially, the smart charging profiles. However, in this scenario, this reduction is much more noticeable for the smart profile. The dumb profile increases again the wind spillage during these hours.

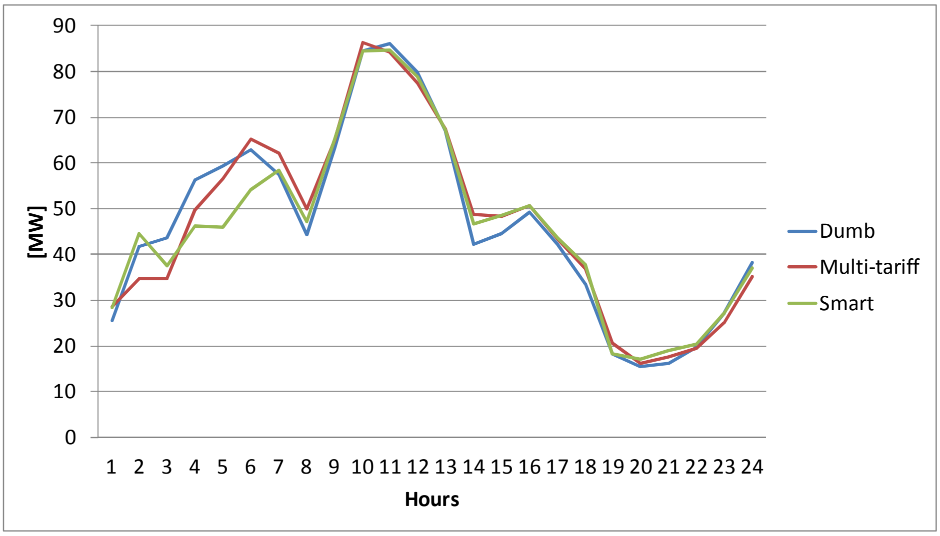

Figure 6.45 Average wind spillage profile for weekdays for different charging profiles with 142000 EVs in Greece 2020.

7 CONCLUSIONS (TO BE INCLUDED IN SECTION CONCLUSIONS)

This section has the objective of evaluating the economic and environmental impacts of the future deployment of EVs into the Spanish, the Portuguese and the Greek systems for the year 2020 using the ROM Model.

Analyzing the three systems, similar results have been achieved. The wind spillage produced in the system is reduced when higher volumes of EVs are introduced. The Portuguese system is the one achieving better results (with a wind spillage reduction up to 20%) due to the flexibility of its generation units. Besides, the CO_2 emissions and the total cost of the system have a little increase. The wind spillage reduction is much more noticeable for the Spanish and, specially, the Portuguese system than for the Greek system, while the increase in the CO_2 emissions and in the specific cost of the system is similar. This difference in the wind spillage reduction between Spain and Portugal respect to Greece may be due to the fact that the charging profiles have been conceived for Spain (Portugal has a very similar load profile with Spain), not for Greece.

The increase in CO_2 emissions is explained because with EVs in the system, an increase in the demand is produced. However, it has to be taken into account how much these emissions would be if instead of introducing EVs, more internal combustion vehicles were used. The equivalent CO_2 emissions for the EVs in Portugal are in a range of 24-43 gCO_2/km, for Spain these equivalent emissions augment to a range of 70-82 gCO_2/km and finally, for Greece have a range of values between 159-187 gCO_2/km. The equivalent CO_2 emissions for the EVs for Spain and Portugal are much lower than the limit fixed by the EU. In the case of Greece these CO_2 emissions are larger due to the use of a large share of coal units.

The weekday wind spillage profile for Spain and Portugal shows that the hours with high wind spillage are during the night, while for Greece the peak hours are, approximately, at midday. In this situation, the smarter charging strategies for Spain and Portugal imply charging during the night. Nevertheless, in Greece, a smart strategy would be to charge at midday hours when there is a higher wind generation. Because of this coincidence between the EV charging hours and hours of high wind generation a higher wind spillage reduction is achieved when introducing EVs into the system for the Spanish and Portuguese cases.

The use of smarter profiles results in a little decrease in the specific cost of the system in the Spanish, the Portuguese and the Greek system. The application of these profiles for the Spanish case produces best results for the cost and the CO_2 emissions. For the Portuguese system, the application of smarter profiles (specially the smart one) produces better costs, but also more CO_2 emissions. For the Greek case, these smarter profiles also reduce the specific cost of the system, but they also produce a little increase in the CO_2 emissions.

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