DOI: 0

ELECTRIC VEHICLES ENVIRONMENTAL COMPETITIVENESS FOR 2014 AND 2030 AS A FUNCTION OF RECHARGE: AN LCA APPROACH

Jorge Enrique Velandia Vargas
Joaquim Eugênio Abel Seabra
Arnaldo Cesar da Silva Walter
Carla Kazue Nakao Cavaliero
Daniela Godoy Falco

Universidade Estadual de Campinas

ABSTRACT

Electric Vehicles (EV) are considered as an alternative for Greenhouse gas emissions, however, real advantages are strongly dependent on local electricity mix. This study analyses flex fuel and electric vehicles for use in Brazil for 2014 and 2030 scenarios.The results show that EVs in the current context still present disadvantages. For 2030, EVs close the gap becoming more competitive, not competitive enough to overtake Ethanol options although. However some uncertainties are still making the analysis open to interpretation.

Keywords: Life cycle assessment, Electric vehicle, flex vehicle, peak hour

1. INTRODUCTION

The Transportation sector is largely responsible for greenhouse gases (GHG) released into the atmosphere, ground, and bodies of water, the effects of these emissions are perceived by different receptors (humans, ecosystems , etc.) both in locally and globally.As a result, the electric vehicles (EV) are taking an increasing role in future scenarios of transportation, being considered as an alternative for mitigation of GHG emissions from internal combustion vehicles (ICV) (e.g., nitrogen oxides, carbon monoxide and particulate material) and other substances that can have negative effects on ecosystems and living beings.

From the point of view of GHG emissions, EVs adoption potential benefits will strongly depend on local electricity generation mix (which includes the generation matrix at a given location) and how the batteries will be recharged (time, period reloading, etc.) as a possible increase on electricity demand might imply an impact on electrical generation system and hence emissions. This means that, despite the EVs present environmental advantages during the operation stage, an impact assessment restricted to use phase is proven to not to be complete, a coherent analysis should consider those impacts associated with materials and energy overall demand, besides including operation and maintenance for the vehicle and the vehicle itself.

One way to evaluate the EV insertion impacts is to use the tool known as Life Cycle Assessment (LCA). Through the LCA are identified all input streams (energy and mass) and output (waste) from the product system, or service, therefore it is possible to see what are the steps that contribute the most to any particular environmental impact, usually analyzed from materials extraction, going through the use and final disposal, in other words it looks forward to complete a cycle " from cradle to grave."

The main objective of this research is to compare the potential environmental impacts of passenger transportation by EVs and ICVs (flex fuel cars, using ethanol and gasoline) in the Brazilian context, considering both the life cycle of vehicles as of energy sources. The analysis will be done by evaluating current conditions (considering the year 2014) and future conditions a few years forward (2030). The study is embedded in the context of the research project: "Project R & D PA0060". This project is run by the State University of Campinas, through the Faculty of Mechanical Engineering (FEM) and the Interdisciplinary Center for Energy Planning (NIPE) and aims to analyze the potential impacts of integration of electric vehicles in corporate fleets in the metropolitan region Campinas (SP), the project is developed in partnership with CPFL.

On this topic, there is plenty of available literature. There is an important number of articles published in scientific journals, research reports and consulting firms including publications and associated with the automotive industry: (FARIA et al., 2013; HAWKINS et al., 2013; HELMS et al., 2010; MA et al., 2012; MESSAGIE et al., 2014; RAJAGOPAL et al., 2012; RENAULT, 2011), all of them agree on Well to Tank (WTT) fundamental contribution to overall life cycle.

LCA models a product Life Cycle by reproducing the characteristics of the product system which is the set of activities, inputs and outflows required to create a product or service and the set of consequences as well, this system can perform one or more defined functions. The essential nature of this product system is characterized by its function and cannot be defined solely in terms of any final product. These systems are composed of elementary processes (resource usage and emissions to air, water and soil) connected to each other by intermediate product streams and / or for waste treatment. A product system can also be characterized as a set of processing units that share or exchange materials and energy to build the product.

2. METHODOLOGY

Mainly two approaches of LCA are used in practice; Attributional and consequential, with the former being more widely used. The attributional Life Cycle model describes the current supply chain – or the planned one -, as well as their interactions with the value chain of the end of life of the analyzed system. That system (current or planned) is incorporated in a static technosphere, it means that the technological and technical conditions of the environment will not change during the analysis. Main methodological parameters are shown in Table 1.

2.1. Well to Tank (WTT)

The WTT phase is bounded to fuel/electricity production from the primary energy source to the fuel tank or battery. This section describes the main sources of data that are used to estimate their lifecycle inventories.

2.1.1. Hydrous Ethanol

Figure 1 illustrates the flowchart of ethanol production process and transport Brazil in São Paulo state areas. The scope of hydrous ethanol covers the current mean condition based on averages for the 2006/2007 harvest in the Center-South region of Brazil (SEABRA et al., 2011), which is responsible for about 90% of the national production of this fuel. These are the latest available data that show the level of detail and internal consistency required, particularly in relation to sugarcane crop. Table 2 shows energy allocation results for hydrous ethanol sub -products.

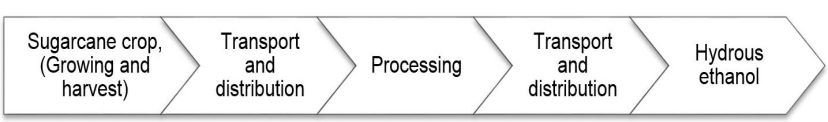

Figure 1 – Hydrous ethanol process flowchart

Table 1 – LCA main methodological parameters

Considered systems	Passenger and light duty vehicle Renault Kangoo. Using flex fuel technology using gasoline C, and ethanol and electric Kangoo with lithium-ion battery.

Boundaries	Well to wheel approach. Covering exploration and production, processing, transport and distribution of fuel, electricity and EV and ICV. Infrastructure contribution present in background and foreground processes will also be considered. Direct changes in land use are not covered.
Geographic scope	Ethanol: Brazilian Center-south region production profile, use in mixed profile in Campinas (road and urban); Gasoline: Brazilian national production crude oil mixed with international imported profile, refining process in REDUC and REPLAN only, use in Campinas, in mixed profile (road and urban); Electricity: National mix generation system, average operation and increased demand hours (peak hour); Internal combustion vehicle: Manufacturing in Argentina, use in Campinas, in mixed profile (road and urban); Electric vehicle: mounting in France, use in Campinas, in mixed profile (road and urban).
Time scope	2014 and 2030
Functional unit	1 km
Treatment of co-products	Energy based allocation
Inventory Modeling	Attributional approach
LCIA method	CML 2000 Baseline
Environmental impact categories	Abiotic depletion of resources; depletion of fossil fuels; global warming; acidification; eutrophication; human toxicity; Terrestrial ecotoxicity; depletion of stratospheric ozone; photochemical oxidation.

Data Source	Primary Data Collection (CPFL, CPqD), Ecoinvent databases and scientific literature.

Table 2 – Energy allocation results for hydrous ethanol sub-products on 2014

Sub-products	Amount (Kg)	Allocation Percentage
Hydrous ethanol	27	34,4
Anhydrous ethanol	13,44	18,6
Sugar	54,2	41,8
Bagasse	8,7	3,2
Electricity	10,7*	2,0

*kWh

Parameters for 2030 sugar cane production and ethanol processing in autonomous distilleries are based on conditions projected for 2020 by SEABRA & MACEDO (2011). It is considered that as a result of Brazil's current economic crisis the parameters originally proposed for 2020 will only be achieved a few years later, therefore it is assumed that this study is still a valid reference to adopt for 2030 scenario.

Authors reported that for 2030 scenario there is a prospect of increased sugarcane productivity per hectare besides of a significant decrease on nitrogenous fertilizer and agrochemicals (P2O5 and K2O) use in the planting phase.

2.1.2. Gasoline C

Brazil's common gasoline does contain 22% of hydrous ethanol (volumetric mixture). For Gasoline refining model it is considered that this fuel in Brazil will have only two possible origins, the Duque de Caxias Refinery (Reduc) and the Paulinia refinery (Replan). It is also assumed that only a share of oil used as raw material in such refineries is Brazilian, meaning that an important share is imported as shown in Table 3.

Ecoinvent V3.0 (SWISS CENTRE FOR LIFE CYCLE INVENTORIES, 2015) processes that describe oil extraction were used, based on their similarities to Brazilian extraction features, however, the overall process underwent some adjustment based on da Silva (2013). Moreover, in order to properly estimate distances for oil transportation imported from the Middle East and Nigeria, we call upon Theodora (2013) database which reports the existence of three main pipelines in Nigeria, the largest one having a length of 674 km (Escravos - Kaduna). Only the largest wells in each country were considered, for Nigeria's case Ramuekpe well and for Saudi Arabia, the well of Ghawar.

Table 3 – Shares of Incoming oil to REDUC and REPLAN by geographical source (country)

	Share	Ecoinvent processes	Source	% total
REPLAN	17% Imported	Petroleum {NG}| petroleum and gas production, on-shore | Alloc Def, U	Nigeria	68,8
		Petroleum RME}| petroleum and gas production, on-shore | Alloc Def, U	Saudi Arabia	31,2
	83% National	Petroleum {NO}| petroleum and gas production, off-shore | Alloc Def, U	Brazil (onshore)	91,4
		Petroleum {NO}| petroleum and gas production, on-shore | Alloc Def, U	Brazil (offshore)	8,6
REDUC	50% Imported	Petroleum {NG}| petroleum and gas production, on-shore | Alloc Def, U	Nigeria	68,8
		Petroleum RME}| petroleum and gas production, on-shore | Alloc Def, U	Saudi Arabia	31,2
	50% National	Petroleum {NO}| petroleum and gas production, off-shore | Alloc Def, U	Brazil (onshore)	91,4
		Petroleum {NO}| petroleum and gas production, on-shore | Alloc Def, U	Brazil (offshore)	8,6

2.1.3. Electricity

The National Energy Balance (BEN) 2015, prepared by EMPRESA DE PESQUISA ENERGÉTICA (2015) was used as a base document to define the average profile of electric generation in Brazil in the year 2014. It was considered that the 2014 generation mix as reported for National Interconnected System (SIN) in the current conditions.

Thus, the average generation profile considered the generation from Public Power Plants and Energy Self-production. Although the self-production is theoretically intended for own consumption, in practice it is known that an increasing share of electricity generated by autoproducers has been made available to the distribution network, making also the amount of electricity from biomass (especially sugar cane bagasse). Ecoinvent processes were used and adapted to emulate to current Brazilian electricity generation efficiencies found on BEN 2015. The proposed mix for 2014 and 2030 is shown on Table 4. For 2030 scenario, a new electricity generation mix was proposed, based on estimations of capacity factor and demand forecasts, thus creating 4 potential conditions, lower and higher emissions (based on electricity mix evolution) for peak, and non-peak hours.

Table 4 – Brazilian electricity generation mix for 2014

Energy source	**Case 2014**	
	Non peak hour mix (%)	**Peak hour mix (%)**
Hidraulic	65,2	71,0
Small hydro	-	-
Solar photovoltaics	-	-
Wind	2,3	1,2
Nuclear	2,9	1,9
Biomass	8,0	6,9
Natural gas	13,0	10,8
Coal	3,2	2,5
Fuel oil	3,2	2,9
Diesel	3,2	2,8

2.2. Tank to Wheel (TTW)

Tank-to-wheel refers to what happens during the use of vehicles, i.e., the consumption of electricity and fuel (ethanol and gasoline) and the outflow of standardized emissions from hydrous ethanol and gasoline C in vehicles. For EVs essential information is the electricity consumption per kilometer, while for the ICV flex essential information is the fuel consumption per kilometer. For EVs, on current conditions, the consumption used in this study is derived from record monitoring carried out by project partner CPFL/CPqD. Data were extracted from FADU (Daily Use Form Tracking) consolidated data which collected on-site tests data. However, it drew our attention the number of records that show unexpected results e.g. being or too far from the average in the sample. It significantly reduced the database for analysis. Fuel/ electricity consumption values are shown in Table 5, while Table 6 shows consumption values for 2030 scenario. Moreover, standardized emissions were taken from ANFAVEA (2015) and evaporative losses were based on MINISTERIO DO MEIO AMBIENTE (2013). For 2030 standardized emission values were modified on a consumption basis with regards to 2014 scenario.

Table 5 – Fuel/electricity consumption for all of the three transportation options for 2014

Vehicle	Values	Values
Electric vehicle	(22,8 kWh/100 km)	(15,7 kWh/100 km)
Hydrous ethanol	(11,88 L/100 km)	(7,73 L/100 km)
Gasoline C	(8,27 L/100 km)	(7,32 L/100 km)

2.3. Vehicles

2.3.1. Electric vehicles

EV parameters used in the project are based on processes available in Ecoinvent; its mass was adjusted to accurately describe the mass of Renault Kangoo ZE. Moreover, Ecoinvent processes were modified and does not include dismounting of the vehicle, reuse and recycling of materials.

Renault Kangoo Z.E. mass is 1,410 kg, it includes an electric engine and a rechargeable lithium-ion battery (290 kg). The process for this type of battery is found in the Ecoinvent platform, and it is considered that it accurately models the Li-Ion battery. As guaranteed by the manufacturer, both for the vehicle and the battery, a 150,000 km lifetime was adopted. For 2030 scenario, EV parameters suffer no alteration, as a consequence of the lack of trustworthy information with regards to EV evolution. Only lifespan varies to 200000 Km.

2.3.2. Internal Combustion vehicles

For flex vehicles, just as for the EVs, the software input parameters are based on inventories existing in Ecoinvent; in the same way as for EVs, the Ecoinvent processes were also adjusted to reflect Kangoo features e.g. vehicle mass 1105 kg and 200000 km lifespan. Disassembly processes, reuse and recycling of materials were excluded.

3. RESULTS

Noting the results of the contribution analysis by phase shown in Figure 2, which corresponds to the results for current conditions and non-peak hour generation mix, it is noted that in the case of electrical transport most of the potential impacts to the environment are associated with production of the electric vehicle. Vehicle maintenance contributes fort over 80% to Photochemical oxidation (due to ethylene emissions), and only for global warming contribution related to electricity generation accounts for more than half of impacts. Despite the predominance of water source in the Brazilian energy matrix, significant emissions of methane and CO2 resulting from land use change are attributed to reservoirs, thus affecting the environmental profile of potential electric mobility. When considering an electricity generation mix during peak hours, the same conclusions are applicable, since the generation profile in peak and average hours shows a relatively small variation.

In the case of transportation with ethanol TTW phase is leading for global warming, photochemical oxidation, acidification and eutrophication. While emissions from combustion of ethanol in vehicles represent significant contributions to the whole life cycle particularly for global warming and, although there is a high emission of CO2 in fuel combustion, these emissions were treated as neutral because of the CO2 capture during sugarcane growth.

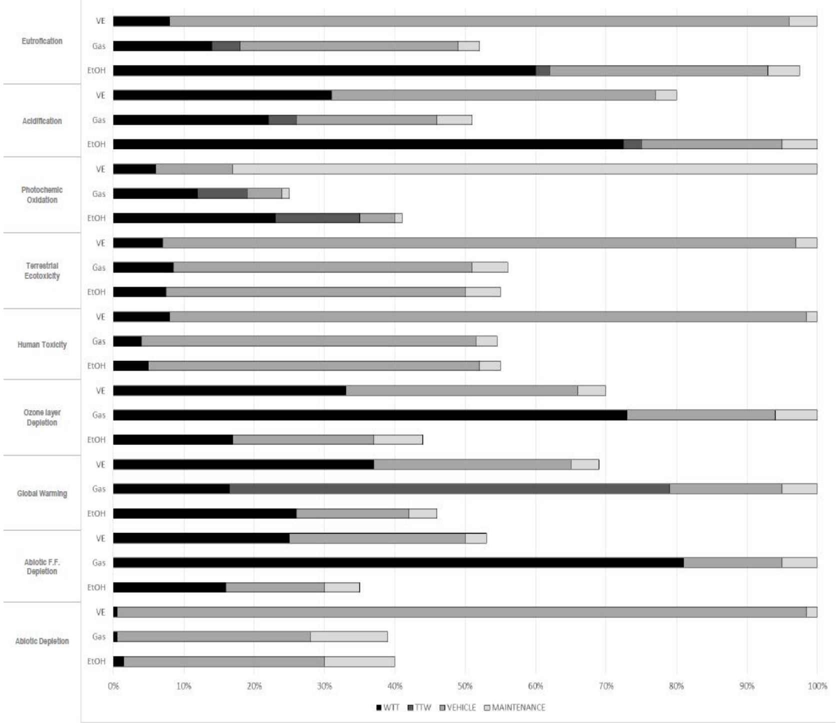

Figure 2 – Phase contribution for 2014 scenario during non-peak hours

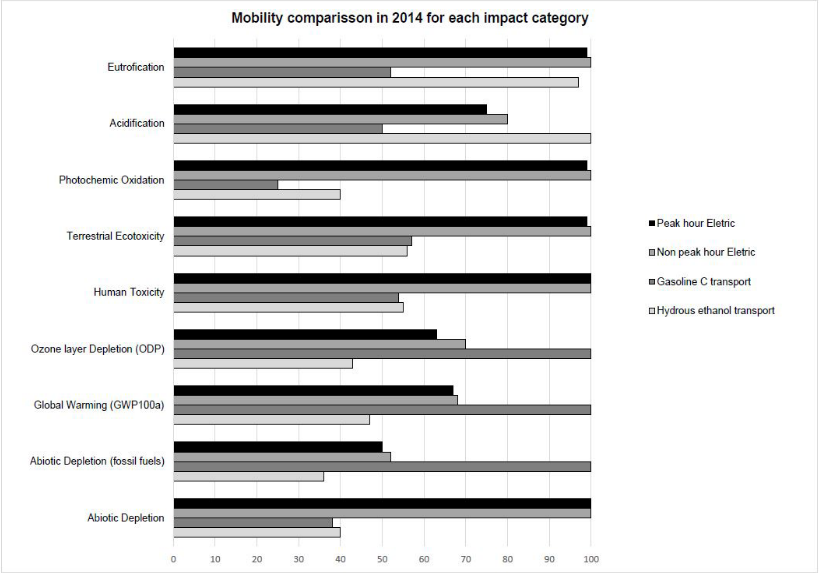

Figure 3 – Comparison for 9 impact categories for flex vehicles using ethanol and gasoline C and EVs during peak hour and non-peak hour

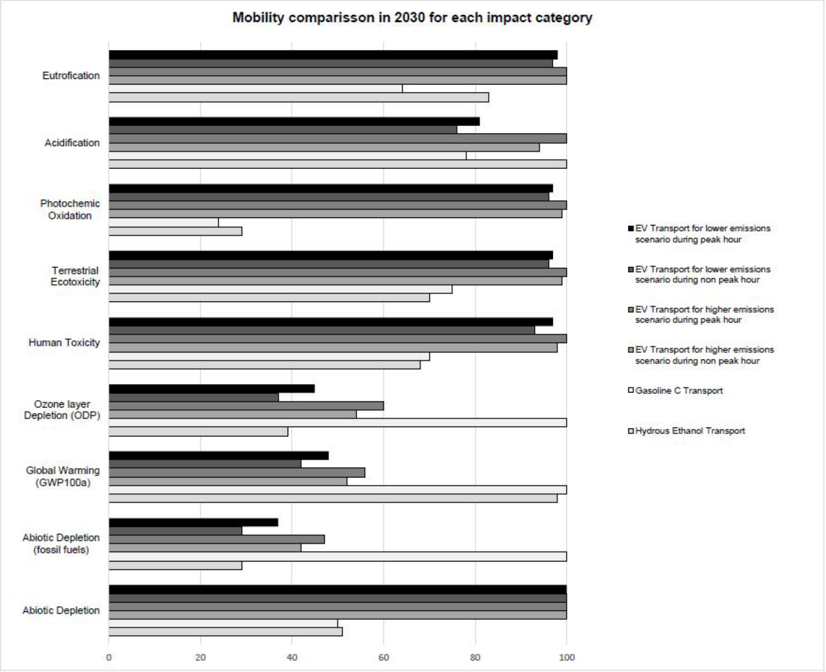

Figure 4 - Comparison for 9 impact categories for flex vehicles using ethanol and gasoline C and EVs during peak hour and non-peak hour and higher and lower emissions scenarios

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