Effects of integration of the electric mobility in the Italian energy sector: how to account for them in an LCA perspective

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ABSTRACT: LCAs on electric mobility are providing a plethora of diverging results. The selection of the electricity mix used to recharge the vehicles has been proved to be a key aspect in determining the overall results. 26 articles published from 2008 to 2018 have been investigated to find the extent and the reason behind this deviation. The major cause of the diverging results has been identified in a lack of clear guidelines for the selection of the appropriate electricity mix. Marginal and averge electricity mixes are often used as a proxy for the development of either a consequential or an attributional LCA. According to our literature survey results, if the aim is to identify the consequences of a widespread introduction of electric vehicles, a larger system boundary has to be included (i.e. including the mutual effect of transportation on the power sector and viceversa). As a proof of concept, we modeled the effect of introducing a consistent amount of electric vehicles in the Italian fleet in 2030.

KEY WORDS: Electric Vehicles, Life Cycle Assessment, Consequential LCA, Attributional LCA, Energy System Analysis, EnergyPLAN, Vehicle-to-Grid

1. INTRODUCTION

It is generally understood by LCA practictioners that the way electricity is generated is a key topic in defining the environmental viability of electric vehicles [(1)] . Notwithstanding the awareness of the important role of electricity generation on the final results of electric vehicles LCAs, literature often fails in providing clear guide-lines to the stakeholders, posing difficulties in driving them to the correct strategies for an integrated, environmentally friendly transport/energy system.

Through a detailed analysis of the literature, the main failure has been identified to be the lack of a rigorous agreed structure to guide the practitioner in the selection of the right methods according to the goal. The controversial issue of Consequential vs Attributional LCA is one of the major examples.

Yet, when the selection of the method has been addressed, its application is not always straightforward.

In the context of electric vehicles assessment, the energy use phase is particularly relevant. As a result, the polarity between Consequential LCA and Attributional LCA has been oversimplified in many studies as the simplistic use of the marginal energy mix over the average energy mix in the life cycle inventory.

This oversimplification contributes to rise the confusion in the definition of the right method to be used according to the assigned goal. Since the selection of one energy mix rather than the other could lead to very different results [(2)] , doubts raise that a precise methodological choice could mask an interest in leading the results.

Another aspect highlighted in the literature review is the way the time horizon is addressed: most of the studies focus on the 'here and now' situation, even when directing their results at the decision makers. Thus, time perspective is missing, which is quite singular in a sector that is evolving quite rapidly [(3)] .

A synoptic view of literature survey is reported in Table 1. The high variability in the emission intensity used to account for electricity production in the analysed scientific papers is particularly clear.

2. AIM AND SCOPE

Starting from the considerations emerged from the literature review, we believe that if LCA studies are intended to evaluate the environmental viability of EVs adoption, a holistic approach - able to model the entire energy system - is required. This approach should include the effect of EVs on the energy system and the effect of the energy system changes on the final impact assessment. Comparison on ‘here and now’ using present technologies and historical data of energy production are missing the goal of assessing the viability of a transition to electric mobility.

This study tries to put this conclusion into practice through the development of a case study: the integration of electric mobility in the Italian energy system. The mutual effect of the Italian energy system on EV LCA results and the effect of adoption of electric transportation on the Italian energy system has been focused. The analysis is made considering different policies, scenarios, and technologies implementation.

3. MATERIALS AND METHODS

This work started from the observation of the diverging literature results in LCAs of electric vehicles. 26 articles published between 2008 and 2018 have been analysed in order to find a reason behind this spread.

Considering only the climate change impact categories, the results spans from 326 g CO2eq/km, obtained by Ma et al. (4) when assessing EV introduction in the UK market in 2015, using short term marginal energy mix, to 27.5 g CO2eq/km, obtained by Van Mierlo et al. (5) presenting the Well-to-Wheel results of an EV in the Belgium environment.

The selection of the electricity mix has been found to play a key role in the final results and the diverging values of the electricity mixes used are reported in Table 1, along with some useful information regarding the mix: the geographical region, the time horizon of the study (which is not always coherent with the timespan of the data of the electricity mix), the use of average or marginal electricity mix (or both).

In particular, the selection of the short term marginal electricity mix when assessing consequential LCAs has been contested.

All the marginal mixes found in the literature review are the so called “short term marginal mixes”, either for studies focusing on present or in future energy system.

The outcome is that the effects of using present or future energy systems convey similar results, because technologies on the margin tend to remain the same also in the future energy scenarios. Therefore, EVs do not benefit from the general decarbonization in the energy system that is happening at present and that will tend to continue in the future.

This study wants to assess the effect of EVs in combination with the role that they play in the energy system; including these effects in the environmental assessment allows us to deploy a consequential LCA, with long-term meaningful effects to present to policy makers.

As proof of concept the Italian 2030 situation is considered.

For this simulation the EnergyPLAN tool has been used. EnergyPLAN (6) is a deterministic model, aiming at identifying the optimal operation strategies of a national energy system, through an hourly simulation of one year.

Among all the available tools, EnergyPlan has been selected because its design emphasises the option of looking at the complete energy system as a whole and presents a dedicated and flexible section to include the transport sector (7) . Moreover, it is also suitable for modelling future energy systems.

To depict the Italian context at 2030, forecasts and targets set by the National Energy Strategy presented in 2017 by the Ministry of the Economic Development have been analysed.

Two different penetration scenarios have been compared: a ‘business-as usual’ one, considering an almost null share of electric cars, and a higher penetration one.

3.1. Italian Energy System

The National Energy Strategy is a ten-year plan that the Italian Government drew up to anticipate and manage the change of the national energy system: a document looking beyond 2030, and laying the groundwork for building an advanced and innovative energy model (38).

The general aim of the strategy is to bust italian energy system's:

- competitivity
- sustanibaility
- security

to obtain these goals the target is to increase the production from renewables energy.

Table 1 Literature Review.

Authors	Country/ Region	Time Horizon	Electricity mix		Energy mix data source	W-t-W	Complete LCA	Grid emission intensity
			Average	Marginal				
Archsmith et al. 2017 [10]	U.S (regions)	2011; 2040	x	x	CESM; GREETnet EIA forecasts for 2040	-	x	Marginal 2011: range 1258 - 513 g $CO_{2,eq}$/kWh
Bartolozzi et al. 2013 [11]	Italy		x	-	EcoInvent (unspecified version)	-	x	-
Crossin and Doherty 2016 [12]	Australia	2015	x	x	Australian Energy market operator	-	x	Marginal: 794 g $CO_{2,eq}$/kWh Average: 1006 g $CO_{2,eq}$/kWh
Dallinger et al. 2012 [13]	Germany	2030	-	x	Own calculation; Elgowainy et al. 2010 [14]	x	-	247 g $CO_{2,eq}$/kWh
Faria et al 2012 [15]	EU Portugal France	2009	x	-	EEA, Eurostat	x	-	378 g $CO_{2,eq}$/kWh 365 g $CO_{2,eq}$/kWh 78 g $CO_{2,eq}$/kWh
Freire and Marques 2012 [16]	Portugal	2009-2010	x	-	REN (Portuguese TSO)	-	x	390 g $CO_{2,eq}$/kWh
Garcia and Freire 2016 [17]	Portugal	2015-2017	x	x	REN (Portuguese TSO)	-	x	352 g $CO_{2,eq}$/kWh
Girardi et al. 2015 [18]	Italy	2013; 2030	-	x	TRENA (Italian TSO)	-	x	-
Hawkins et al. 2013 [19]	EU		x	-	EcoInvent v. 2.2	-	x	569 g $CO_{2,eq}$/kWh*
Helmers et al 2017 [20]	Germany	2004; 2013	x	-	EcoInvent 2.2 (data for 2004) IEA (data for 2013)	-	x	719.5 g $CO_{2,eq}$/kWh 707.4 g $CO_{2,eq}$/kWh
Helmers and Marx 2012 [21]	Germany	2010	x	-	German Federal Environmental Agency	-	x	536 g $CO_{2,eq}$/kWh
Lee et al 2017 [22]	US (states)	2014	x	x	EPA's CEM hourly data and NEI database	-	x	-
Lucas et al 2012 [23]	Portugal	2010	x	-	REN (Portuguese TSO)	-	x	-
Ma et al. 2012 [4]	UK California	2009-2010	-	x	BM report, McCarthy and Yang 2009 [24]	-	x	798 g $CO_{2,eq}$/kWh 626 g $CO_{2,eq}$/kWh
McCarthy and Yang 2009 [24]	California	2010	x	x	eGRID v.1.1 (2007)	-	x	250 g $CO_{2,eq}$/kWh 626 g $CO_{2,eq}$/kWh
Nordelöf et al. 2014 [3]	EU	2008	x	-	Edwards et al. 2011 [25]	x	-	467 g $CO_{2,eq}$/kWh

Authors	Country/ Region	Time Horizon	Electricity mix		Energy mix data source	W-t-W	Complete LCA	Grid emission intensity
			Average	Marginal				
Noshadravan et al 2015 [26]	US	2009	x			x		227.1-894.2 g CO_2-eq/kWh 560.65 g CO_2-eq/kWh
Onat et al. 2015 [27]	US: states	2009, 2020	x	x	eGrid; Hadley and Tsvetkova 2009 [28]	-	x	marginal: range 644-911 g CO2,eq/kWh national average 663.4 g CO2,eq/kWh
Stephan and Sullivan 2008 [29]	US (regions)	2002	x	x	EPA	-	x	national average: 608 g CO2,eq/kWh
Thomas 2012 [30]	US (regions)	2020	-	x	Hadley and Tsvetkova 2009 [28]	x	-	-
Van Mierlo et al. 2017 [5]	Belgium	2011	x	-	Messagie et al. 2014 [31]	-	x	190 g CO2,eq/kWh
Weis et al. 2016 [32]	US PJM	2010, 2018	-	x	NEEDS database and EPA projections	-	x	-
Woo et al. 2017 [33]	70 countries	2014	x	-	IEA (2015), EIA (2015) and World Bank (2016)	x	-	-
Yuksel et al. 2017 [34]	U.S (states)	2011	-	x	Siler-Evans et al. 2012 [35]	-	X	430–932 g CO2,eq/kWh
Giordano et al. 2017 [36]	Germany Norway Italy Portugal UK France	2015	x	-	EcoInvent v. 3.0 updated with data for 2015 from Entso-e	-	x	579 g CO2,eq/kWh 36 g CO2,eq/kWh 512 g CO2,eq/kWh 553 g CO2,eq/kWh 688 g CO2,eq/kWh 588 g CO2,eq/kWh
Lombardi et al. 2017 [37]	Italy USA France		x	-	EcoInvent v. 2.2	-	x	640 g CO2,eq/kWh 770 g CO2,eq/kWh 93 g CO2,eq/kWh

* authors’calculation from data available in the reviewed paper

The italian energy system has already experienced a rapidly increasing introduction of solar and wind energy production in the past decade [8] and the forecast from ENTSO-e [9], included in the model, presents the following installed capacity expected at 2030:

- Wind: 23.46 GW;
- PhotoVoltaic: 42.17 GW.

3.2 Italian transport sector

Two penetration scenarios of electric vehicles and three differnet charging strategies have been compared.

The first scenario, considering a negligible penetration of EVs, has been considered as a reference scenario.

Another scenario, including a higher penetration (6.5 milion vehicles, corresponding to the 17% of the 38 milion electric vehicles expected in 2030) has been choosen referring to the forecasts from ENTSO-e and TERNA (Italian Transmission System Operator). In this scenario three different charging strategies have been considered:

- Dump charging
- Smart charging
- Vehicle-to-Grid (V2G)

The results are presented in terms of Tons of CO_2 emitted in one year by the whole Italian Energy System (power production, heating/cooling and transport sector) as reported in Figure 1.

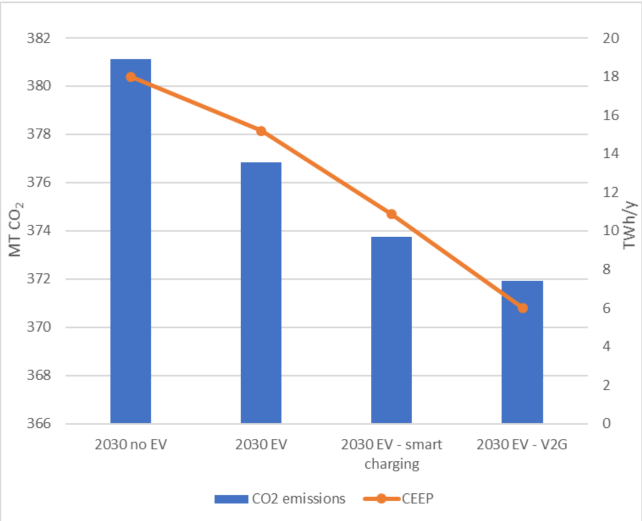

Fig. 1 Annual emission from the Italian energy system in 2030 including different penetration scenarios and charging technologies.

Compared to the scenario with a negligible introduction of Electric vehicles (2030 no EV in the graph), the scenario considering a share of EV of 17% of the total road vehicles provide a reduction of the total CO_2 emitted at national level.

This is not only a consequence of the better performance of Evs compared to ICEv, but also of their help in stabilizing the system with a flexible demand that can enhance the exploitation of renewable sources. This aspect is highlighted in the graph by the CEEP (Critical Excess Electricity Production) that is decreasing more and more as the flexibility of the demand is increased by changing the charging technology (from dump charging to Vehicle-to-Grid - V2G in the graph).

This case study wants to represent in a simple way what should a consequential LCA of electric mobility include in order to provide meaningful information to policy makers on the effect of moving through electric mobility in the recent future.

3. CONCLUSION

Diverging results in LCAs of Electrc vehicles and the lack of a clear goal and scope definition in guiding practioctioners and policy makers in how to use them, lead to a lack of consensus on the future of electric mobility.

All the reviewed studies aimed at informing policy makers, but analyses in general lack a political dimension: no clear time frame, no clear and reliable future scenarios, inconsistency between variables in the scenarios.

In the issue of policy information, the selection of short term marginal electricity mixes has to be discussed. Even though these mixes are useful for the modelling of short-term effects of a rapid, albeit unlikely, introduction of EVs, in the authors' opinion they are not the correct instrument to inform policy makers, since they only offer a partial view: focusing on short term effect is no more than a form of burden shifting in time.

An holistic approach including all the main sectors of national energy system (electricity, heating/cooling and transport) and the mutual effects between them, is more appropriate than the selection of a short term marginal electricity mix, when providing policy makers with the effects of transitioning to electric mobility. For this reason the selection of the EnergyPLAN model has been done, to present the proof of concept of the Italian Energy system in 2030.

The widespread introduction of electric vehicles in the transport system was found to affect the overhall national system.

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