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ESD.S30

Electric Power System Modeling for a Low Carbon Economy

Impact of EV penetration in some electric systems

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Massachusetts Institute of Technology (MIT). January 2013

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Introduction

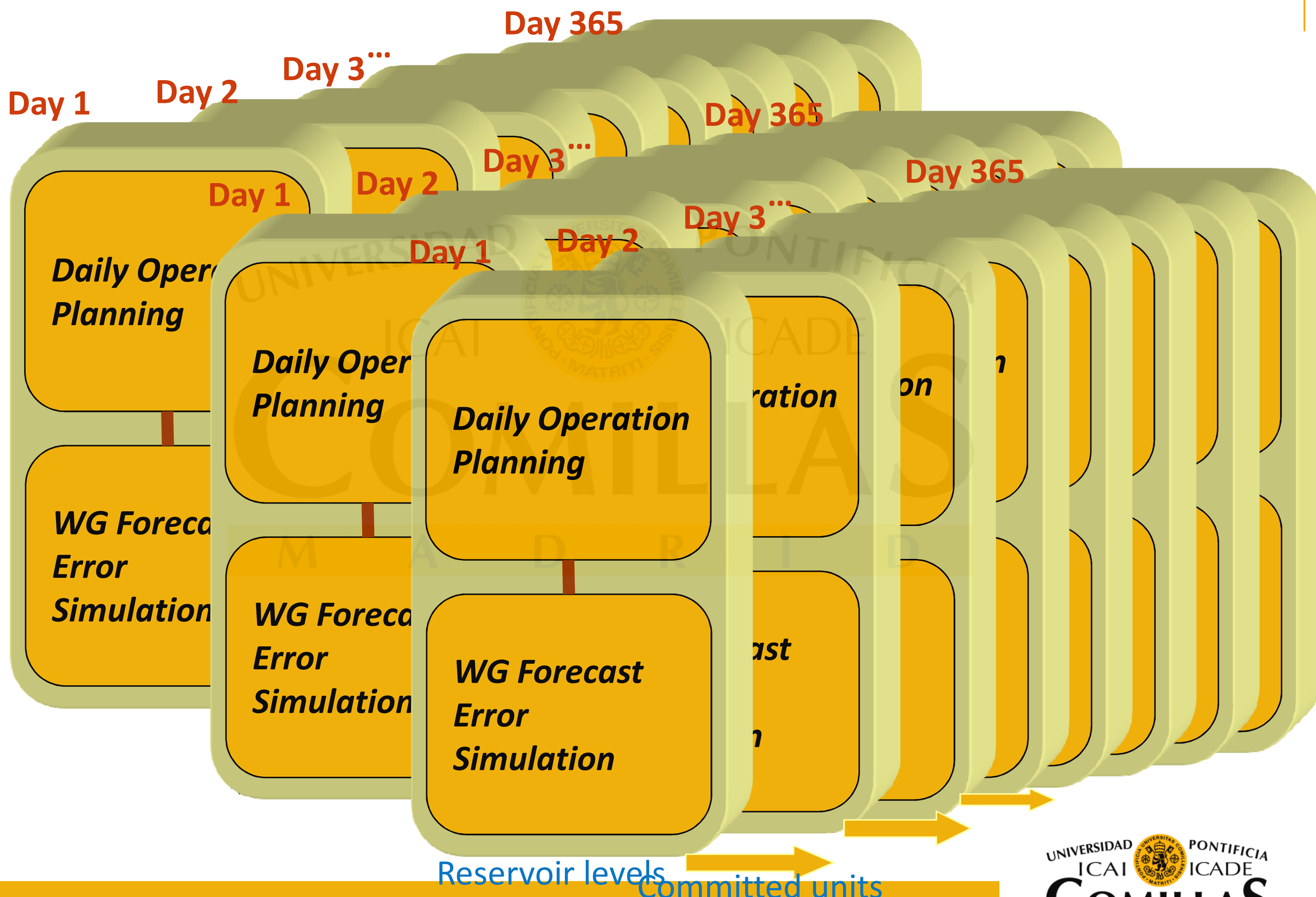
Objectives

- Evaluate the impact of EV share in the operation and management of the electric system in year 2020
- Quantify the impact of EV in the amount of RES that can be integrated in the electric system
- Analysis and design of optimal EV charging strategies to maximize the share of RES

ROM Model

- ROM model (Reliability and Operation Model for Renewable Energy Sources) represents in detail the technical and economic operation of the electric system
- It has been used to assess the impact of EV in the electric system in several European and Spanish projects:
  - MERGE (http://www.ev-merge.eu/) Mobile Energy Resources in Grids of Electricity
  - CENIT-VERDE (http://cenitverde.es/) Consorcio Estratégico Nacional en Investigación Técnica. Vehículo Eléctrico.
  - TWENTIES (http://www.twenties-project.eu/node/1) Transmission system operation with large penetration of Wind and other renewable Electricity sources in Networks by means of innovative Tools and Integrated Energy Solutions.
  - SUSPLAN (http://www.susplan.eu/) Planning for Sustainability.
- And a preliminary model version was used in the report *The Future of Natural Gas* by MIT

ROM Overview



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Spanish reference case

Main attributes (i)

- Yearly energy demand and summer and winter peaks
- Up and down operating reserve
- Installed capacity of conventional thermal generation
  - Nuclear, Coal, Oil/gas, CCGT, Gas turbines (peakers)
- Natural gas price and CO2 emissions
- Installed (or maximum) capacity of non conventional generation
  - Run-of-the-river and storage hydro, pure and combined pumped storage hydro
  - Wind, Solar PV, CSP, CHP, Biomass, other RES
- Hydro inflows
  - Can be separated in very-dry, dry, average, wet and very-wet
- Import/export capacity
- Number of EV

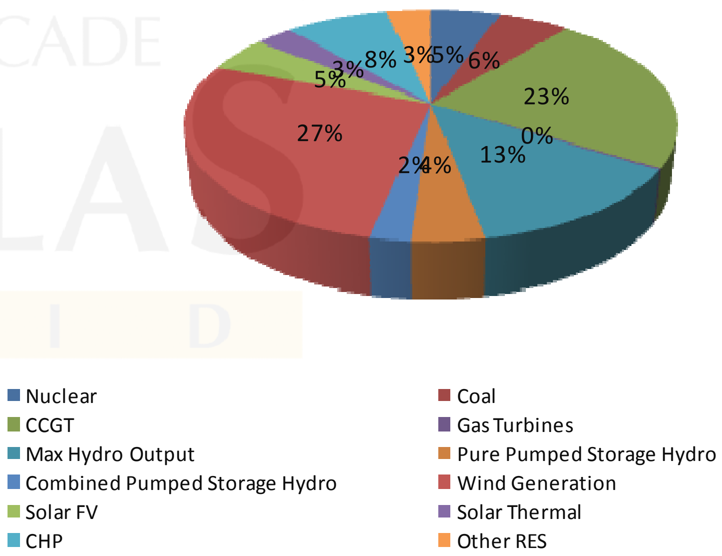
Main attributes (ii)

- Pumped storage hydro plants
  - Pure: no natural inflows
  - Combined: with natural inflows
- Wind generation (WG)
  - Based on historical series from SO (System Operator)
- Solar generation
  - Solar PV, thermal solar with and without storage based on data from SO (output as a % of the installed capacity scaled up to the installed capacity foreseen in the National Renewable Energy Action Plan NREAP)
- Biomass, small hydro and CHP
  - Based on historical series from SO

Reference case 2020 (i)

Energy	[TWh]	331
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]	24491
Gas/Fuel	[MW]	301
Max Hydro	[MW]	16692
Pure Pumped Storage Hydro	[MW]	5185
Combined Pumped Storage Hydro	[MW]	2884
Wind Generation	[MW]	34820
Solar PV	[MW]	6250
Solar Thermal	[MW]	3810
CHP	[MW]	10310
Other RES	[MW]	4460
Natural Hydro Inflows	[TWh]	27,9
Nuclear Price	[€/Mcal]	0,002
Coal Price	[$/short tons]	124,7
Natural Gas Price	[$/MMBTU]	11,0
CO2 Price	[€/t CO2]	30

Installed capacity



Reference case 2020 (ii)

		Nuclear	Carbón	CCGT monoeje	CCGT multieje	Gas
SOR	[p.u.]	0,06	0,07	0,03	0,03	0,03
EFOR	[p.u.]	0,06	0,05	0,06	0,06	0,10
Min Out	[MW]	908	146	191	199	61
Max Out	[MW]	908	316	391	805	204
Ramp Up	[MW/h]		173	200	581	240
Ramp Down	[MW/h]		173	200	581	240
Var Heat Rate	[te/MWh]	2500	2528	1581	1555	2453
No Load Heat Rate	[te/h]		64304	315480	544671	121507
Fuel Cost	[€/te]	0,002	0,018	0,032	0,032	0,032
CO2 Cost	[€/t CO2]		15	15	15	15
Specific Emiss	[t CO2/MWh]		1,025	0,371	0,365	0,575
O&M Var Cost	[€/MWh]	0,060	0,042	0,055	0,055	0,025
Startup Cons	[te/str]		1440400	380000	760000	488000
Startup Hours	[h]		23	7	7	15

Coal price 0.018 €/MCal = 124.66 $/short ton
Natural Gas price 0.032 €/MCal = 10.99 $/MMBTU
Crude Oil price 0.035 €/MCal = 69.70 $/bbl

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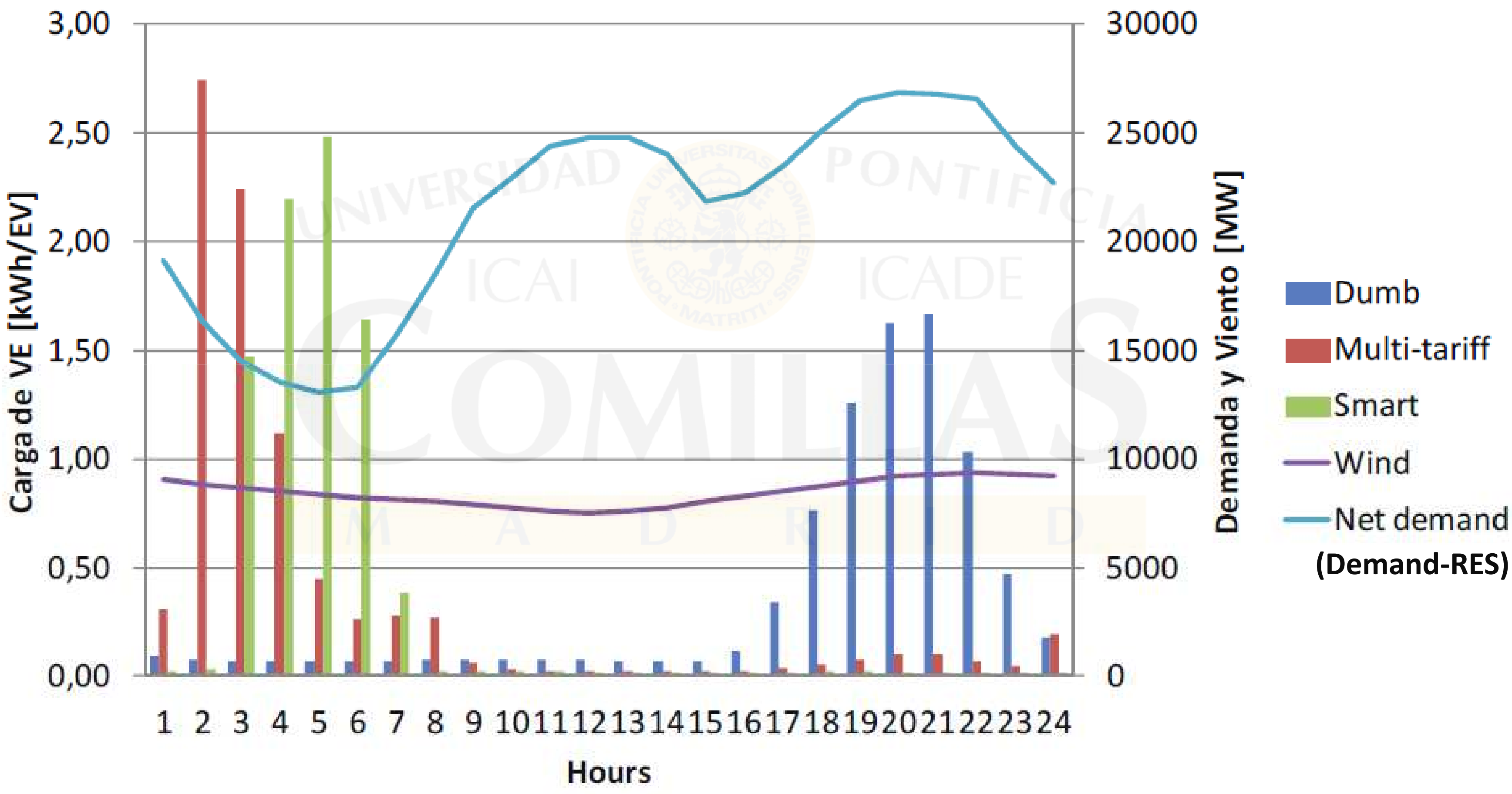
Analysis of Spanish reference case

EV charging profiles for a working day

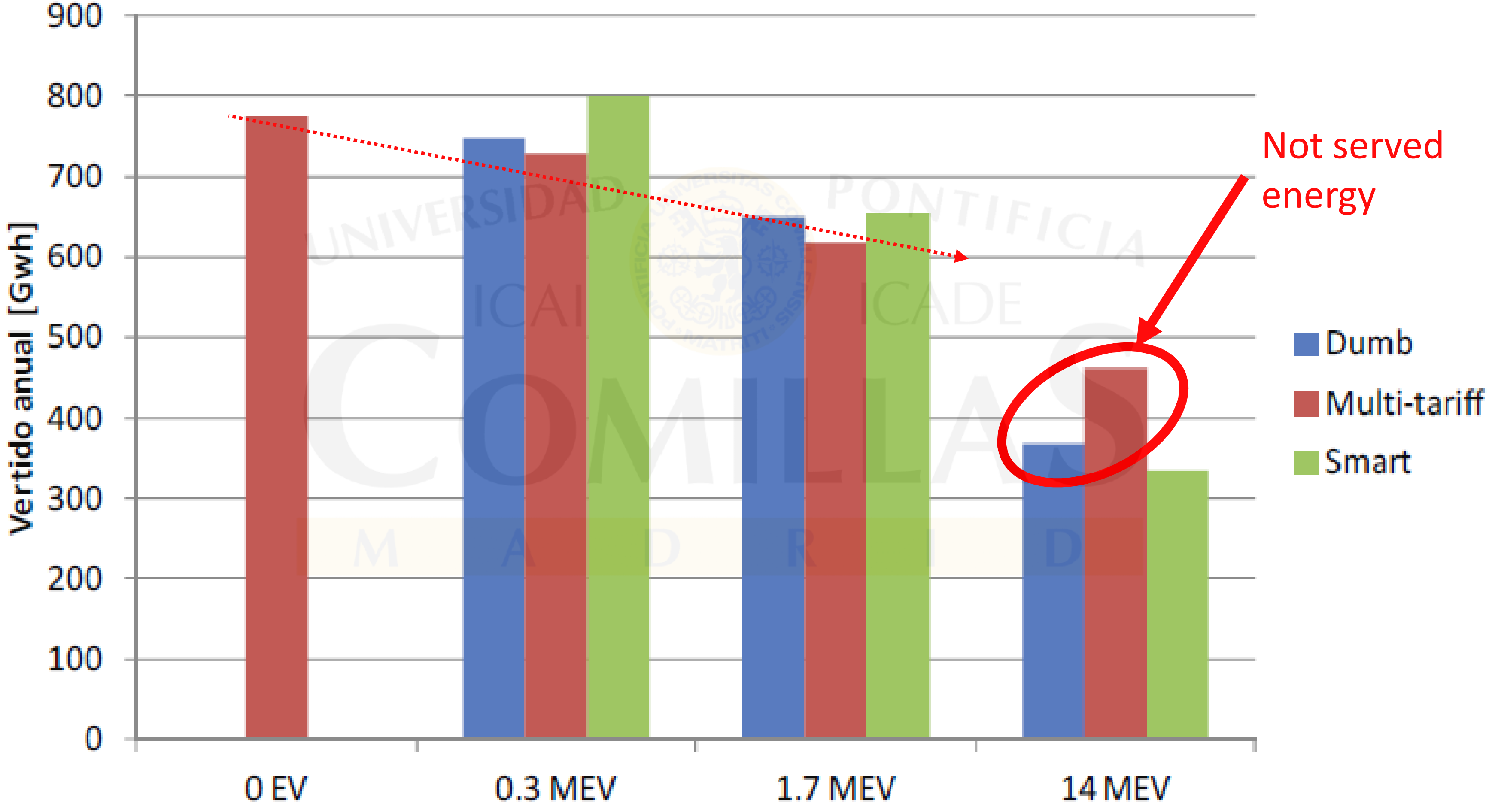
All the EV charging profiles are predefined for the UC model



In weekends only multi-tariff EV charging strategy is used

Yearly WG curtailment

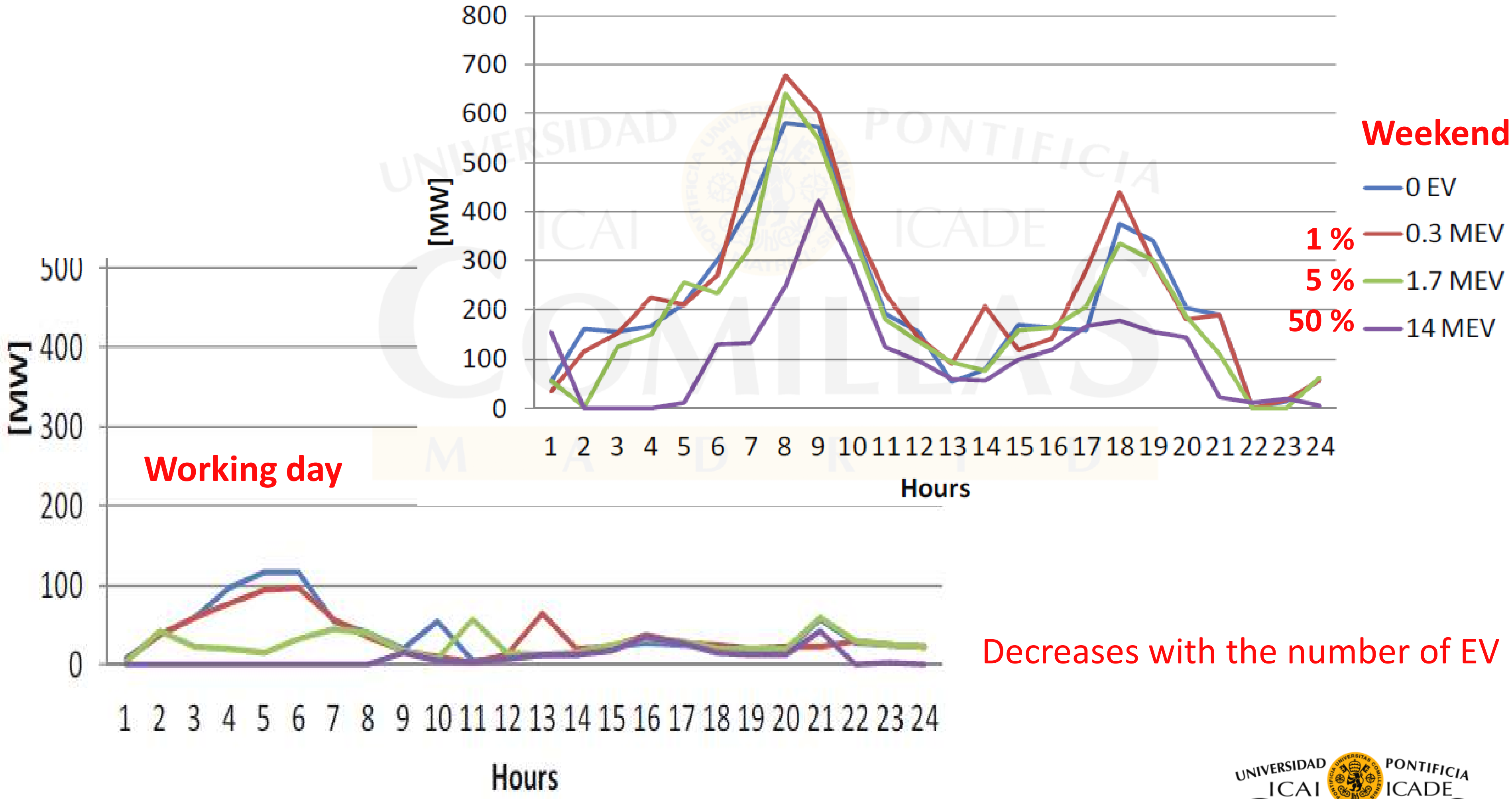
Low WG curtailment: 0.2 % of total demand, 1 % of WG



Why with smart charging is there more WG curtailment?

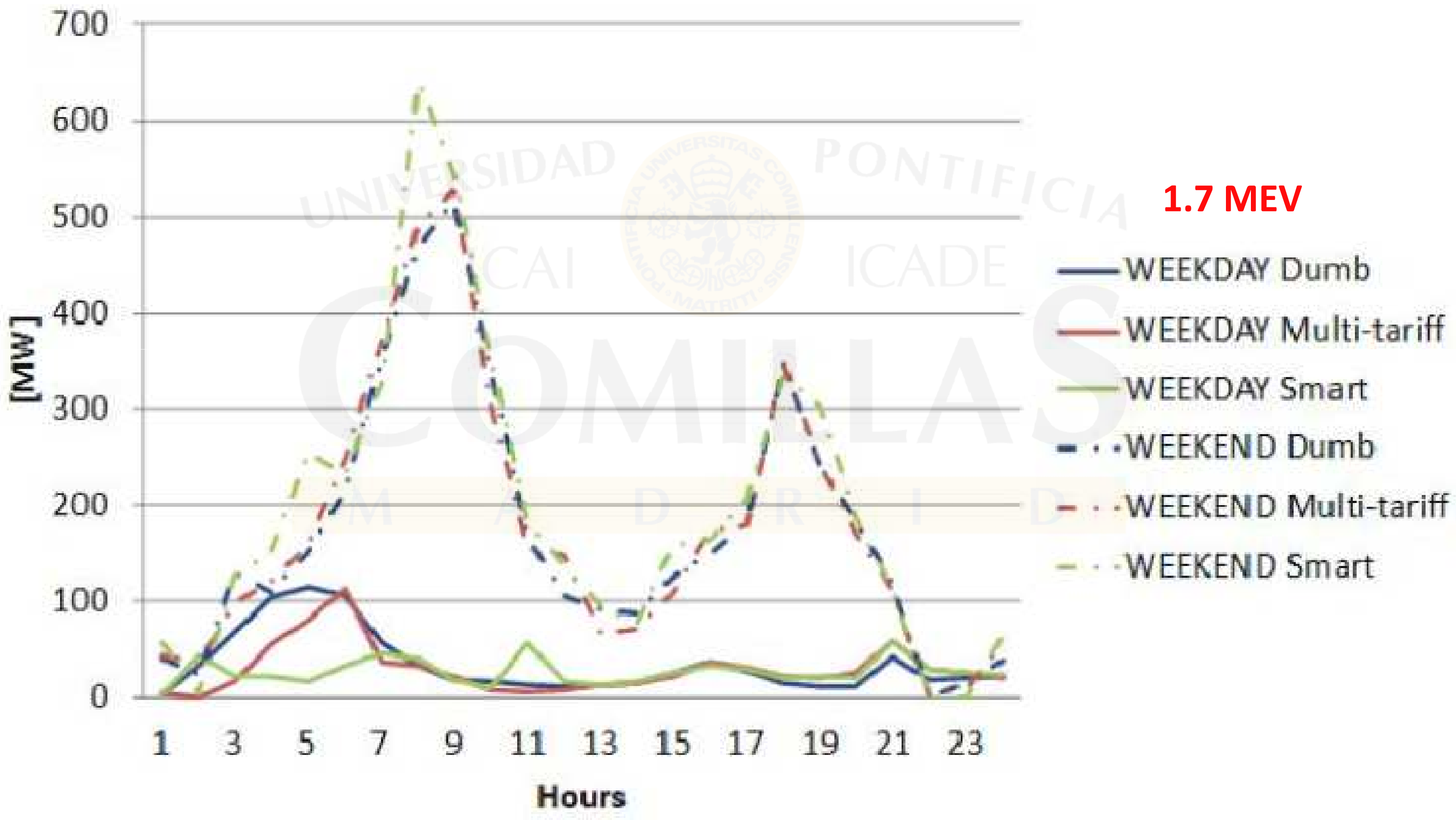
- With smart charging profile some thermal units avoid to be disconnected in the working days, avoiding startup costs.
- But these connected thermal units produce an additional pumping to circumvent WG curtailment arriving with full reservoirs to the weekend
- But in the weekend the demand is low and if there is a lot of WG this causes high WG curtailment

Yearly WG curtailment

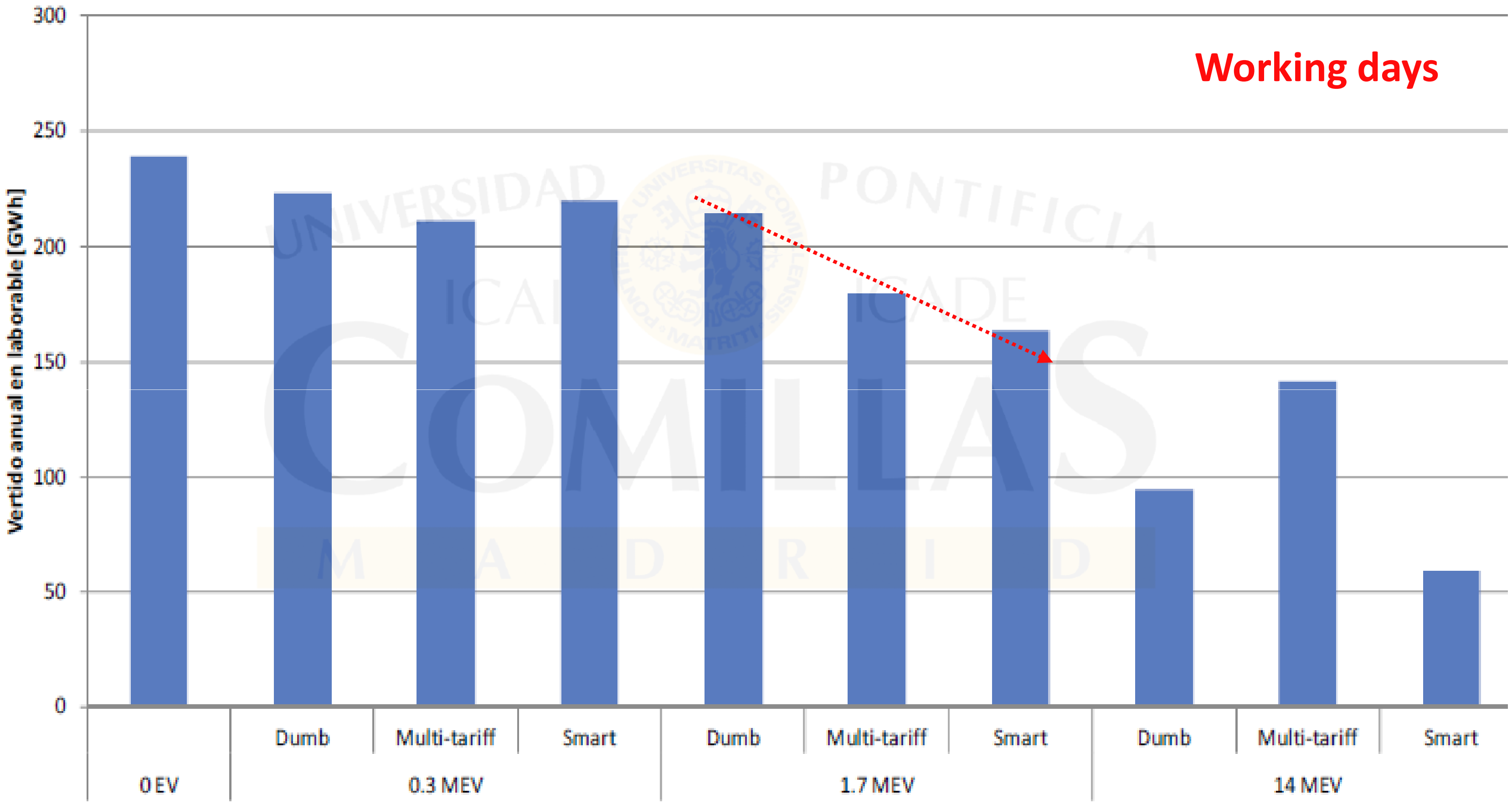


Decreases with the number of EV

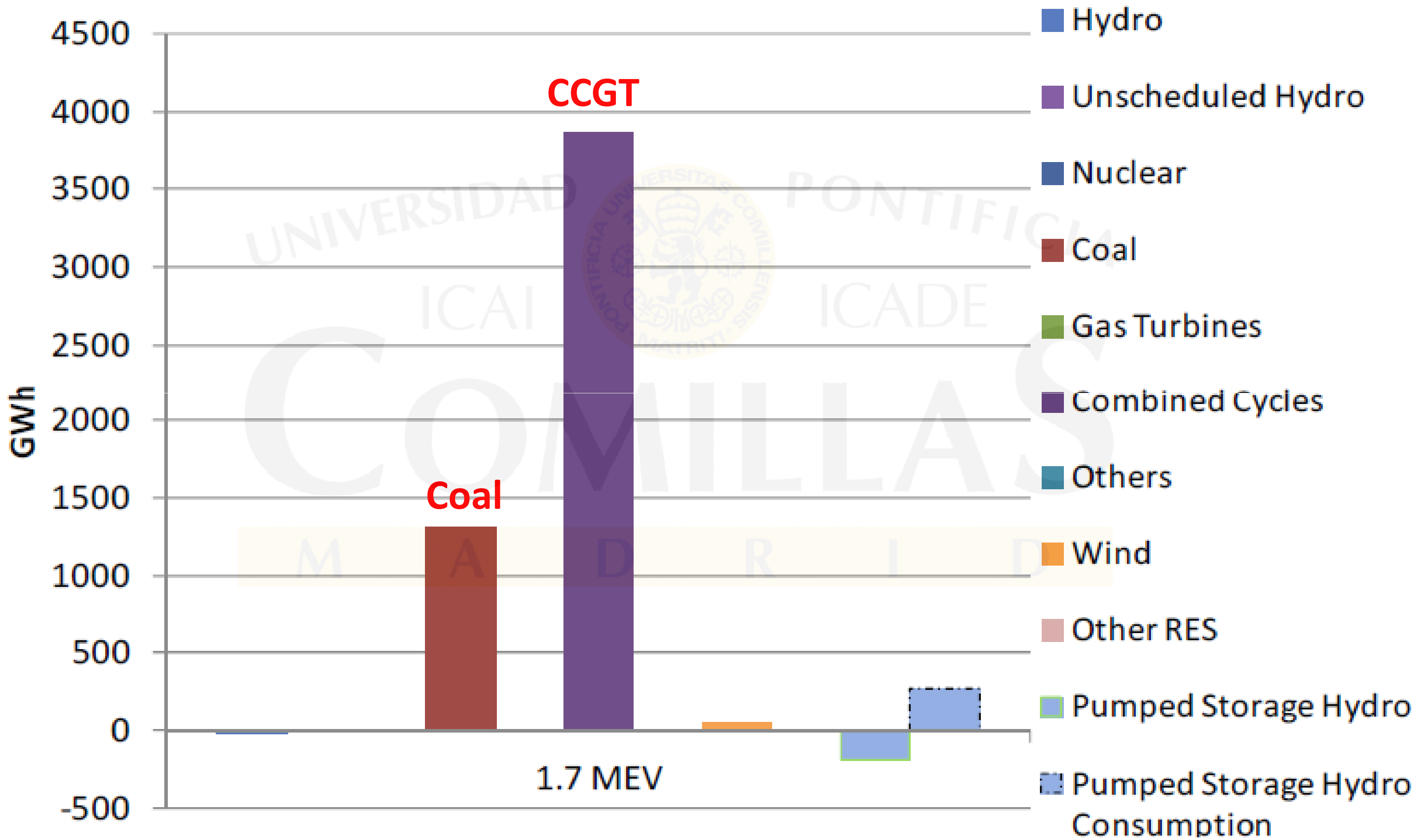
Yearly WG curtailment



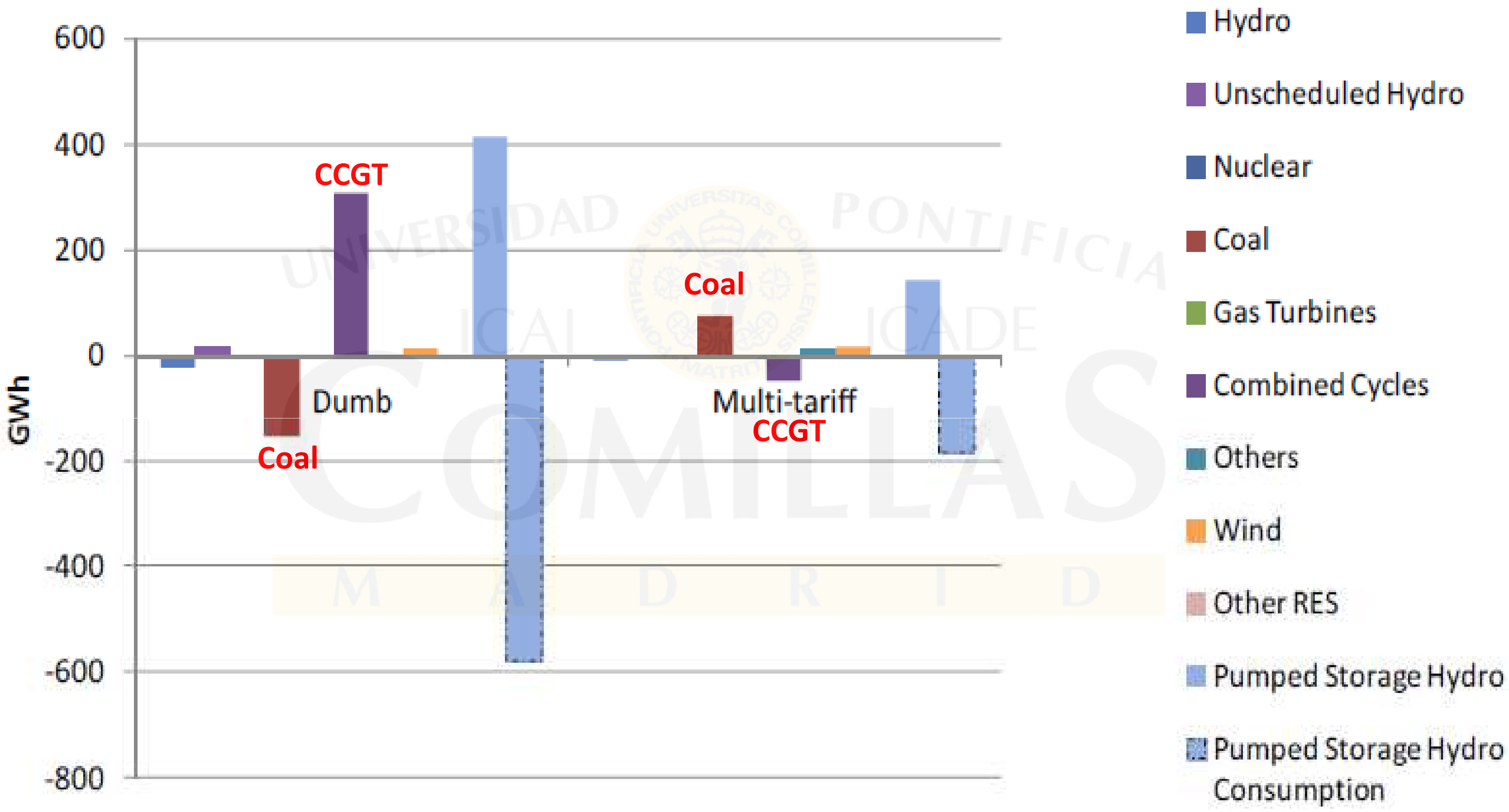
Yearly WG curtailment



Production by technologies (0 EV vs. 1.7 MEV with smart charging)



Production by technologies (1.7 MEV with smart charging vs. dumb vs. multi-tariff charging)



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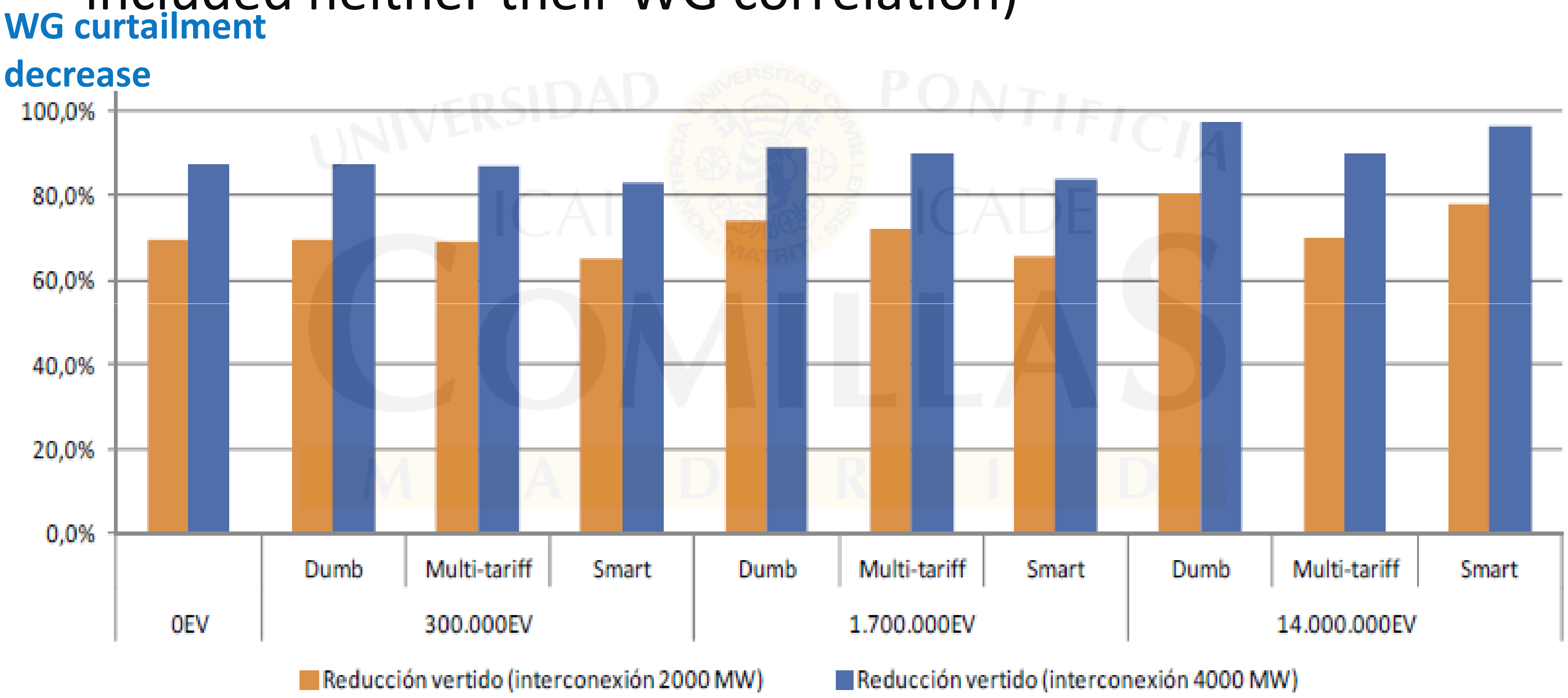
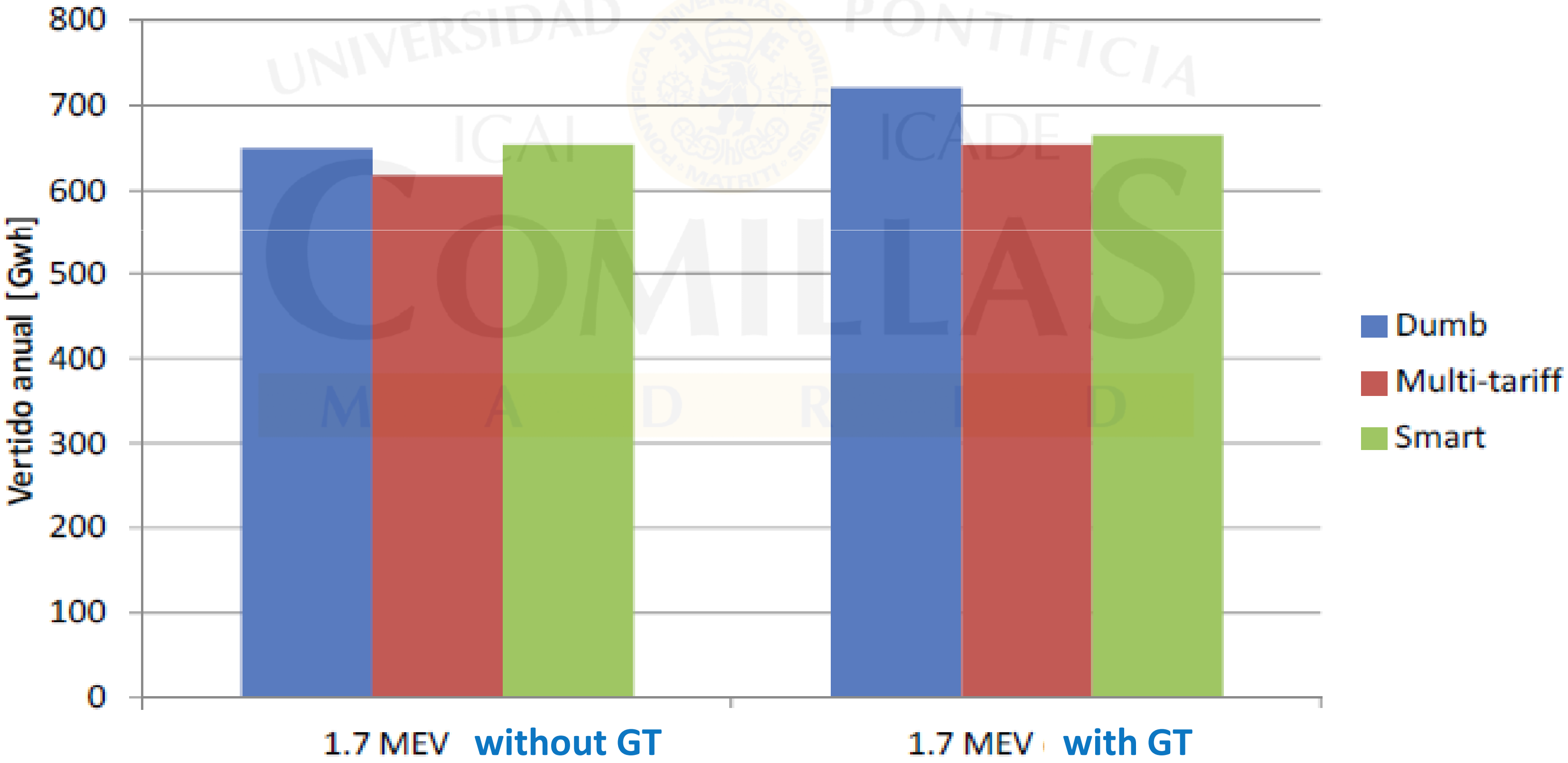
WG curtailment. Effect of cross-border interconnections

- The cross-border interconnection can mitigate high share of WG curtailment (although neighboring countries are not included neither their WG correlation)



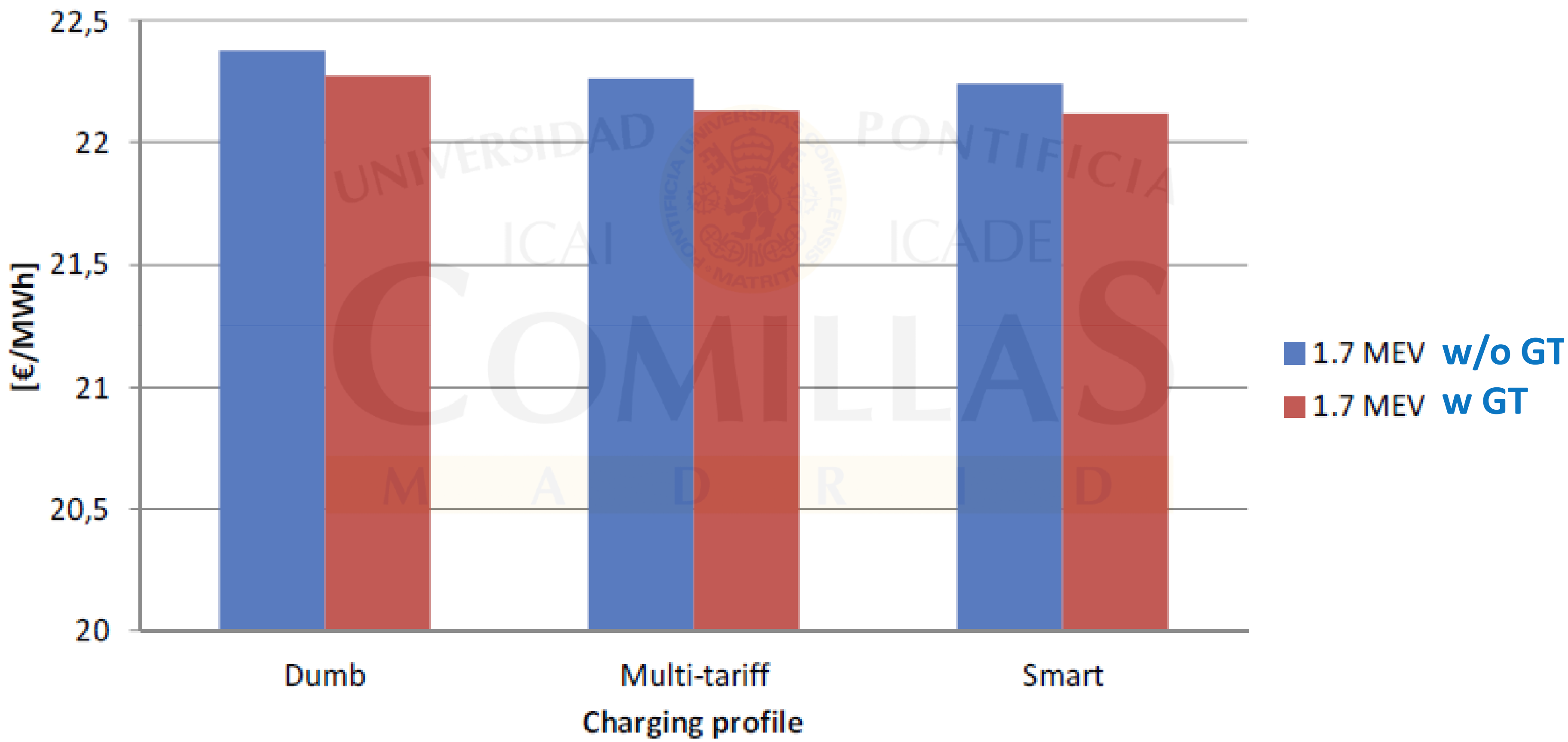
Yearly WG curtailment. Effect of introducing gas turbines instead of CCGT

- Flexibility of gas turbines is balanced with the increase in coal generation (less flexible) given that CCGT are eliminated
- No major effects in WG curtailment



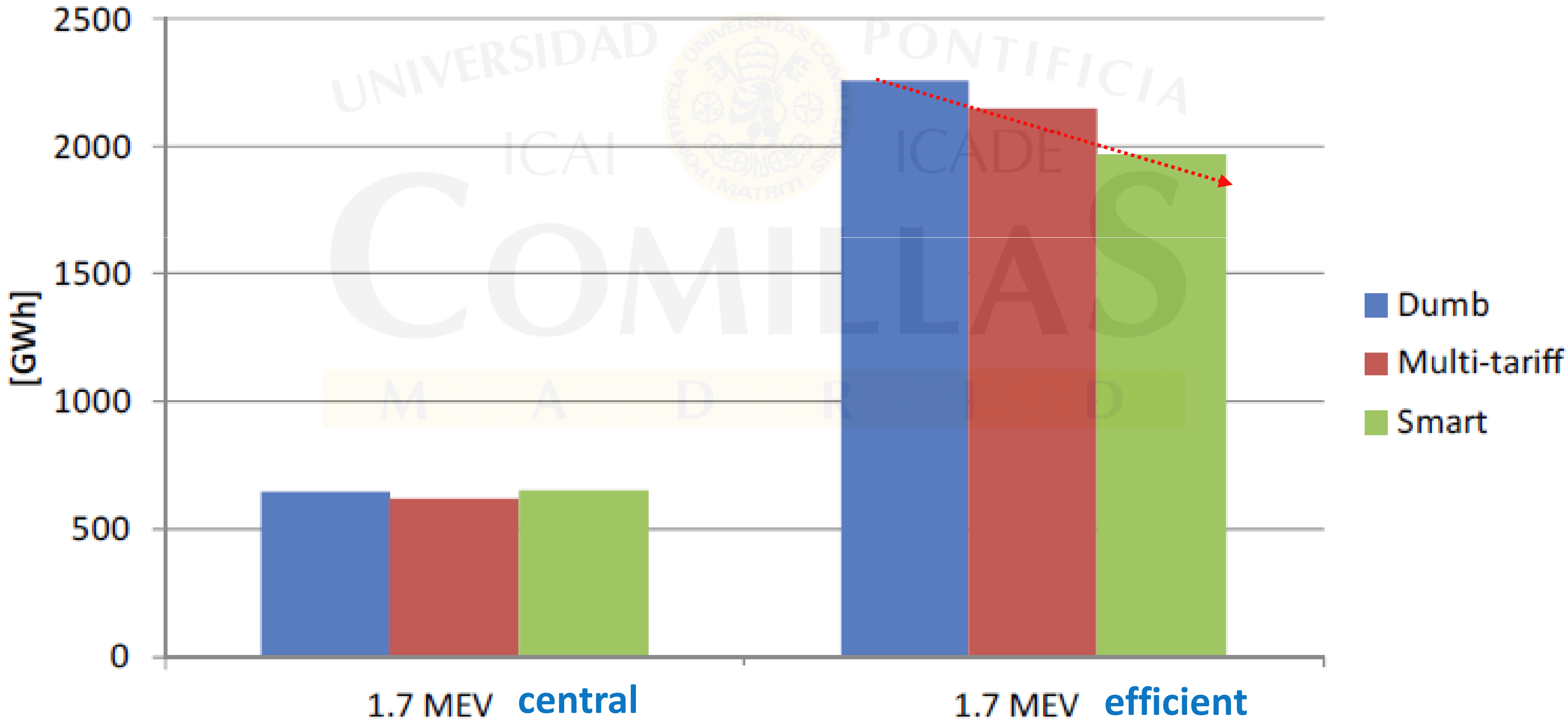
Operation costs. Effect of introducing gas turbines

- … but it affects the operation costs

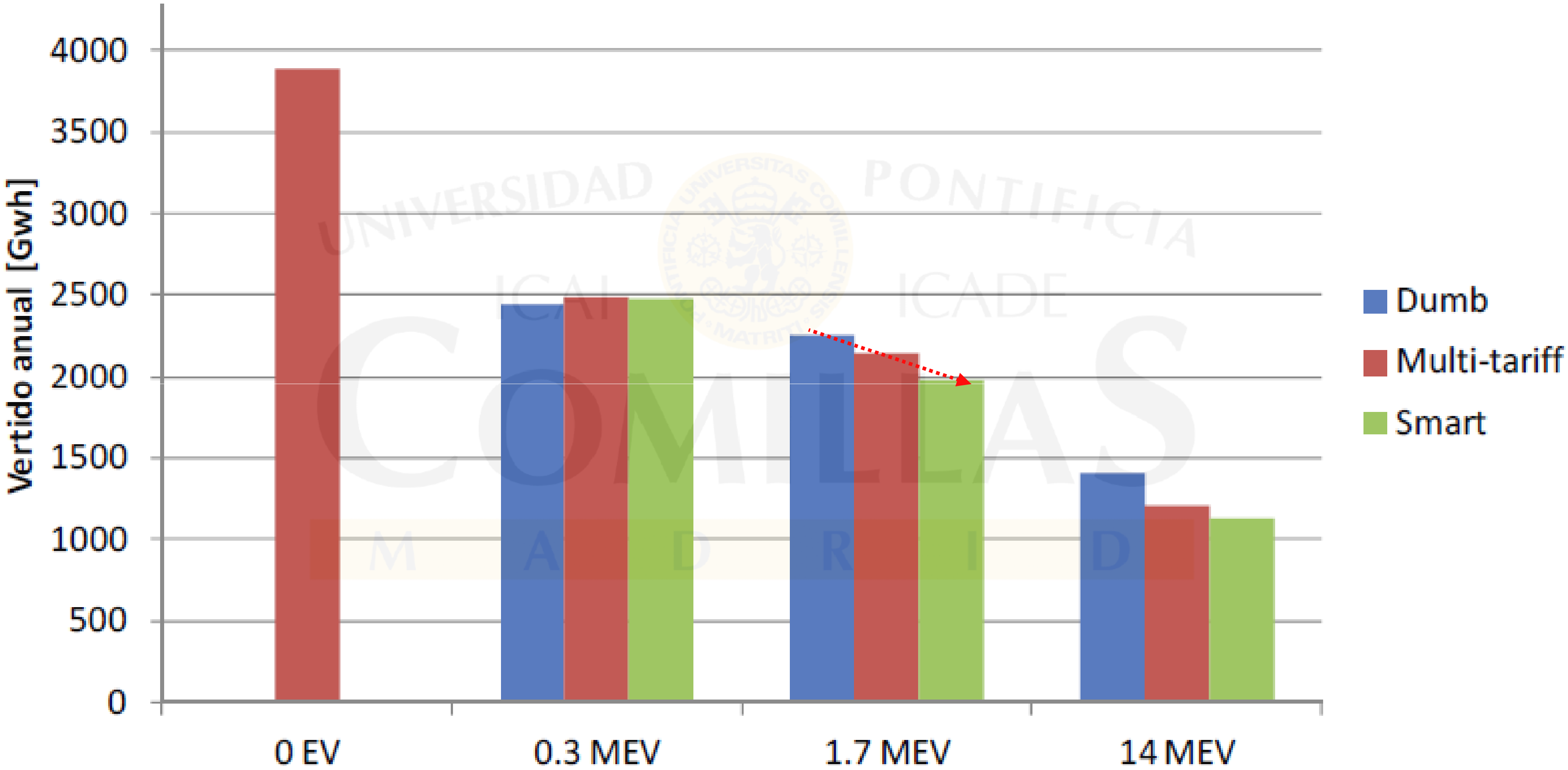


Yearly WG curtailment. Effect of efficient demand

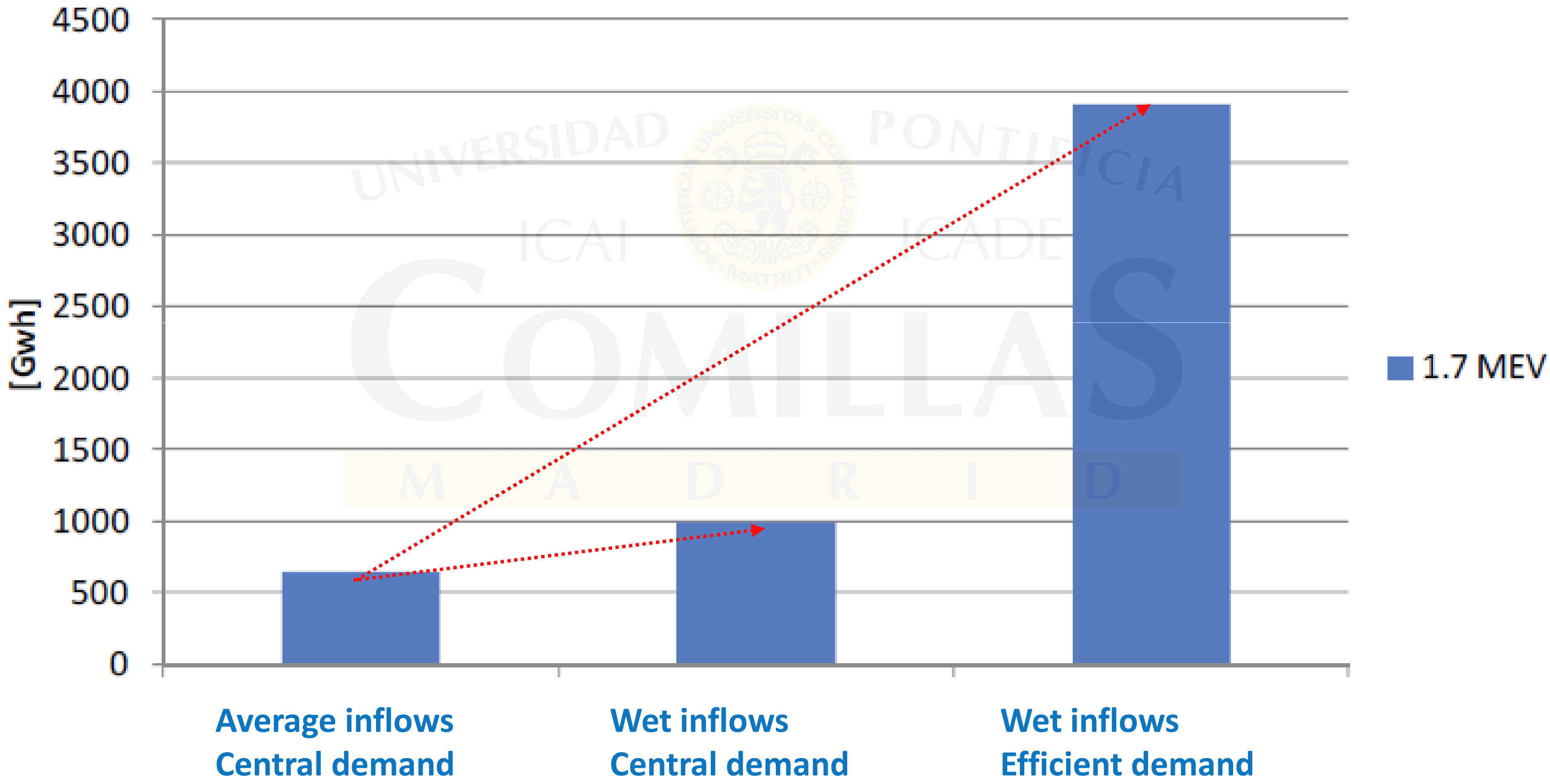
- An efficient (reduced) demand may multiply by four the WG curtailment, increasing the value of smart charging



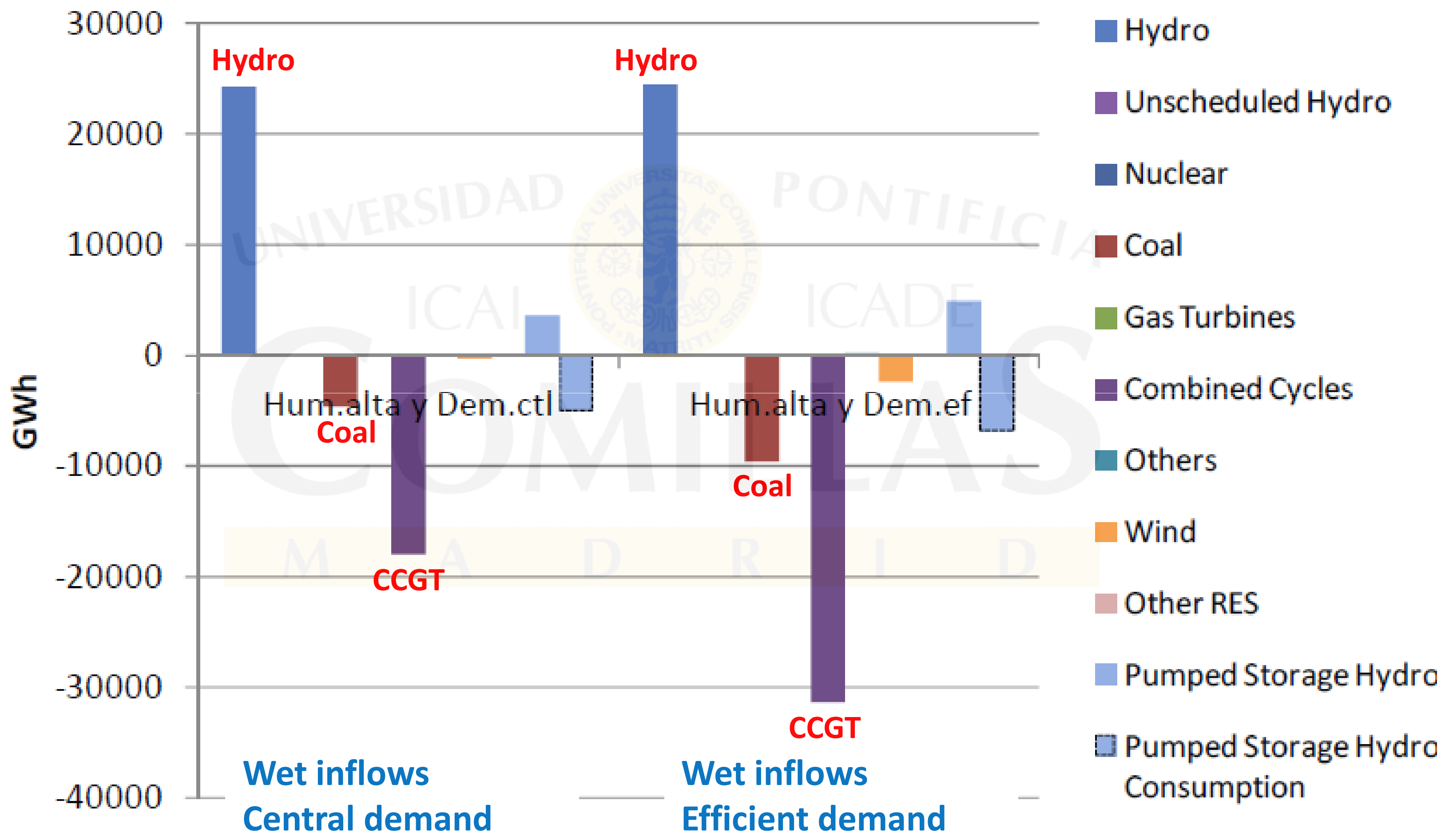
Yearly WG curtailment. Effect of efficient demand



Yearly WG curtailment. Effect of hydro inflows



Production by technologies (wet scenario with reference demand or efficient demand)



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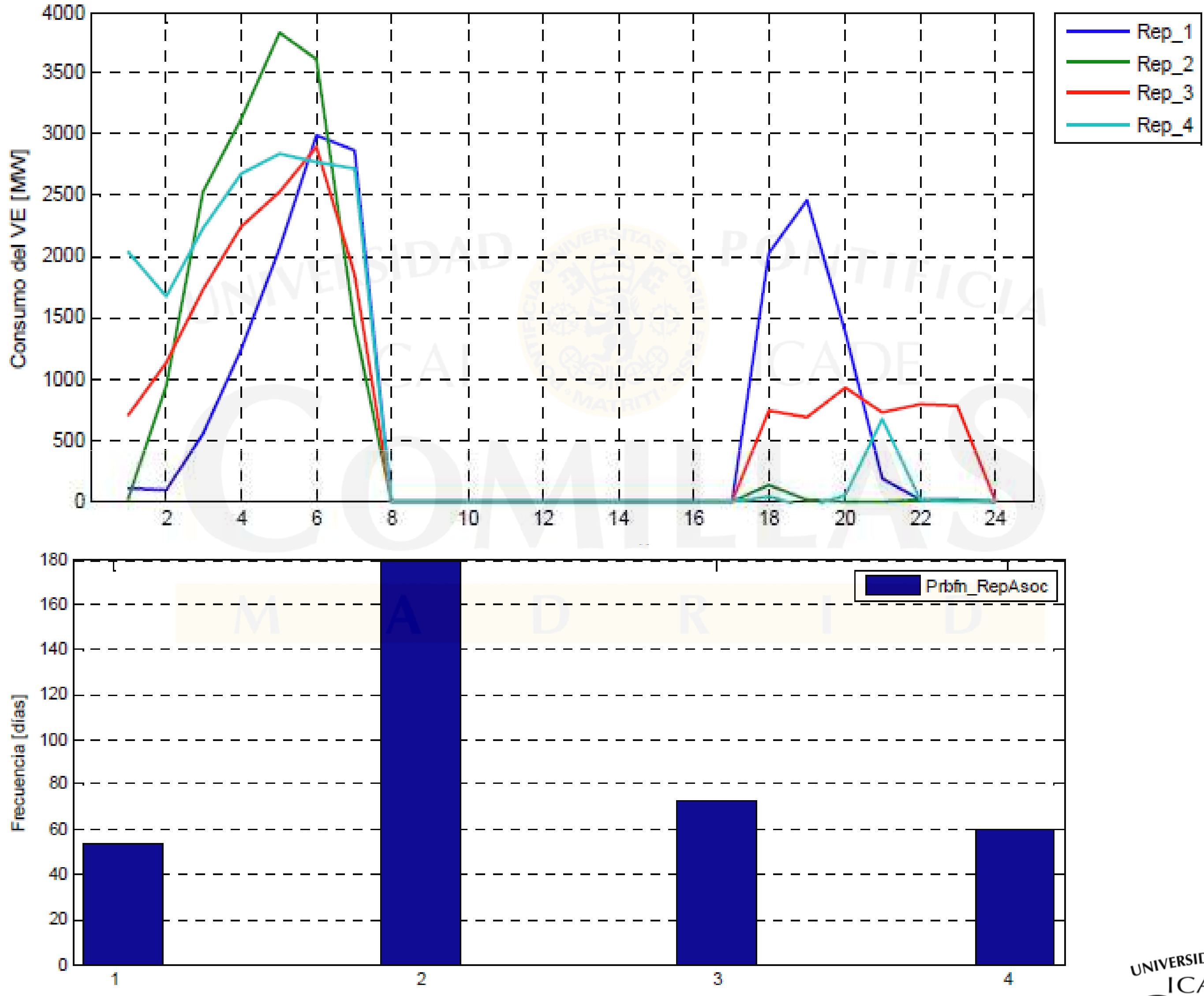
Design of optimal EV charging strategies for Spanish reference case

Idea

- Obtain some few clusters that represent EV charging profiles
- Substitute daily system optimization of EV charging by the corresponding cluster

Clusters of EV charging profiles

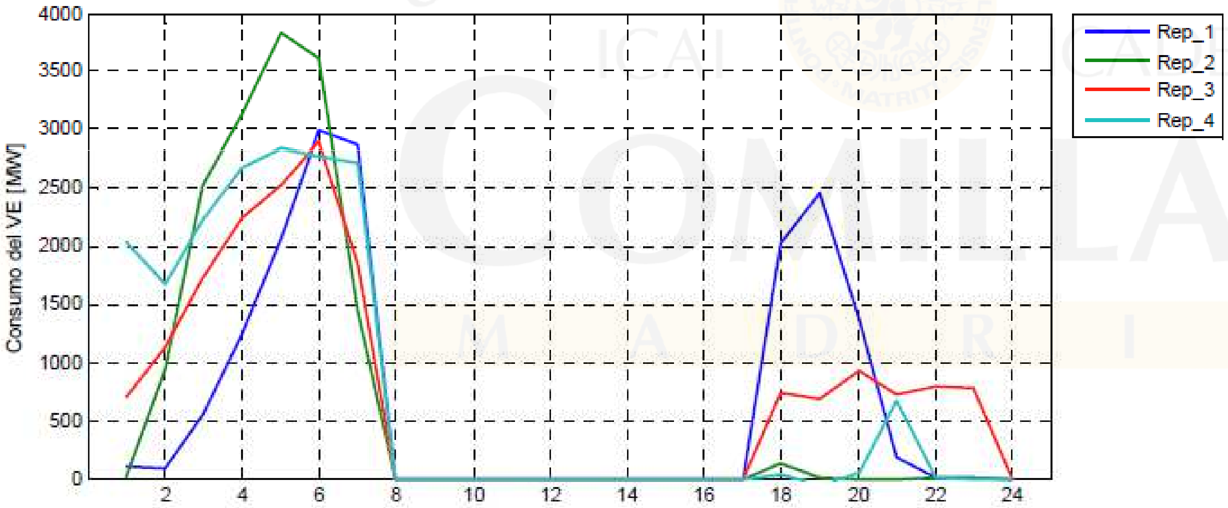


Association of clusters to days of the week

	Days of the week						
	M	T	W	Th	F	Sa	Su
1			3	2	2	4	4
2	2	3	2	2	2	1	3
3	2	2	2	3	3	3	5
4	2	3	2	2	2	3	5
5	3	3	2	2	2	3	4
6	2	2	2	2	2	3	4
7	2	2	2	2	2	5	6
8	3	3	2	2	2	3	4
9	2	2	2	3	3	3	4
10	2	2	2	2	2	3	3
11	3	2	2	2	3	2	3
12	2	2	2	2	2	2	4
13	2	2	1	2	2	3	5
14	3	2	2	3	3	4	4

Simulation of system operation with EV charging clusters

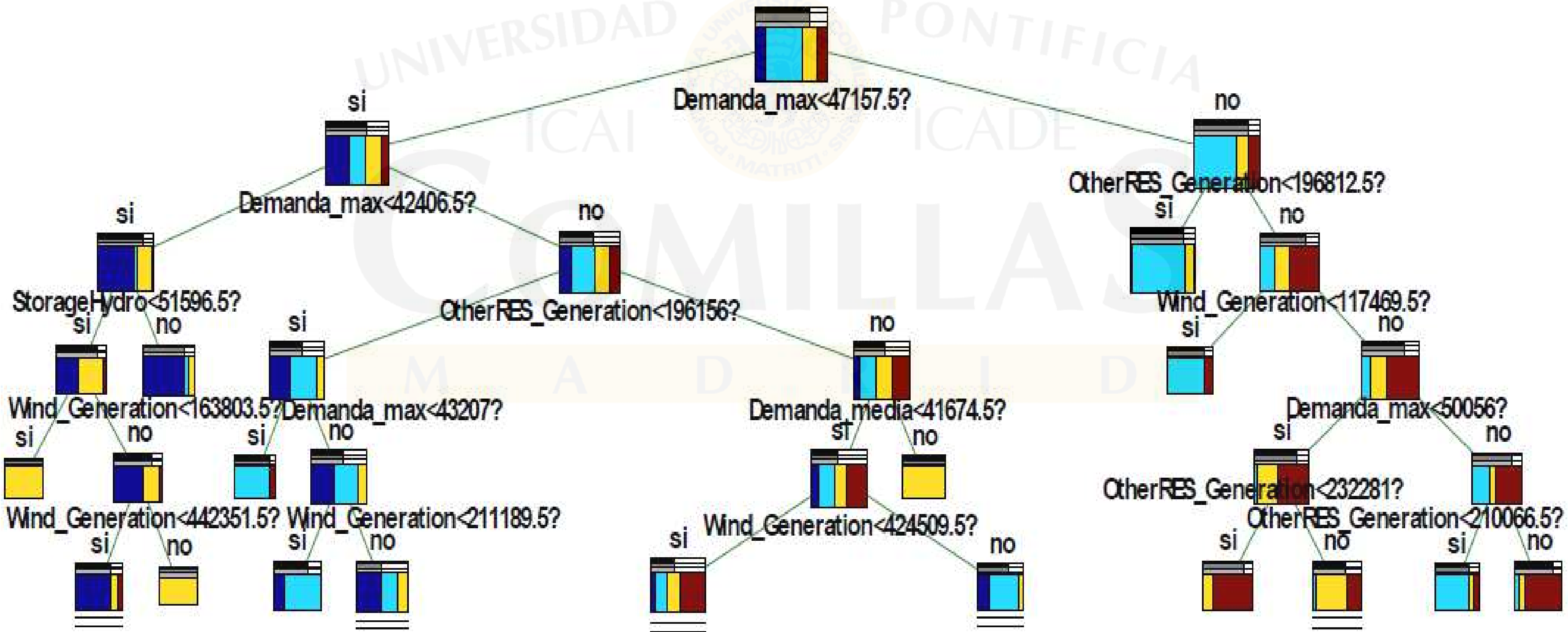
- The yearly operation of the electric system is simulated based in these EV charging profiles



SEMANAS	DÍA DE SEMANA						
	L	M	X	J	V	S	D
1			2	2	2	2	2
2	2	3	2	2	2	1	2
3	2	2	2	2	2	1	1
4	2	2	2	3	2	2	1
5	2	2	2	2	2	1	1
6	2	2	2	2	2	2	1
7	2	2	2	2	2	3	1
8	2	2	2	2	2	1	2
9	2	2	2	3	3	2	1
10	3	2	2	2	2	3	1
11	2	2	2	2	2	2	2
12	2	2	2	2	2	2	1
13	2	2	2	2	3	1	1
14	2	2	2	1	1	1	1
15	2	2	3	3	3	1	2
16	1	2	3	1	2	1	1
17	2	2	2	2	3	1	1
18	1	2	4	2	3	1	1
19	2	3	3	1	3	1	1
20	2	4	4	2	2	1	3
21	3	2	3	2	1	1	1
22	3	3	4	3	3	3	3
23	3	3	3	3	4	4	1
24	3	4	3	3	4	1	1
25	2	4	4	3	4	4	1
26	2	4	4	3	4	3	1
27	4	4	3	3	4	3	1
28	4	4	3	4	3	3	3
29	3	4	4	4	4	3	3
30	2	4	3	4	4	4	1
31	2	4	3	4	4	3	1
32	4	3	4	4	4	3	3
33	4	3	4	3	4	1	1
34	4	4	4	4	4	1	3
35	4	4	4	3	4	4	4
36	2	2	4	4	3	3	1
37	2	2	4	2	3	4	3
38	2	3	2	2	2	2	3
39	2	2	2	4	4	2	2
40	2	4	3	2	4	2	1
41	2	1	2	4	2	3	2
42	2	2	2	2	2	1	1
43	3	2	2	2	2	2	3
44	2	4	2	2	2	2	2
45	2	3	2	2	2	2	1
46	2	2	2	2	2	2	1
47	2	2	2	2	2	3	2
48	2	2	2	2	2	2	3
49	3	2	2	2	2	2	2
50	2	2	2	3	2	2	2
51	2	2	2	2	3	2	2
52	2	2	2	2	3	1	2
53	2	2	2	2			

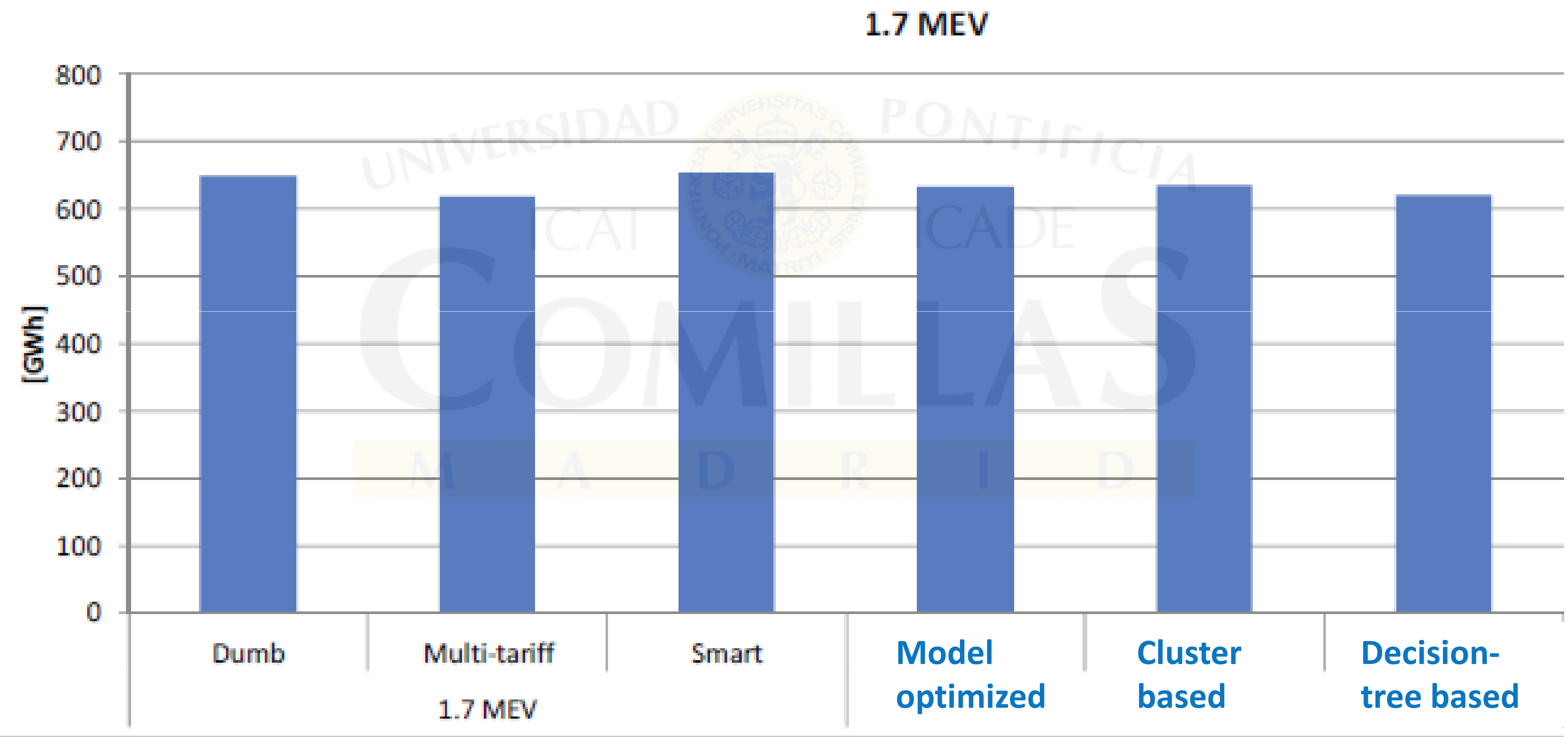
Decision tree to select each cluster

- Which are the differences among clusters (therefore, among different EV charging profiles)?



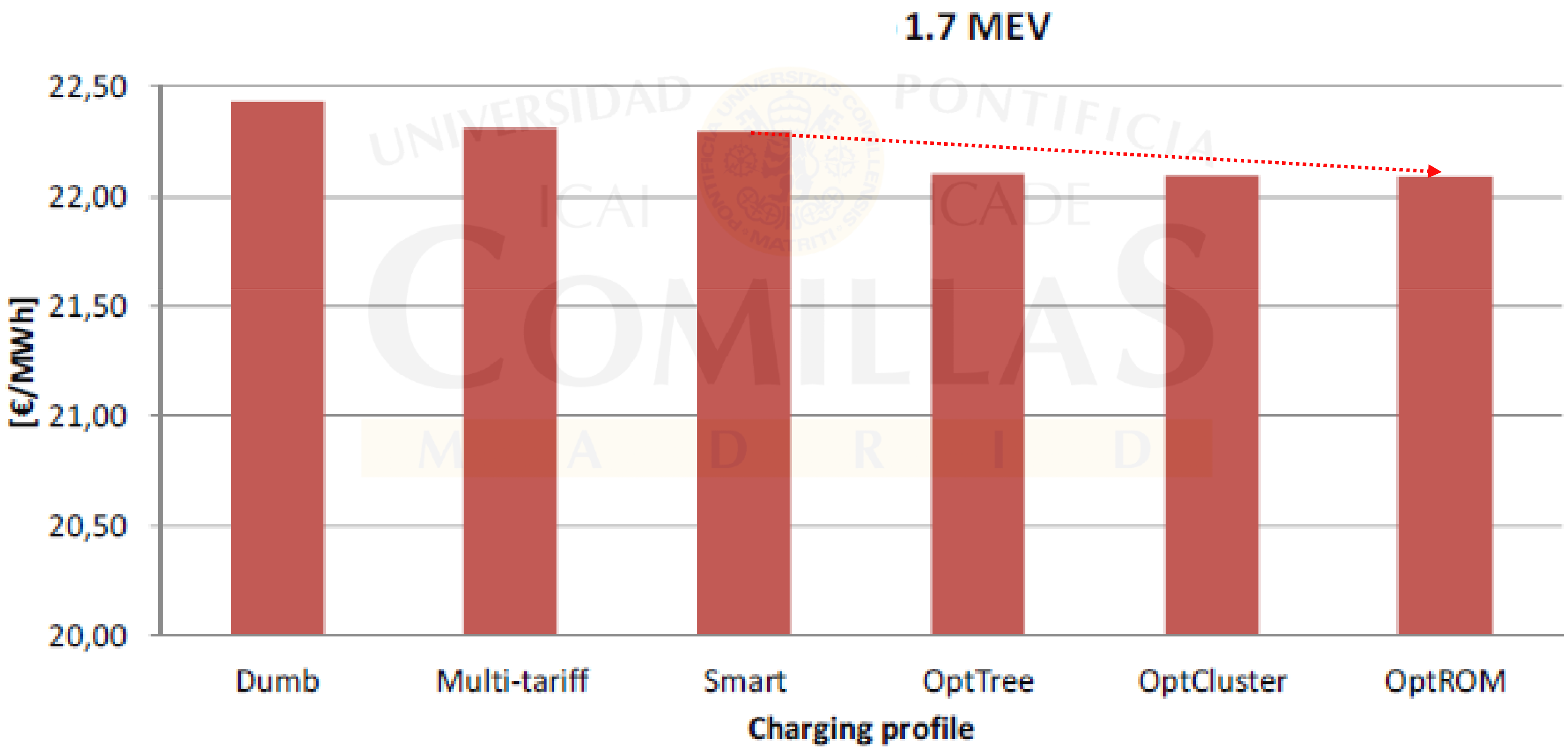
Yearly WG curtailment. Effect of EV charging strategies

- No major differences in WG curtailment



Yearly WG curtailment. Effect of EV charging strategies

- … but it affects the operation costs



Conclusions for the Spanish system

- WG curtailment decreases with the number of EV. To observe this effect it is needed a high share of EV (1.7 MEV)
- WG curtailment decreases with the intelligence of the EV charging but this effect is observable only with high share of EV
- Increase in operation costs due to the additional demand of the EV, limited if intelligent charging is applied

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Greek reference case

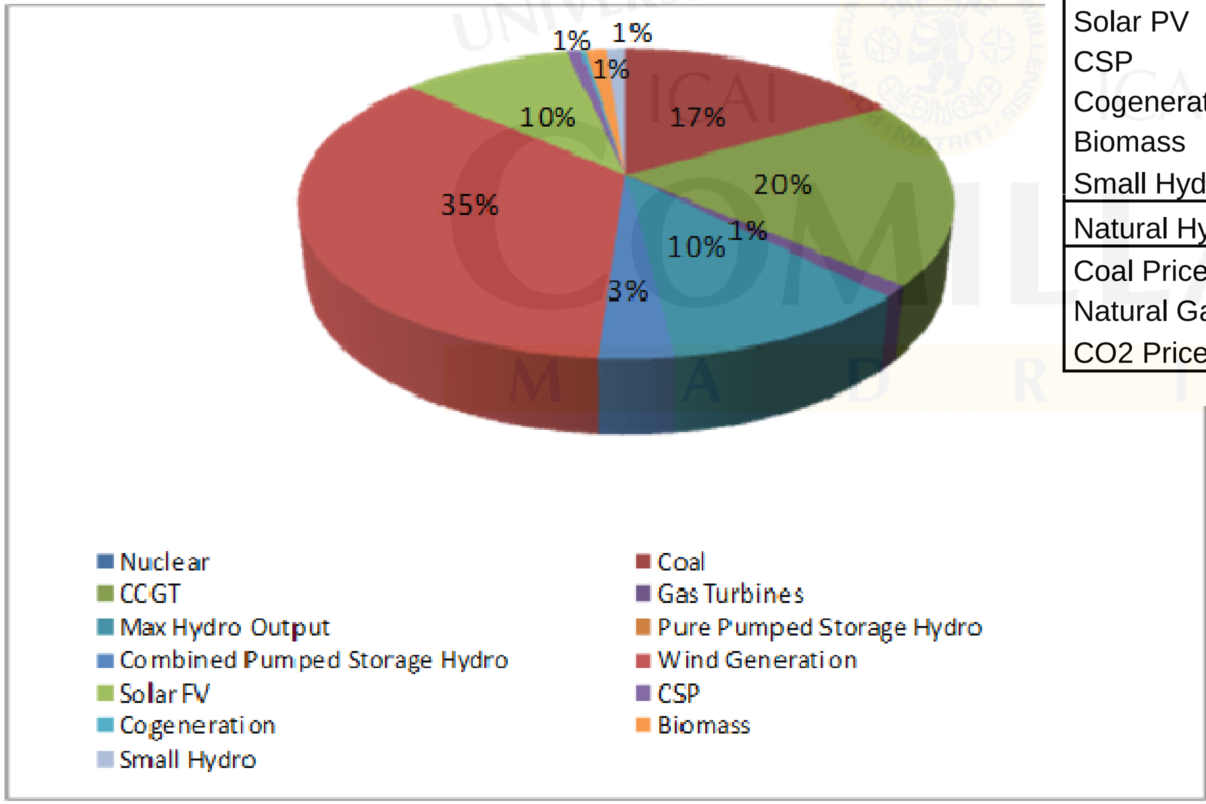
Input data for Greece

- General electric system information

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

Input data for Greece

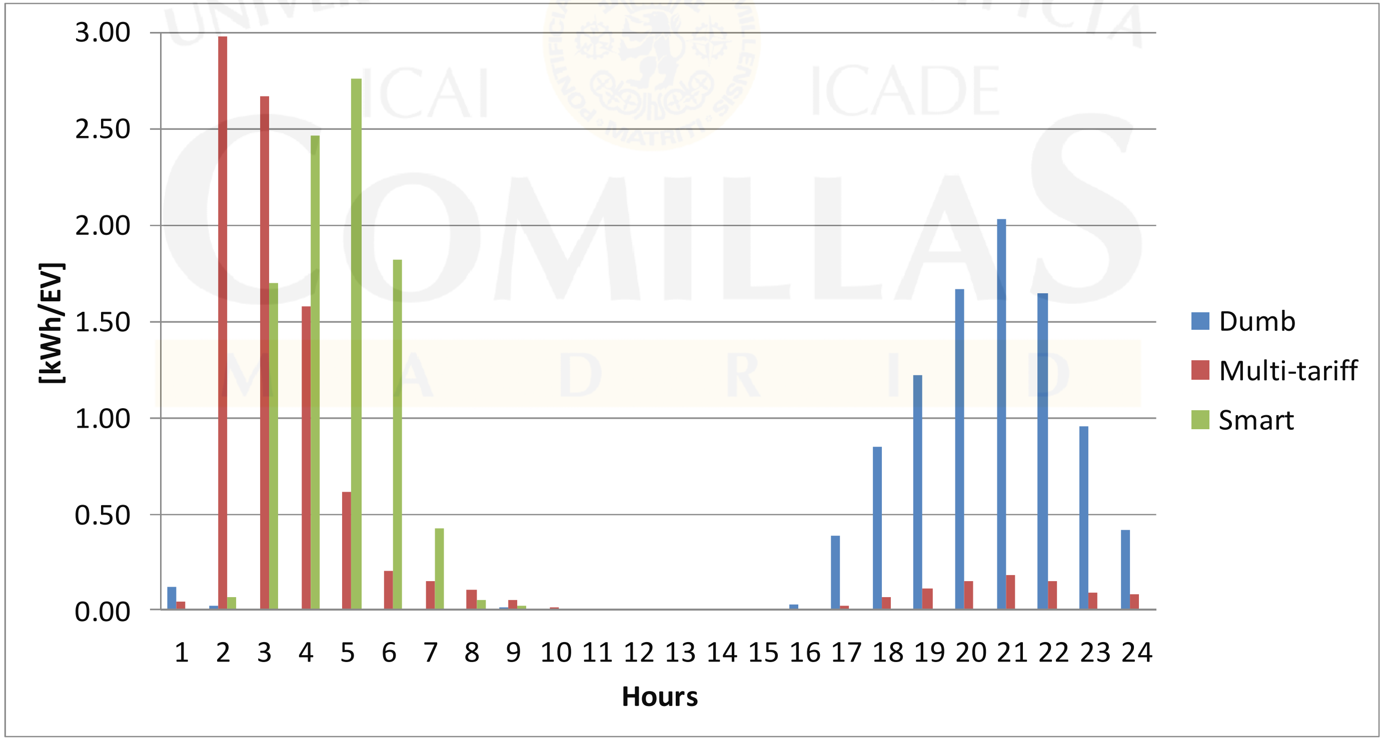
- Generation mix



2020 case study		
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

Input data for Greece

- Electric vehicles
  - Penetration of 34000, 70000 and 142000 EV (~0.5%, 1% and 2% of the total number of vehicles)
  - Pre-defined charging profiles



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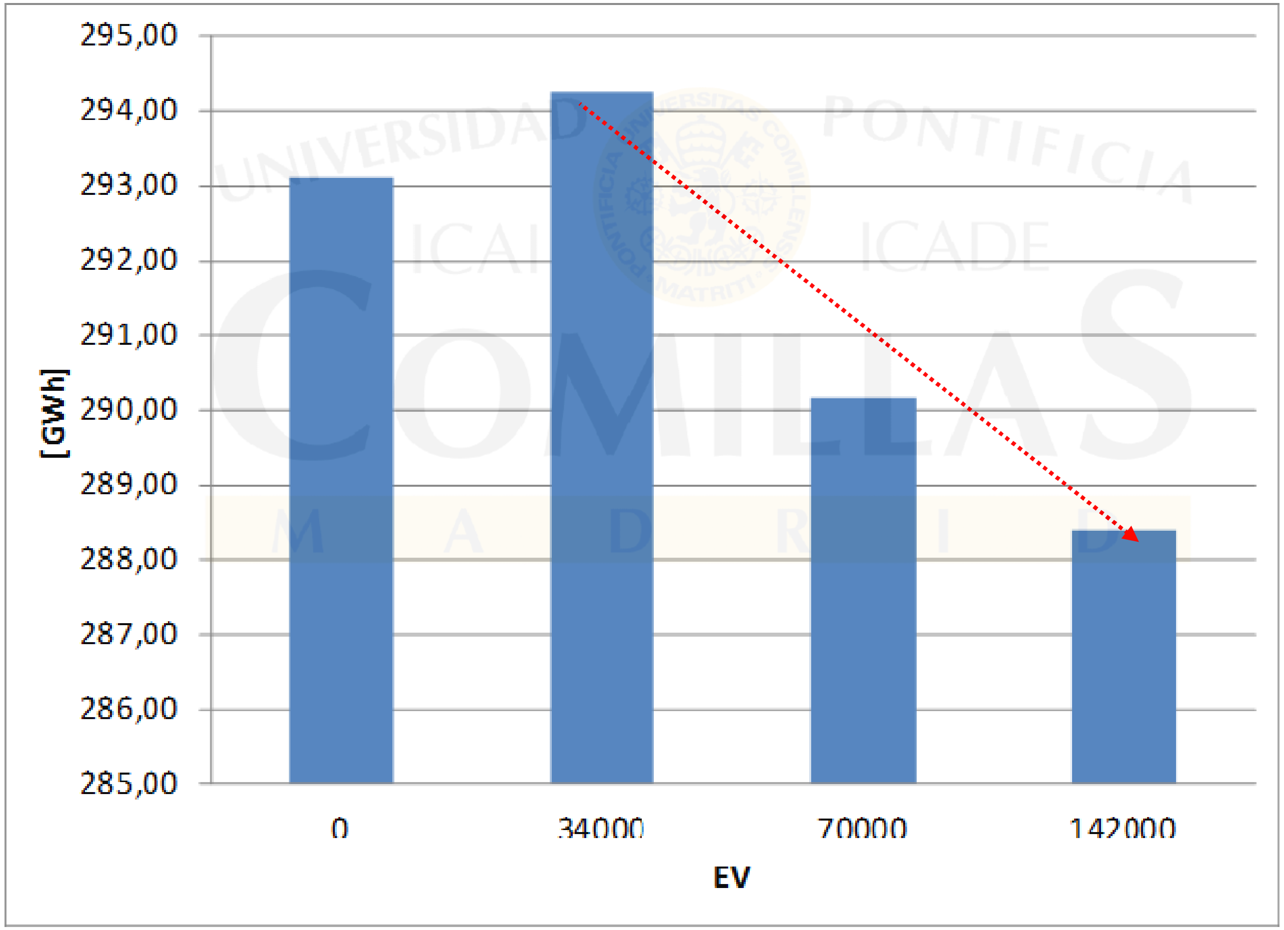
Analysis of Greek reference case

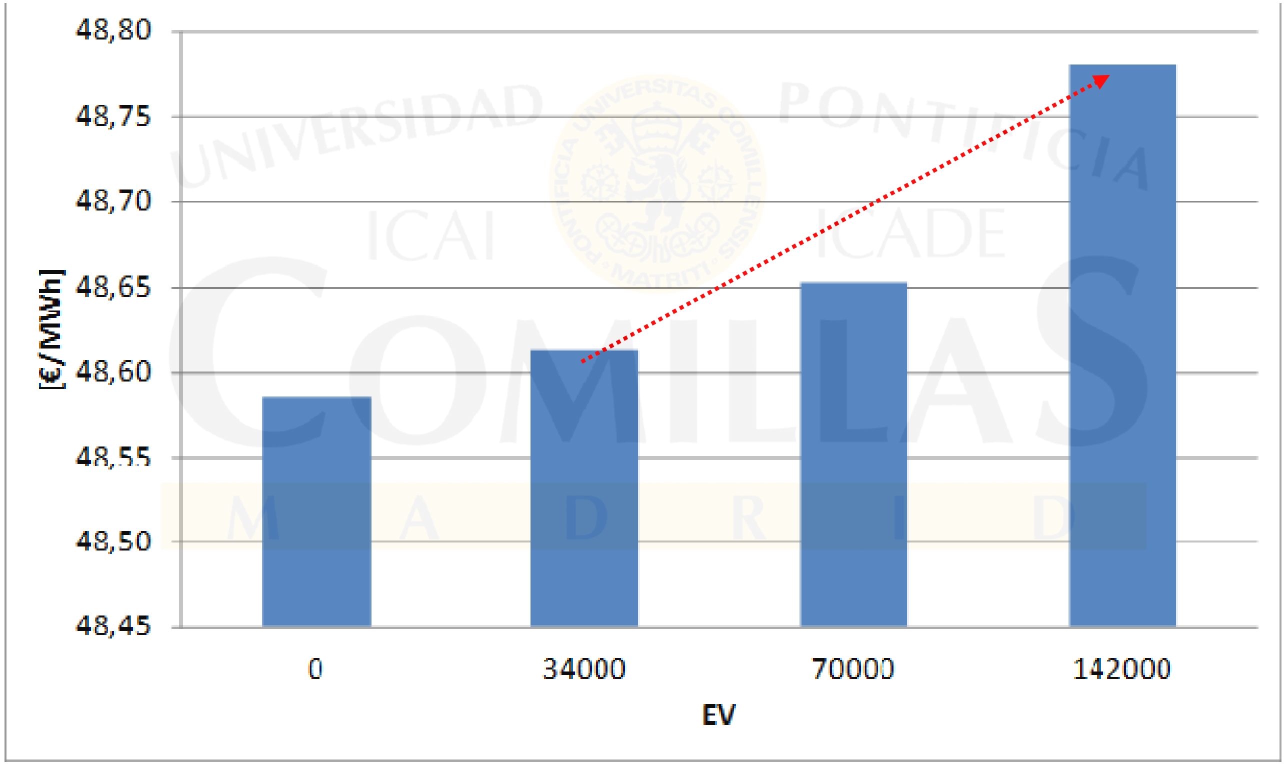
Yearly WG curtailment

- With EV smart charging, workdays



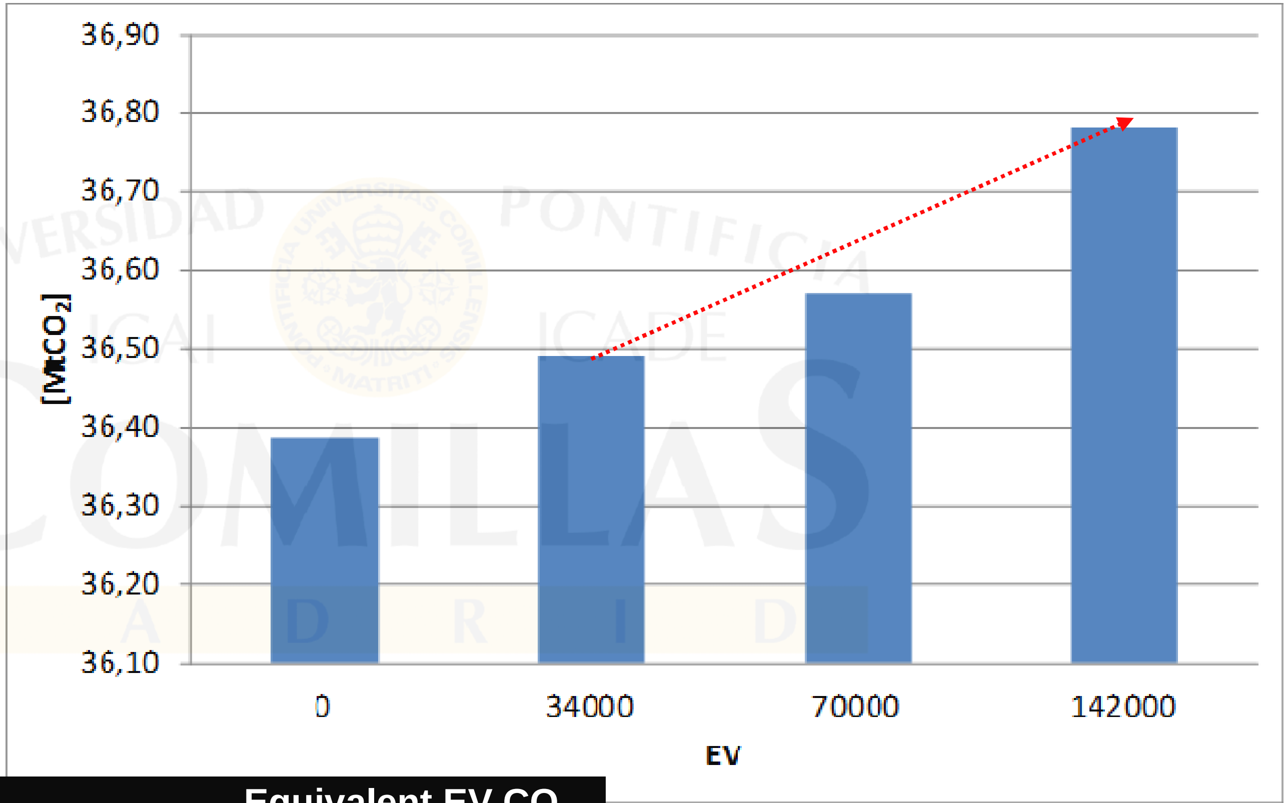
Yearly specific cost

- With EV smart charging, workdays



Yearly CO2 emissions

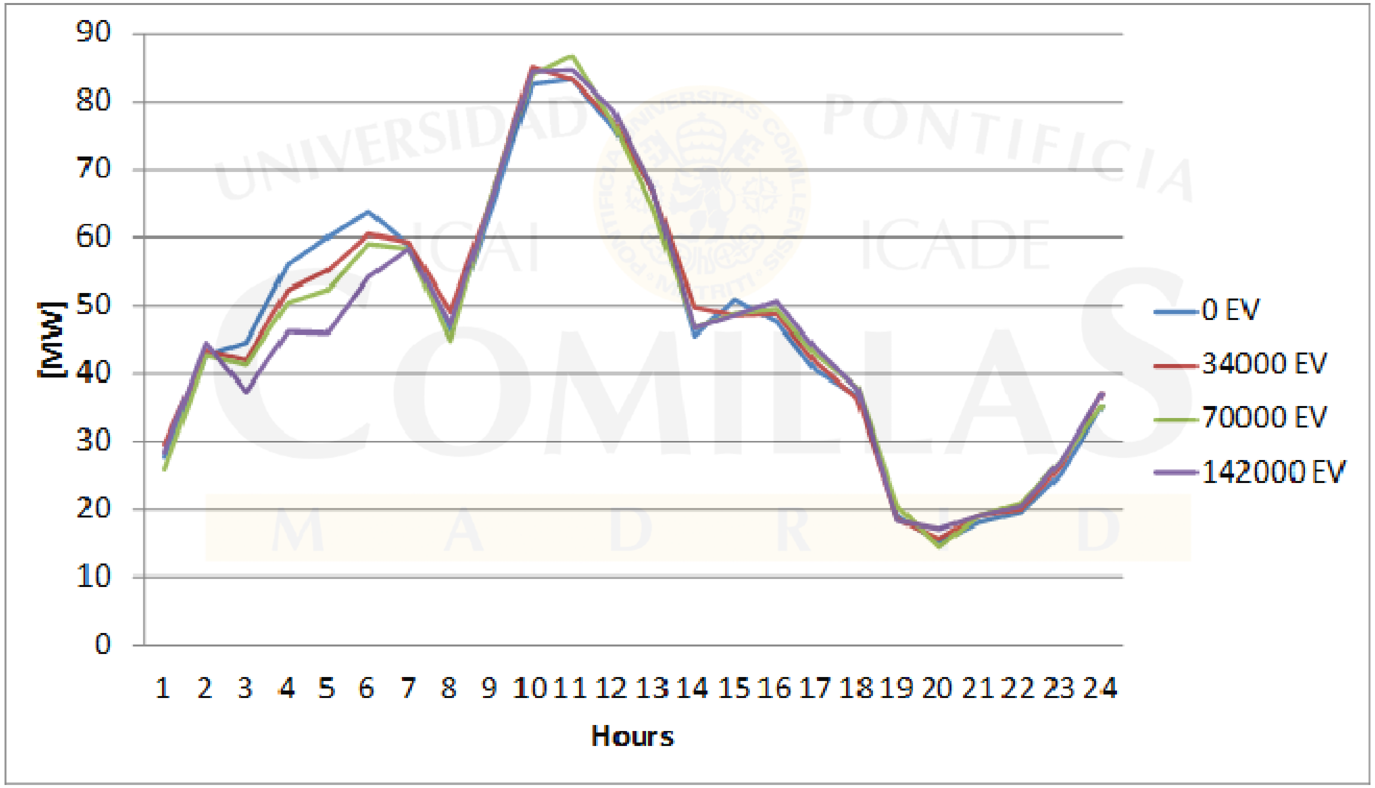
- With EV smart charging, workdays



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

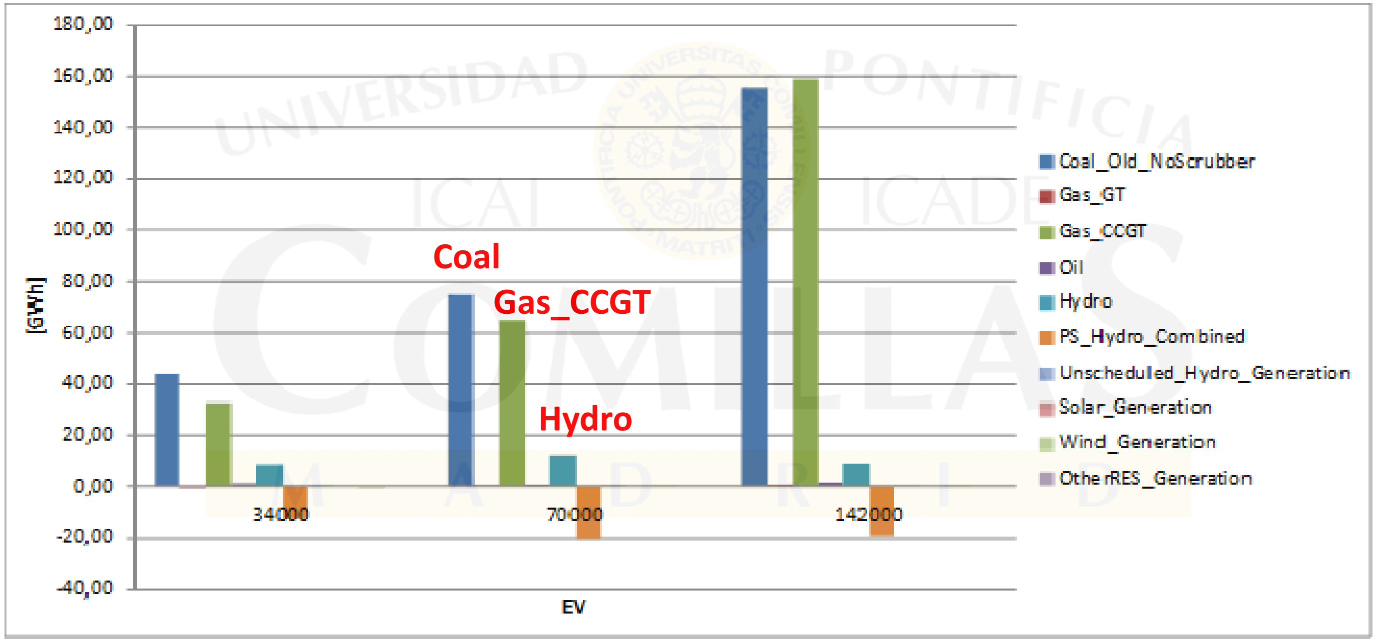
Daily WG curtailment

- With EV smart charging, workdays



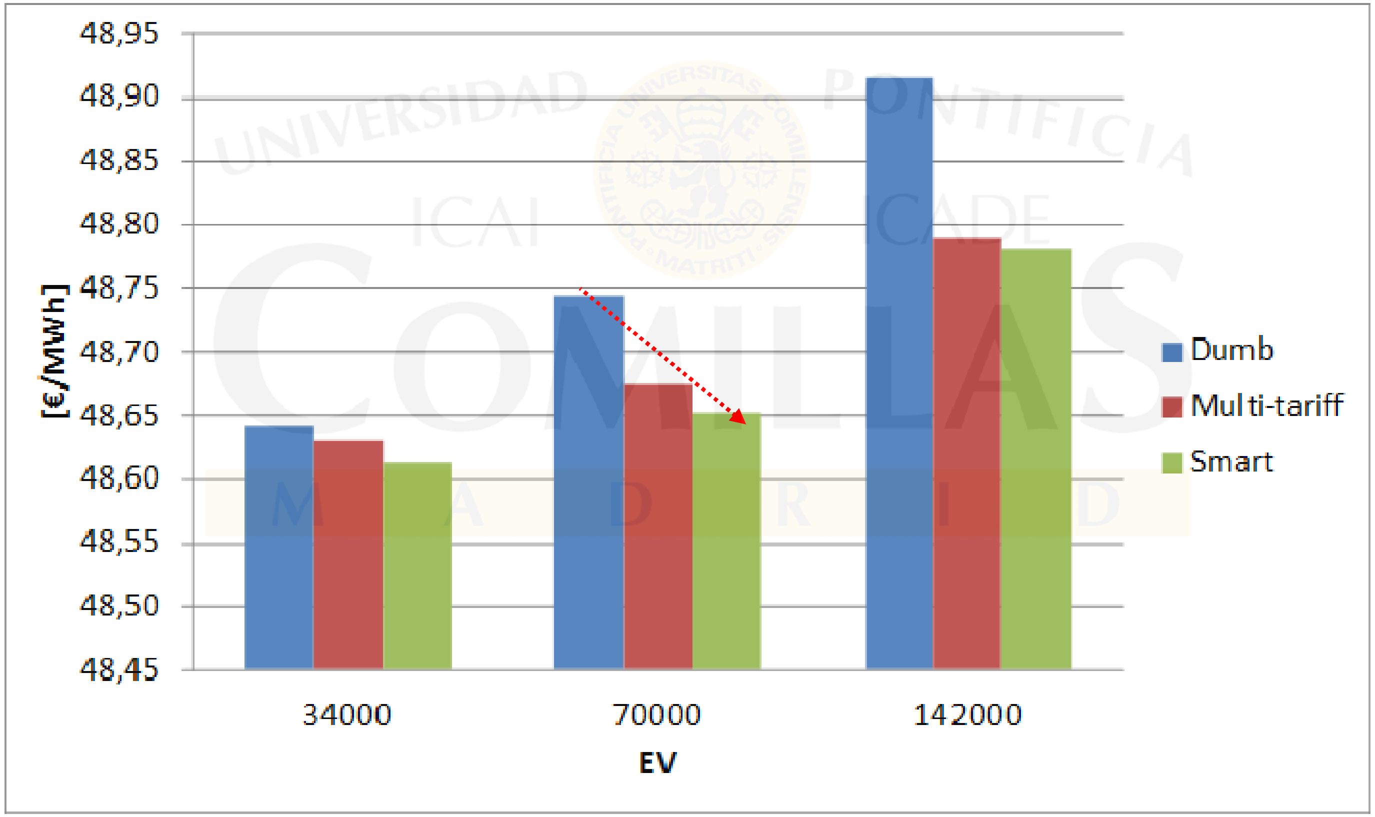
Production by technologies

- With EV smart charging, workdays



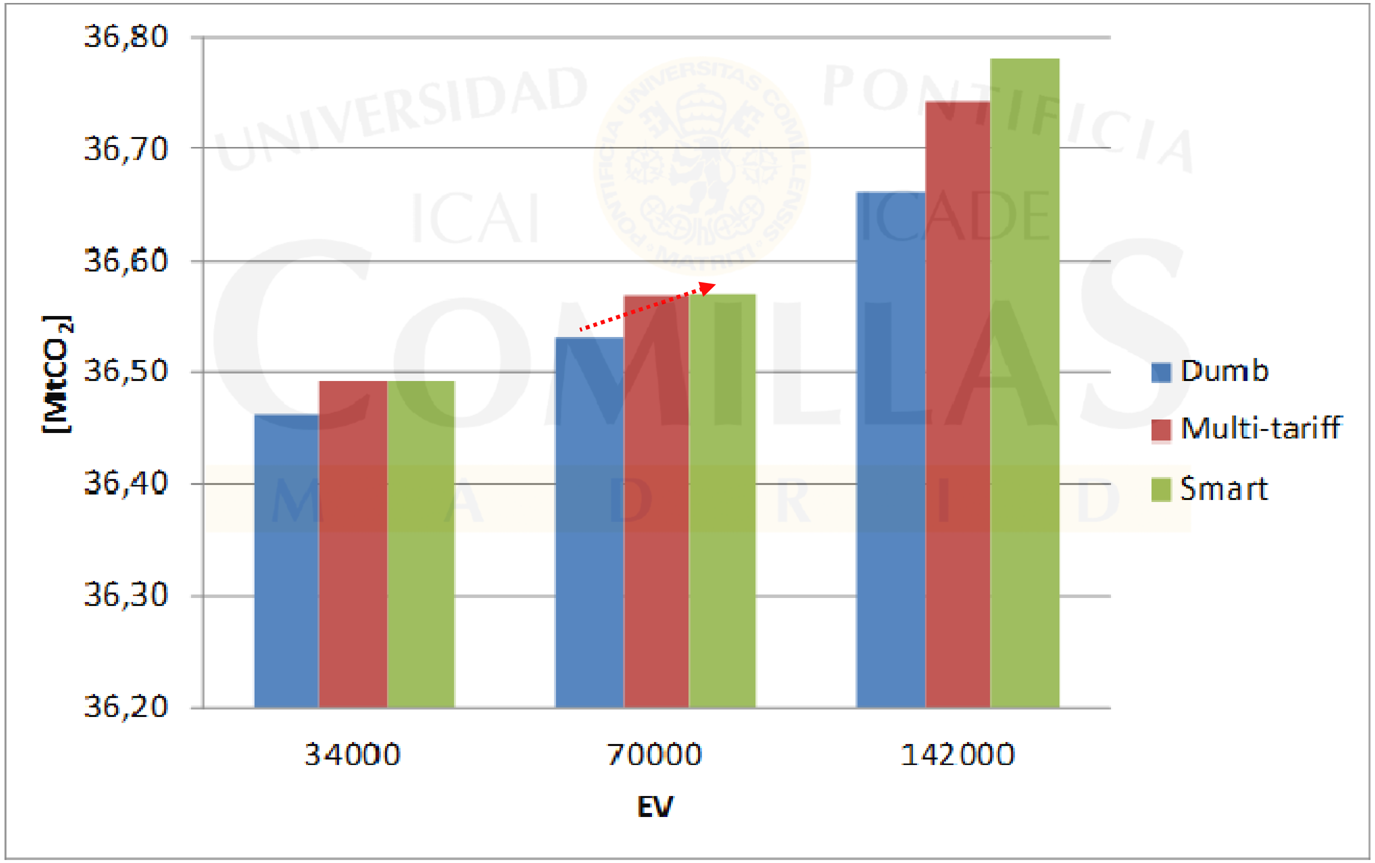
Yearly specific cost

- For each EV charging profile, workdays



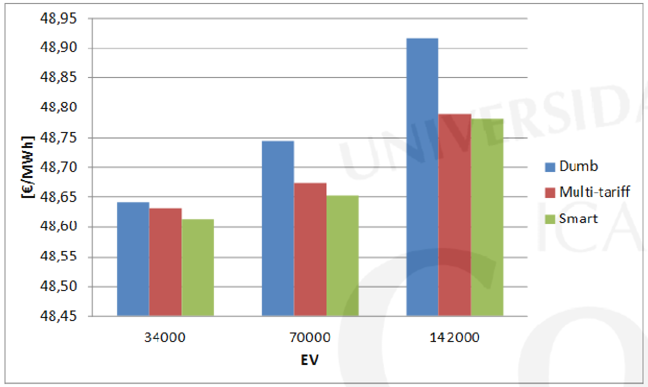
Yearly CO2 emissions

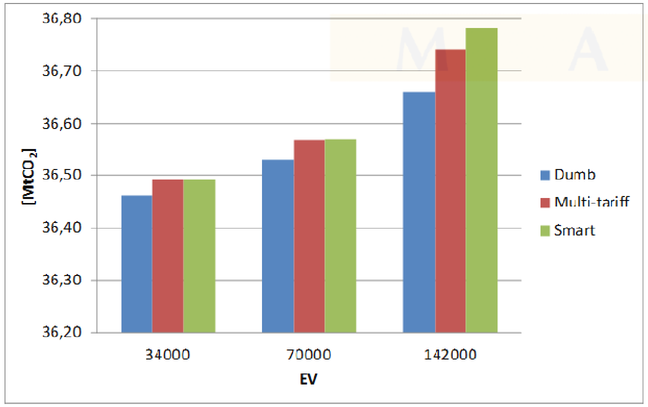
- For each EV charging profile, workdays

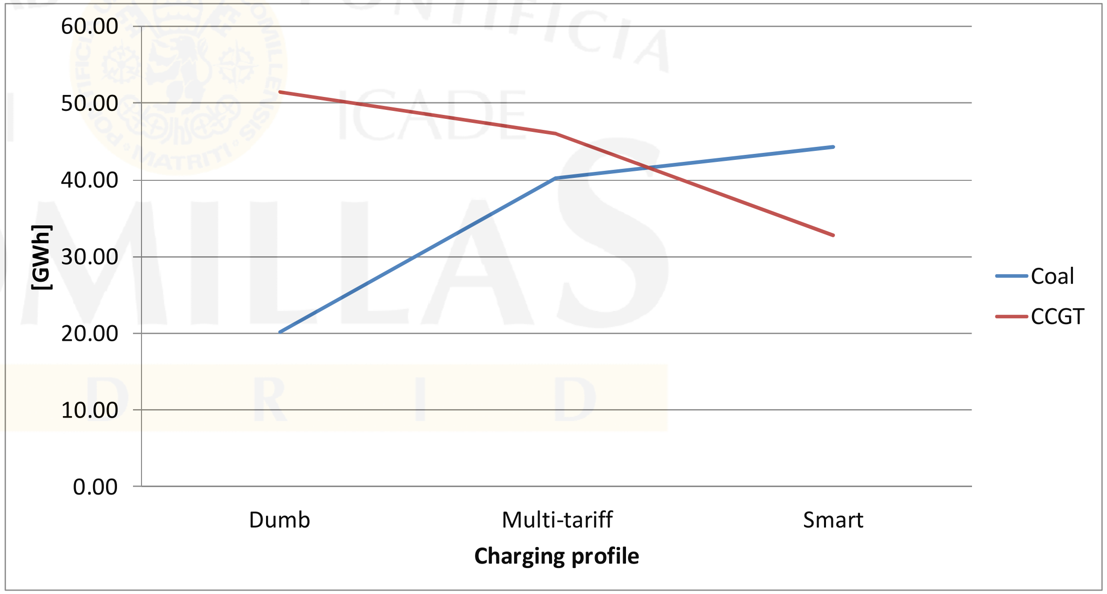


Yearly specific cost and CO2 emissions

- For each EV charging profile, workdays (34000 EV)

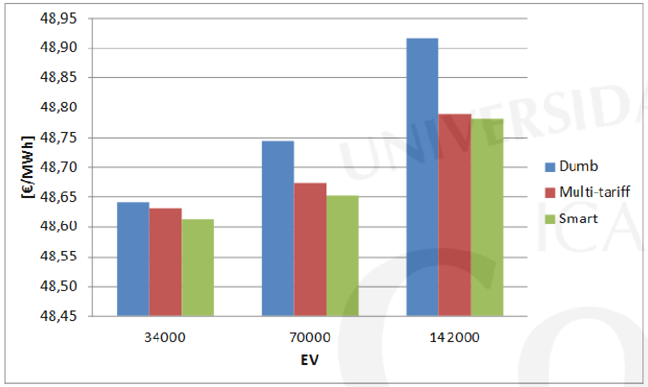


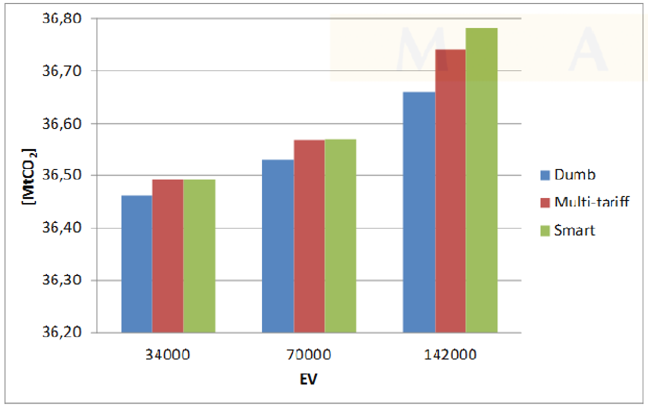


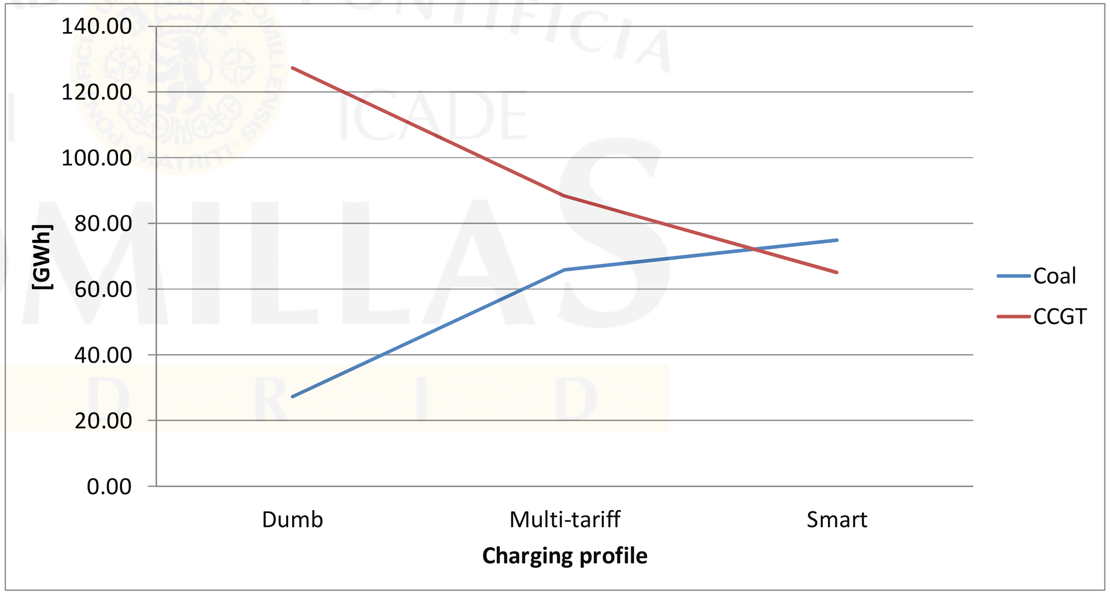


Yearly specific cost and CO2 emissions

- For each EV charging profile, workdays (70000 EV)

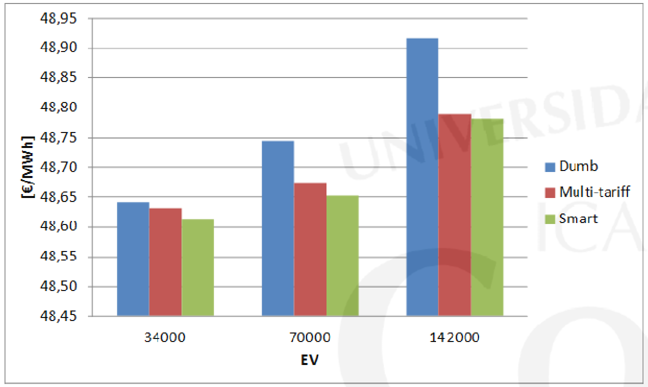


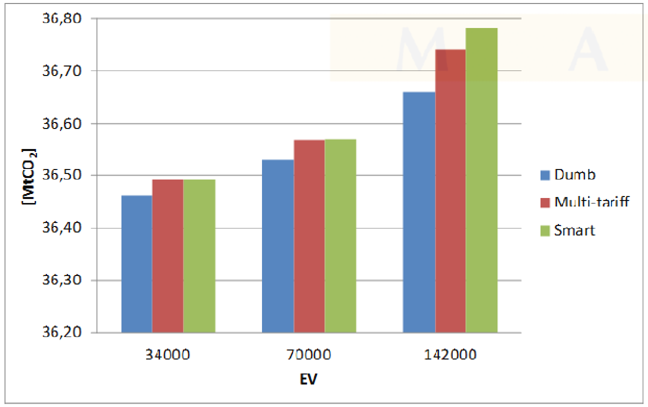


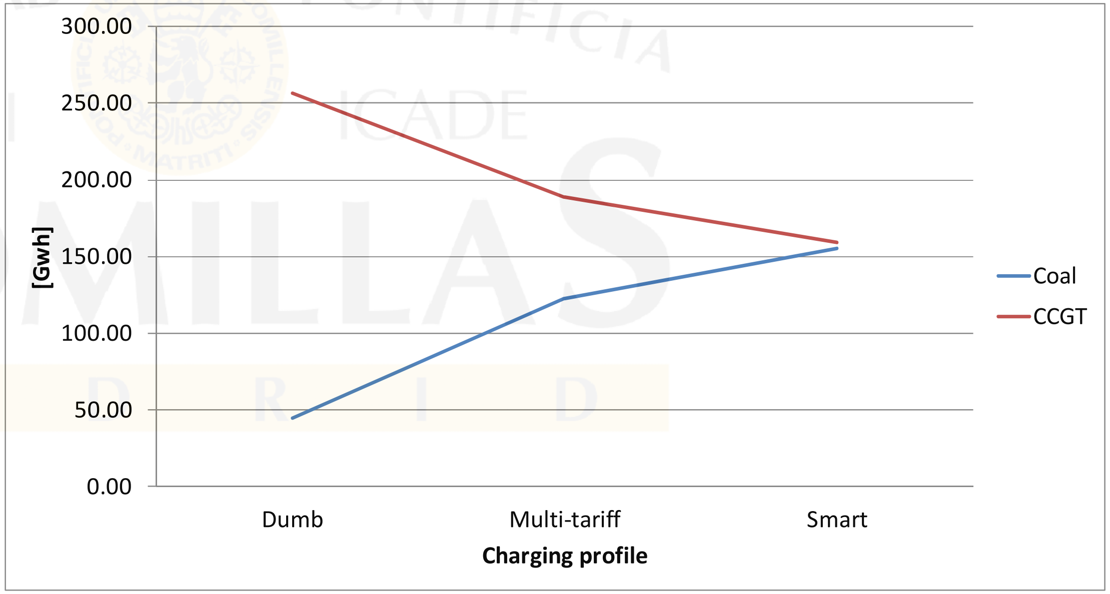


Yearly specific cost and CO2 emissions

- For each EV charging profile, workdays (142000 EV)

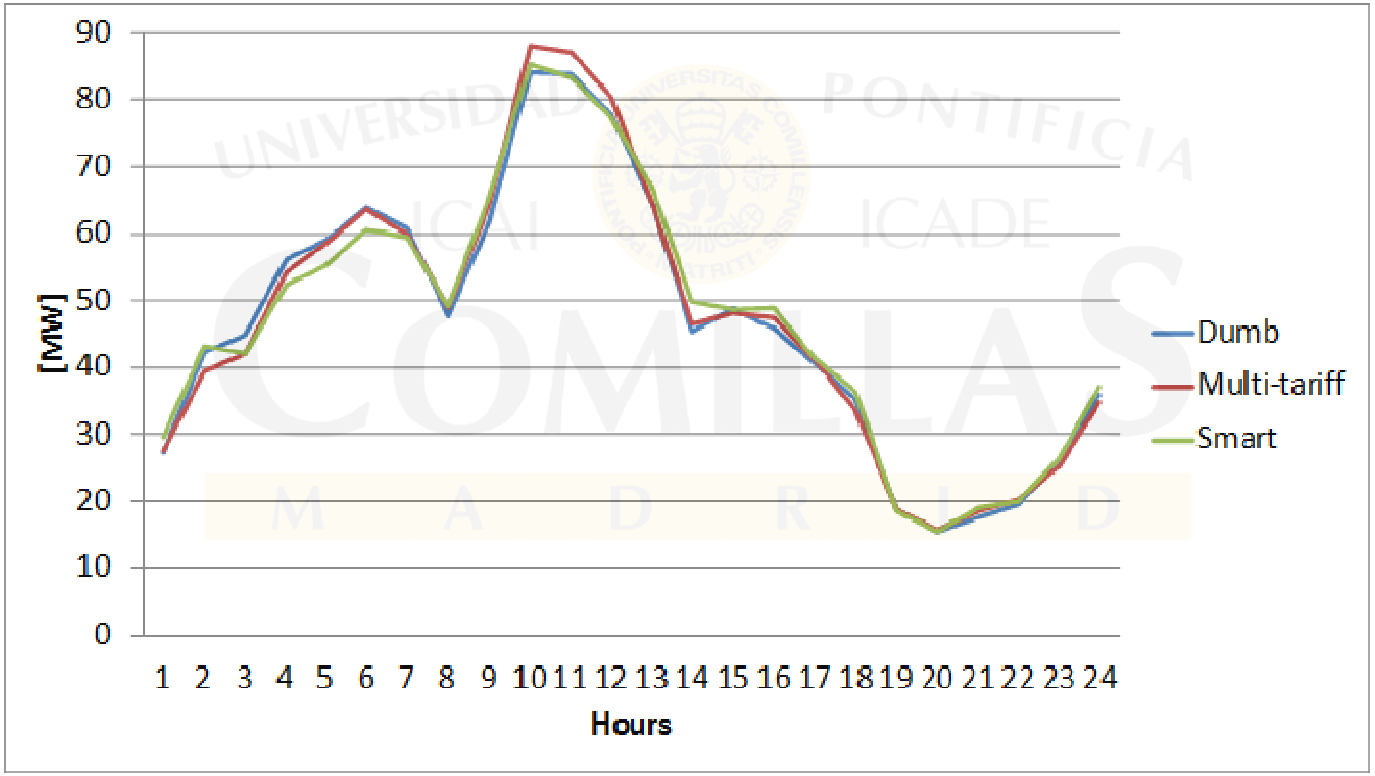






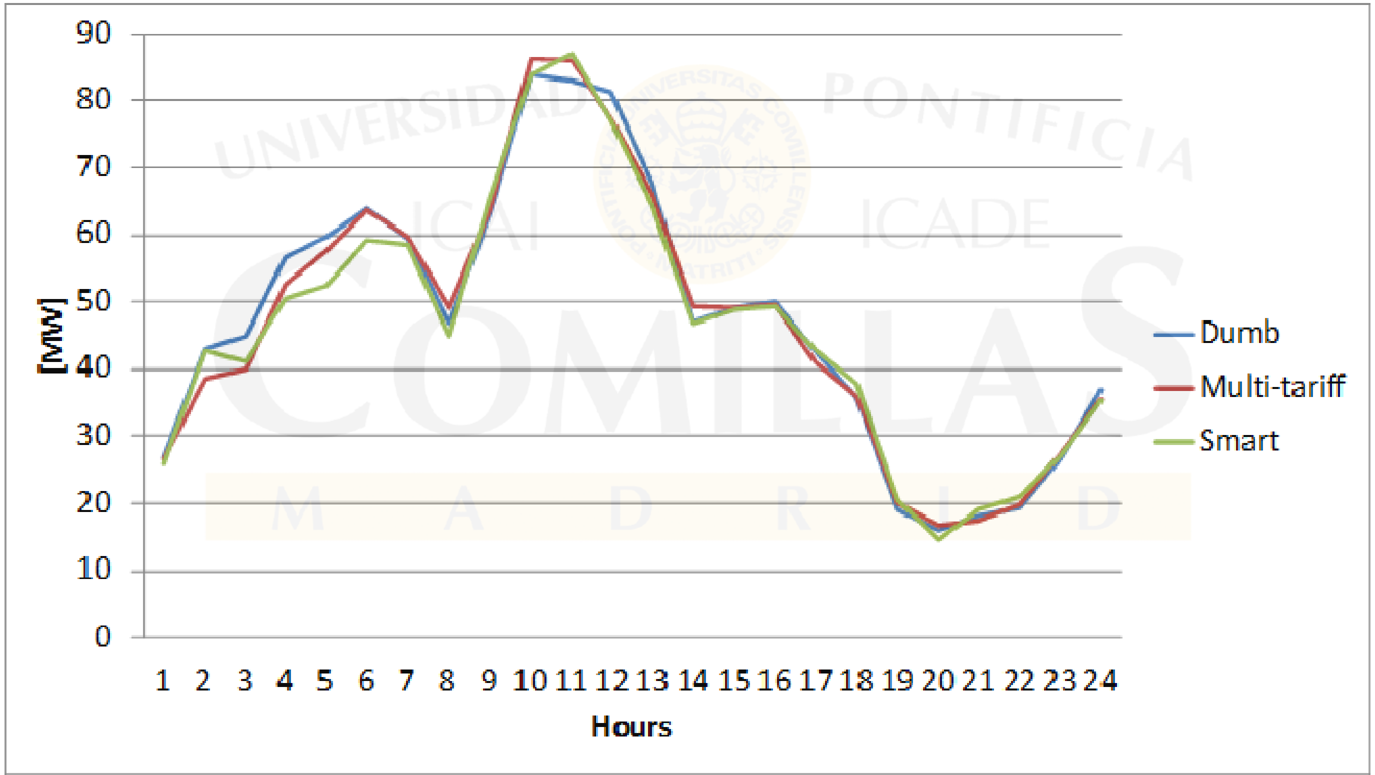
Daily WG curtailment

- For each EV charging profile, workdays (34000 EV)



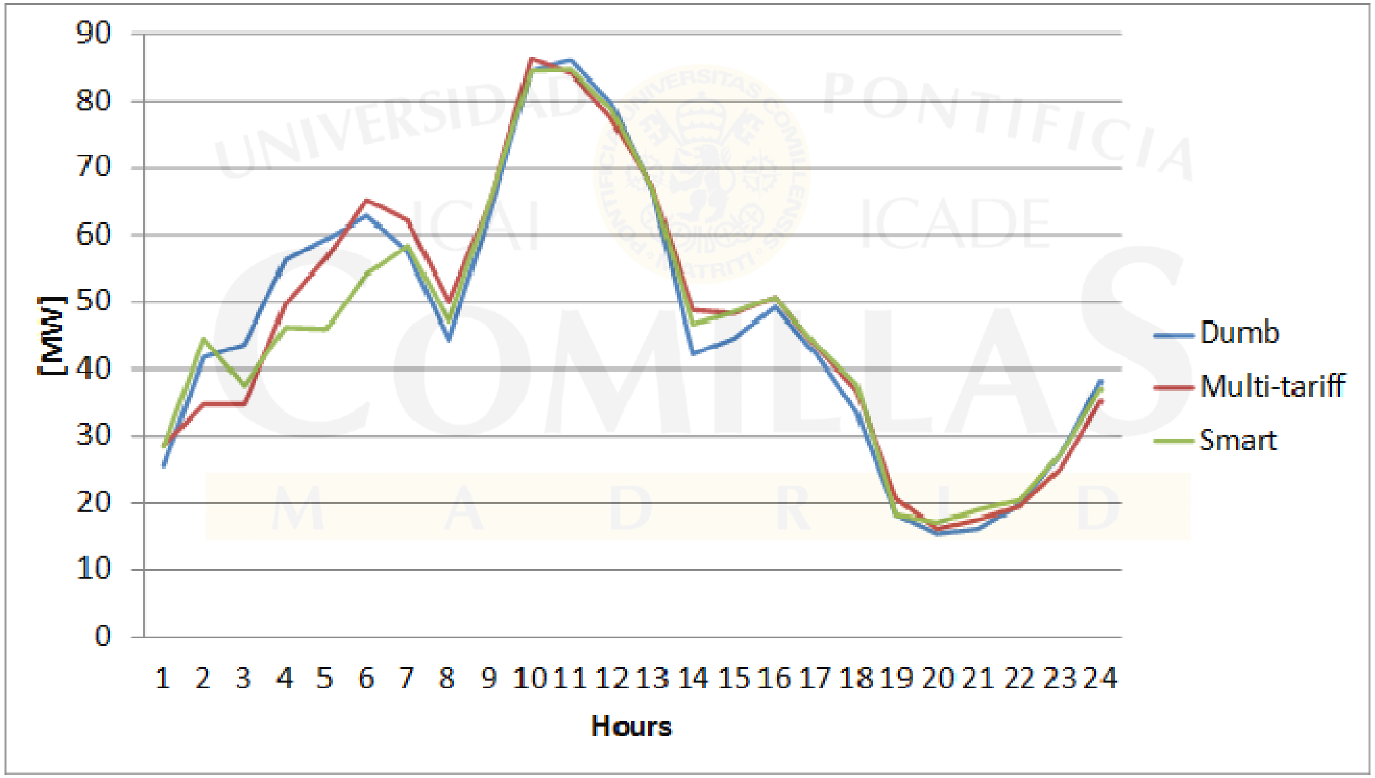
Daily WG curtailment

- For each EV charging profile, workdays (70000 EV)



Daily WG curtailment

- For each EV charging profile, workdays (142000 EV)



Conclusions for the Greek system

- WG curtailment is reduced with large amounts of EV
  - Except for very low penetration shares
- Equivalent CO_2 emissions for the EV
  - 159-187 g CO_2/km
- Charging strategy (for WG curtailment reduction)
  - At midday hours

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