ECONOMIC AND ENVIRONMENTAL IMPACTS OF LONG-TERM SCENARIOS OF LOW EMMISIONS MOBILITY IN SPAIN

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Overview

According to the European Commission, transport is responsible for more than 30% of CO2 emissions, where road transport accounts for 72%. Within the objectives of economic and environmental sustainability, the European Union has propossed a set of objectives for transport that pursue reducing emissions by 55% from 1990 to 2030 and to nearly all passenger cars, vans, buses as well as new heavy-duty vehicles will be zero-emission by 2050 (European Commission, 2019 and 2020). These objectives have been transferred to national policies in Europe with specific targets for the introduction of zero emission transport. In order to correctly define these objectives, there is a need to develop evaluation tools that allow the impact of each of these policies to be analyzed and taking into account the specific characteristics of this sector. Previous works studied this effect in France and Sweden (Millot, 2020) or Spain (E4E, 2021), using different methodological approaches such as (Lemme, 2018), (Leighty, 2012), (Danesin, 2018) or (Krause, 2020).

Building on previous research works, this paper presents a methodology to study the economic and environmental impacts of long term scenarios for transition of different traction technologies and fuels in road transportation, based on a detailed characterization of the vehicle fleet, both existing and future. For this purpose a long term simulation model is built, where aging and renewal of vehicle fleets is modeled in detail including new traction technologies. Results show the evolution of environmental and energy consumption indices in the mid and long terms, allowing policy makers to understand the impact of different road transportation strategies.

Following this introduction, next section provides a detailed description of the model that can be used to any transportation segment. Section 3 applies the proposed model to passengers cars in Spain. Finally, section 4 provides the main conclusions of the paper and future work.

Nomenclature

Indices

m	traction technology
r	route (eg. urban, interurban, …)
t	year of study
a	year of registration
z	region of study
e	type of emission (CO_2, NO_X, particles)
f	final energy (eg. petrol, natural gas, electricity, …)
p	primary energy (eg. oil, natural gas, renewable, …)

Parameters

$\beta_{dis}(m, r, t-a)$	coeficient to correct the mileage as a function of the age
$\beta_{dec}(t-a)$	coeficient to correct the decommission percentage ratio as a function of the age
$\tau_{rep}(a)$	replacement percentage ratio (percentage of new cars in year a)
$i_{dec}(m, t-a, t)$	decommission percentage ratio (percentage of cars decomissined in year t)
$\alpha_{sales}(m, a)$	percentage of new vehicles sales per technology

Variables

$Mileage(m, r, a, t)$	annual driven distance
$Fleet(m, t)$	number of vehicles at the end of year t
$Energy(m, r, a, t)$	energy consumption
$Emissions(e, m, r, a, t)$	emmissions
$\left[\mathcal{M}atrix_{fin}^{pri}(z, m, t, p, f)\right]$	matrix that relates the final and primary energy consumption

Methods

To properly evaluate the transition of traction technologies and fuels in road transportation a long term model optimization is required as the replace rate of the vehicles expands over ten years on average.

From a general perspective, the transition towards a more sustainable transportation system should consider to reduce the overall emissions while guaranteeing that people can freely move. Then the proposed model builds on the idea that people could move using the most efficient and clean technology alternative. The aggregated annual driven distance (1), both in urban and non-urban areas, is modeled as a function of the age of the vehicle, $t-a$, based on historical information. The older the car the lower the annual driven distance, as defined by the parameter $\beta_{dis}(m,r,t-a)$.

$$Mileage(m,r,a,t) = Mileage^{ref}(m,r,t) \cdot \beta_{dis}(m,r,t-a) \qquad (1)$$

Therefore, one input for the optimization model is the aggregated driving distance $Mileage_{OBJ}$, that can incorporate inputs from other models where public transportation policies compete with private or commercial transportation. Then, the objective function of the model (2) fits the objective driving distance for every year, both in urban and road travels of the study period, calculating the new and retired vehicles of each technology fulfilling the total mileage.

$$min\left\{\sum_{t,r}\left(\sum_m Mileage_{TOT}(m,r,t) - Mileage_{OBJ}(r,t)\right)^2\right\} \qquad (2)$$

The model takes into account the ratio, i_{dec}, of cars decommissioned each year, t. This ratio depends on the engine technology, m, and age of vehicles, $t-a$:

$$i_{dec}(m,t-a,t) = i_{dec}^{ref}(t) \cdot \beta_{dec}(t-a) \qquad (3)$$

On the other hand, the number of new cars in the year a is estimated by the replacement percentage ratio, $\tau_{rep}(a)$, that is the result of the aforementioned optimization algorithm:

$$Fleet_{new}(a) = \sum_m Fleet(m,a-1) \cdot \tau_{rep}(a) \qquad (4)$$

The renewal of the fleet is distributed among the different traction technologies. The optimization model is technology neutral, so different traction technologies can compete to provide the driving distance at different emission rates. For instance, the following traction technologies can be considered: petrol, diesel, bio-diesel, compressed natural gas CNG, liquified natural gas LNG, battery electric vehicle BEV, plug-in hybrid electric vehicle PHEV, hybrid electric vehicle HEV, or fuel-cell. Different scenarios can be obtained according to public policies preferences, which are included in the model using a coefficient α for new vehicle sales per technology.

$$Fleet_{new}(m,a) = Fleet_{new}(a) \cdot \alpha_{sales}(m,a) \qquad (5)$$

$$\sum_m \alpha_{sales}(m,a) = 100\% \qquad (6)$$

Once the fleet and the mileage for urban and non-urban areas are obtained for every year, the model calculates the tank-to-wheel (TTW) energy consumption for each traction technology m (7). Tank-to-wheel emissions are estimated based on the ratio of CO_2, NO_x, or particulates emited per kWh of energy consumed as a function of the age, type of route and traction technology (8).

$$Energy(m,r,a,t) = \frac{\begin{pmatrix} Fleet(m,a,t-1) \cdot Mileage(m,r,a,t-1) \cdot c(m,r,a,t-1) \\ + \\ Fleet(m,a,t) \cdot Mileage(m,r,a,t) \cdot c(m,r,a,t) \end{pmatrix}}{2} \qquad (7)$$

$$Emissions(e,m,r,a,t) = \frac{\begin{pmatrix} Fleet(m,a,t-1) \cdot Mileage(m,r,a,t-1) \cdot c(m,r,a,t-1) \cdot e(e,m,r,a,t-1) \\ + \\ Fleet(m,a,t) \cdot Mileage(m,r,a,t) \cdot c(m,r,a,t) \cdot e(e,m,r,a,t) \end{pmatrix}}{2} \qquad (8)$$

To properly assess the total impact of vehicle use, both emissions and energy consumption also take into account tank-to-wheel (TTW) and well-to-wheel (WTW) values. The TTW value consideres the efficiencies of the fueling the tank and traction technologies, while WTW adds to TTW values the well-to-tank values (WTT) to obtain the full value chain starting in the extraction process of the primary energy, shipping, processing and transportation to the gas-stations or, transmission through energy networks to the charging stations. Thus, the results can show, for a specific region or country, the effect in domestic and external emissions and energy use or energy dependency.

The model considers the appropriate matrix transformations to evaluate the impact, both at domestic and external levels, since many extractions of raw materials, shipments and other processes may occur in zone z outside the studied region or country (9).

$$\left[Energy_{pri}^{TTW}(z,m,t,p)\right] = \left[\mathcal{M}atrix_{fin}^{pri}(z,m,t,p,f)\right] \cdot \left[Energy_{fin}^{TTW}(m,t,f)\right] \qquad (9)$$

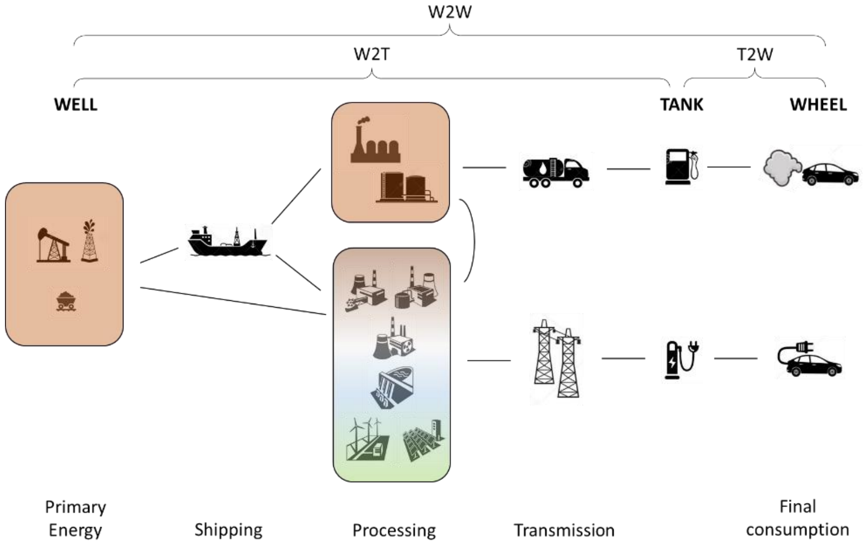

Figure 1: Well To Wheel energy and emissions analysis

The electrical generation sector model takes into account the planned upgrading of the generation mix in the evaluated region for the studied period. This makes it possible to dynamically consider the evolution of electricity generation towards a renewable mix.

Results

Case study definition

The previous methodology is used to study the effect of different policies in Spain for private passenger cars technology transition in line with national and European Green Deal targets (European Commission, 2019). The study period extends until 2050 to incorporate the dynamics of the evaluation of the fleet. The Spanish case is representative of many European countries where the transition towards zero emission transportation is backed by a strong Renewable Electricity Generation objectives. In Spain there are almost 35 million vehicles, from which 24.5 million are passenger cars in 2020, and the current traction technology share is 44.2% petrol, 55.2% diesel and 0.6% other technologies (DGT, 2021). Zero emission vehicles have still low penetration levels (0.1% electric vehicles as shown in Fig. 2), although it is expected that sales will increase in the coming years (OVEMS, 2021).

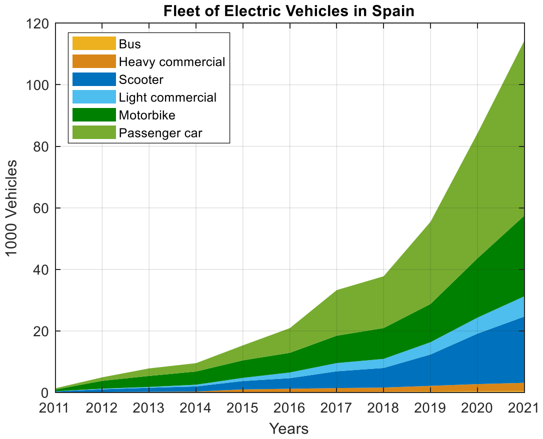

Figure 2: Electric Vechicle Fleet in Spain

According to currency policies in Spain, we consider a single scenario that targets 40% and 80% of sales of electric vehicles (including BEV and PHEV) in 2030 and 2050, respectively. As required by the model, a detailed characterization of the Spanish car fleet since the year 1990 is included, together with the technological trends of the different traction alternatives, including efficiencies and emissions obtained from different sources (Moreno, 2020), some shown in Table 1. Finally, the detailed transition of the Spanish electrical production system for all generation technologies consideres (as shown in Table 2), based on national plans, a share of renewable generation for 2030 of around 70%, slightly below the 74% official plans (PNIEC, 2019).

Table 1: Passenger cars characterization for 2018

Fuel Type	Fuel consumption [l/100km]	CO_2 emissions [g/km]	NO_X emissions [mg/km]
Diesel	5.93	155.93	341.41
Petrol	7.31	165.16	67.35
HEV	5.96	135.60	6.55
LPG	8.81	156.90	72.01
BEV	0.00	0.00	0.00
PHEV	2.09	48.14	41.44
CNG	5.00	130.10	52.51

Table 2: Spanish Long Term Electric Power Generation

Power generation Scenario	2020	2030	2050
RES (%)	44	68	79
Average CO_2 emmissions (tCO_2/MWh)	0.154	0.059	0.035

Finally, in this case study it is assumed that the aggregated distance remains constant, based on improvements of public transportation will cover the increased travelled distance. Aggregated travelled distance is 286,000 Gm/year, that corresponds to an average distance per car of 11,500 km/year. Based on historical record, 1/3 of this distance is covered in urban areas, and the remaining 2/3 in non-urban areas.

Analysis of results

The results obtained from the simulation show the evolution of the passanger car fleet for each traction technology. In Fig. 1 we can observe that although electrification incentives are set for today, changes in the fleet will need almost 15 years to be representative. A full transformation of the passanger car fleet will require more than 30 years. The transition to new technologies is limited by the sales of vehicles every year -between 1.3 and 1.5 million cars-, associated with the purchasing power and needs of consumers in Spain (ANFAC, 2021).

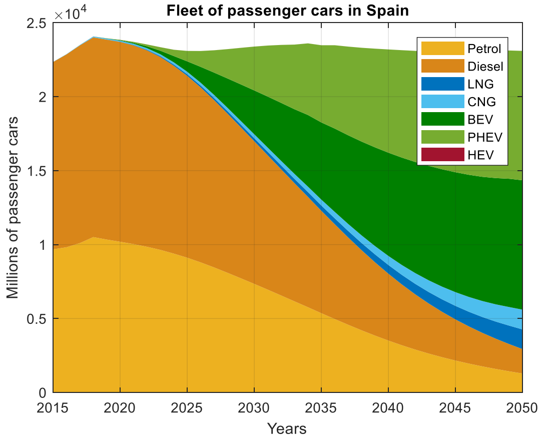

Figure 2. Passenger car fleet evolution in Spain

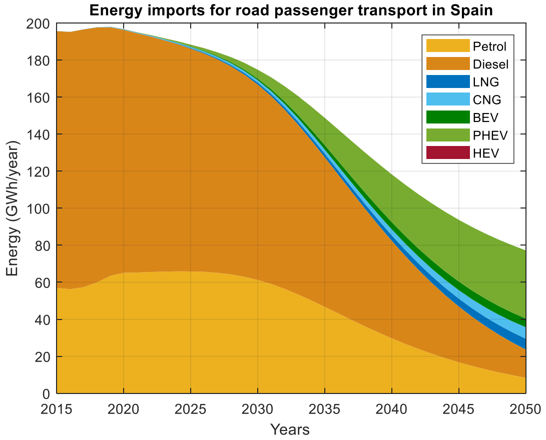

Figure 3. Energy imports for road passenger transport in Spain

The effect on the primary energy consumption trends is associated with the integration of new technologies in the fleet but also with the steady improvement of conventional fuel based vehicles with higher efficiencies and lower emissions (incorporating the updated European regulations on this issue). Under the hypothesis of this electro mobility scenario by 2050, Spain could reduce by a half the imports of energy dedicated to passenger cars. Although it is expected a high penetration of renewable generation by 2050, still combined cycle power plants running on imported gas should be required to cover part of the energy consumed by Electric Vehicles.

Finally relevant results on emissions due to passenger cars show that NO_X, the main pollutant in urban areas, could be reduced by 91% in 2050 from a starting value of almost 150 ktonnes/year. Similarly, reduction on CO_2 emmisions in the period 2020-2050 is 71%, a bit lower as it is encompassed with the power generation conversion on renewable sources.

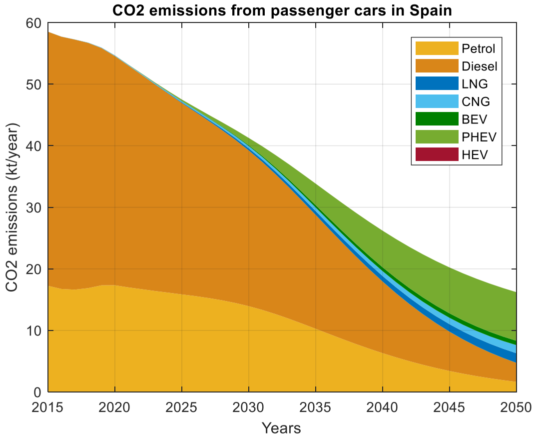

Figure 4. CO_2 emisions from passenger cars in Spain

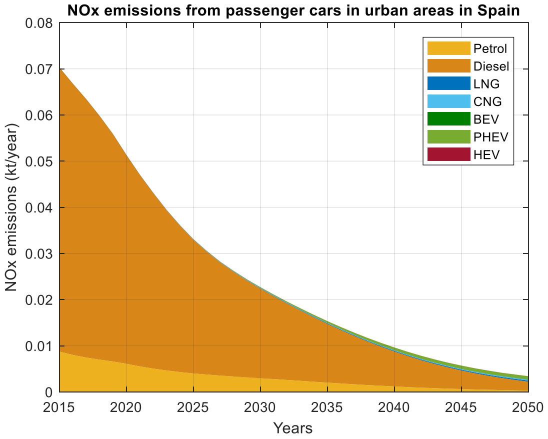

Figure 5. NO_X emissions from passenger cars in urban areas in Spain

Conclusions

The proposed modelling of the transportation sector adequately allows to study the long term effects on the economic and environmental indices. As the electrication of the transportation is expected to be the predominant technological option in the mid and long terms, WTW analysis requires the characterization of the power generation portfolio. The proposed model requires accurate technical information of the different fleets and technological trends for transportation.

According to the results of the Spanish case study, the expected transition towards a more sustainable transportation takes time, even in the case of price parity between combustion and electric technologies, as the replacement rate of passenger cars is still slow, in the range of 10 years, giving enough time for policy makers to prepare the transition. Consequently, the impact on energy imports and Spanish energy dependency becomes relevant after a decade towards electro mobility, which emphasizes the need of national agreements with a long term vision. Environmental benefits are also identified, both globally as 71% of CO_2 emmissions reductions, and locally with 91% NO_X less emmisions in urban areas.

Although private passenger cars are responsible for more than half of the energy consumption and CO_2 emmissions, a more accurate analysis should also consider other transport alternatives such as heavy trucks and busses, light commercial, motorbikes, flights, mairitimie and the transfer of freight transport from road to the already electrified railway, being this year the European Year of Rail.

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