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ELECTRIC MOBILITY: IMPACT ON OVERALL GHG EMISSIONS AND ON THE ELECTRICAL GRID

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Abstract *In this paper the correlation between the Electric Vehicle (EV) driving profile and energy consumption and Greenhouse Gas (GHG) emissions and the impact on the electrical grid is analysed.*

The driving profile influences greatly the overall emissions of the vehicle during the operation phase and consequently will shift the importance of each phase (production, use and disposal) of the vehicle life cycle in terms of GHG emissions.

Despite both driving profile and electricity mix contribute directly to overall GHG emissions they are independent and their weight depends heavily on the scenario where and how the EV is used. An EV driven in aggressive way charged in a electricity mix with a high share of renewable energy source can have the same associated GHG emissions of an EV driven in an environmentally way charged in electricity mix with high GHG emissions.

The impact on the electrical grid was also analysed using measurement results for normal power and high power DC charging methods. The results include the characterization of voltage and current harmonic distortion during the charging operations.

1. INTRODUCTION

The use of electric vehicles as a viable alternative for a personal mobility as grown over the last years. Electric mobility is seen as one of the solutions to reduce the global greenhouse gas emissions from the road transportation sector, which in the European Union contributes with around 20% of the total emissions [1]. To meet the increasing demand for transport and at the same time to reduce GHG emissions and improve air quality, the paradigm of personal transportation has to change. This change embraces alternative vehicle and fuel technology as well a smarter infra-structure, through the electrification of the powertrain, using batteries or fuel cells, and the use of alternative fuels, such as biofuels, natural gas and hydrogen [2].
Powertrain electrification has been advocated for decades, as an alternative for the internal combustion engine vehicle (ICEV), due to zero tailpipe emissions and higher efficiency, by using an electric motor [3]. The shift from fossil fuels to electricity also provides a higher security in terms of energy dependency and a more efficient use of energy, due to the higher efficiency of the electric motor opposed to internal combustion engines [4].
To assess the contribution on EV to a reduction of GHG emissions, an assessment form a cradle to grave perspective is performed taking into account the driving profile and electricity mix. The impact on the electrical grid is also assessed, due to the large number of vehicles charging at the same time, which could lead to power quality issues.

2. IMPACT OF THE DRIVING PROFILE AND ELECTRICITY MIX

A global perspective was considered for the vehicles life cycle and their key components, such as battery, and as well to the electricity generation. The manufacturing phase was considered common to all vehicles and scaled based on the vehicle weight. An additional burden, due to the use of a battery, is added to EVs based on battery weight. Several life-cycle studies shown that the most critical phase in terms of GHG emissions is the operation phase, whether is an electrical or conventional vehicle [5]. The exception is for EVs charged with electricity in a mix with low GHG emissions, where the production phase is the most critical. Gasoline and diesel ICE vehicles have the higher emissions during the operation phase followed by Plug-in Hybrid Vehicles (PHEV) and Battery Electric Vehicles (BEV) while the emissions during the production phase are similar to all vehicle technologies, excluding the battery production. During the vehicle production, the battery used in PHEVs and BEVs is the most critical component in terms of GHG emissions, contributing with 30-50% of total emissions, mainly due to the materials and quantities required for the battery production [6].
In order to assess the impact of the driving profile in the energy consumption and GHG emissions during the operation phase a data acquisition system (Figure 1) was installed in a Nissan Leaf, a fully battery powered electric vehicle, with is main characteristics can be found on Table 1. The energy losses along the several components of the system were also taken

into account to accurately determine the GHG emissions during the EV operation phase (Figure 2). Using this data acquisition system it is possible to correlate the energy consumption with the road profile and with the driving profile. It was considered that the vehicle travelled 200000 km during its life cycle using only one battery pack.

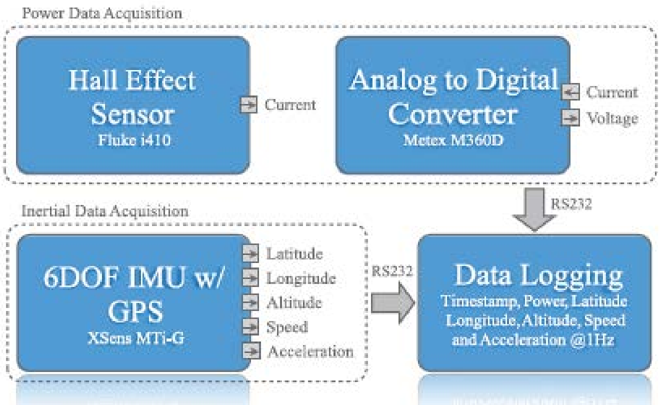


Figure 1 – Data acquisition system installed on the Nissan Leaf

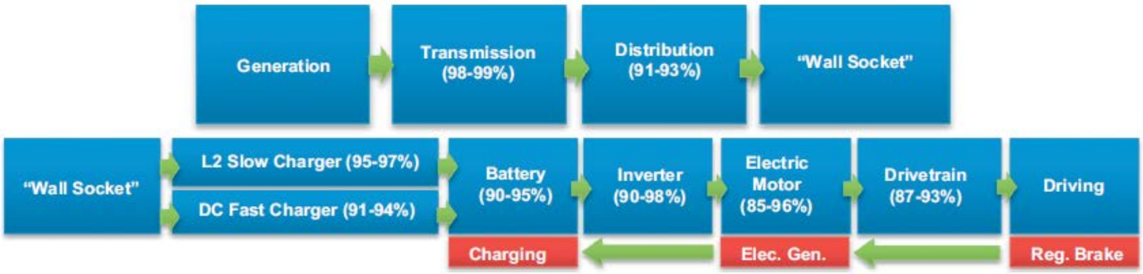


Figure 2 – Efficiency of the different components in the energy path of an EV

	Nissan Leaf
Electricity consumption (Wh/km)	140
Electric Motor (kW)	80
Battery Weight (kWh)	24
Battery Capacity (kg)	300
Curb Weight (kg)	1520

Table 1 – Main characteristics of the Nissan Leaf

Several real world driving cycles were performed in two predefined routes, one urban and other suburban, under different driving conditions (aggressive, normal and ECO) and with different settings for the climate control (A/C OFF, A/C in cooling mode and A/C in heating mode). The aggressive profile differs from the normal profile mainly in the acceleration and braking phase, where the aggressive has fast accelerations and sudden braking to maximize the energy consumption. The ECO driving profile is characterized by slow accelerations, lower top speed and the braking is mainly ensured with regenerative braking, to minimize the overall energy consumption. For the driving cycles, the climate control was set in manual mode at 21ºC (with an ambient temperature of about 30ºC) with the fan at medium speed, both for cooling and heating, being the baseline with the climate control OFF. Figure 3 presents the power and energy requirements for a BEV to maintain a constant speed in different slopes.

Table 2 summarizes the average energy consumption and estimated range for the considered scenarios. As expected, an ECO driving profile is more efficient than an aggressive one, which can reduce the driving range to 90 km due to an increase energy consumption of 47%. The use of climate control also has a significant impact, increasing the energy consumption in 24% in cooling mode and 61% in heating mode for the ECO driving profile [7].

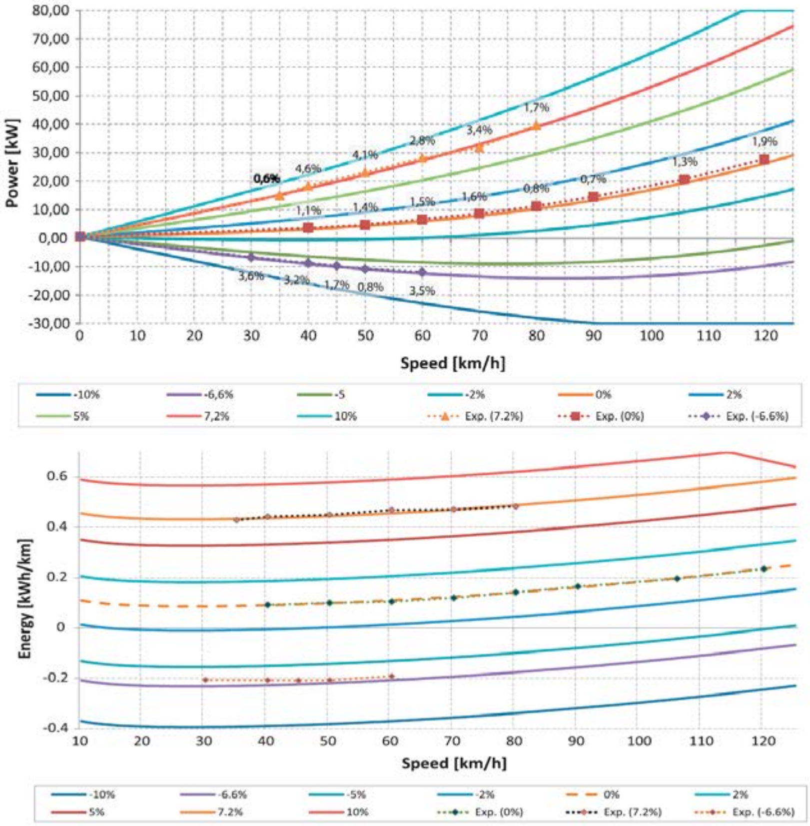


Figure 3 – Power and energy required to maintain a constant speed over several degrees of inclination

Driving Style	AC OFF		AC ON - Cooling		AC ON - Heating	
	Wh/km	km	Wh/km	km	Wh/km	km
Aggressive	155.4	139	177.7	113	213.4	94
Normal	131.0	153	151	132	182.8	109
ECO	104.7	191	129	155	167.1	120

Table 2 – Energy consumption and estimated range based on the driving profile and climate settings

To assess correctly the impact of an EV, the electricity mix used to charge the vehicle must be known. The primary energy source used for electricity generation contributes directly to the overall GHG emissions of the generation mix, which in turn affect the operation phase emissions of an EV. Emissions associated with fuel production are more or less constant over time, mainly affected from where the crude oil is extracted, and could be considered over a large geographic area unlike electricity generation that depends directly from the share and type of power plants on the system and could vary significantly from country to country. Other key aspect to take into consideration is that the share of each type of energy source contributing to the overall electricity mix varies daily and is also dependent on the season [8]. In this assessment three mixes were considered based on their share of renewable energy sources and quantity of GHG emissions, presented on Figure 4.

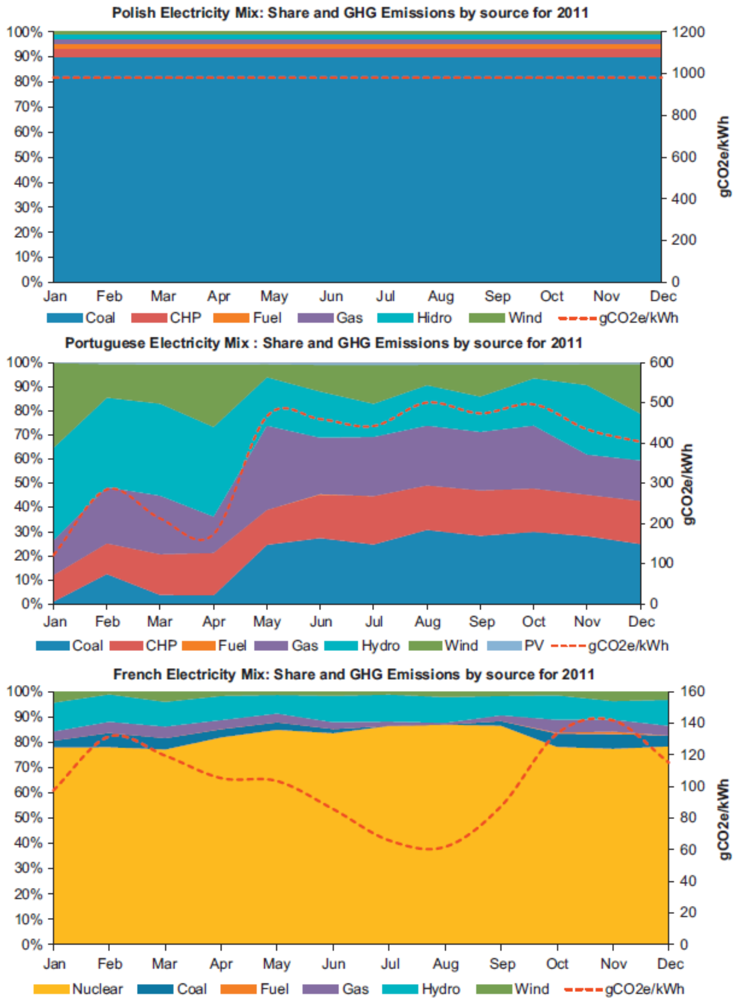


Figure 4 – GHG emissions and share by source for the electricity mixes considered during 2011

From Figure 4 is easily noticeable that the mix varies considerably over the year and also during the day, due to the intermittence and share of renewable sources for the overall electricity generation. This variation is very noticeable in mixes with a large share of renewable sources or nuclear, such as Portugal and France, where fossil powered plants are required to be in standby, leading to higher overall GHG emissions. In a mix mainly ruled by fossil fuel powered power plants, the associated GHG emissions are fairly constant over the year and over the day [9]. Table 3 shows the associated emissions by scenario and electricity mix based on the energy consumption of the EV.

Figure 5 presents the impacts, per km travelled, due to different driving profile and the use of climate control against a baseline scenario, for the considered electricity mixes. For an electricity mix with low GHG emissions the way an EV is operated will not affect the life-cycle emissions in a significant way. However, as the electricity mix associated GHG emissions increase, more relevant will be the impact of the operation profile of the vehicle.

Driving Style	AC OFF			AC ON - Cooling			AC ON - Heating		
	PL Mix	PT Mix	FR Mix	PL Mix	PT Mix	FR Mix	PL Mix	PT Mix	FR Mix
Aggressive	177	68	19	202	78	21	243	93	26
Normal	149	57	16	172	66	18	208	80	22
ECO	119	46	13	147	56	15	190	73	20

Table 3 – Estimated GHG emissions per km travelled for the operation, based on the driving profile and climate control settings, for the considered electricity mixes.

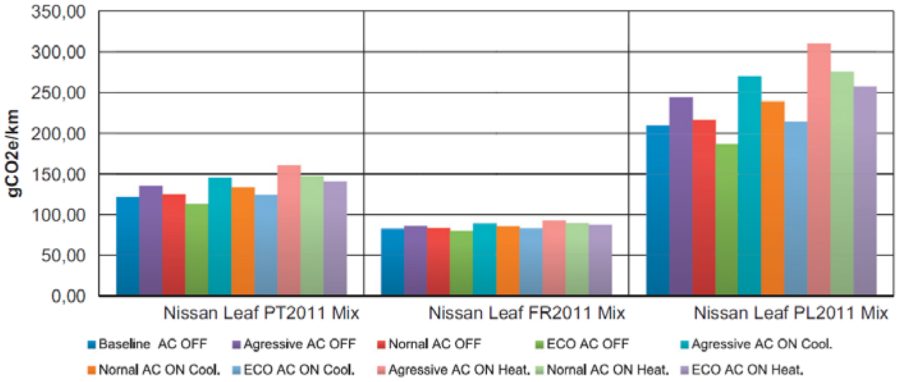


Figure 5 – Impact of the operation phase on the overall life cycle emissions per km travelled

Figure 6 correlates the vehicle energy consumption (in Wh/km), directly related with the emissions per km travelled (in gCO_{2e}/km), and the electricity mix life-cycle emissions (in gCO_{2e}/kWh) on the EV overall life-cycle GHG emissions. The emissions per km travelled take into account the emissions associated with vehicle production.

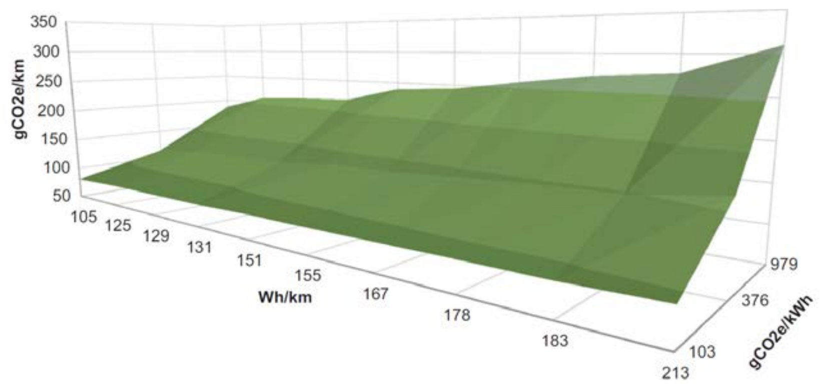


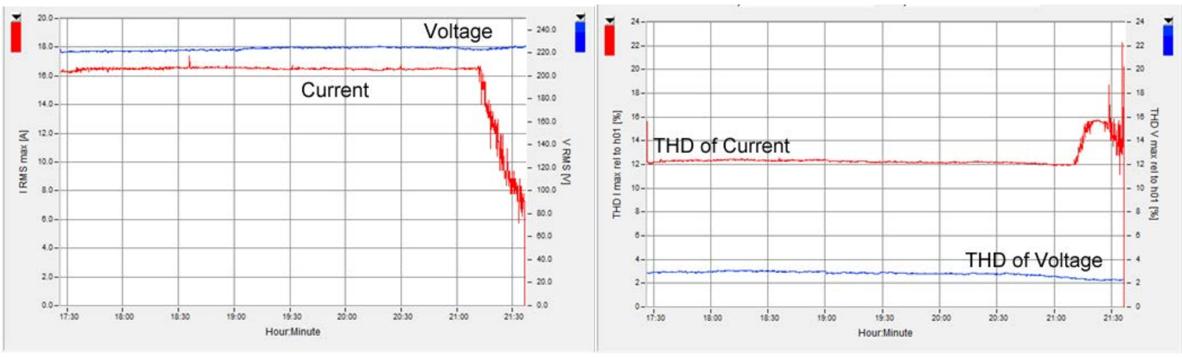
Figure 6 – Variation of life cycle GHG emissions, per km travelled

3. IMPACT OF EVS ON THE ELECTRICAL GRID

EVs chargers are typically characterized by 1-phase (230 VAC) or 3-phase (400 VAC) rectifiers to convert AC in DC power to charge battery packs, which typically store energy at 300 – 400 VDC. As any other non-linear electronic load, these rectifiers may generate some harmonic currents. The harmonic distortion is an important issue that is drawing attention in the field of integration of EVs in power systems and should be analysed for normal power and high power DC charging methods.

The analysis and characterization of the impact of Normal Power charging on the supply network were based on voltage and current monitoring of the on-board 1-phase charger, during a charging operation by Mode 2 in a standard non-dedicated socket outlet in an office-building. Measurements were carried out with the a Nissan Leaf, with a battery pack of 24 kWh, during a charging operation of 14.4 kWh, from on-board displayed 64 km range to 166 km range.

Figure 7 (a) shows the root mean square (RMS) values of current and voltage during the charging period of 4:10 h. Voltage has remained constant (about 225 V) during all operation time. Current has also remained constant (about 16.4 A) during the first 3:44 h. In the last 26 minutes, the current has decreased progressively from 16.4 A to about 6 A, followed by the automatic switch-off. Regarding harmonic distortion, Figure 7 (b) shows the maximum values of Total Harmonic Distortion (THD) of current and voltage during the charging period. The values of THDV have been among the typical values recorded in office-buildings (2% - 3%), supplied in Medium Voltage (MV). The values of THDI have remained constant (12%) during the first 3:44 h and they have reached a maximum of 16% in the last 26 minutes, with lower charging currents.



(a) (b)

Figure 7 – RMS values (a) and THD values (b) of current voltage

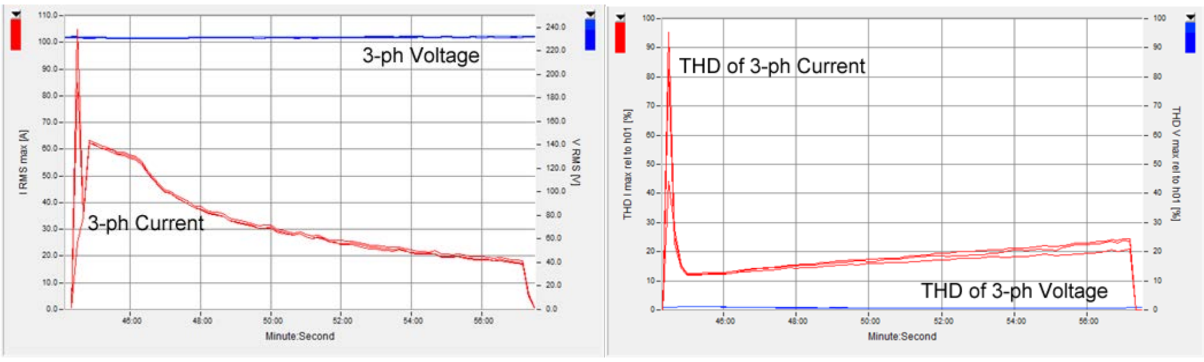
The 3rd harmonic current reached maximum RMS values around 1.9 A (11.6%), during the initial period of 3h44min, being by far the most significant component contributing to the THDI. These significant values of the 3rd harmonic component show that charging a PEV can contribute to increase the harmonic distortion in Low Voltage (LV) networks, supplied typically by power transformers in delta-star connection, inducing additional losses in neutral conductors and power transformers.

3.1. Results in High Power DC Charging

The analysis and characterization of the impact of High Power DC charging method on the supply network were based on voltage and current monitoring of the 3-phase charger input, during a charging operation. Measurements were carried out in a High Power DC charging point, supplying a Mitsubishi i-MiEV, with a battery pack of 16 kWh, during a charging operation of 4.3 kWh, from on EVSE displayed 57% to 82% of the battery capacity.

Figure 8 (a) shows the RMS values of current and voltage during the charging period of 13 minutes. Voltage has remained constant in 3 phases (about 231 V) during all the time. The charging operation started with a significant inrush current of 105 A in 2 phases, followed by a stabilization period of 2 minutes around 60 A and by a progressive decreasing during the remaining charging time.

Figure 8 (b) shows the maximum THD values of current and voltage during the charging period. Values of THDV have remained quite low (lower than 1%) during all charging period. The maximum values of THDI reached a very high peak (95%) during the inrush current event, drooping suddenly to around 12%. After this initial transient, maximum values of THDI have progressively increased in opposition to the current reduction. In 12 minutes, the maximum current values have decreased from 60 A to 17 A and maximum THDI values have increased from 12% to 24%. One of the most significant harmonic components contributing to the THDI is the 5th harmonic current, showing a constant increasing similar to THDI, with its maximum values rising from 3% to 12% in 12 minutes.



(a) (b)

Figure 8 – RMS values (a) and THD values (b) of current voltage

4. CONCLUSIONS

In terms of GHG emissions, the impacts of BEV depend directly on the electricity generation mix and driving style. For mixes with low GHG emissions associated with electricity generation, an aggressive driving style is not as critical as in a mix with a large share of fossil sources. For the present EU mix, the emissions reduction impact is substantial, and will be reduced even more in the future due to the increasing use of renewable energies in the energy mix.

In terms of impact on the electrical grid, the simultaneous operation of several 1-phase chargers (Normal Power charging) in the same LV feeder can have a significant impact on distribution networks. In these situations, the right technologies should be adopted in order to prevent the potential impact of the 3rd harmonic current on neutral conducts and power transformers. High Power DC charging shows a larger potential to impact the public distribution network, when installed directly in LV networks, especially in points with lower short-circuit power. High Power DC charging points should be preferably installed in facilities supplied by dedicated MV/LV transformers.

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