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How to raise consumer awareness of the environmental impact of vehicle attributes? A big data analysis

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Abstract

The introduction of the Euro 7 emission standard is expected to significantly change the typology of the European passenger car. This study analyzes the environmental impact resulting from future trends in fleet composition and proposes an innovative vehicle classification system focused on raising consumer awareness of the importance of their choices with regard to key attributes such as body type, engine power and vehicle weight. A sensitivity analysis of the fleet's greenhouse gas emissions to deviations in their composition is carried out, considering the preferences expressed by the consumers in 2022 and the vehicle's specifications reported by the automotive industry on European digital platforms embodying Industry 4.0 principles. The findings show that internal combustion fleet emissions are expected to rise 0.30% per 1% increase in engine power and 0.44% to 0.69% per 1% increase in weight, according to the Worldwide Harmonised Light Vehicle Test Procedure (WLTP). The plug-in electric vehicle (PHEV) segment is the fastest growing in terms of market share. This trend will continue in the future, as this is the segment best suited to comply with the emissions targets imposed on manufacturers. Another relevant conclusion is that the environmental impact of PHEV vehicles is potentially very negative if the drivers' charging habits do not reflect the manufacturer's design intention. Thus, the development of consumer environmental awareness tools is urgent. This is the study's main motivation: to develop a tool in the scope of the Industry 4.0 while promoting the emergent concept of Industry 5.0, sustainability based and human-centered.

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Keywords: WLTP; PHEV; Euro 7; Sustainability; GHG emissions; vehicle fleet; vehicle labeling; vehicle database; Industy 4.0

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1. Introduction

The typology and technological level of the vehicles in a fleet affect its environmental impact [1]. However, is the consumer effectively aware of this? Does the information provided to them at the time of purchase effectively alert them? It is recognized that the attributes of a car influence the buyer's preferences and willingness to pay for them [2–4]. On this matter, a recent study conducted in Portugal [5] has find out that the price factor is dominant, followed by indicators of performance and environmental impact, the latter strongly dependent on the consumer's level of sensitivity to this aspect [6].

In this context, the climate changes resulting from greenhouse gas emissions (GHG) produced by vehicles equipped with Internal Combustion Engines (ICE) have led policymakers to implement regulatory measures aiming to achieve greater transparency in measuring this impact and to stimulate a more sustainable technological development in the sector. Examples of these measures include the introduction of the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) in 2021 [7,8], replacing the New European Driving Cycle (NEDC), and the implementation of the EURO 7 standard, which is perhaps overly restrictive and penalizing for the European automotive industry, in the words of Stellantis CEO [9]. Regarding this matter, Carlos Tavares (Stellantis CEO) warned that this standard demands a disproportionate effort from the sector for a marginal environmental benefit. The anticipated costly technical solutions will reduce profit margins inherent to the production of small passenger cars and/or increase the cost of this product, thus reducing its attractiveness to both the industry and the consumer. This potential disinterest in small vehicles can have a pernicious rebound effect and lead to an increase in the size of the European car, making it closer to the North American fleet. If this happens, the desired environmental benefits may be more limited and/or individual mobility penalized. This negative social impact will be felt more strongly in countries with more fragile economies, such as Portugal.

1.1. Study motivation, objectives and structure

An alternative path to mitigate the environmental impact of private transportation could be the introduction of effective measures to raise consumer awareness about the importance of their preferences when purchasing a vehicle. In this regard, this study proposes a visual and intuitive model for ranking the environmental performance of a vehicle within the market in which it operates, an approach possible through big data sources analysis. If regulated, this path could be easily implemented by the automotive industry. A consumer more sensitive to environmental issues would thus have a dynamic information tool promoting self-regulating behaviors. Any agent becomes more aware and participative in a process when he has timely feedback on the consequences of his actions and choices. This feedback can be provided through the graphical rating system proposed here, which the owner could access easily and in real time via mobile applications (apps to be developed) or through the vehicle's infotainment system. The materialization of this model is possible through integration with existing databases [10,11], currently available online, on the type-approval emissions of new vehicles registered in Europe, which also include the main attributes of vehicles purchased by each individual consumer. These databases were used in this study to accomplish the following objectives:

i. Typify the Portuguese new passenger car fleet regarding key attributes (vehicle body and powertrain).
ii. To correlate these attributes with the WLTP emission levels.
iii. To propose a visual intuitive environmental ranking tool.

This tool materializes yet another way in which the automotive industry can share data on digital platforms, data that is currently of no use to the consumer, since it only complies with a regulatory obligation for statistical or inventory purposes. In this context, the proposed tool stems from an Industry 4.0 principle that is intended to be extended to society in general (consumers), further materializing the emerging concept of Industry 5.0 [12,13].

The main contributions of this study are: (a) to disclose functional relations between CO_2 emissions and the vehicle attributes and (b) to extend the scope of the current WLTP emissions public reporting system, from a quantitative single point rating (WLTP CO_2 combined cycle emissions) to a qualitative raking system easy to perceive by the consumer. The main research questions addressed are:

1) What will be the change in the CO_2 emissions of the Portuguese car fleet, by driving mode, if the production of compact cars were to be discontinued?
2) How sensitive are fleet emissions to engine power and vehicle weight/size?
3) How can we improve the environmental awareness of an uninformed buyer?

This study falls in the research domain of vehicle classification, but is focused on explanatory modeling aiming the development of an user-friendly environmental ranking tool, rather than on the development of mathematical tools for the identification and recognition of vehicles in the context of traffic surveillance and monitoring systems [14,15]. In fact, the relationships referred to in point (a) do not follow any classification system (e.g., UNECE, ACEA, Euro NCAP). Such segmentation strategy would undermine the effectiveness of the intended classification tool. In reality, these vehicle categories are generally unknown or poorly perceived by the consumer due to its ambiguity, since a vehicle can fall into more than one segment at the same time. This grouping may also compartmentalize the consumer's perception of the actual environmental performance of the vehicle of their choice. A Lamborghini Huracan V10-LP640 might be seen as an environmentally friendly vehicle in the 'supercar' segment when compared to a Bugatti Centodieci, the WLTP specific greenhouse gas emissions being 36% lower [10], but certainly neither would be an ecologically sustainable choice, even in an ideal world.

This study is organized as follows: Section 2 presents the methodology; Section 3 typifies the Portuguese car fleet; in Section 4 the environmental impact of different fleet trends is discussed; and finally, Section 5 presents the main conclusions and suggests future research paths.

2. Methodology

2.1. Database construction

Vehicle attributes of the Portuguese new passenger cars registered in 2022 were retrieved from the European Environment Agency (EEA) [10], namely: mass in running order, MRO (kg); WLTP test mass, TM (kg); WLTP specific GHG emissions, SE (g_{CO2}/km); wheel base, WB (mm); track width (mm); fuel type; engine capacity, EC (cm^3); engine power, EP (kW); and WLTP combined fuel consumption, FC (dm^3/100 km), in accordance with WLTP definitions in [7]. The vehicle models are identified through the vehicle family identification number.

The provisional database above was enlarged in order to include CO_2 emissions and fuel consumptions for the low, medium, high and extra high phases of the worldwide light-duty test cycles, class 3a, level 1A [7]. These data, lacking in [10], were retrieved from the UK Vehicle Certification Agency (VCA) [11]. The vehicles were matched by make, commercial name, engine capacity, rated power and fuel type.

The database thus gathered was further enlarged with the following vehicle specifications not given in [10,11] retrieved online: length, L (mm); width, W (mm); height, H (mm); rated engine torque, RT (Nm); rated engine speed, RES (rpm), at maximum power; and vehicle maximum speed MS (km/h). This tedious data collection process was deemed necessary not only to eliminate gaps in the databases, but to validate the database constructed.

2.2. Database validation

Small differences were encountered between the different sources consulted, but EEA database was found to be entirely reliable, with one exception, regarding 32 improper registrations of the Sport Utility Vehicle (SUV) Dacia-Duster 1.3, which is reported as having a rated power of 11 kW, when the true value is 110 kW. Regarding the VCA database [11], the WLTP fuel consumption values given in metric units are somewhat more uncertain, with a matching efficiency of 99.0% for a mean absolute deviation $MAD \leq 1$ dm^3/km, in relation to values computed form fuel efficiencies reported in miles per imperial gallon. Restricting this criterion to $MAD < 0.1$ dm^3/km, only 97.0% of the reported WLTP fuel efficiencies match. These typographical or conversion errors are not significant in the scope of this study.

2.3. Modeling approach

In order to infer the fleet's GHG emissions sensitivity to deviations in their composition, the fleet was filtered by powertrain/fuel type, rated engine power, and vehicle mass and size. Regarding the latter, a novel classification system was implemented, denominated by Size Ranking by Quadrant (SRQ), based solely on the vehicle side view aspect ratio, AR, between the vehicle length L and its height H,

$$AR = L/H \tag{1}$$

The SRQ rating is a dynamic indicator that compares the dimensions of a given vehicle with the respective median values of the fleet population. The SRQ is fleet dependent. The first quadrant class Q1, shaded area in figure 1, includes vehicles longer and taller than the median vehicle, i.e., the upper front corner of the rectangular envelope of its side view (discontinuous red line in figure 1) falls in the first quadrant of a Cartesian referential placed at the homologous point of the median envelope (continuous red line). Each quadrant corresponds to a class, namely Q1, (larger vehicles with a similar AR), Q2 (vehicles taller and shorter than the median), Q3 (small vehicles whit a similar AR) and Q4 (slender vehicles). The purpose here is to rank vehicles by size through a quantitative input. The ranking systems referred previously do not allow it.

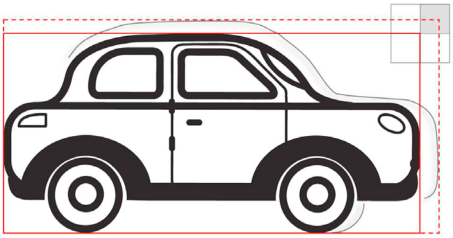


Fig. 1. Size Ranking Quadrant (SRQ). The red continuous line is the median fleet´s dimensions. The dimensional deviations of a given vehicle are classified by quadrants, centered on the upper front corner of the median envelope.

The SRQ rating Qn, with n = 1 to 4, can be further refined by car silhouette type: one-box, two-box and three-box designs, defined as subcategories m = 1, 2 or 3. The quadrant classification is given as Q$n.m$. For instance, a MPV would be Q1.1, a SUV a Q1.2 and a luxury car like a Bentley a Q1.3, the common hatchback being a class Q4.2. In the context of this study only the impact on emissions of the most important vehicle attributes X_i are considered, such as weight and size (interrelated attributes), drivetrain rated power and fuel/energy type [16,17]. Consequently, the vehicle energy efficiency and specific emissions were not studied by Q$n.m$ classes. These specifications are gathered in the [big data] sources consulted [10,11], presently available.

In order to answer the first research question, the models equipped with internal combustion engines (ICE), petrol and diesel, 1152 models in all, were isolated among the 155470 new cars registered in Portugal in 2022 (identified by the vehicle code in the EEA database). Then all vehicles in Q3 (the smallest class) were assumed as compact cars and the respective registrations frequencies, per model i, set to zero, i.e., $P_{i\in Q3} = 0$, being the respective population P_{Q3} of the ICE population P redistributed by the remaining Q classes in accordance with the consumer's preferences in 2022. Finally, resorting to the enlarged vehicle's database, described previously, fleet average CO_2 emissions were computed for the WLTP combined cycle and low phase cycle, representative of city driving (the worst case scenario). The results are weighted averages for the current distribution P_i and for the $P_{i,Q3} = 0$ hypothesis,

$$P_{i|\mathrm{Q3}} = \frac{P}{P - P_{\mathrm{Q3}}} \cdot \begin{cases} 0, & i \in \mathrm{Q3} \\ P_i, & i \in \text{others} \end{cases} \tag{2}$$

The ICE population P represents 73% of the total vehicles registered that year. This sample consists of new and technologically more advanced vehicles than the average car on the road, thus the results obtained should be considered as conservative (underestimation of drawbacks or overestimation of benefits).

To answer the second research question, it is assumed that the production of vehicles with a rated power below a certain threshold *EP* will be discontinued: because they are usually cheaper and due to the expected reduction in profit margins following the introduction of the EURO 7 standard. The hypothesis considered leads to the fleet composition, $P_{EP,i}$. The fraction of the population discontinued $P_{EP,i\leq EP}$ is assumed to be redistributed in accordance with the present day consumer's preferences by the remaining car models, EP_i being the rated power of each. The new distribution is,

$$P_{EP,i} = \frac{P}{P - P_{EP_i \leq EP}} \cdot \begin{cases} 0, & EP_i \leq EP \\ P_i, & EP_i > EP \end{cases} \tag{3}$$

The effect of increasing engine power, a current trend, on fleet emissions was inferred by gradually increasing the *EP* threshold in steps from 5 to 10 kW. The same procedure was applied with respect to the effect of increasing vehicle mass, also a current trend.

3. Fleet characterization

In Portugal the year 2022 was the first since 2019 not directly affected by the COVID-19 pandemic. In this period the Portuguese passenger car market experienced a significant change towards electric mobility. In fact, the market share of vehicles with electric traction registered in Portugal, whether battery operated (BEV) or plug-in electric vehicles (PHEV), rose from 5.7% to 21.9%. This trend, although uncertain to some extent due to the dramatic drop in car sales, from 223799 units in 2019 to 155470 in 2022, nevertheless represents a 2.7-fold increase. The demand for PHEV vehicles increased 3.1 times in this period. Despite this, the demand for vehicles equipped with ICE engines remains very high, 89.7% in 2022 *vs*. 96.9% in 2019 [10,18].

Figure 2 shows the Portuguese consumer preferences in 2022. The abandonment of diesel powertrains is evident. The fraction of the market denoted as "others" is composed by ICE powertrains using alternative fuels, such LPG and E85, more environment-friendly.

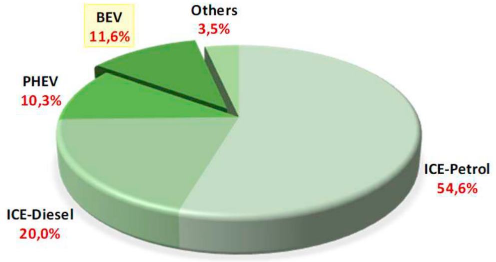


Fig. 2. Portuguese passenger car registrations in 2022 by fuel type: internal combustion engines (ICE), plug-in hybrid electric vehicles (PHEV), and battery electric vehicles (BEV). The segment 'Others' refers to alternative fuels, such as LPG and E85.

One of the consequences of embracing electric mobility is the increase in weight and power of passenger cars. In three years, the average mass in running order (MRO) has increased 8.1%, from 1341 kg to 1450 kg, and the average power 13.5%, from 89 to 101 kW. Given the rapid grow of the PHEV share of the market and knowing that the actual emissions of this type of vehicles can surpass considerably type-approval values, up to 6 times depending on the type of use and driving patterns [19,20], then a rapid abandonment of the ICE powertrains in favor of PHEV units can have an uncertain (and possibly negative) environmental impact if users are unaware of the limitations of this mobility option. The fact is that they weigh considerably more than the conventional gasoline powered vehicle (MRO of 1910 kg against 1256 kg) and that they are equipped with larger capacity engines, thus if charged sporadically they will operate mainly as a heavy ICE vehicle with a pronounced negative environmental impact.

The main attributes of the different mobility options are shown in figure 3. The trend towards a heavier and more powerful fleet is quite evident with the adoption of electric powered vehicles. The blue lines represent the average vehicle. The others are a measure of dispersion of a given attribute *X* within each population, the distance between lines being the standard deviation of *X*.

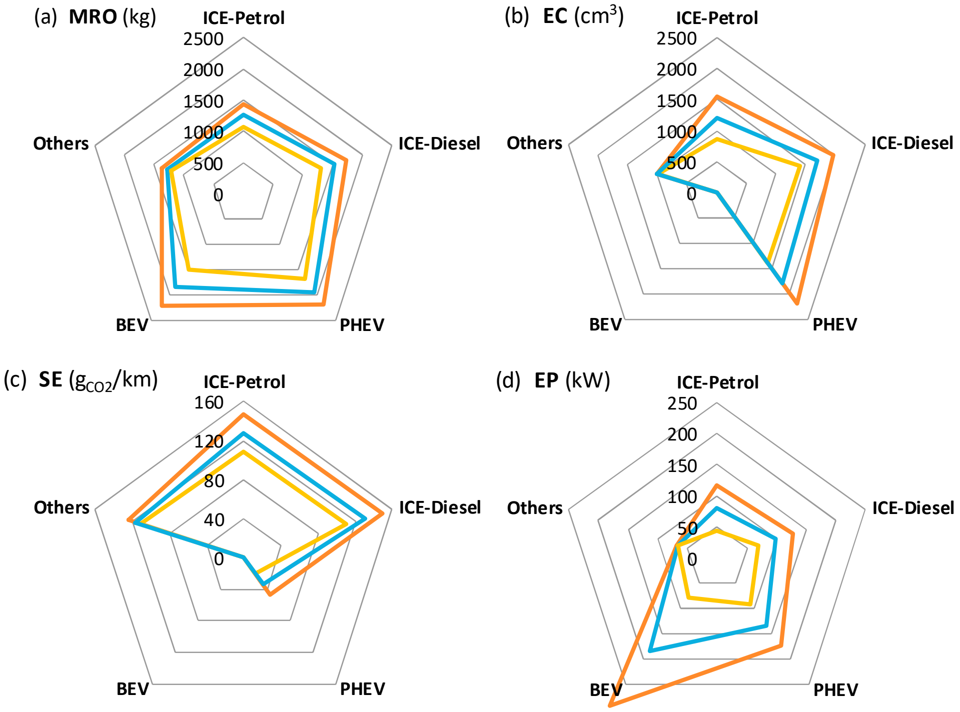
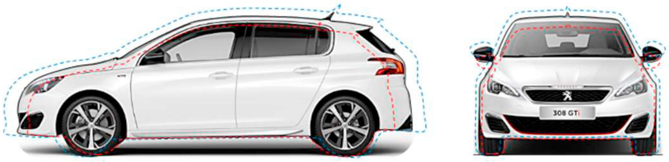


Fig. 3. Main attributes of the Portuguese passenger car fleet per fuel type: (a) MRO, mass in running order (driver included); (b) EC, engine capacity; (c) SE, specific emissions; (d) EP, engine power.

The ICE population is by comparison quite uniform, as shown in figures 4 and 5. The first picture depicts the average dimensions of the fleet (length, *L*; width, *W*; height, *H*) and the respective standard deviations, portrayed by the dashed lines. Figure 5 shows the proposed SRQ classification by size quadrants. The area shaded in red encompasses 50% of the population around the median vehicle dimensions. The amplitude of this region is ±5.4% of the median values for length L_m and height H_m, 4226 mm and 1504 mm, respectively. The area of the bubbles is proportional to the number of registrations for each vehicle model/version identified. Figure 5 also shows the most frequent body type associated with each quadrant. The category Q1 consists mainly of SUVs, MPVs (Multi-Purpose Vehicles). Crossovers fall into the Q2 group, the Q3 class is dominated by compact cars and the Q4 class by hatchbacks and sedans. The latter is the only class in which diesel vehicles still lead consumer preferences. Table 1 summarizes the main attributes of these categories. The specific power is a measure of the vehicle's level of performance, or its ability to accelerate [7,21,22]. The most environmentally friendly group is the compact cars segment. The CO_2 emissions of this class Q3 are 14.2% lower than those of the segment Q1-SVUs for the WLTP combined cycle.

Table 1. Characterization of the Portuguese ICE vehicles registered during 2022 per size quadrant (see figure 1).

Vehicle Class SQR	**Market Share** (%)	**Distribution Petrol-Diesel** (%)	**Body Dimensions Length-Width-Height** (mm)	**Unladen Mass** (kg)	**Engine Capacity** (cm^3)	**Engine Power** (kW)	**Specific Power** (W/kg)	**WLTP Emissions** (g_{CO2}/km)
Q1	32,9	63-37	4450-1828-1616	1396	1443	94,5	67,7	137,1
Q2	17,6	91-9	4120-1777-1549	1146	1128	77,8	67,9	125,8
Q3	29,9	91-9	3964-1741-1460	1054	1160	66,8	63,4	117,6
Q4	19,7	46-54	4533-1819-1445	1415	1608	105,9	74,8	131,0



$$\bar{L} \pm L_\sigma \times \bar{W} \pm W_\sigma \times \bar{H} \pm H_\sigma\text{:}\ \ 4263 \pm 299\ \times 1791 \pm 59\ \times 1524 \pm 98\ [\text{mm}]$$

Fig. 4. Average Portuguese ICE passenger car. The distances between the dashed lines and the vehicle's silhouette are proportional to the standard deviations of length L, width W and height H.

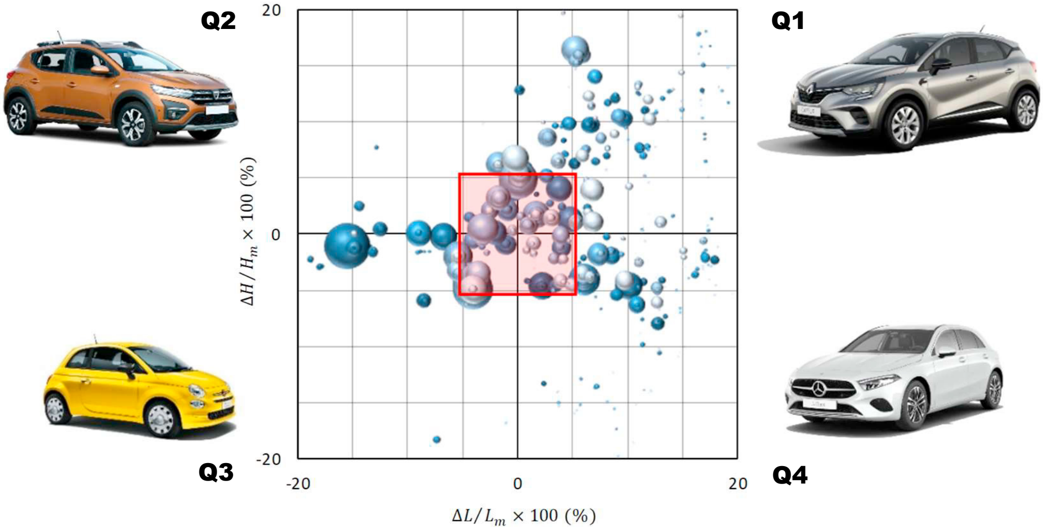


Fig. 5. Portuguese car size distribution around its median dimensions. The vehicles illustrated represent the most popular body types for each quadrant. The area of the bubbles portrays the number of registrations The shaded area encompasses 50% of the ICE vehicles registered in 2022.

4. Environmental impact of different fleet trends

4.1. Production of small cars discontinued

The worst case scenario alluded to by the CEO of the Stellantis Group is assumed here [9], namely that EURO 7 emission standards will reduce the profit margin inherent to the production of small cars to the point where it is no longer a commercially viable segment. This scenario was simulated eliminating from the fleet the class Q3 and redistributing its population among the other classes in according to consumer preferences in 2022 (see Section 2.3.). Table 2 presents the results obtained. The increase in CO_2 emissions is evident for all driving cycles, the worst case occurring for city driving, with an increase of 4.70%. Highway driving is less affected. Being lighter cars, the dissipation of propulsive energy associated with successive acceleration and braking cycles in urban circuits is naturally lower, making these vehicles naturally more efficient than others. On the highway this advantage is diluted because shorter cars typically have higher drag coefficients [23–25].

Table 2. Impact of halting the production of the Q3 class on fleet specific CO_2 emissions, by WLTP driving cycle.

WLTP Urban Change (%)	**WLTP Suburban** Change (%)	**WLTP Rural** Change (%)	**WLTP Highway** Change (%)	**WLTP Combined** Change (%)
+ **4.70**	+ 3.90	+3.43	+**2.73**	+3.46

4.2. A preference for more powerful engines

The shift of consumer preferences towards the SUV-PHEV segment can produce a rebound effect of altering the general perception of the consumer about the ‘need’ for power, simply by contagion effect. The vast majority of these vehicles can partially or fully combine both powertrains, resulting in advertised power ratings considerably above those of an ICE vehicle, presently +56% on average. This do not necessarily mean a higher performance level, due to weight increase, but it is uncertain that the consumer is aware of this. So, it is only natural to expect an increase demand for ICE vehicles more powerful, especially if small cars became more expensive, thus less attractive.

That said, the effect of demand for more powerful vehicles was studied removing from the fleet those below a certain power threshold, gradually increased, and redistributing the respective population by the remaining vehicle models, according to consumer preferences in 2022 (see Section 2.3.).

Figure 6 shows the CO_2 emissions *vs*. the fleet´s average power (blue lines). The fraction of the fleet discontinued is shown also (orange lines). The main conclusions is that for a 1% increase in fleet power, CO_2 emissions increase by 0.3% uniformly (Figure 6.a). This tendency was checked removing from the fleet vehicles on right tail of the density distribution of engine power. The same tendency was detected. In this case, 1% decrease in the fleet´s horsepower reduced the emissions by 0.3%. It is also noteworthy that the cessation of demand (or production) for naturally aspirated 3-cylinder vehicles will result in a 2% increase in CO_2 emissions.

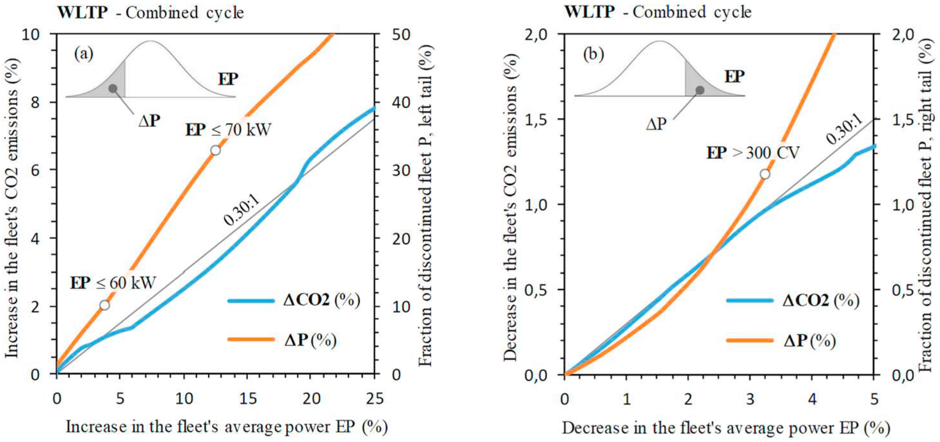


Fig. 6. Fleet emissions sensitivity to engine power.

4.3. A preference for larger and heavier vehicles

The increased demand for hybrid electric vehicles will result in a sharp increase in the weight of the average car. This effect will need to be verified. This scenario was simulated in a similar way as previously described regarding the engine power. In this case, the fleet composition was subordinated to a given MRO threshold. By increasing it gradually, in steps of 25 kg, and redistributing the filtered population by the remaining heavier vehicle models, also according to the Portuguese consumer preferences in 2022, different fleet compositions were obtained and the respective weighted-average vehicle attributes computed. Figure 7 shows the evolution of the fleet’s emissions with the average mass in running order (MRO). It is possible to see for Portuguese case (Figure 7.a) that WLTP combined cycle emissions will increase at a rate of 0.44% per 1% increase in the fleet’s MRO (blue line). Stepping the MRO threshold by 100 kg leads to a 3.5% CO_2 increase (orange line). Naturally, for city driving (Figure 7.b) the relative positive acceleration is higher, a situation that worsens this scenario [26,27]. The sensitivity of specific emissions with the average MRO rises to 0.50% per 1% mass increase. Above the MRO threshold of 1100 kg CO_2 emissions are expected to rise more pronouncedly, 0.69% per 1% mass increase. This stepping of the growth rate is a combined effect of the increases in mass and in engine power needed to maintain the same level of performance.

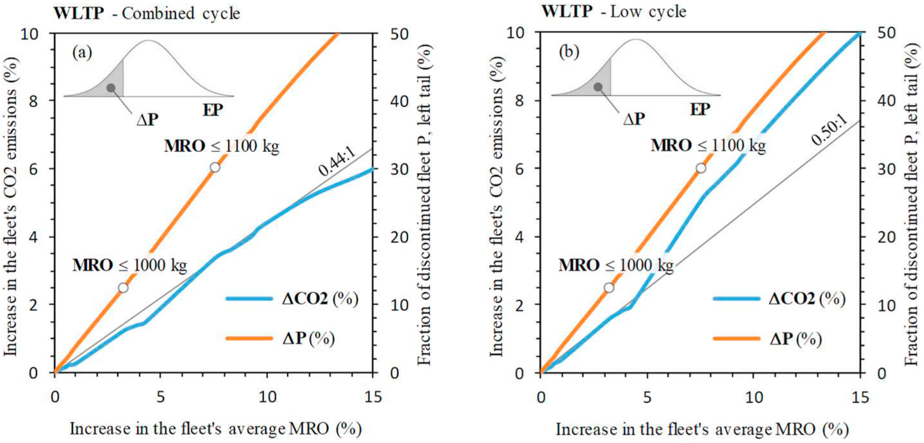


Fig. 7. Fleet emissions sensitivity to vehicle weight.

4.4. Vehicle Percentile Labeling System (VPLS)

Is the average driver aware of the environmental impact of the vehicle they drive? One would think so. Fuel economy and related emissions are among the deciding factors at the time of purchase, the price being the most important factor for a buyer with less purchasing power [4,5]. Design, luxury and performance will be decisive for those with greater purchasing power [2,4]. In this context, vehicle attributes such as weight and dimensions are tangible and user-independent. The same can be said about the acceleration capability and maximum speed. They are seen as measures of capacity directly related to engine power. However, regarding emission levels, the consumer is led to believe that this is a *static* characteristics of the vehicle, when in fact it depends on both vehicle attributes and driving patterns, either external (e.g., traffic conditions in urban or rural routes) or endogenous (e.g., driver's attitude and vehicle utilization) [28–30]. In this respect, type-approval fuel consumptions and emissions levels are ambiguous indicators. Much has been said about the real-world emissions deviation from type-approval values [23,31]. This state of affairs creates, to some extent, a general disbelief in the emissions indicators publicized. More, the alteration of procedures, e.g., from NEDC to WLTP, led to the changes in reported values for a same vehicle [30], a situation that makes this indicator even more obscure. Looking at this situation in a less passionate way, perhaps it is not surprising, in a world as competitive as the automotive industry, that manufacturers seek to obtain the most favorable results possible, even if unrealistic, within the limits set by the regulations in force. The same applies to any competitive human activity. Pushing our limits in a competitive context is not a daily activity or routine (a real-world emission), by definition. On the other hand, the relative positioning of the different manufacturers in the automotive industry regarding performance and technological level is much more insensitive to regulatory changes.

Knowing this, a new vehicle labeling system is proposed based solely on its percentile positioning within the fleet where it is registered. This relative scoring system is to be shown in a label in an intuitive manner, portraying the vehicle position in relation to the fleet´s leader. Regarding any positive indicator, such as power-to-weight ratio, the positioning would be obtained sorting the population in ascending order, the opposite being applied for a negative attribute such as an emission level.

Additionally, for any electric powered vehicle, charged externally, the specific CO_2 emissions per unit of energy supplied at the consumer's level should be accounted for labeling purposes according to each country's energy-mix. Similarly, the type-approval fuel consumptions and emissions of any plug-in electric vehicles should be converted to the fuel equivalent values based on a reference combined thermal efficiency (ICE and electric charging system), presented as a worst-case scenario: that of improper or absent charging habits. The average Portuguese PHEV has a WLTP electric energy consumption of 17.7 kWh per 100 km, and one liter of gasoline 95 RON has a heat content of 8.7 kWh and an emission factor of 2.26 kg_{CO2}/dm^3. Thus for a cycle-average combined thermal efficiency of 30% the equivalent fuel consumption would be $17.7/(8.7\times30/100) = 6.8$ $dm^3/100$ km or 154 g_{CO2}/km. This figure, which reflects the effect of regularly driving the vehicle with the battery discharged (at the minimum permitted level), is 21% higher than the emissions produced by the average Portuguese petrol car (127 g_{CO2}/km). The typical consumer is not aware of this fact, nor is he expected to be. The goal is simply to raise awareness among consumers to the practice of sustainable behaviors.

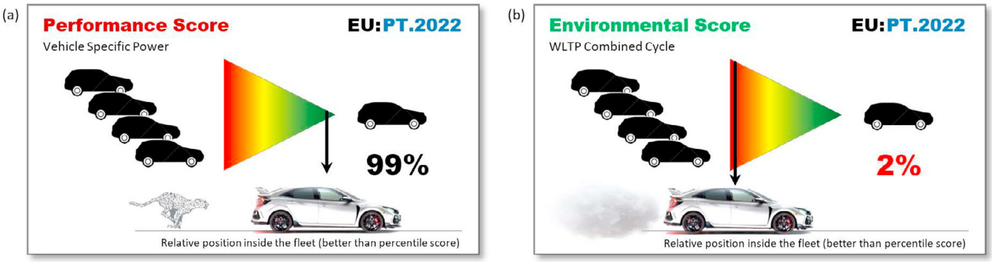


Fig. 8. Vehicle Percentile Labeling System.

5. Conclusions and future research perspectives

The introduction of the EURO 7 emission standard may lead the automotive industry to increase the production of plug-in vehicles as a way to meet emission targets. However, these cars are only environmentally friendly if operated primarily as electric vehicles. Consumer preferences already confirm this trend, perhaps because they are not aware of the impact that improper use of these vehicles will have. The plug-in vehicles are advertised with very low CO_2 emissions, despite their considerable weight, ranging from 1570 kg to 2810 kg (MRO of the heaviest SUV on the Portuguese market). This is true for the WLTP combined cycle because the distance traveled, 23 km, is within the average electric range of these vehicles, 63 km in the case of the Portuguese PHEV. This fact allows a residual use of the ICE during type-approval testing.

However, is it wise to consider a 2-ton car as a city car? Its maneuverability in the city does not seem compatible with this concept. But such an electric range is also not compatible with an all-electric use on medium to long distance trips. These premises lead to the conclusion that these vehicles need regular charging to fulfill its design intention. In fact, the low capacity batteries can be charged at home with relative ease. But is this practiced routinely by the average driver? A simple glance at urban residential areas, typically with vertical construction, reveals the behavioral pattern of leaving the car on the street at night and not in the garage. Perhaps for the convenience of the driver or because he does not own one (or he owns more than one car). This conclusion leads to another. To realize the full potential of a plug-in vehicle it will be necessary to resort to public charging stations also, as with BEV. As such, it is imperative to provide conditions to charge these vehicles in an urban environment where vertical construction predominates and do it on a widespread basis in the close proximity of residential and work spaces. The energy stations for these vehicles could be of medium to low power, in order to allow its massification and to take advantage of the small capacity of their batteries. Neglecting such an infrastructure in an urban environment, where charging at home can only be practiced sporadically, and relaying solely on service stations capable of fast charging will lead drivers to the use primarily the combustion engine: simply for convenience of use. This study has shown that the environmental impact of such behavior is expected to quite negative. Presently the average plug-in vehicle is 44% heavier than the average ICE conventional vehicle. Based on the computed weight sensitivity of the fleet´s emissions obtained, a misuse of the PEHV fleet as a heavy ICE can lead to a potential CO_2 increase of 22 to 30%, for the worst case scenario: a fully hybridized fleet and a complete disregard for external charging.

The typical consumer is not aware of these facts, nor is he expected to be. The VPLS rating proposed can be made as a dynamic tool by interlinking databases, thus raising future consumer awareness.

The intention is to continue this work by developing mobile applications that allow access to the dynamic information tool proposed in this study (graphic classification system). Its limitations are expected to be of an institutional nature, since no classification system can be implemented publicly without the appropriate regulatory framework, naturally in the European context.

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