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Energy reduction potential from the shift to electric vehicles: The Flores island case study

André Pina [a,*], Patrícia Baptista [b], Carlos Silva [a], Paulo Ferrão [a]

[a] IN+, Center for Innovation, Technology and Policy Research-Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal
[b] IDMEC - Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal

HIGHLIGHTS

- High shares of RES in electricity do not guarantee a low energy use by EVs.
- The introduction of EVs can help reduce CO_2 emissions by 11% in 2030.
- Flexible time of recharging strategies allows a 2.5 times higher share of RES.

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ABSTRACT

The increase of fossil fuel demand raises concerns on availability of resources for future energy demand and on potential environmental impacts. Electric vehicles (EVs) appear as one alternative to shift from fossil fuels to renewable energy resources. This research work analyzes the benefits of the introduction of EVs in a small energy system, the Flores island, Azores, in terms of primary energy and CO_2 emissions. Four scenarios were designed considering different penetration rates of EVs (Low and High) and different time of recharging strategies (Fixed and Flexible). The high shares of RES in the electricity production system (60–62%) did not guarantee a significant use of RES for the recharging of EVs (10–40%), as the additional electricity required had to be produced mainly from the diesel generators. The flexible recharging strategies allowed doubling the share of RES in the recharging of the EVs when compared to fixed recharging, and consequently double the impact on the reduction of primary energy consumption and fossil fuels imports. While the reduction of primary energy ranged between 0.2% and 1.1%, for CO_2 emissions there was a decrease between 0.3 and 1.7%, proving that EVs can help improve the sustainability of energy systems.

1. Introduction

The increasing demand for fossil fuels in the World has raised concerns about the availability of resources for future energy demand, as well as the potential environmental impacts that the continuous increase in local and global emissions may have. To address these issues, several technologies have been developed to take advantage of endogenous and clean renewable energy resources, though they are mainly used for the production of electricity or water heating.

As such, several countries and regions have been investing in the production of electricity using renewable energy sources. In the EU27, the share of RES has increased from 14% in 2001 to 20% in 2010, with countries such as Norway (90% in 2010), Austria (61%) and Portugal (50%) being some of the most active (EUROSTAT, 2012). However, the investment in additional capacity of RES is generally limited in order to avoid excesses of renewable electricity that cannot be used by the systems due to mismatches between supply and demand (Pina et al., 2011). To address this problem, the combined investment of RES with complementary dynamics and the introduction of flexible loads that can be used to optimize the electricity production system are being studied (Pina et al., 2012).

Another of the main energy consuming activities is transportation, and in particular the road transportation, which was responsible for 32% of all energy consumed in the EU27 in 2007, and 40% in Portugal in the same year (EUROSTAT, 2011). While the overall CO_2 emissions per MJ of total energy consumed has decreased on

Abbreviations: CO_2, carbon dioxide; EDA, Electricity of the Azores; EU, European Union; EV, electric vehicle; GHG, greenhouse gas; HDV, heavy duty vehicles; LDV, light duty vehicles; RES, renewable energy sources; TTW, tank-to-wheel; WTT, well-to-tank; WTW, well-to-wheel

* Corresponding author. Tel.: +351210407022x5219; fax: +351214233598.
E-mail address: andre.pina@ist.utl.pt (A. Pina).

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average 12% in the EU27 between 1995 and 2008, the CO_2 emissions per MJ used by the transportation sector reduced only 3% in the same period (EUROSTAT, 2012).

In the transportation sector, improving vehicle's efficiency, promoting alternative vehicle technologies and energy sources have been the main focus of action (Baptista et al., 2012; IEA, 2010). In terms of alternative technologies, hydrogen and electricity are regarded as an opportunity for significantly reducing the amount of CO_2 emitted by the transportation sector (Baptista et al., 2011) and increased renewable energy penetration (Offer et al., 2010). However, in the case of hydrogen, the low efficiency of the process, the high cost of the vehicle and the need to have a completely new distribution network for the hydrogen create significant barriers that have been delaying the deployment of such technology until it can be further developed and improved (Jorgensen, 2008).

As such, electric vehicles (EVs) are currently considered as a better alternative for the use of conventional fossil fuels in the transportation sector, which has led major vehicle manufacturers to develop their own vehicles (e.g. Nissan, Mitsubishi, Renault, etc.). Shifting from conventional internal combustion engines to EVs enables the reduction of local and global emissions, as these are not made during vehicle operation but during electricity production using more efficient processes (JRC/EUCAR/CONCAWE, 2011a). Therefore, quantifying the use of RER to power EV is crucial to estimate the potential CO_2 emissions and energy reductions from the introduction of EVs, as well as to avoid the transfer, and consequently the responsibility, of CO_2 emissions from the transportation sector to the electricity production sector.

The full benefits of the introduction of EVs are determined by the energy source that is used to recharge the vehicles, which depends on two crucial factors: the electricity supply system, which determines the set of electricity generation technologies available, and the recharging strategies adopted, particularly by carefully controlling its timings, which determine the electricity generation unit that will be used to produce the necessary electricity (JRC/EUCAR/CONCAWE, 2011b; Pina et al., 2008). In a system with a low penetration of RES or nuclear energy, the environmental benefits of EVs are less significant since the traditional transportation fuels are being substituted by other fossil fuels such as natural gas, coal or fuel oil, whereas in systems with a high penetration of RES, the amount of greenhouse gas (GHG) emissions relative to the transportation sector is expected to be reduced significantly (Granovskii et al., 2006). Regarding the time of recharging, peak consumption hours have, in general, higher marginal GHG emission factors due to the use of fossil fuel plants, whereas low consumption periods can have excess of electricity from RES that can be used to recharge EVs (Ekman, 2011). The controlled charge of electric vehicles can be performed through the use of information and communication technologies that enable the connection of an aggregator, responsible for coordinating the charging of EVs, with the charging stations and the characteristics of each EV, such as vehicle controller (VC) of the charging/discharging process of batteries (Bessa and Matos, 2012).

Furthermore, the large scale introduction of EVs can pose a real problem for electricity systems if the additional electricity demand occurs during peak hours and more investment is necessary in peak power plants (Hadley and Tsvetkova, 2009). However, if an intelligent recharging strategy is adopted, EVs can be an important asset in the management of electricity systems as the recharging of batteries can be done in periods with low consumption or in periods in which there is plenty electricity production from RES.

On the long-run, the possibility of having EVs exchanging electricity with the grid from the vehicle to the grid (V2G) can provide significant benefits for grid stabilization and by serving as distributed storage systems (Sovacool and Hirsh, 2009). However, the impact on the life cycle of the batteries would also have to be accounted for.

Several studies have been made to understand the potential impacts of EVs, focusing mainly on how different configurations of electric systems can cope with the introduction of EVs, whether they use flexible time of recharging strategies (Lund and Kempton, 2008) or test different fixed time of recharging scenarios (Camus and Farias, 2012; Camus et al., 2011). In more detail, flexible time recharging may require small fluctuation on battery state-of-charge for longer periods of time, as opposed to regular use of the battery under vehicle operation with higher impact on depletion of battery lifetime. However, the introduction of such technologies requires a holistic analysis of the energy systems in order to understand what is the overall impact on energy use by the transportation sector and how the increased demand in electricity is produced.

This research work analyses the introduction of EVs in the island of Flores, Azores, and assesses how the penetration of EVs can influence the investment in new RES generation capacity, how much RES can be used in the electricity produced for the EVs and what is the potential for reduction of energy use and emissions in the island from the shift to EVs. The impact of being able to optimize the time of recharging of EVs in order to increase the use of RES is also studied, while the possibility of using the EVs to store energy was not considered. A detailed temporal analysis in terms of years, months and hours of the day is performed to identify which time periods are more favorable for the introduction of EVs and which policies should be pursued to maximize their benefits, particularly in terms of reducing energy use in the island and fossil fuel imports. Additionally to that, the avoided fossil fuel energy consumption and emissions in the transportation sector is accounted for and compared to the corresponding increase in the electricity production sector.

2. Flores island, Azores

Flores is an island belonging to the Azores archipelago, located in the middle of the Atlantic Ocean between Europe and North America. It is one of the most isolated islands of the Azores, with an area of around 141 km^2, and a population of around 3788 inhabitants (Serviço Regional de Estatística dos Açores, 2012). The island of Flores had a significant economic growth from 1994 to 2010, in line the rest of the archipelago of the Azores, which resulted in a significant increase in primary energy and electricity consumption (Serviço Regional de Estatística dos Açores, 2012). Nonetheless, the last few years were already characterized by a slowdown of the growth, reflecting the convergence of the Azores with mainland Portugal in terms of energy use and the recent worldwide economic situation.

Due to the isolated nature of the islands and the abundance of natural resources, the Government of Azores has an ambitious energy strategy that aims to achieve 50% of renewable electricity production in 2013 and 75% in 2018, on average of all islands (OJE/Lusa, 2010). This is in accordance with Electricity of the Azores (EDA) strategy to increase renewable penetration, which includes several investments in geothermal power plants in the major islands, like São Miguel, and several wind farms and hydro stations in the smaller islands, such as Flores. Another policy goal of the Government is to increase the renewable energy penetration in terms of primary energy up to 40% (considering the partial substitution method), which is an extremely difficult target to achieve as all sectors of energy consumption must be addressed (electricity, transportation, domestic water heating and cooking, among others).

2.1. Energy system

The energy system of Flores in terms of primary energy (accounted with the physical content method) is dominated by diesel fuel, as shown in Fig. 1 (DGEG, 2013). In 2010, diesel accounted for 72% of all primary energy used, while renewable energy sources