Analysis of the Impact of Electric Vehicle Penetration on Italian Electric Supply System

Sara Bellocchi*
Department of Industrial Engineering
University of Rome Tor Vergata, Rome, Italy
e-mail: sara.bellocchi@uniroma2.it

Michele Manno
Department of Industrial Engineering
University of Rome Tor Vergata, Rome, Italy
e-mail: michele.manno@uniroma2.it

ABSTRACT

Electric vehicles are progressively emerging in the light-duty passenger market as a promising alternative to oil-dependent road transport in the attempt to achieve greenhouse gas and pollutant emissions reduction. However, it is necessary to study in detail and to assess how a high penetration of electric vehicles in the private passenger vehicle fleet would affect strategic planning of large scale energy systems in the medium-long term period.

This study evaluates the integration of electric vehicles in the Italian energy scenario, assessing the impact on power generation capacity, energy consumption, CO_2 emissions on a medium-long term perspective (up to 2030–2050), with the support of the EnergyPLAN software tool.

The national energy system has been accurately characterized using currently available data and its operation has been simulated with varying degrees of electric vehicle penetration through an integrated analysis method. The energy scenarios developed take into account realistic growth trends for variable renewable energy sources.

The results obtained assess the potential impact of electric vehicles in cutting transport carbon emissions and highlight potential sensible primary energy savings. Nevertheless, the analysis also reveals that an increase in electric vehicle penetration does not necessarily correlate directly to a growth in generation from renewable energy sources, because electric vehicle recharging strategies, and in particular the time of day when most vehicles are recharged, influence which power plants are mostly used to cover the additional electric energy needs.

KEYWORDS

EVs; PHEVs; RES; electricity excess production, EnergyPLAN; integrated energy systems analysis.

* Corresponding author

INTRODUCTION

The level of carbon dioxide concentration in the atmosphere has been rising at an average rate of 2 ppm/year over the past decade [1] and is unequivocally responsible for the recent warming of the Earth's climate [2].

With the world energy consumption expected to grow by 30% to 2040 [3], global negotiations and energy policies have become essential for the achievement of a sustainable development. The Paris Agreement on climate change, signed in December 2015 by 195 countries, establishes a global action plan to fight climate change by keeping a world temperature rise this century well below 2 °C above pre-industrial levels [4]. A new technology framework in the energy sector, alone responsible for approximately 60% of global anthropogenic emissions [5], is essential to reach the goals of the Agreement. Indeed, electricity and heat generation accounted for the largest share of global emissions (42%) in 2014, followed by transportation sector producing 23% of world CO_2 emissions [5]. Both sectors rely heavily on carbon-intensive fuels: in 2014, 40% of electricity production was from coal while 93% of world vehicular fuel needs were still catered for by oil products [6].

Renewable energy sources (RES), energy efficiency and transport electrification are thus regarded as key solutions to mitigate and preventing CO_2 emissions [7–9]. With this respect, Özbuğday & Erbas [10] empirically assessed the role of energy efficiency, renewable energy and industrialization in curbing CO_2 emissions, showing that a one percent increase in both energy efficiency and renewable energy reduces CO_2 emissions by respectively 0.55% and 0.11% over the long term. In addition, according to the European Environment Agency, assuming a 30% share of electric vehicles in the EU-28 in 2030 and an 80% share in 2050, CO_2 emissions from road transport can be reduced respectively by 42% and 84% compared to 2010 levels, taking also into account the additional power sector emissions due to the extra electricity demand [11,12].

Renewable power generation has grown by more than 30% over the period 2010-2015, and it is forecast to expand by another 30% between 2015 and 2020, while EV sales registered a 40% increase in 2016 over the previous year [13]. Nevertheless, according to the International Energy Agency, a 50% chance of meeting Paris Agreement's emissions target requires an additional 40% increase of energy generation by renewable sources over the period 2020-2025 and implies that the 2016 growth rate of electric vehicles sales remains unchanged in future years [13]. On the other hand, a large-scale integration of both intermittent renewable energy sources and electric vehicles would pose technical challenges in the electricity grid management [11,14].

Technical conditions to integrate ever larger shares of intermittent RES into the electricity system have been widely explored in literature [15–21], stressing the necessity of balancing measures such as curtailments, storage, backup power generation and demand-side management to ensure a reliable and low-cost supply. On the other hand, the impact of electric vehicles on national European grids has been investigated in many research studies proving that the overall impact of electric vehicles on electricity systems highly depends on how vehicles are charged, as well as on the local context (quality of grid infrastructure and generation mix) [11]. Without a proper management of charging, an increasing penetration of EVs would have a negative impact on the grid infrastructure [22,23] even at electric vehicle penetration rates of around 10% [24–26] or in relatively well-developed national infrastructure [27]. In this context, smart charging management become essential to reducing both the intensity of electric vehicle charging and the additional electricity generation by conventional power plants.

Moreover, renewable sources generation and electric vehicles can effectively support each other. Indeed, EVs can provide storage capacity for the curtailed electricity produced by intermitted RES, and supply energy to the grid during period of peak demand and lack of RES production through a Vehicle-to-Grid (V2G) approach [28,29], while RES would represent a cost effective and carbon-free way of EVs energy supply [28].

Joining the Paris Agreement, Italy developed a new National Energy Strategy which sets a target of 30% greenhouse gas emissions reduction by 2030 compared to 2005, an annual 1.5% increase in energy efficiency and a 27% growth in energy generation from renewable sources [30].

Implications related to renewable energy penetration within the Italian energy system have been explored in various research studies in terms of wholesale electricity price [31,32], CO_2 average abatement costs [33] and emissions reduction at various levels of penetration [34–37]. Results show that, in a grid with a moderate penetration of RES (wind and photovoltaics), the reduction of CO_2 emissions is lower than expected in the short-run, and is related to the level of RES penetration and the season of the year [34]. Paris Agreement's target achievement requires however a significant share of intermittent RES in the Italian electrical system which cannot be achieved unless adequate operating thermal backup systems and electricity storage capacity are included [36,37].

Energy system modelling is an essential tool for a proactive planning of renewable and low-carbon energy policies to qualitatively understand and quantify potential benefits and drawbacks and ultimately advise policy makers. Different software tools are currently available to this aim [38–40]

In this study, scenarios of the Italian energy system including progressively increasing shares of RES are proposed along with technical solutions to overcome related grid balancing issues and renewable power curtailments. The Italian energy system scenario has been modelled with reference to TERNA [41] for the year 2014. Simulation has been carried out with the help of EnergyPLAN computer tool [40] widely used in literature for modelling complex energy system scenarios which include generation from renewable sources [16,37,42–50].

First, this work identifies a base case scenario, represented by the Italian energy system at 2014 and characterized in terms of its energy supply and demand, CO_2 emissions and primary energy consumption. A gradual increase in RES penetration has then been implemented using business-as-usual projection for the year 2030 and 2050; results have been examined and compared to the base case. Model results for the national energy system have been analysed with respect to two critical indicators: annual excess production and CO_2 emissions. The model identifies Critical Excess Electricity Production (CEEP) as the production that exceeds the transmission line capacity. Such parameter, that becomes inevitable with high RES penetration, is not allowed in real life, as this will cause a breakdown in the electricity supply, but has been used in this work to study its magnitude variation using different RES/EVs combinations, in line with the analysis carried out by Lund & Kempton [51]. This study also assesses the positive interaction between increasing RES and EVs shares, the capability of EVs to act as electricity storage system and to what extent the charging strategy used affects the excess of production.

CURRENT NATIONAL ENERGY SYSTEM DEFINITION

Demand

The Italian energy system has been modelled with the support of EnergyPLAN [40]. The software allows the characterisation of the whole energy system with respect to a certain country and, according to the regulation strategy selected, optimizes its operation from a technical and/or economic perspective by defining a planning strategy that minimises loads from fossil fuel power plants thus reducing both primary energy consumption and CO_2 emissions. Different scenarios can be created and compared by modifying input data and parameters related to the various energy sectors (e.g. installed power, fuel distribution, user demand, etc.).

The Italian energy system has been characterised at 2014 in terms of electricity, thermal and transport sectors with reference to available data. According to Terna, the grid operator for electricity transmission in Italy, the annual electricity demand (including power plant auxiliary power consumption and network losses) was 310.5 TWh with a peak load of 51.6 MW in June [41]. The amount of imported electricity has been set to 46.51 TWh [52]. An electricity hourly distribution, defined as the ratio between the power at a particular hour and the yearly peak value, has been derived from ENTSO-E (European Network of Transmission System Operators for Electricity) consumption data for 2014 [53] and displayed in Figure 1.

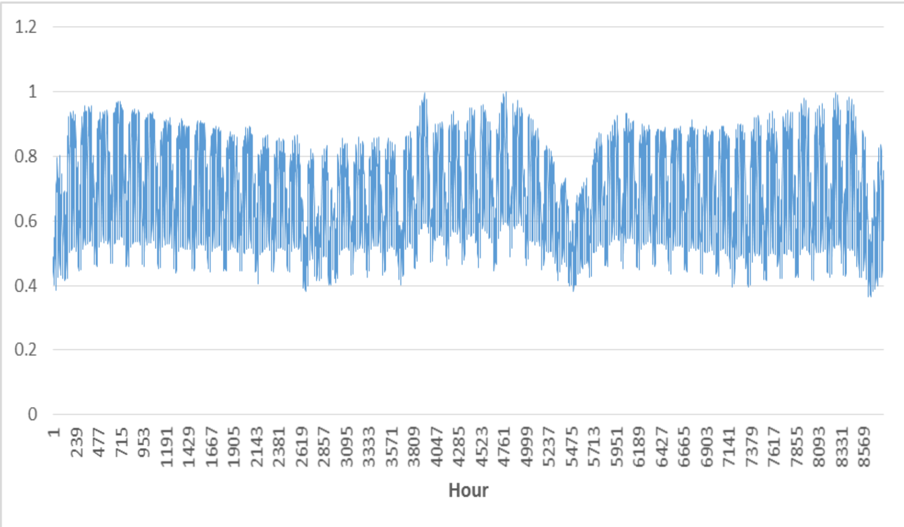

Figure 1. Italian electricity demand hourly distribution over the year 2014

The other distributions used in the model (e.g. heating and cooling, renewable energy power distributions over the year, etc) all refer to a 2010 case study for the Italian energy system [54] and accessible from EnergyPLAN website [40]. The annual heat production has been distributed among the different energy systems according to EnergyPLAN subdivision. In particular, the software requires heat production to be partitioned into three main groups: individual boilers, district heating boilers (DHP), small-size cogeneration power plants (CHP2) and large cogeneration extraction plants (CHP3). With respect to the Italian case, combined cycle power plants (CC) account for 45.6% (25.61 TWh[1]) of heat generated by the whole mix of cogeneration plants (56.23 TWh) [41]. Under the assumption that only combined cycle power plants with a capacity above 200 MW belong to CHP3 group, with reference to Terna annual report [41] and

[1] In this paper, all energy-related parameters are expressed in TWh, regardless of their nature (electricity, heat, primary energy), as required by the software used for the analysis.

assuming that all CCs work the same number of equivalent, average electric and thermal efficiencies have been estimated for CHP3 group (46.03% and 18.14% respectively). As a result, 16.04 TWh have been assigned to CHP3 power plants and 40.19 TWh to CHP2 group, which is made up of 91.17% internal combustion engines, 2.21% gas turbines, 2.94% combined cycle, 1.23% backpressure and 2.45% extraction plants. District heating boilers consumption (from both renewable and fossil fuel sources) has been set to 2.83 TWh as provided by AIRU (Associazione Italiana Riscaldamento Urbano) [55].

With respect to derived heat, biomass/waste consumption for heating purposes, data are available for 2014 from the GSE (Gestione dei Servizi Energetici) report concerning national usage of renewable energy sources [56]. Results, divided in direct consumption and derived heat (district heating), are summarized in Table 1.

Table 1. Direct consumption and direct heat production from renewable sources for 2014

Renewable source	***Direct consumption (TWh)***	***Derived heat production (TWh)***		***Total (TWh)***
		DHP	**CHP**	
Solar thermal	2.088	0.001	0	**2.089**
Solid biomass	67.916	0.754	7.131	**75.801**
Biodegradable waste	2.478	0		**2.478**
Bioliquid	0	0.003	0.383	**0.386**
Biogas	0.518	0.003	2.773	**3.295**
Geothermal	1.294	0.212	0	**1.507**
Total	**74.294**	**0.974**	**10.288**	**85.556**

Heat pump consumption for 2014 was 18.44 TWh [56], with an average COP of 2.6 [56]. The amount of electricity consumed for electric heating devices different from heat pumps has been obtained by subtraction from the total electricity consumed for space heating in Italy, i.e. 29 TWh [57], and results equal to 10.56 TWh.

With respect to fossil fuel consumption for heating purposes, IEA Sankey diagrams [52] provide the overall primary energy consumption for each sector; however, disaggregated data for fossil fuel are needed as EnergyPLAN requires the energy consumed for heating only to be inputted. With reference to GSE consumption data for 2013 [58] the percentage of the energy required for individual heating, divided by fuel, over the total fuel consumption, has been estimated for the residential and services sector, net of consumption for space cooling and home cooking, as displayed in Table 2 and Table 3 respectively. Domestic hot water has been included in the commerce and services consumption, as disaggregated data do not exist.

Table 2.Residential consumption in Italy for 2013

Residential consumption (TWh) - 2013							
	Oil products	Natural gas	Coal	Electricity	Derived heat	RES	**Total**
Space heating	25.105	174.315	0.000	4.384	9.454	76.280	**289.537**
Space cooling	0.000	0.000	0.000	1.384	0.000	0.000	**1.384**
Hot water	1.721	23.221	0.000	5.058	1.360	1.826	**33.186**
Cooking	4.674	12.849	0.000	3.233	0.000	0.477	**21.233**
Other uses	0.000	0.000	0.000	52.919	0.000	0.000	**52.919**
Total	**31.500**	**210.385**	**0.000**	**66.977**	**10.814**	**78.582**	398.259
% of space heating	**80%**	**83%**	**0%**	**7%**	**87%**	**97%**	

Table 3. Commerce and services consumption for 2013

Commerce and services consumption (TWh) - 2013							
	Oil products	Natural gas	Coal	Electricity	Derived heat	RES	**Total**
Space heating and hot water	7.111	84.408	0.000	11.926	1.790	1.990	**107.223**
Space cooling	0.000	0.000	0.000	4.942	0.000	0.000	**4.942**
Other uses	0.000	0.000	0.000	72.097	0.000	0.000	**72.097**
Total	7.111	84.408	0.000	88.965	1.790	1.990	**184.262**
% of space heating and hot water	**100%**	**100%**	**0%**	**13%**	**100%**	**100%**	**58%**

The same percentages have been applied to 2014 data as provided by IEA and total consumption for space heating has been estimated as shown in Table 4.

Table 4. Heating consumption for residential and services sector at 2014

Heating consumption (TWh) - 2014			
	Residential	Services	**Total**
Oil products	21.785	6.977	**28.762**
Natural gas	164.859	69.768	**234.627**
Coal	0.000	0.000	**0.000**
Electricity	8.360	11.846	**20.206**
Derived heat	9.302	3.488	**12.791**
RES	67.033	2.326	**69.359**
Total	**271.340**	**94.405**	**365.746**

As for cooling consumption an overall value of 34 TWh has been considered [57], with an average COP of 2.5 [59]. Electricity for cooling refers to energy consumption from all sectors.

As for the industry sector and other sectors (e.g. agriculture, fishing, etc), there are no disaggregated data for space heating, being heating the sum of process heating/desiccation, space heating and hot water. As a result, heating consumption for these sectors will be directly taken into account in the industry overall energy uses as provided by IEA and reported in Table 5 along with overall consumption from other/non-specified sectors, which includes non-heating uses for both residential and services sector. EnergyPLAN also requires primary energy losses, which represent the energy lost while producing the fuel (such as in refineries), own use and transportation losses and are estimated from IEA Sankey diagrams [52] as percentage of the total fuel consumed.

Table 5. Industry and various sector primary energy consumption

Source	***Primary energy consumption (TWh)***		
	Industry	Various	Losses
Oil	25.582	31.938	4%
Coal	18.605	0.000	0%
Natural gas	98.838	31.266	1%
Biofuel and waste	6.977	1.976	0%

Transport

Transport sector energy consumption has been modelled with reference to available 2014 data from ISPRA (Istituto Superiore per la Protezione e Ricerca Ambientale) [60], which are summarized in Table 6.

Table 6. Energy consumption for the transport sector at 2014

Source	***TWh/year***	***% of total***
Jet Fuel	7.462	2%
Diesel	263.808	63%
Bio	12.056	3%
Petrol	92.570	22%
Natural gas	10.023	2%
LPG	20.058	5%
Electricity	10.111	2%
Total transport	**416.087**	

Electric transport only accounts for 2% of the total consumption, while 63% of fuel for transport consists of diesel and 22% of petrol. The amount of electricity consumed by electric vehicles (EVs) has been estimated to understand their level of penetration at 2014. Given the overall EVs sales over the period 2010-2016 (sales prior 2010 are only few units), the average battery capacity has been estimated, along with the driving range with reference to NEDC driving cycle, (with the exception of Tesla vehicles, whose data refer to EPA driving cycle) for both battery (BEVs) [61] and plug-in electric vehicles (PHEVs) [62]. Data are shown in Table 7. BEVs sales and technical specifications and Table 8 respectively. Both 2014 and 2016 total sales have been estimated; 2014 data will be inputted in the reference scenario model while data up to 2016 will be considered to generate future projections.

Table 7. BEVs sales and technical specifications

	Battery Electric Vehicles (BEV) sales										
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Tot 2014**	**Tot 2016**	**Capacity (kWh)**	**Range (km)**
Fiat Panda	31	9	0	0	0	0	0	40	40	**19.2**	**120**
Fiat 500e	22	7	4	0	0	0	0	33	33	**24**	**160**
Renault Fluence	0	0	38	38	30	0	0	106	106	**22**	**185**
Nissan Leaf	0	5	146	323	336	390	473	810	1673	**24**	**199**
Renault Zoe	0	0	0	204	156	328	210	360	898	**22**	**210**
Mercedes B 250e	0	0	0	0	0	80	90	0	170	**28**	**200**
Th!nk city	0	0	0	3	0	0	0	3	3	**24**	**160**
KIA soul	0	0	0	0	0	0	15	0	15	**27**	**210**
Bmw i3	0	0	0	34	124	111	91	158	360	**22**	**190**
Tesla Roadster	4	0	7	0	0	0	0	11	11	**53**	**393**
Tesla model X	0	0	0	0	0	0	23	0	23	**90**	**414**
Tesla Model S	0	0	0	19	55	134	218	74	426	**60**	**390**
Citroen C-Zero	0	87	146	55	15	164	145	303	612	**14.5**	**150**
Mitsubishi iMiev	3	36	14	0	0	0	0	53	53	**16**	**160**
Smart fortwo electric drive	33	80	37	155	252	115	0	557	672	**16.5**	**135**
Vw e-Up!	0	0	0	0	52	54	56	52	162	**18**	**160**
Peugeot iOn	0	59	116	17	25	0	26	217	243	**14.5**	**150**
Renault Kangoo	0	0	78	25	23	23	0	126	149	**33**	**200**
Fiat Doblo	12	6	0	0	0	0	0	18	18	**43**	**150**
Fiat (QUBO) Fiorino	10	4	0	0	0	0	0	14	14	**23**	**200**
Piaggio Porter	1	0	0	0	0	0	0	1	1	**17**	**80**
Tot BEV Sales	**116**	**293**	**586**	**873**	**1068**	**1399**	**1347**	**2936**	**5682**		

Table 8. PHEVs sales and technical specifications

	Plug-in Electric Vehicles (PHEV) sales										
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Tot 2014**	**Tot 2016**	**Capacity (kWh)**	**Range (km))**
Opel Ampera	0	3	62	19	0	0	0	84	84	**16**	**56**
Toyota Prius	0	0	39	8	87	0	0	134	134	**4.4**	**23**
Chevrolet Volt	0	0	38	38	0	0	0	76	76	**16**	**56**
Fisker Karma	0	0	6	0	0	0	0	6	6	**20.1**	**51**
Volvo V60 PHEV	0	0	0	135	59	0	0	194	194	**11.2**	**43.5**
Porsche Panamera	0	0	0	23	0	0	0	23	23	**9.4**	**32**
Mitsubishi outlander	0	0	0	0	85	133	0	85	218	**9.8**	**52.8**
Bmw i8	0	0	0	0	34	99	0	34	133	**7.1**	**37**
Vw Golf GTE	0	0	0	0	0	180	158	0	338	**8.7**	**50**
Audi A3 e-tron	0	0	0	0	0	86	0	0	86	**8.8**	**50**
Bmw 225xe	0	0	0	0	0	0	308	0	308	**7.6**	**41**
Bmw330e	0	0	0	0	0	0	107	0	107	**7.6**	**25**
Volvo XC90 PHEV	0	0	0	0	0	0	90	0	90	**9**	**40**
Others	0	0	0	9	76	242	654	85	981	**4.4**	**23**
Tot PHEV Sales	**0**	**3**	**145**	**232**	**341**	**740**	**1317**	**721**	**2778**		

Unione Petrolifera provides statistical data on vehicle fleet composition in Italy on a yearly basis [63] which have been used to estimate EV percentage with respect the total vehicle fleet in use at 2014 as displayed in Table 9 and Table 10 with reference to total annual sales and overall fleet respectively.

Table 9. Battery Electric Vehicles (BEV) market and overall share

	2010	***2011***	***2012***	***2013***	***2014***	***2015***	***2016***
Tot BEV sales	116	293	586	873	1068	1399	1347
Tot vehicle sales	1961569	1749092	1402980	1304557	1360533	1575612	1825760
BEV in use	116	409	995	1868	2936	4335	5682
Overall vehicle fleet (Millions)	33.1	33.4	33.6	33.54	33.52	33.69	34.05
% BEV (annual sales)	0.006%	0.017%	0.042%	0.067%	0.078%	0.089%	0.074%
% BEV (total fleet)	0.000%	0.001%	0.003%	0.006%	0.009%	0.013%	0.017%

Table 10. Plug-in Electric Vehicles (PHEV) market and overall share

	2010	***2011***	***2012***	***2013***	***2014***	***2015***	***2016***
Tot PHEV sales	0	3	145	232	341	740	1317
Tot vehicle sales	1961569	1749092	1402980	1304557	1360533	1575612	1825760
PHEV in use	0	3	148	380	721	1461	2778
Overall vehicle fleet (Millions)	33.1	33.4	33.6	33.54	33.52	33.69	34.05
% PHEV (annual sales)	0.000%	0.000%	0.010%	0.018%	0.025%	0.047%	0.072%
% PHEV (total fleet)	0.000%	0.000%	0.000%	0.001%	0.002%	0.004%	0.008%

BEVs and PHEVs account for a very small percentage of the total fleet of vehicles in use (0.017% and 0.008% respectively, at 2016), however showing an increasing trend, which grows at a higher rate for PHEVs.

EV have then divided in three main categories depending on the battery capacity: small vehicles for capacities below 18 kWh, medium vehicles for capacities between 18 and 28 kWh, and large vehicles when battery capacities are higher than 53 kWh. PHEVs have been all considered medium vehicles. This subdivision will be used in modelling future scenarios to allow a correct substitution of EVs into the equivalent traditional vehicle category. The energy required per year has been evaluated considering a weighted average for battery capacity and driving range, an average commuting distance of 33.4 km/day as assessed by ISFORT (Istituto Superiore di Formazione e Ricerca per i Trasporti) with reference to 2014 [64], 250 working days per year and a charging efficiency of 0.9. Values are displayed in Table 11, where a total annual consumption of 3.92 GWh show that EVs' consumption represent a negligible part of the total amount of electricity consumed in the transport sector, i.e.10.11 TWh.

Table 11. EV annual electricity consumption at 2014

		No. of vehicles	*Share by size*	*Average Capacity (kWh)*	*Average Range (km)*	*Consumption (GWh)*
BEV	**Small**	1182	40%	15.66	143.82	0.97
	Medium	1510	51%	23.05	196.68	1.33
	Large	85	3%	59.09	390.39	0.10
	Van	159	5%	33.15	193.58	0.20
Total BEV		**2936**		**21.67**	**180.84**	**2.60**
PHEV		**721**		**9.86**	**40.53**	**1.32**
Total EV		**3657**		**19.34**	**153.18**	**3.92**

Supply

Energy supply section has been modelled with reference to Terna annual for 2014 [41]. Table 12 summarizes both installed power and efficiency for the different plants acting in the energy system.

As concerns renewable sources proper corrective factors have been added to power distribution to calibrate the annual electricity production with respect to the actual one.

With regard to dammed hydro plants, a storage capacity of 200 GWh has been considered [36].

Table 12.Capacity and efficiency of different types of power plants at 2014

	Power (MW)	*Electric efficiency*	*Thermal efficiency*
Heat and electricity			
• DHP			0.90
• CHP2	8674.4	0.37	0.30
• CHP3	10965.0	0.46	0.18
Electricity only			
• PP	51193.1	0.40	
• Geothermoelectric	821.0	0.10	
• Dammed hydropower	17249.9	0.90	
Intermittent RES			
• Wind	8703.1		
• PV	18609.4		
• River hydro	5184.6		

EnergyPLAN also requires the fuel distribution among the different plants. With this respect, data have been inserted with reference to IEA balances [65] and Terna consumption values for the thermoelectric sector [41] and are summarized in Table 13.

Table 13. Distribution of fuel among power plants

	Distribution of fuel (TWh/year)			
	Coal	***Oil***	***Natural gas***	***Biomass***
Heat and electricity				
• DHP				0.97
• CHP2	5.80	41.06	56.25	38.20
• CHP3			88.31	
Electricity only				
• PP	116.40	7.71	62.70	37.09

Solid urban waste is also required in the software, separated from biomass consumption, equal to 2.43 TWh [55]. CO_2 content in the fuels also need to be inputted to estimate correctly the emissions, data have been inputted with reference to IPCC emission factors [66].

Model validation

The reference scenario for 2014 has been validated taking into account CO_2 emissions [5] and TPES (Total Primary Energy Consumption) [65], and electricity production from RES as provided by IEA for 2014. In particular, given that EnergyPLAN do not take into account the "non-energy use" of TPES, this amount has been subtracted from IEA TPES value for 2014 to allow a correct comparison. Such energy indicators are summarised and compared in Table 14. The percentage difference is acceptable (below 1%).

Table 14. Comparison between energy indicators.

	Model	*Actual data*	*Difference (%)*
TPES (TWh)	1624.05	1612.74	0.7%
CO_2 emissions (Mt)	321.59	319.70	0.6%
RES el. production (TWh)	120.90	120.70	0.2%

POSSIBLE FUTURE SCENARIOS DEFINITION

Different future scenarios have been defined for the Italian energy system assuming an electricity demand equal to 345 TWh [67] and a progressively increasing penetration of both EVs in the transport sector and RES as for electricity production. Installed power from the other plants remains unchanged along with individual heating and cooling demand. Different combination of EVs and RES share have been simulated to assess the impact on Critical Excess Electricity Production (CEEP) (that inevitably affects the system when RES penetration becomes significant), CO_2 emissions and primary energy supply.

EnergyPLAN allows to choose between different technical simulation with respect to thermal units. In these scenarios, all heat producing units are producing solely according to the heat demand.

As for CEEP, none of the regulation strategies listed in the software has been used in order to quantify this value and its variation with respect to different RES/EVs scenarios.

Renewable energy sources penetration

Different cases have been analysed with regard to renewables penetration:

- 2014 RES: production from RES remain stable at 2014 level (ca. 40% of electricity production);
- 60% RES: production from RES covers 60% of the electricity production;
- 90% RES: production from RES covers 90% of the electricity production.

In any of the above-mentioned cases, electricity demand has been set to 345 TWh [67]. Installed power and production from RES at 2030 have been modelled taking into account the installed power as reported in IREX annual report 2015 [67]; the expected energy production is provided by EnergyPLAN using the same power distribution and correction factors. Data are summarized in Table 15.

Table 15. Installed capacity and expected electricity production from RES (60% RES scenario: ca. 60% of electricity production).

RES	*Power (GW)*	*Estimated electricity production (TWh)*
PV	35.5	42.6
CSP	2.0	8.0
Hydro	23.0	66.7
Onshore wind	20.0	37.2
Offshore wind	8.0	9.6
Geothermal	2.0	13.9

As for biomass, the software requires the source consumption to be inputted. With reference to IREX annual report projections, the increase in electricity produced from biomass doubles from 2013 to 2030. As a result, additional 76.26 TWh of biomass consumption has been here considered, properly distributed among power plants. Such modelled scenario provides 63.6% of RES electricity production.

With respect to 90% electricity production from RES scenario, PV, wind and CSP capacity has been doubled with respect to 60% RES scenario as displayed in Table 16. This scenario leads to 92.1% of electricity production from RES.

Table 16. Installed capacity and expected electricity production from RES (90% RES scenario: ca. 90% of electricity production).

RES	*Power (GW)*	*Estimated electricity production (TWh)*
PV	71	74.3
CSP	4.0	15.2
Hydro	23.0	66.7
Onshore wind	40.0	74.3
Offshore wind	16.0	19.2
Geothermal	2.0	13.9

Electric vehicles penetration

As for EVs penetration, different scenarios have been created as follows:

- UP 2030: projection by Unione Petrolifera (UP) at 2030, consisting of 700 000 units of electric cars [63];

- LogFun 2030: A logistic growth function fit, which foresees a 14% penetration of EVs at 2030;
- RSE 2030: RSE projections for 2030, where 10 Million EVs are expected to be in use;
- Parametric: A parametric analysis where the number of EVs progressively increases, until covering the entire private vehicle fleet.

For each EVs penetration scenarios, three different cases have been analysed according to different battery charging modality:

- Dump charge: EVs charge without regulation, when parked depending on the demands or habits of the consumers;
- Smart charge: EVs charge during low-power demand in order to meet the needs of the drivers to recharge the vehicle at a certain time as well as to avoid a grid overloading;
- Smart charge and Vehicle to Grid (V2G): EVs are able to feedback electricity to the grid and their charge is partly controlled to meet the needs of the power system.

High power line connections (19.2 kW) have been assumed [68], in order to provide flexibility when the vehicle is charged along with other benefits such as fast recharge.

When implementing the smart type charge, EnergyPLAN models the batteries of the EVs as one big battery for the entire vehicle fleet, and as a result the battery capacity is equal to the sum of all individual batteries. Input parameters for smart and V2G charge as listed in Table 17. The share of parked V2G cars connected to the grid and the maximum share of V2G cars which are driving during peak demand hour, have been set according to Lund & Kempton [51], reasonable for typical driving patterns under some financial incentive to stay plugged in when parked.

Table 17. Specification for smart charge and V2G

Smart charge and V2G specifications	
Max share of cars during peak demand	0.2
Share of parked cars grid connected	0.7
Efficiency (grid to battery)	0.9
Efficiency (battery to grid)	0.9

Italian transport demand is shown in Figure 2, values are expressed as a percentage of the maximum power. This distribution has been used to calculate the energy demand, which must be met by energy stored in batteries for electric vehicles, since they are inevitably disconnected from the grid when driving, or directly by the electric grid for all other electric transportation means.

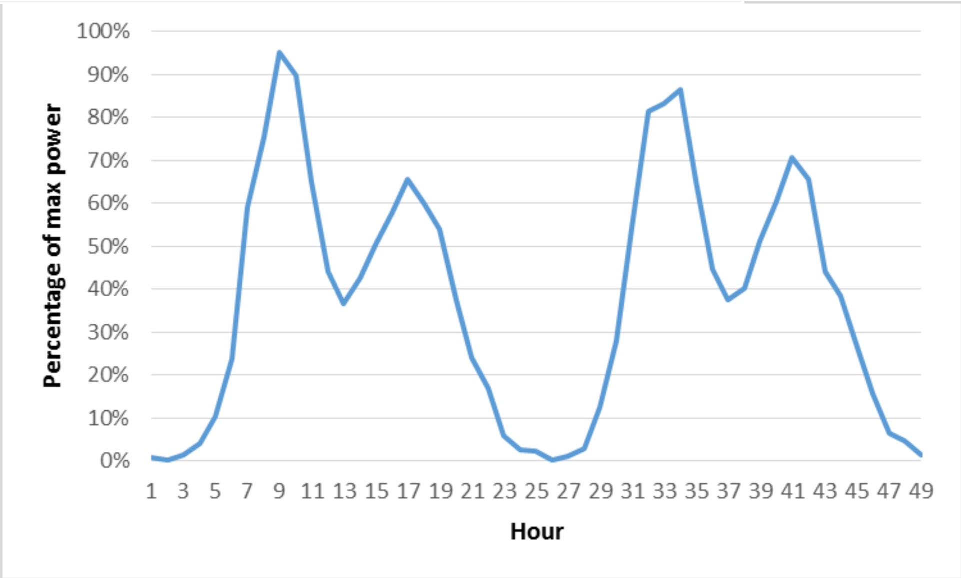

Figure 2. Italy transportation demand (expressed as a percentage of the maximum power).

EVs fleet composition has been partitioned considering a 30% BEV and a 70% PHEV [69].

Figure 3 shows yearly forecast of EVs penetration modelled as a logistic growth function, already used in the context of technology spread forecasting [70]. Starting from available data over the past year regarding EVs percentage of total vehicles in use, the best logistic growth function fit has been found based on the least squared residual, and the value at 2030 has been assessed.

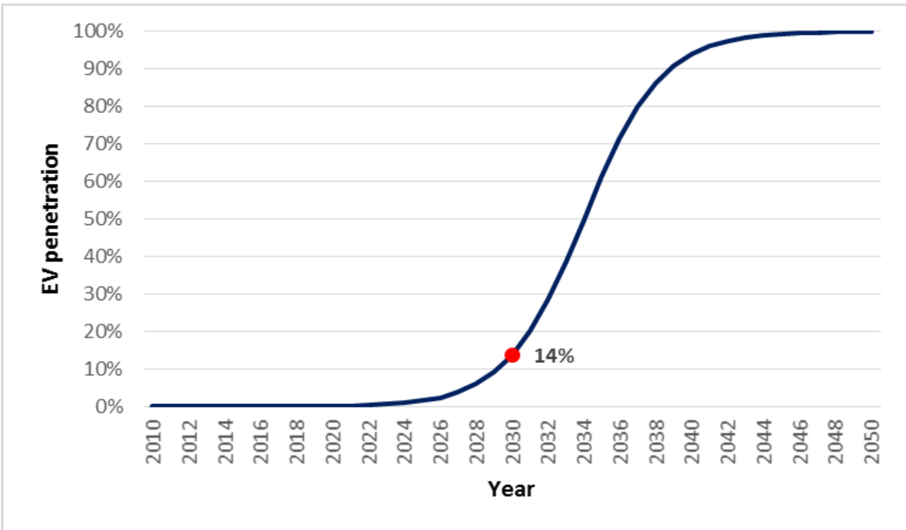

Figure 3. Logistic function of EVs penetration
(expressed as a percentage of total vehicle in use).

In order to substitute EVs in the equivalent category for traditional vehicles and evaluate properly the resulting energy savings, fuel consumption for private transportation only has been estimated and further divided into different categories based on vehicle displacement.

The number of petrol and diesel private cars has been considered for the year 2014, resulting respectively equal to 16.58 Million (excluding plug-in vehicles, accounting for 721 units at 2014 [62]) and 14.50 millions of cars. LPG-powered vehicles account for 2.07 Million units. An average daily commuting distance has been set to 25, 44 and 30 km/day for petrol, diesel and LPG cars respectively to give a weighted average value of 33.4 km/day as provided by ISFORT [64]. Given a yearly petrol and diesel consumption of 5.60 and 8.93 Mtoe respectively [63], and assuming a fleet made up of 56.5% of vehicles up to 1400 cm^3 of displacement, 36.6% between 1400 and 2000 cm^3 and 6.9% above 2000 cm^3 [71], the consumption for each category has been estimated for petrol and diesel cars respectively. Consumption values are referred to a mixed city/highway driving cycle [72].

Table 18. Petrol vehicles number and consumption at 2014

Petrol vehicles number and consumption at 2014			
Vehicle category	**No. of vehicles (Millions)**	**Fuel economy (l/100 km)**	**Consumption (TWh)**
Small	9.37	6	31.73
Medium	6.07	8	27.41
Large	1.14	11	7.10
Total	**16.58**		**66.24**

Table 19. Diesel vehicles number and consumption at 2014

Diesel vehicles number and consumption at 2014			
Vehicle category	**No. of vehicles (Millions)**	**Fuel economy (l/100 km)**	**Consumption (TWh)**
Small	7.99	5.5	50.33
Medium	5.18	7.2	42.68
Large	0.98	10.5	11.74
Total (TWh)	**14.15**		**104.75**

Quantified fuel consumption for private transport only, transport consumption reported in Table 6 can be disaggregated. Petrol and diesel consumption for other usage (e.g. motorcycles, commercial vehicles, etc) has been obtained by subtraction and results equal to 26.33 and 159.05 TWh respectively for petrol and diesel transportation. This component will remain unchanged when EVs share progressively increases.

UP 2030. Consumption for traditional vehicles has been assessed at 2030 according to UP data [63]. The lower consumption is due to an assumed reduction to 13.1 and 13 Million units respectively for petrol and diesel vehicles. The number of hybrid electric vehicle has been taken into account to derive a weighted average value of fuel economy, i.e. 6.95 l/100km, gained assuming a value of 4.3 l/100km for hybrid cars [72] and 2900 vehicles at 2030.

Table 20. Petrol vehicles number and consumption at 2030 – UP 2030

Petrol vehicles number and consumption – UP 2030			
Vehicle category	**No. of vehicles (Millions)**	**Fuel economy (l/100 km)**	**Consumption (TWh)**
Small	7.4	6	25.08
Medium	4.8	8	21.66
Large	0.9	11	5.61
Total private transport	**13.1**		52.35
Variation with respect to 2014	*-3.5*		*-21%*
Other petrol consumption			**26.33**
Total petrol consumption			**78.68**

Table 21. Diesel vehicles number and consumption at 2030 – UP 2030

Diesel vehicles number and consumption – UP 2030			
Vehicle category	**No. of vehicles (Millions)**	**Fuel economy (l/100 km)**	**Consumption (TWh)**
Small	7.3	5.5	46.24
Medium	4.8	7.2	39.22
Large	0.9	10.5	10.78
Total private transport	**13**		**96.24**
Variation with respect to 2014	*-1.2*		*-8%*
Other diesel consumption			**159.05**
Total diesel consumption			**255.29**

With respect to 2014, the projected reduction in the number of oil-powered vehicles leads to a decrease in fuel combustion of 21% and 8% for petrol and diesel vehicles respectively.

LPG, natural gas and biodiesel consumption are also provided in the UP outlook, resulting equal to 21.32, 20.58 and 26.02 TWh respectively [63].

The number of total vehicle in use is equal to 33.7 Million of vehicles; EVs are estimated to be 700 000 units (where 400 000 are PHEVs and 300 000 are BEVs), i.e. 2% of the total fleet. Considering EVs fleet distribution unchanged with respect to 2016, the average electricity consumption has been estimated as showed in Table 22. Average capacity and battery range have been estimated as weighted average values with respect to the number of vehicles.

Table 22. EV annual electricity consumption and total battery capacity at 2030 – UP 2030

		Share of vehicles	*No. of vehicles*	*Average capacity (kWh)*	*Average range (km)*	*Consumption (GWh)*	*Total capacity (GWh)*
BEV	**Small**	40%	120 777	15.64	145.45	97.32	1.89
	Medium	51%	154 292	23.33	199.28	135.36	3.60
	Large	3%	8 685	61.33	391.27	10.20	0.53
	Van	5%	16 247	33.13	194.40	20.75	0.54
Total BEV			**300 000**	**21.87**	**182.90**	**263.63**	**6.56**
PHEV			**400 000**	**9.86**	**40.53**	**728.90**	**3.94**
Total EV			**700 000**	**15.01**	**101.55**	**992.54**	**10.50**
Total vehicles in use			**33 700 000**				
% of EVs			**2.07%**				

Considering 700 000 vehicles connected at 19.2 kW, capacity of battery to grid connection has been set to 13.44 GW.

As for dump charge, the software needs a distribution that combines electric transport demand from other means of transportation (e.g. trains, trams, etc) and EVs demand. This latter is based on vehicles starting to charge after 4pm and continuing gradually until fully charged [51]. The new normalized distribution is displayed in Figure 4, gained by normalising the distribution that gives 10.11 TWh for electric transport (same as Figure 2) and 0.99 TWh night charge distribution.

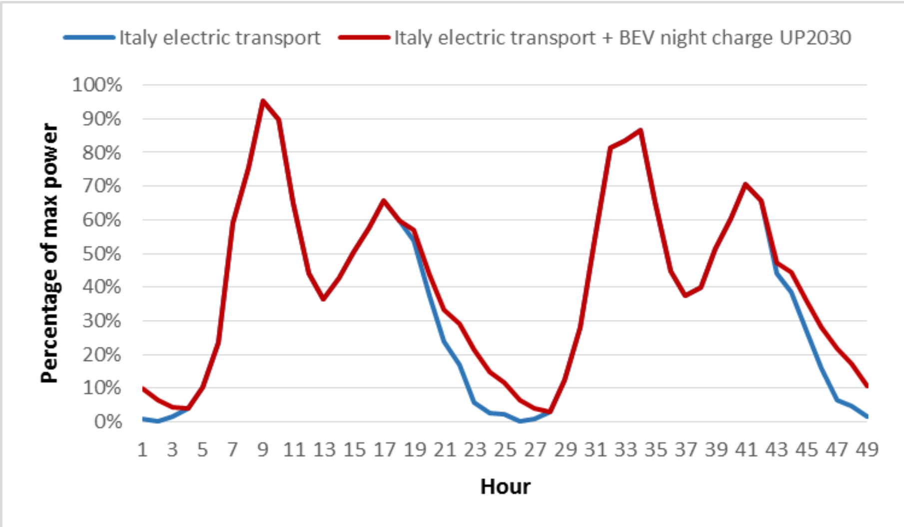

Figure 4. Italy transport distribution with and without BEV night charge for UP 2030

In order to assess the impact of higher shares of EVs on national energy system operation, other scenarios have been defined, characterised by a EVs penetration level progressively increasing from the level projected in UP 2030until replacing the entire oil powered vehicles share of the fleet, i.e. 77.5%.

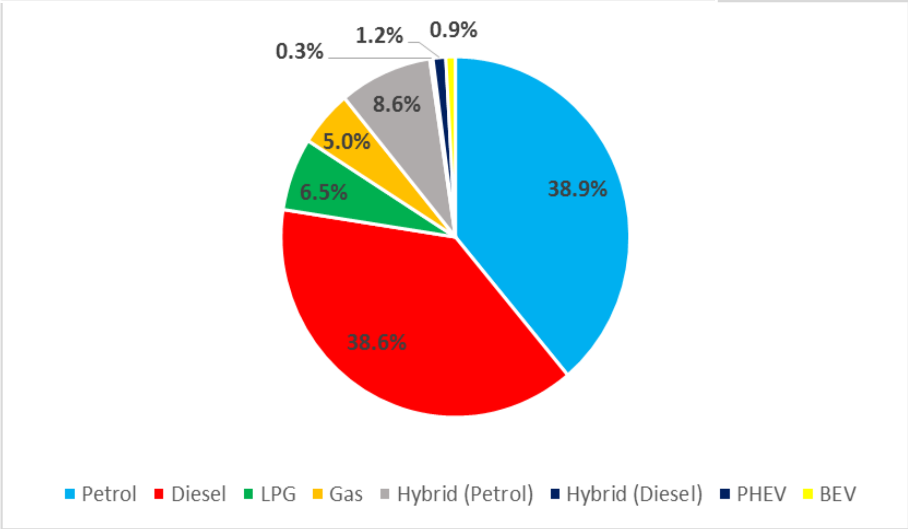

Figure 5. UP 2030 vehicles in use fleet composition.

Overall battery capacity UP 2030 scenario assumes 700000 EVs at 2030; additional EVs, resulting from the other scenarios where penetration is higher, will substitute traditional vehicle in the right category distributed between petrol and diesel. As for LogFun 2030 and RSE 2030, 60% of the additional EVs will replace petrol vehicles while 40% of the fleet will substitute vehicles in the diesel category.

LogFun 2030. In this scenario EVs account for 14% of the total fleet in use, as a result of a logistic function fit of EVs shares over the past year as displayed in Figure 3. The reduced fuel consumption with respect to traditional vehicles is displayed in the following tables.

Table 23. Petrol vehicles number and consumption at 2030 – LogFun 2030

Petrol vehicles number and consumption – LogFun 2030			
Vehicle category	**No. of vehicles (Millions)**	**Fuel economy (l/100 km)**	**Consumption (TWh)**
Small	7.1	6	24.12
Medium	2.7	8	12.42
Large	0.8	11	5.49
Total private transport	**10.7**		42.02
Variation respect to UP2030	*-2.4*		*-20%*
Other petrol consumption			**26.33**
Total petrol consumption			**68.35**

Table 24. Diesel vehicles number and consumption at 2030 – LogFun 2030

Diesel vehicles number and consumption – LogFun 2030			
Vehicle category	**No. of vehicles (Millions)**	**Fuel economy (l/100 km)**	**Consumption (TWh)**
Small	7.2	5.5	45.05
Medium	3.4	7.2	27.97
Large	0.9	10.5	10.62
Total private transport	**11.4**		83.64
Variation respect to UP 2030	*-1.6*		*-13%*
Other diesel consumption			**159.05**
Total diesel consumption			**242.70**

Table 25 shows EVs annual consumption and total available battery capacity with regard to LogFun 2030 scenario. With respect to UP 2030 scenario, electricity consumption and available battery capacity grow from 0.99 to 7.11 TWh and from 10.5 to 62.15 TWh respectively.

Table 25. EV annual electricity consumption and total battery capacity at 2030 –LogFun 2030

		Share of vehicles	*No. of vehicles*	*Average capacity (kWh)*	*Average range (km)*	*Consumption (GWh)*	*Total capacity (GWh)*
BEV	**Small**	40%	557 613	15.64	145.45	449.33	8.72
	Medium	51%	712 349	23.33	199.28	624.96	16.62
	Large	3%	40 099	61.33	391.27	47.09	2.46
	Van	5%	75 009	33.13	194.40	95.79	2.49
Total BEV			**1 385 070**	**21.87**	**182.90**	**1217.17**	**30.29**
PHEV			**3 231 830**	**9.86**	**40.53**	**5889.23**	**31.86**
Total EV			**4 616 900**	**13.46**	**83.24**	**7106.40**	**62.15**
Total vehicles in use			**33 700 000**				
% of EVs			**13.7%**				

With 4.6 Million of EVs, capacity of battery to grid connection is equal to 88.64 GW.

In order to model dump charge another transport distribution has to be inputted due to the higher penetration of EVs. The new normalized distribution is showed in Figure 6.

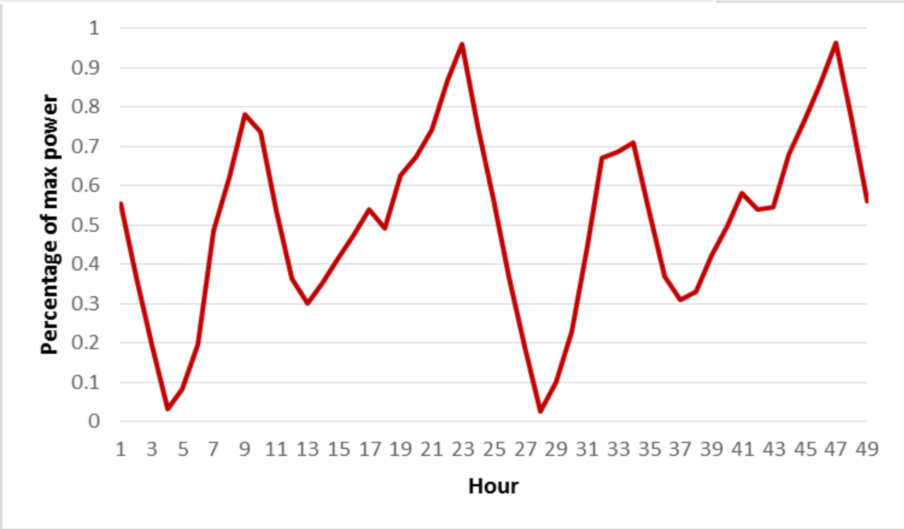

Figure 6. Italy transport distribution with BEV night charge for LogFun 2030

RSE 2030. According to RSE outlook for 2030 [69], 10 Million of EVs are foreseen to be in use. In line with LogFun 2030 scenario, fossil fuel reduction from transport along with EVs consumption and battery capacity have been estimated. In particular, given that 60% of medium EVs exceeds in this case the equivalent traditional vehicle category, additional 100000 vehicles have been substituted in the small category.

Table 26. Petrol vehicles number and consumption at 2030 – RSE 2030

Petrol vehicles number and consumption – RSE 2030			
Vehicle category	**No. of vehicles (Millions)**	**Fuel economy (l/100 km)**	**Consumption (TWh)**
Small	6.6	6	22.45
Medium	0.0	8	0.00
Large	0.9	11	5.31
Total private transport	**7.5**		**27.77**
Variation respect to UP 2030	-5.6		*-47%*
Other petrol consumption			**26.33**
Total petrol consumption			**54.10**

Table 27. Diesel vehicles number and consumption at 2030 – RSE 2030

Diesel vehicles number and consumption – RSE 2030			
Vehicle category	**No. of vehicles (Millions)**	**Fuel economy (l/100 km)**	**Consumption (TWh)**
Small	6.9	5.5	43.42
Medium	1.5	7.2	12.52
Large	0.9	10.5	10.39
Total private transport	**9.3**		**66.33**
Variation respect to 2014	*-3.7*		*-31%*
Other diesel consumption			**159.05**
Total diesel consumption			**225.39**

As shown in Table 28, RSE 2030 implies a total annual consumption of 15.39 TWh and 134.61 GWh of total battery capacity.

With 10 Million of EVs, capacity of battery to grid connection is equal to 192 GW. This value however exceeds the EnergyPLAN limit of 100 GW, as a result not all the vehicle can deliver electricity to the grid.

Table 28. EV annual electricity consumption and total battery capacity at 2030 –RSE 2030

		Share of vehicles	*No. of vehicles*	*Average capacity (kWh)*	*Average range (km)*	*Consumption (GWh)*	*Total capacity (GWh)*
BEV	**Small**	40%	1 207 766	15.64	145.45	973.22	18.89
	Medium	51%	1 542 916	23.33	199.28	1353.64	36.00
	Large	3%	86 853	61.33	391.27	102.01	5.33
	Van	5%	162 466	33.13	194.40	207.47	5.38
Total BEV			**3 000 000**	**21.87**	**182.90**	**2636.33**	**65.61**
PHEV			**7 000 000**	**9.86**	**40.53**	**12755.81**	**69.01**
Total EV			**10 000 000**	**13.46**	**83.24**	**15392.14**	**134.61**
Total vehicles in use			**33 700 000**				
% of EVs			**29.7%**				

Normalized transport distribution for RSE 2030 is displayed in Figure 7.

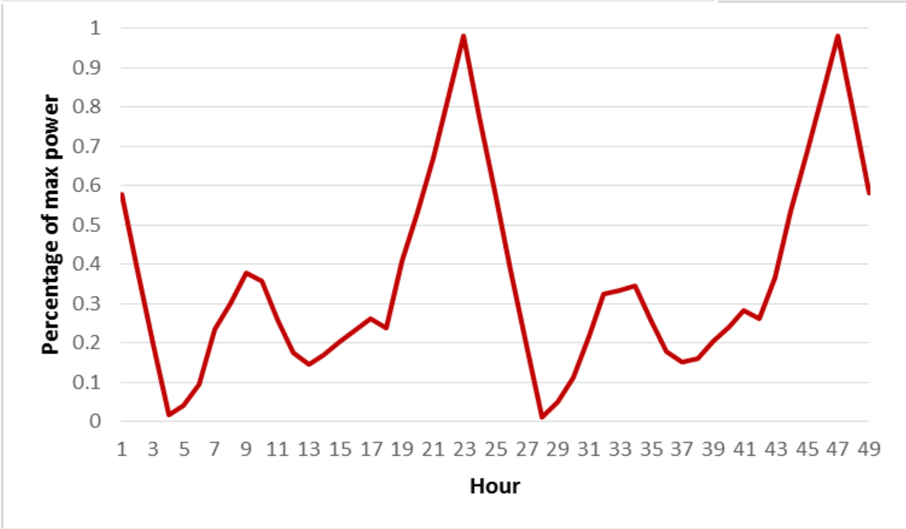

Figure 7. Italy transport distribution with BEV night charge for RSE 2030

50% EV. In this scenario, EVs account for 50% of the vehicles in use fleet. Since medium category of EVs (BEVs and PHEVs) exceeds significantly the equivalent category for traditional cars, the overall fleet of EVs in small and medium category has been equally distributed among small and medium category of traditional vehicles for replacement. Data, in terms of fuel savings and EVs technical specifications are listed in Table 29 - Table 31.

Table 29. Petrol vehicles number and consumption at 2030 – 50% EV

Petrol vehicles number and consumption – 50% EV			
Vehicle category	**No. of vehicles (Millions)**	**Fuel economy (l/100 km)**	**Consumption (TWh)**
Small	2.6	6	8.80
Medium	0.0	8	0.00
Large	0.8	11	5.09
Total private transport	**3.4**		**13.86**
Variation respect to UP 2030	-9.7		*-74%*
Other petrol consumption			**26.33**
Total petrol consumption			**40.19**

Table 30. Diesel vehicles number and consumption at 2030 – 50% EV

Diesel vehicles number and consumption – 50% EV			
Vehicle category	**No. of vehicles (Millions)**	**Fuel economy (l/100 km)**	**Consumption (TWh)**
Small	4.1	5.5	26.08
Medium	1.6	7.2	12.83
Large	0.8	10.5	10.11
Total private transport	6.5		49.02
Variation respect to 2014	-6.5		*-49%*
Other diesel consumption			**159.05**
Total diesel consumption			**208.07**

Table 31. EV annual electricity consumption and total battery capacity at 2030 –50% EV

		Share of vehicles	*No. of vehicles*	*Average capacity (kWh)*	*Average range (km)*	*Consumption (GWh)*	*Total capacity (GWh)*
BEV	**Small**	40%	2 035 085	15.64	145.45	1644.81	31.83
	Medium	51%	2 628 600	23.33	199.28	2313.06	61.34
	Large	3%	146 347	61.33	391.27	172.40	8.98
	Van	5%	273 755	33.13	194.40	350.63	9.07
Total BEV			**5 055 000**	**21.87**	**182.90**	**4480.89**	**111.22**
PHEV			**11 795 000**	**9.86**	**40.53**	**24394.17**	**116.27**
Total EV			**16 850 000**	**13.46**	**83.24**	**28875.06**	**227.49**
Total vehicles in use			**33 700 000**				
% of EVs			**50%**				

77.5% EV. This is the scenario with the highest level of EVs, i.e. 26.1 Million. Oil-powered vehicles for private transport are totally replaced by electric cars. Petrol and diesel consumption for private transport is null and EVs specifications are displayed in Table 32.

Table 32. . EV annual electricity consumption and total battery capacity at 2030 –77.5% EV

		Share of vehicles	*No. of vehicles*	*Average capacity (kWh)*	*Average range (km)*	*Consumption (GWh)*	*Total capacity (GWh)*
BEV	**Small**	40%	3 152 268	15.64	145.45	2547.74	49.31
	Medium	51%	4 071 600	23.33	199.28	3582.84	95.01
	Large	3%	226 686	61.33	391.27	267.03	13.90
	Van	5%	424 036	33.13	194.40	543.11	14.05
Total BEV			**7 830 000**	**21.87**	**182.90**	**6940.73**	**172.27**
PHEV			**18 270 000**	**9.86**	**40.53**	**33392.65**	**180.11**
Total EV			**26 100 000**	**13.46**	**83.24**	**40333.37**	**352.38**
Total vehicles in use			**33 700 000**				
% of EVs			**77.45%**				

Results and discussion

The above-described scenarios have been modelled in EnergyPLAN. Results are summarised in Figure 8 and Figure 9 and have been analysed in terms of CO_2 annual emissions and Critical Excess Electricity Production (CEEP) for different combinations of RES and EVs penetration using different charging strategies.

For the particular case of Italian energy system, no difference have been registered between smart and V2G type of strategy, meaning that, for an optimal operation of the system, vehicles are not required to deliver energy to the grid. As a result, only dump and smart type of charge have been considered.

With reference to a particular EVs share, when RES penetration grows from 2014 level (ca. 40% of electricity production) to 90% of electricity production, CO_2 emissions register a reduction that ranges from 15% to 18% for dump charge and from 15% to 19% for smart charge strategy. In absolute values, increasing RES electrical production from 40% to 90% and EVs share from 2% to 77.5%, emissions vary from 320.31 to 245.43 Mt.

With respect to a given level of RES penetration, CO_2 emission levels are reduced between 5% and 9% for RES penetration respectively at 2014 level and accounting for the 90% of production. However, under the same RES scenario, emissions are not significantly reduced from dump to smart charge since, even in the best-case scenario with RES accounting for 90% of production and complete oil powered vehicles replacement by EVs, the difference between charging strategy is equal to 1.9%.

CEEP, which has been shown as a percentage of the total electricity demand, is null when RES production is kept at 2014 level and below 1% for 60% RES scenario. However, it grows exponentially with RES penetration and can be as high as 15.8% of the total demand when RES provide for 90% of electricity production and EVs fleet accounts for 2% of total vehicles in use. Nonetheless, results show that it can be partly reduced by increasing the number of EVs and switching charging strategy.

By implementing a smart charge strategy, CEEP can be reduced up to 7.9% and 12.6% (respectively for 75% RES and 90% RES scenarios) if compared to the equivalent dump charge option.

Regardless of charging strategy, being EVs able to store part of the excess production, their increased penetration positively interact with the growing RES level. For 75% and 90% RES scenario using smart charge, when EVs increase from 2% to 77.5%, CEEP is reduced by 31% and 27%, ranging from 37.1 to 25.48 TWh (i.e. 10.8% and 8% of electricity demand) for 75% RES and from 54.36 to 39.74 TWh (15.8% and 11.5% of total electricity demand) for 90% RES scenario.

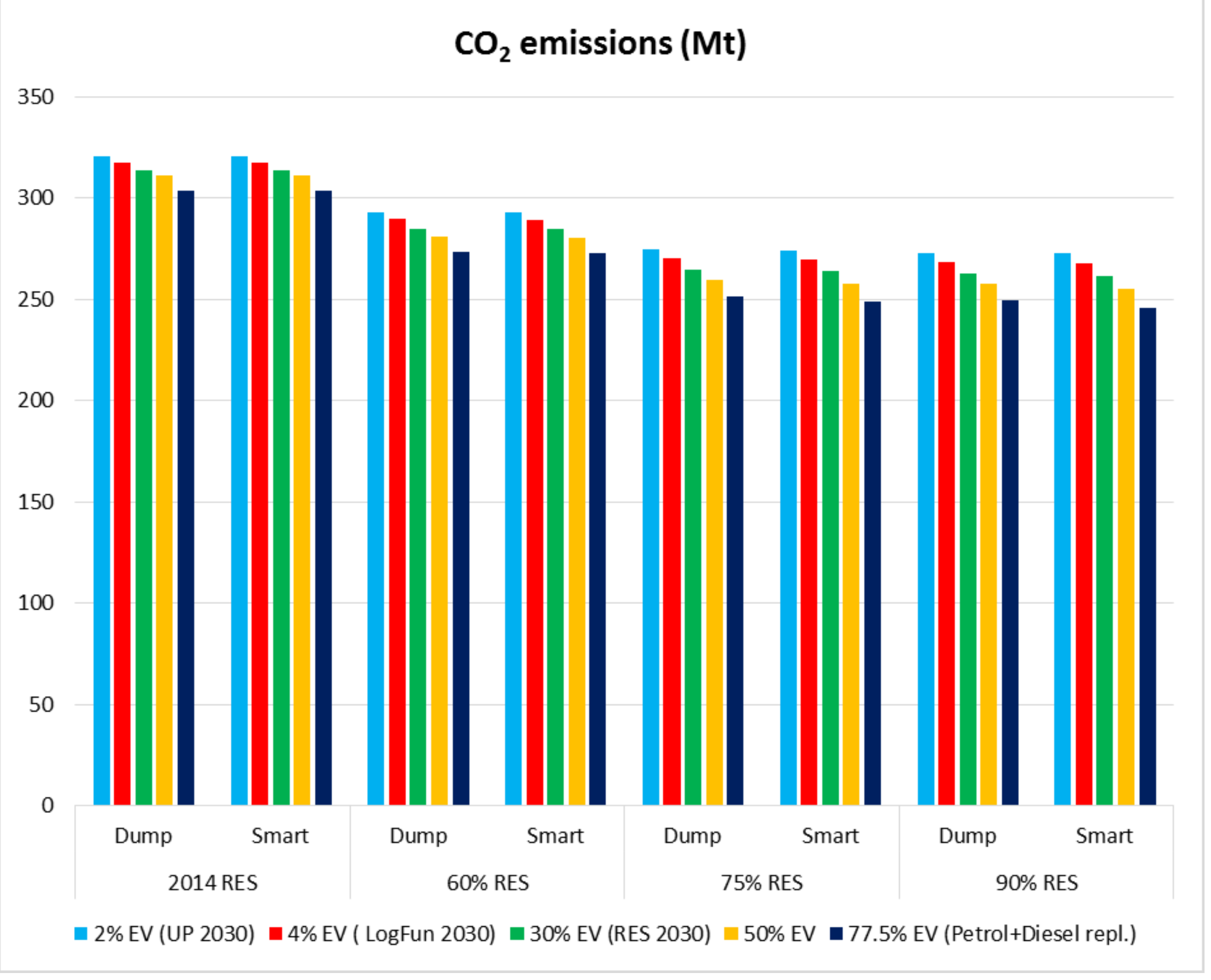

Figure 8. CO_2 annual emissions for RES and EVs levels of penetration with respect to different battery charging strategy.

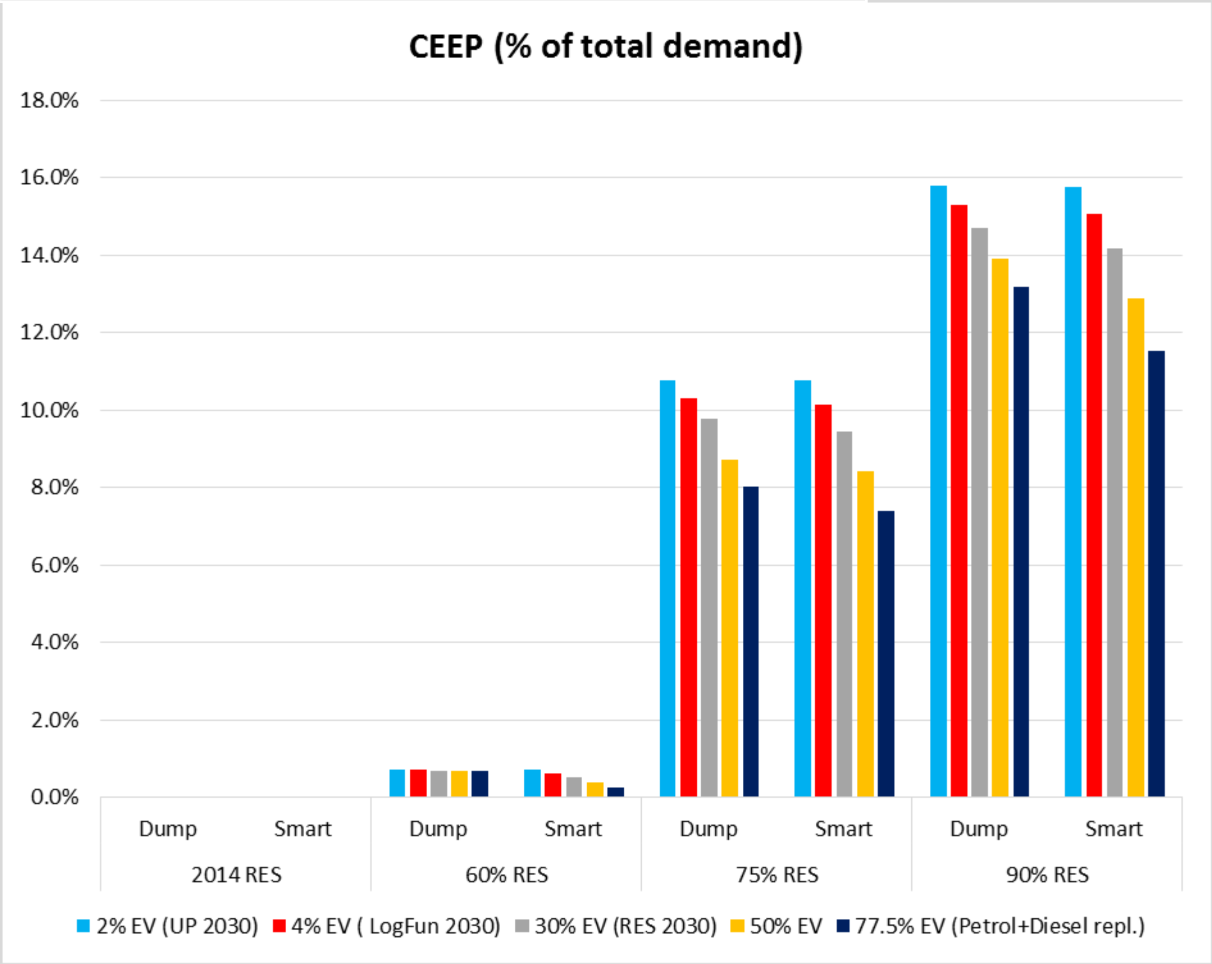

Figure 9. CEEP (expressed as a percentage of total electricity demand) for RES and EVs levels of penetration with respect to different battery charging strategy.

A preliminary study has been carried out to assess if shifting energy consumption for heating away from natural gas (which currently represents 66% of demand for individual heating) toward electricity could affect the excess of production. The impact of electric heating on the magnitude of excess of production has been analysed on 90% RES, both being quite long-term scenarios. Results are shown in **Error! Reference source not found.** where excess of production is displayed with reference to a replacement of 30% and 60% of natural gas by electricity respectively.

In the best case scenario, with EVs accounting for 77.5% and 60% of natural gas consumption replaced by electric heating, CEEP is effectively reduced by 50%. However, it comes at the price of problem management of transmission line during peak hours of electricity demand. The excess of production from renewable is not effectively adsorbed by electric heating whereas more electric from thermoelectric power plants may be required leading even to an increase of CO_2 emissions.

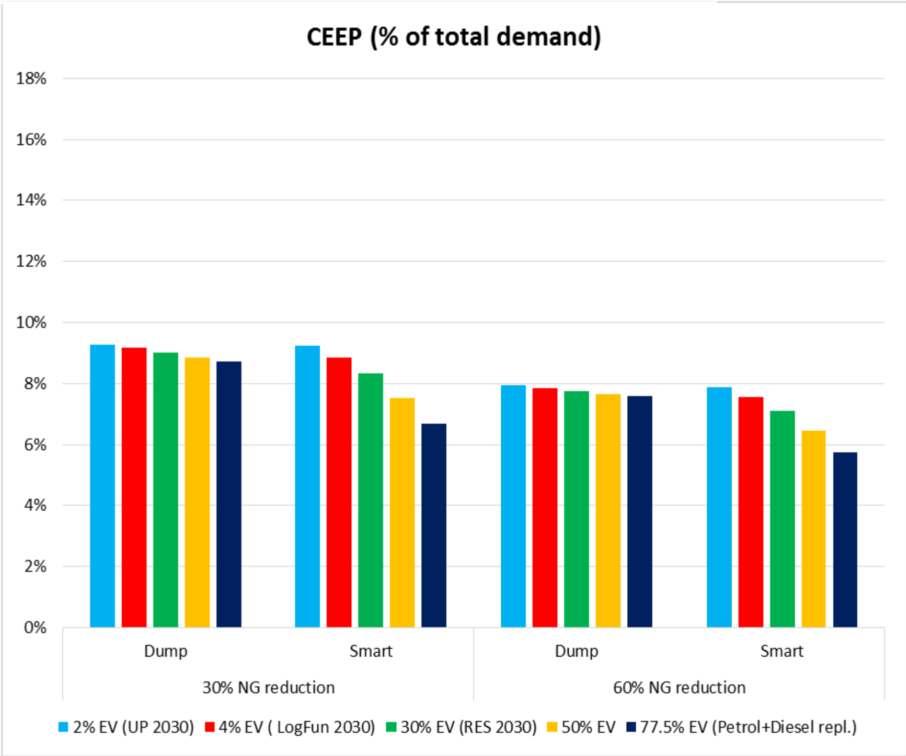

Figure 10. CEEP (expressed as a percentage of total electricity demand) for 90% RES, 30% and 60% natural gas reduction for heating with respect to different EVs levels of penetration and battery charging strategy

CONCLUSION

This study aimed to assess the impact of progressively increasing shares of EVs in scenarios with rising level of production from renewable sources using different charging strategy. Results have been compared with respect to two different indicators: critical excess of energy production (CEEP) and CO_2 emissions.

By increasing RES penetration from 40% to 90% of electricity production and EVs share from 2% to a level that completely replace oil-powered vehicles, CO_2 emissions can be reduced by 23%. This however, comes at the price of an excess of electricity production that goes from zero to 11.5% of the total electricity demand under the same variation of scenarios.

With RES penetration at 90%, a smart charge strategy can only partly reduce the excess of production; even in the best-case scenarios, with EVs accounting for 77.5%, only 12.6% of reduction is possible with respect to dump charge option. Other measures need to be taken to effectively reduce the excess of production that inevitably occurs with significant RES penetration, such as shifting energy consumption for individual heating from natural gas toward electric and battery storage systems, under a proper management strategy of transmission line.

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