Eceee 2019 Summer Study
on energy efficiency
3-8 June

Grid to Vehicle and Vehicle to Grid Systems for Large-Scale Penetration of Renewable Generation

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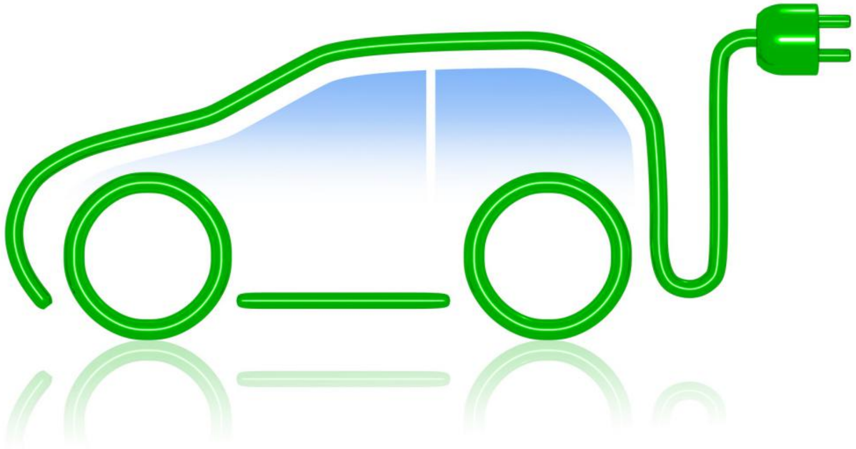
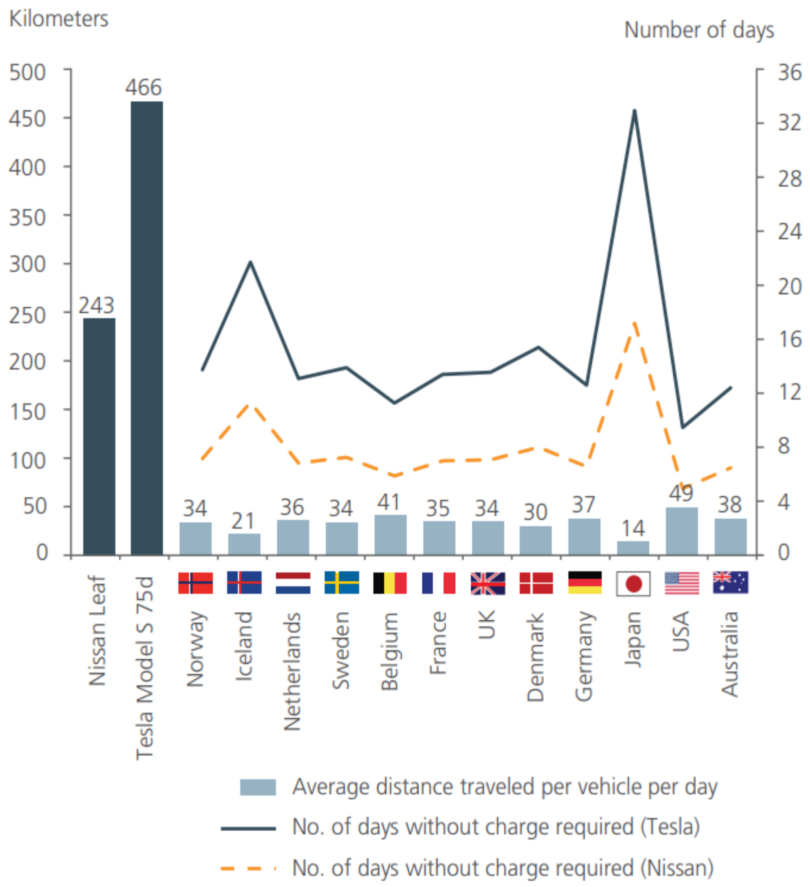
Introduction



- The increasing market of EVs will be responsible for a growing consumption of electricity.
- The generation mix is increasingly based on distributed, intermittent and non-dispatchable sources, being more difficult to ensure the balance between generation and demand.
- It will be fundamental to have new technologies to provide flexibility, mainly energy storage and Demand Response.
- EVs can have an important role, being used as controllable loads, charging in periods with a high renewable generation or low prices, using the Grid to Vehicle (G2V) system.
- Additionally, EVs can also use some of their storage capacity to inject energy into the grid, using the Vehicle to Grid (V2G) system.

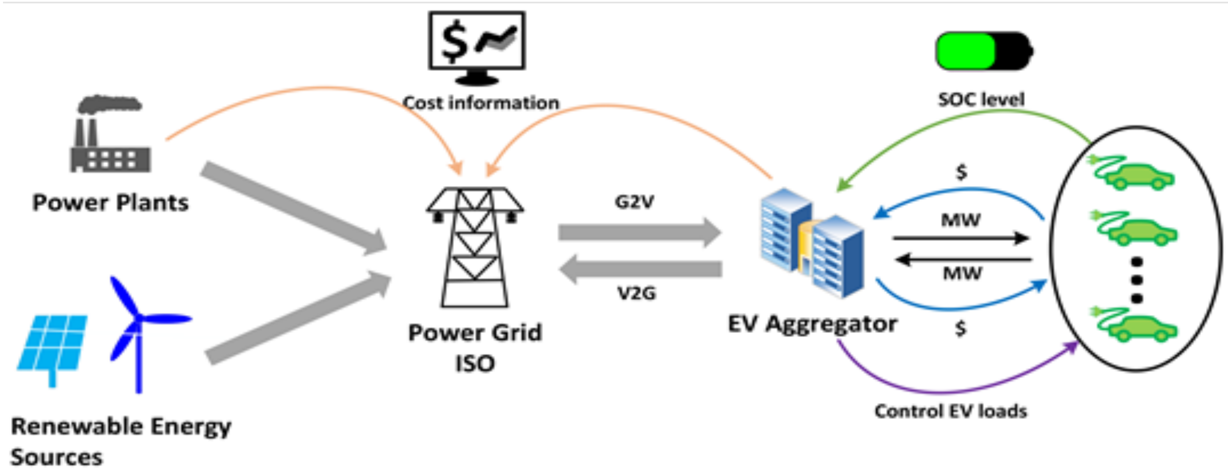
EV as Controllable and Intelligent Load

- The typical profile of the vehicle use is mainly based on pendular movements, traveling on average about 35 km per day in Europe, and being the vehicle parked about 95% of the time.
- The capacity of the batteries continues to increase and is already 30 - 100 kWh.
  - When traveling 35 km/day, only 5 - 8 kWh will be consumed per day.
- When parked, if the EV is connected to the grid, it can act as a controllable load, providing the service of demand following generation.



EV as Controllable and Intelligent Load

- The EV can thus be used as a controllable load when there is renewable generation surplus (G2V) and can inject some of this energy into grid when the generation is low (V2G).



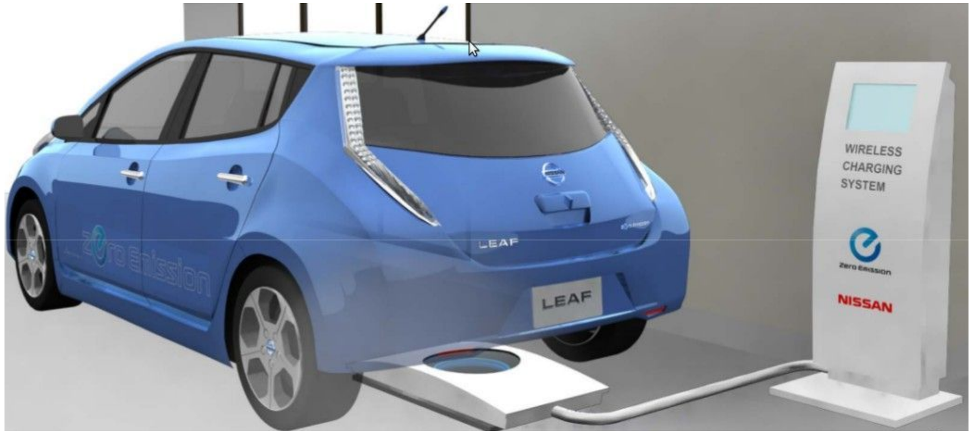
- With the fleet of EVs in each country strongly growing and considering the potential control of the EVs connected to the grid, when not used in transportation, a strong contribution to the system flexibility can be expected.
- It is possible to respond in real time to the intermittent generation variations by adapting groups of controllable loads and to contribute to maintaining the quality of service.

Support Technologies for G2V and V2G

- The current recharging systems are characterized by the use of cables and plugs without uniformity around the EU, being one of the main disadvantages the need to handle, and sometimes to carry, bulky cables.
- In the domestic and private environment, the recharging with cables will continue to make sense due to lower costs, easy implementation, and lower losses.
- In an external environment, this solution entails risks since the points of energy availability and cables constitute obstacles in the public road and are exposed to the possibility of vandalism and theft.
- The overcoming of the current system limitations includes the implementation of wireless inductive recharge systems and the technology for the identification of users in the system with minimal or no need for human intervention.

Support Technologies for G2V and V2G

- The requirements of the recharge infrastructure, in order to facilitate the implementation of G2V and V2G technologies, can be broadly grouped around the following domains:
  - Physical robustness and ease of integration in an urban environment
  - Low implementation and exploitation cost
  - Universality and interoperability
  - Ease of use
  - Reliability and availability
  - High energy efficiency
  - Safety



- The inductive recharging systems, introduces a great simplification in the operation of recharging the EVs eliminating completely the cabling and the human intervention in the operation, ensuring the requirements for the implementation of G2V and V2G systems

Methodology

- The potential impacts of V2G on the Portuguese grid were assessed considering 3 scenarios of penetration of EVs in the Portuguese vehicle fleet.

- The obtained data allowed to analyze the potential of V2G to transfer the generation surplus between hours of low and high demand, considering three typical days for winter, spring and summer.
- The daily degradation of the batteries, associated with the use of V2G, was also evaluated in order to assess the potential economic impact associated with V2G.

EV Data

- 6 EVs were considered in the assessment, taking into account their actual share in the Portuguese market.
- The autonomy of the EVs (considering a combined range with mild weather), total capacity, available capacity and battery cost were characterized .

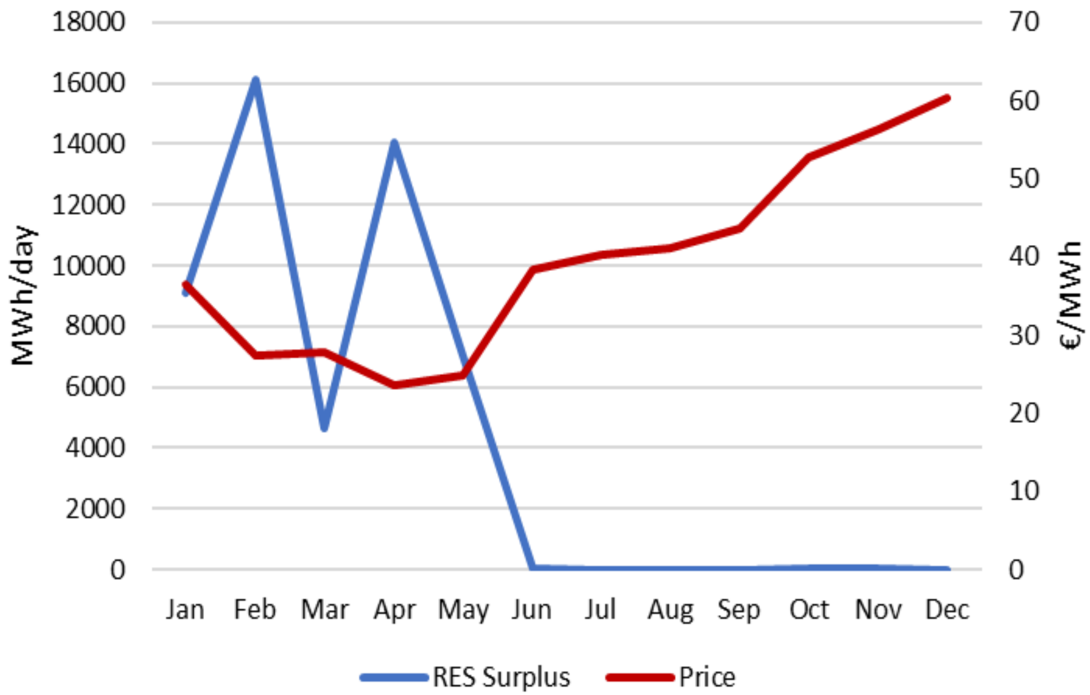
EV	Autonomy (km)	Tot Capacity (kWh)	Available Cap. (kWh)	Battery Cost (€)
Nissan Leaf	193	30	28	€5 610
Renault Zoe	298	41	39	€7 000
BMW i3	193	33,2	27.2	€7 000
Kia Soul EV	201	33	30	€5 900
VW. e-Golf	233	35,8	32	€6 400
Tesla Model S	555	100	94	€16 300

EV Data

- 3 scenarios of penetration of EVs in the Portuguese vehicles fleet were considered, in which EVs constitute 10%, 25% or 50% of the national fleet.
- In each scenario the number of EVs was divided between the 6 models of EVs, considering the actual market share.
- The battery capacity available for V2G in each EV was assessed considering the used capacity with mobility (in order to ensure an average of 30 km/day), the minimum capacity to avoid a quick degradation and a reserve capacity of 10%.

Scenario	EVs (#)	Capacity V2G (MWh)	Power (MW)
10% of EVs	460 000	11 971	3 680
25% of EVs	1 150 000	29 928	9 200
50% of EVs	2 300 000	59 856	18 400

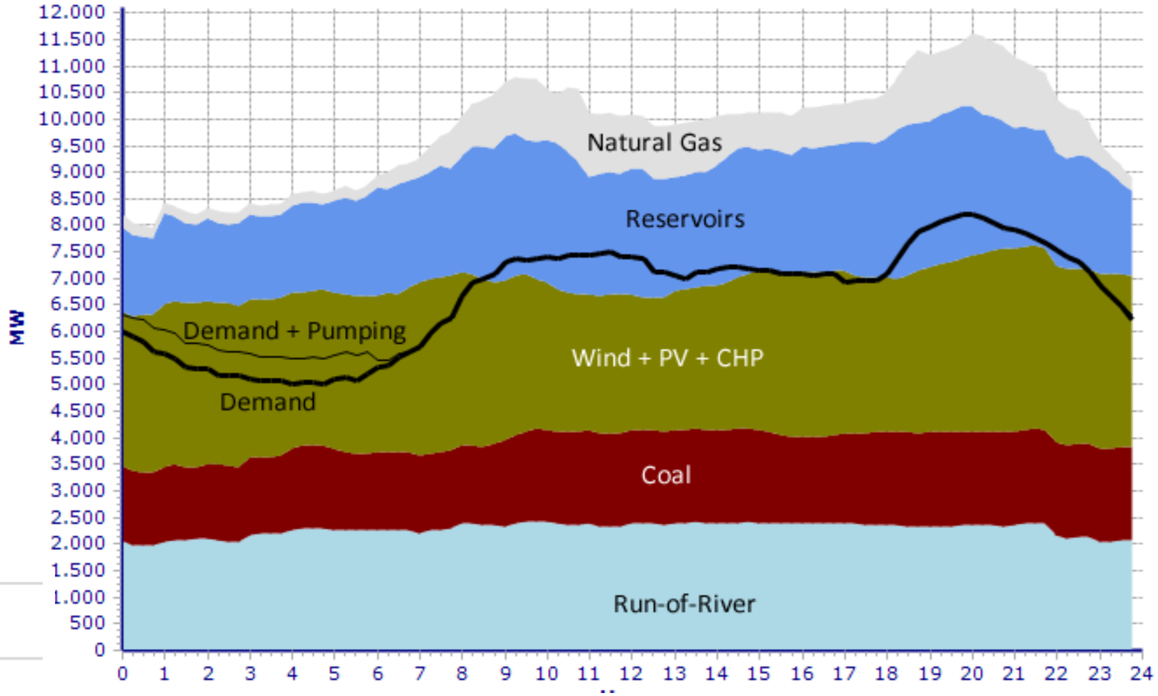
Grid Data

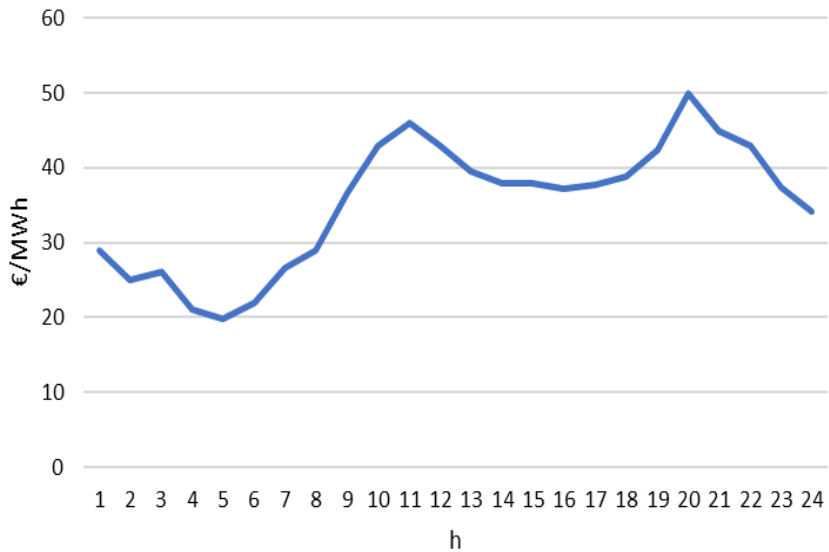


- The data from 2016 was used since 2017 was not a typical year due to the low hydropower generation.
- The largest generation surplus occurs during the winter, when windy and rainy periods occur, favoring hydro and wind power, which are the renewable energies that have most installed capacity in Portugal.
- In summer, although there is no available renewable surplus, it is observed that typically when the average monthly surplus decreases the average tariff increases, so V2G can also be used to take advantage of the daily price variation.

Grid Data

- The criterion for the selection of the representative winter day was the daily renewable generation surplus, being selected February 13, 2016 with a surplus of 16055 MWh.

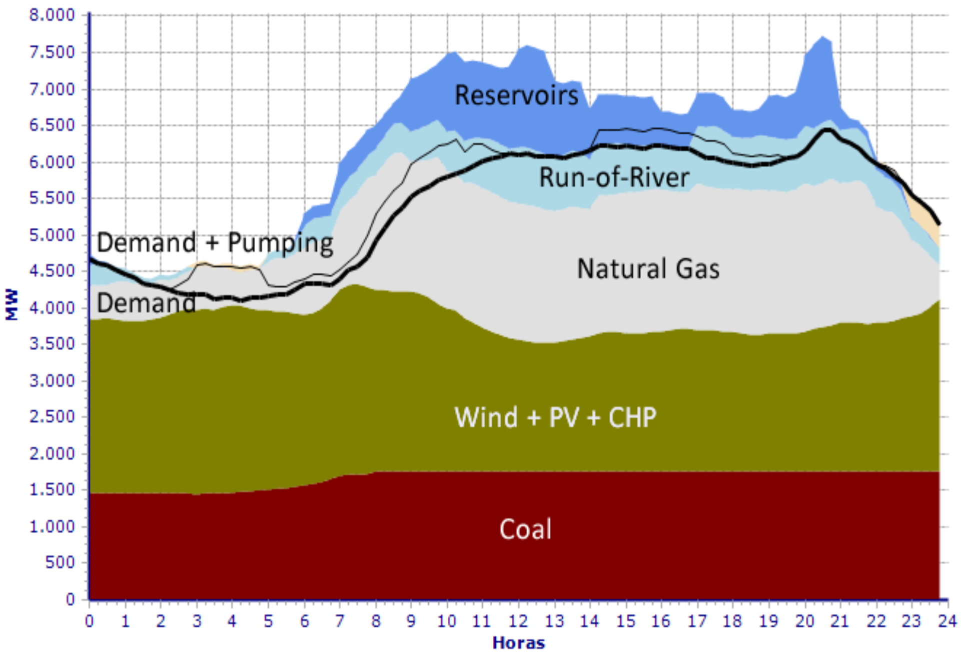


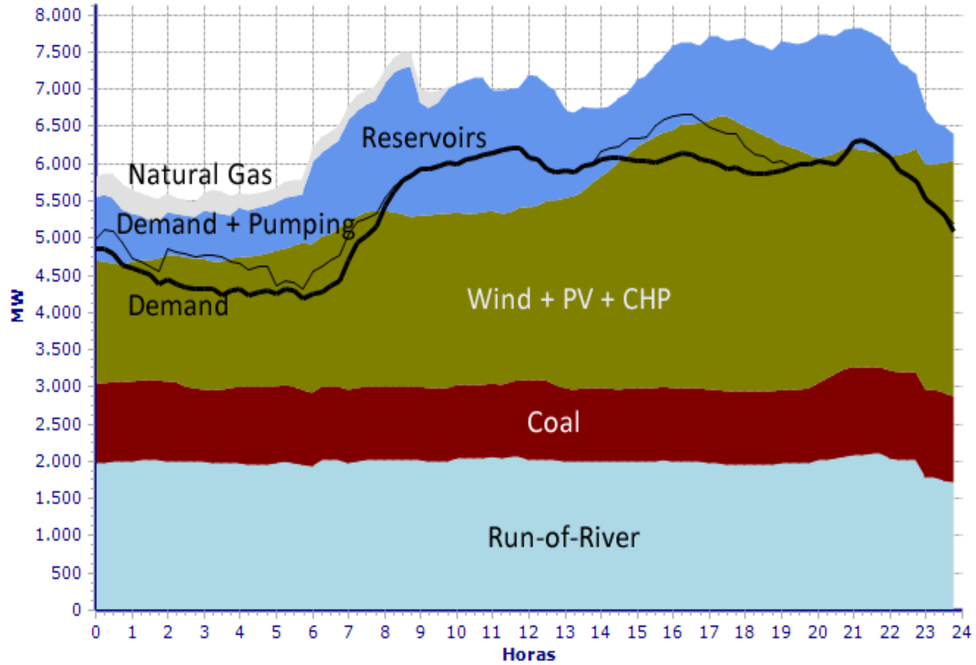


- The wholesale price presents a lower value during periods with higher RES generation and lower demand (night time), which is the period typically used for charging EVs

Grid Data

- In spring (May 18, 2016) there is an intermediate level of renewable generation surplus, with a daily surplus of 8424 MWh.





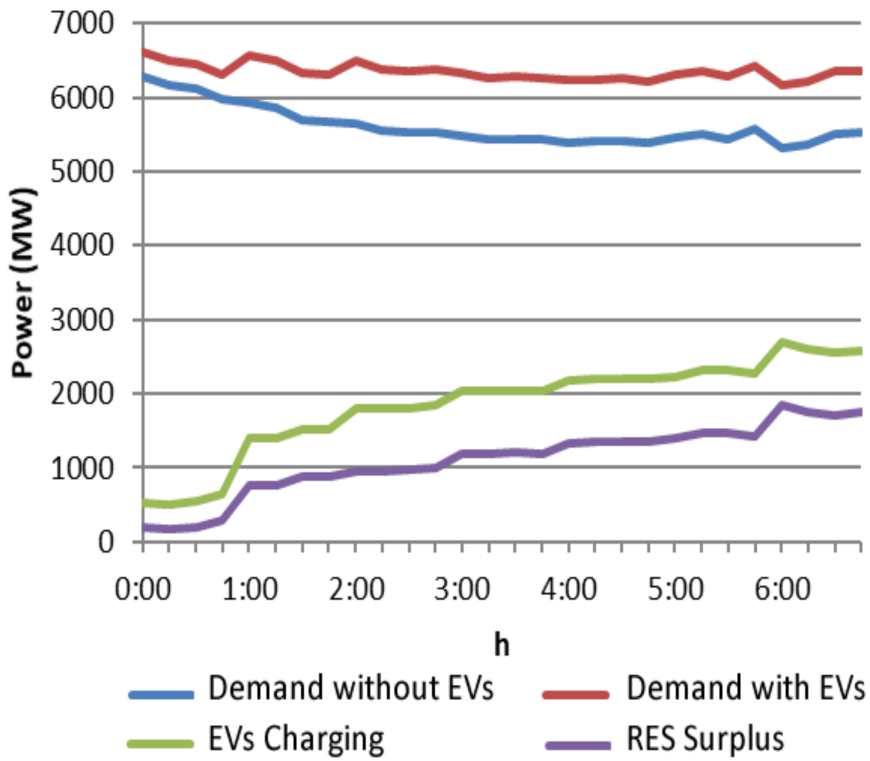
- There is no RES generation surplus in summer, so the criterion for selecting the representative day was the average monthly energy price (41.52 €/MWh), being selected August 29, 2016.

Technical Impact

Winter Day

- It was considered the existence of an aggregator with the ability to select which EVs can charge at all time periods.
- The first objective of the control was to consume or store all renewable generation surplus, which corresponds to 59.75% of the stored energy.
- Since there was still available capacity, the second objective was to concentrate the charging in the hours with the lowest wholesale prices.

Charging in the scenario with 10% of EVs

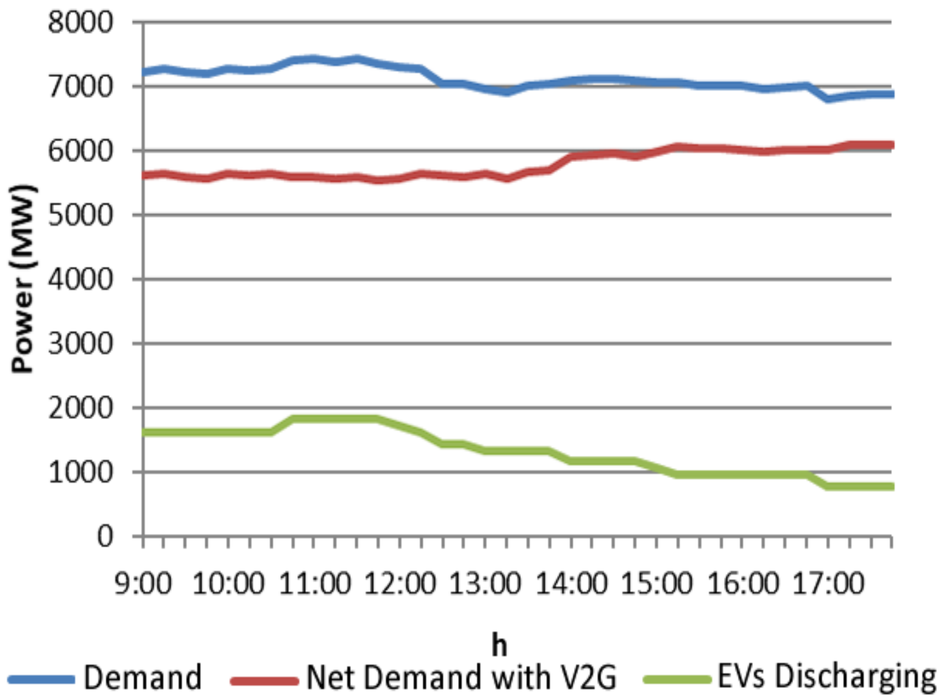


Technical Impact

Winter Day

- The energy was injected preferentially in the hours when the wholesale prices were higher.

Discharging in the scenario with 10% of EVs



Technical Impact

- With 10% of V2G EVs it was possible to absorb all the RES generation surplus.
- In winter and spring 59.8% and 15.8% of the energy required to charge all EVs is ensured by RES surplus.

Scenario	Impact	Winter	Spring	Summer
10% EVs	Stored Energy (MWh)	12 940	12 940	12 940
	Stored RES surplus (%)	100	100	-
	RES surplus in charging (%)	59.8	15.8	0
25% EVs	Stored Energy (MWh)	32 350	32 350	32 350
	Stored RES surplus (%)	100	100	-
	RES surplus in charging (%)	23.9	6.32	-
50% EVs	Stored Energy (MWh)	64 690	64 690	64 690
	Stored RES surplus (%)	100	100	-
	RES surplus in charging (%)	12.0	3.2	-

- Increasing the share of EVs to 25% and 50% does not have any impact from the renewable generation surplus point-of-view.
- Using G2V in one scenario with 10% of EVs, only 19.4% and 37% of the RES surplus, in winter and springer, respectively, is consumed.
- In a scenario only with G2V it would be necessary to have 52% of the fleet with EVs to compensate all the RES generation surplus.

Economic Impact

- The objective was not only the compensation of RES generation surplus, but also to ensure **economic advantages from the grid point-of-view, by storing energy in periods of low wholesale market price and injecting it into the grid in periods with the highest price.**

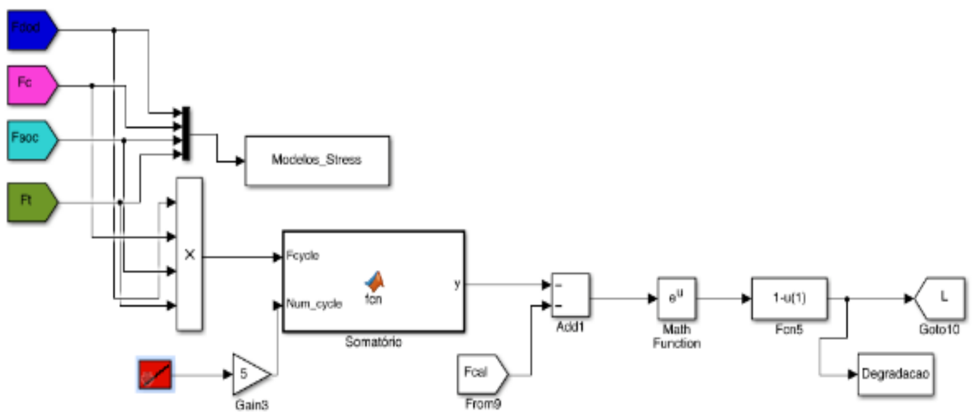
V2G savings, from the grid point-of-view, as a percentage of the charging costs.

Scenario	Winter	Spring	Summer
10% EVs	59.4	33.1	15.8
25% EVs	55.6	28.8	15.8
50% EVs	54.3	26.2	15.7

- The savings are higher in winter due to the variation of the wholesale market price which presents a strong correlation with the availability of renewables.
- Increasing the share of EVs to 25% or 50% slightly reduces the savings, due to the objective of ensuring a flatter load profile.

Economic Impact

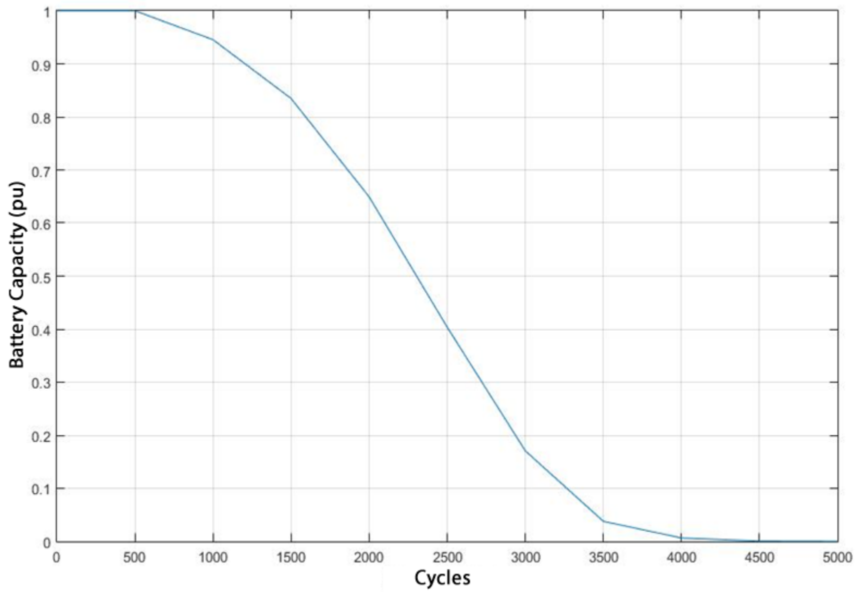
- From the user point-of-view the economic impact was evaluated considering a future real-time tariff.
  - Such tariff was designed with the same average value as the presented by the most typical tariff option nowadays used in Portugal (a time-of-use tariff with two periods), but with an hourly variation proportional to the wholesale market.



- The daily degradation of the batteries, associated with the use of V2G, and their replacement cost, were considered.
- This degradation was evaluated through a model developed in Simulink environment.

Economic Impact (Nissan Leaf Winter)

- In the case of the Nissan Leaf, considering the use for V2G, the battery degrades 30% of its nominal capacity after 1850 cycles (5.1 years).
- Considering a linear relationship, the total degradation is 0.0162%/day.
- In the case of Nissan Leaf, the use of V2G corresponds to 82% of total consumption, being therefore the V2G responsible for a daily degradation of 0.0147%/day.
- Considering the cost of battery replacement, the daily cost associated with battery degradation is 0.75 €/day.
- The degradation cost must be subtracted from the profit obtained with the price difference between the charging and discharging, being the obtained profit 0.59 €/day.



Economic Impact (Nissan leaf)

- Due to the high differences in the profit between the charging and discharging period in different seasons and in scenarios using a different share of EVs there a is a decrease on the V2G profit for summer and for scenarios with a higher number of EVs.

Scenario	Impact	Winter	Spring	Summer
10% EVs	Charge/Discharge Profit (€/day)	1.45	0.93	0.49
	V2G Degradation (%/day)	0.0134	0.0134	0.0136
	Degradation cost (€/day)	-0.75	-0.75	-0.76
	V2G Profit (€/day)	0.69	0.18	-0.35
25% EVs	Charge/Discharge Profit (€/day)	1.37	0.82	0.49
	V2G Degradation (%/day)	0.0136	0.0136	0.0136
	Degradation cost (€/day)	-0.76	-0.76	-0.76
	V2G Profit (€/day)	0.61	0.06	-0.27
50% EVs	Charge/Discharge Profit (€/day)	1.35	0.74	0.46
	V2G Degradation (%/day)	0.0136	0.0136	0.0133
	Degradation cost (€/day)	-0.76	-0.76	-0.74
	V2G Profit (€/day)	0.59	-0.02	-0.28

Conclusions

- The potential of V2G to store the surplus of renewables generated during the night and to inject it into the grid in periods of high demand was assessed.
  - Even with only 10% of Evs with V2G, it was possible to absorb all the renewable energy generation surplus, being the charging of EVs in winter ensured in 60% by such surplus.
- This result was compared with the results obtained with G2V in which it was only possible to store 20% of the renewable generation surplus in winter.
  - In a scenario only with G2V, a fleet constituted in 52% by EVs would be needed.
- In the scenarios with 25% and 50% of EVs the share of renewable generation surplus used in the charging is lower and such reduction has impacts on the economic benefits.

Conclusions

- From the grid point-of-view, the assessed scenarios had savings between 16% and 60% of the charging costs, being such savings higher in winter and with a lower share of EVs.
- The economic benefits from the user point-of-view were assessed considering the daily degradation of the batteries, which was simulated with a Simulink model.
- Even considering the cost associated with such degradation it was possible to ensure profit in winter, but the impact during spring is not relevant and during summer the benefits are not enough to compensate the degradation costs, with the current technology of battery cells.
- Battery degradation costs are falling because of decreasing battery costs (€/kWh) and longer life cycle (number of cycles to reach a minimum capacity – e.g. 80% of original value).

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