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Using B15 in vehicles on real on-road circumstances - A case study

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ABSTRACT

The transport sector is one of the largest contributors of pollutant gas emissions, being also one of the largest consumers of energy, mainly fossil origin, so it is urgent and imperative to act in this sector. The legislation on these emissions has been undergoing constant updates, increasingly incisive on this subject. The imposed reductions in pollutant gases are obvious and demanding, which also demands the use of sustainable energy sources, where biofuels appear as a viable and immediate solution. This study will provide an overview of the utilization of biodiesel in actual on-road driving conditions. The current information analyzes the evaluation of the B15 (15% biodiesel in diesel) use on automobile fleets to achieve this goal through a completely practical approach. To accomplish this goal, it was used monitoring data from car fleets that included both cars and trucks fuelled by conventional diesel and a mixture with 15% of biodiesel during comparable time periods. The 15% biodiesel addition to fuel will result in some differences in fuel consumption for all the evaluated automobile fleets, corresponding to increases or decreases of maximum of 2%, which variance is much lower that the observed between vehicles with different drivers and operation activities. Due to all the benefits a renewable fuel offers, particularly in terms of the reduction of CO_2 emissions and decrease in reliance on fossil fuels, the increase in biodiesel blends can be confirmed as making a positive environmental contribution even when a small average increase in fuel consumption is verified.

1. Introduction

The environmental imbalance that has been shown through unusual climate changes and amplified natural catastrophes is the mirror of extreme pollution, which the planet is no longer able to eradicate. Abusive use of petroleum comes from the energy dependence inherent in the dynamics that society adopts today, and this becomes a huge problem, both economically as environmentally.

Transport has expanded society's horizon, allowing it to reach resources that would once have been impossible and has substantially improved the quality of life. Nowadays, transport is implicit in most of the social and economic activities, expanded and facilitated mobility. It would therefore be necessary to find a way to reduce the harmful impact of gaseous emissions from transport, without abdicating the indispensable benefits inherent to them. Both passenger and freight activities are estimated to more than quadruple by 2050, boosted by greater mobility demand needs in the developing world as economies, populations, and living standards rise. Emissions trends in the transportation sector are influenced by how quickly oil can be replaced; at present, it accounts for 90% of energy usage in transportation (IEA, 2022).

Directive 2009/28/EC, known as RED, defined for Portugal's energy consumption, a renewable energy quota of 20.5% for 2005, a goal which was met, giving Portugal fifth place among the 27 European countries (European Parliament and the Council of the European Union, 2009). In 2019, 30.6% of Portugal's gross final energy consumption were generated from renewable sources, this considers 54% of electricity generated, 42% of heating and cooling demand, and 9% of transportation demand. (IEA 2021).

The RED also establishes "sustainability criteria for biofuels and bioliquids" which are decisive for the deliberation of their efficiency (European Parliament and the Council of the European Union, 2009). Strict requirements for GHG savings, for biodiversity protection and conversion of high-carbon land and for monitoring adverse effects are defined by the standard. The compliance of these criteria can be validated through national verification systems or by voluntary schemes approved by the EU (Flach et al., 2019).

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A consideration for social sustainability has already been seen in 21st Article of Directive (2009)/28/EC, which assigns a double contribution to "biofuels produced from wastes, residues, non-food cellulosic material and lignocellulosic material for the accounting of renewable sources in transport energy consumption (IEA 2021).

Energy efficiency is mentioned by the standard as one of the most essential criteria to achieve the targets for incorporating renewable energy in a sustainable way, being one of the main objectives its optimization by 20% in 2020. The transport sector is of particular relevance in this context, given the growing demand for energy for transport. In addition, energy efficiency is also decisive for the reduction of GHG emissions, justifying the existing own directive on the promotion of energy efficiency in the transport sector (Directive, 2012/27/EU). In 2016, the EC drafted a new energy plan, called "Clean Energy for All Europeans". One of the proposed legislative measures was the recast of the RED. Directive (EU) 2018/2001, called RED II. This enters into application in December 2018, stipulating measures and criteria to be considered between 2021 and 2030. (European Parliament and the Council of the European Union, 2018).

The altered directive moves the legal framework to 2030 and binds the new target for the share of renewable energy in total energy consumption at 32%, with a clause targeting a possible review by 2023. The transport sector has also been updated to a minimum target of 14% renewable energy consumed in road and rail transport by 2030. (European Parliament and the Council of the European Union, 2018) Within this stipulated limit, a maximum value of 7% for first generation biofuels was set, applied to all Member States. If, for a Member State, the limit for first-generation biofuels is lower than 7%, the country may reduce the 14% target by an amount corresponding to that difference (Flach et al., 2019).

Whatever the targets set, each EU member country must draw up national energy action plans, revised every 2 years, where the measures to achieve the objectives are defined. (European Parliament and the Council of the European Union, 2018). In 2021, the European Union (EU) proposes the effective ban of fossil-fuel cars use from 2035 forward. This objective clearly repeats the error that society makes in the last century that is focusing on a single energetic solution for the road transport sector. There are many theories on electric vehicles, in terms of their applicability, feasibility and sustainability; many entities conflict on this issue, assuming antagonistic positions, mainly according to their business area. The method of calculating the CO_2 emissions associated with the use of EVs is not straightforward or easy. It also cannot be done carelessly. Such an assessment could produce very different and even opposing values if done incorrectly. In contrast to conventional IC vehicles, the production of batteries and EVs themselves have various implications and call for different resources and processes. On the other hand, driving an EV requires the use of electricity, which can be entirely generated through renewable resources or through the combustion of fossil fuels like coal or natural gas in a thermal power plant. Utilizing what is referred to as the local energy mix is crucial in this regard. (Jochem et al., 2015).

This reality is accentuated in local contexts of mostly electric circulation because there is no direct emission of gases; the apparent sensation reflects a higher air quality, environmental conservation, and increased quality of life. However, this is an illusory idea. There are other aspects that should be considered; the amplified exploitation of the raw materials needed to build batteries, could have astronomical consequences in poor countries, from where most of the matter is extracted: imbalance of rare minerals in the ecosystem, extreme local pollution, violation of human rights in extraction activities. Also, in terms of applicability, there are still some limitations in the electrification of heavy road transport, particularly high load, maritime and air transport, although there are already advances in this direction. Moreover, although the commercialization of electric vehicles has increased exponentially in recent years, they still represent a very small portion of the world road fleet, requiring a huge investment in vehicles, equipment, and infrastructure to electrify a large part of this fleet, investments that most entrepreneurs cannot afford. All these reasons make electrification unfeasible as a unique and exceptional solution to achieve the reduction of pollutant gas emissions but make electric vehicles a great option for certain situations, combined with other more profitable alternatives for other contexts.

Once excluded the hypothesis of reducing the vehicles in circulation and deferred the option of electrifying the entire vehicle fleet, at least in the short term, the solution to reduce emissions of pollutant gases could be made by making small adjustments in the vehicles themselves, both in terms of equipment and power supply. Thus, this reduction may be achieved by applying new emission-reducing technologies in the vehicles' exhaust system, or improving the existing ones, or by using more sustainable and ecological fuels, from renewable sources, which do not imply significant changes in the vehicles' structure. The application of biofuels in the transport sector arises in this context. If the effects of land change are considered when choosing feedstocks and if, for feedstocks derived from soil, land with high biodiversity and high carbon rates are eliminated, new generation biofuels can dramatically reduce total GHG emissions (Tamburini and Fano, 2020) In resume, the most knowledgeable solution is to understand what the better energetic option for a specific vehicle condition, and compel to use that, instead of choosing a single solution that effectively may well result in greater environmental cost (Tamilselvan and Rajkumar, 2017).

The urgent need to reduce pollutant gas emissions, supported and officialised by the legal requirements imposed by the Renewable Energy Directive (RED II) dictates, without any doubt, that the direction to follow is renewable fuels (Jochem et al., 2015). The nature of this problem and the possible ambiguity are now focused on the type of renewable fuel and where it comes from. Biofuels have the advantage of being the only solution with immediate availability and operability for the actual fleets, without major additional investments, either in infrastructure or in the vehicles themselves. This fact makes biofuels the key to achieve the targets set for GHG emissions by 2030, since electricity and hydrogen are only now making the first appearances (Panoutsou et al., 2021). The strategy defined by the European Union aims to increase the share of renewable energy in transport sector to around 24%. This objective seems ambitious and very substantial since it requires a holistic and integrated approach through further development and deployment of electric vehicles, advanced biofuels and other renewable and low carbon fuels, since in 2015 the transport sector had the lowest share of renewable energy representing only 6% of the total energy consumed (European Comission, 2020).

Technological innovation frequently ignores the behaviors, patterns, and attitudes of everyday mobility. Because new decarbonized technologies often replicate their carbonized counterparts in terms of form, look, and application, cultural iteration endures despite original technological innovation. Therefore, the current challenge is not just to create technologies that can replace the monoculture of combustion-engine vehicles that is currently in place, but also to figure out how to improve new sustainable cultures of mobilities and immobility's (Malene et al., 2020).

Therefore, regardless of the technology utilized, it is crucial to create forms of sustainable mobility that will reduce energy use in the transfer of people and products. Models that can ensure an accurate assessment of energy consumption and analyze the practical sustainability of movement patterns are crucial for defining mobility policies. The combination of big data and experimental data may be useful in terms of model building results (Croce et al., 2022). In this context, also the use of real-life case studies allows to improve the exchanges between communication and information systems in transport and transport system models which will promote the evolution towards intelligent transport systems. This evolution, which is increasingly present and evident in vehicles, will lead to increased capability of mobility-as-a-service (MaaS) models, which will also have positive implications for the further enhancement of sustainable mobility development. (Rindone, 2022).

The efficiency of a biofuel is defined, to some extent, by the engine behaviour upon its application, in performance, consumption and emissions. Biofuels reflect, right from the start, the particular and promising advantage of being originated from renewable sources, i.e., unlimited, unlike fossil fuels. This is an unequivocal and irrefutable reality, which extends to all biofuels. The carbon emissions savings associated with the production of biofuels, compared to the production of fossil fuels, is also a proven reality. However, some authors question the ecological nature of these renewable fuels when they come from sources whose exploitation may cause adverse effects on the ecosystem.

The use of biodiesel in engines and vehicles has been the subject of several studies most of which used dynamometers set up in lab facilities; nevertheless, this entails the use of simulated conditions (Jinlin et al., 2005) also reported in (Ryan and Convery Ferreira, 2006) and (Lapuerta et al., 2008). There has been some research on the use of biodiesel in real-world scenarios, but this kind of methodology has several drawbacks because it is very challenging or even impossible to replicate similar traffic and weather conditions over the course of a day or over the course of a week (Fontaras et al., 2009). These circumstances have a significant impact on the data that are acquired, which suggests that these findings are highly inaccurate (Serrano et al., 2012). On-road testing with TDI engines and common rail cars enables the detection of an increase in consumption while using various blends of biodiesel in diesel (5%, 20%, and 50%) in comparison to diesel (Tzirakis et al., 2007). When comparing the use of biodiesel with the usage of fossil diesel, on-road tests using a car with an indirect injection engine showed considerable variations in consumption in the motorway circuit but no differences in the urban circuit (Senda et al., 2004). An investigation using a Renault Megane, equipped with a 1900 cm^3 engine using a common rail injection system, that runs on fossil diesel and a blend of fossil diesel (80%) and 20% biodiesel through 7500 km found that the two fuels have very similar fuel consumption and injection pressure because the higher oxygen content in the biodiesel balances out the lower energetic content in the fuel (Çetinkaya et al., 2005). Nine automobiles were used in research which consider both lab tests and real roads tests. Five of the vehicles used a fuel blend containing 20% biodiesel while the other four used fossil diesel. The findings of this study suggest that using a biodiesel blend would result in a 2% increase in consumption, yet real-world driving testing found that consumption results across vehicles using the two alternative fuels were very identical (Proc et al., 2006). In a common rail injection system engine from a VW Golf 1.9 TDI automobile, chassis dynamometer testing was combined with actual road tests to provide fuel consumption results in order with the lower energy available in the fuel. However, whether these results were produced under laboratory or on-road settings, it was noted that employing biodiesel in a vehicle had a considerable impact on the findings (Fontaras et al., 2009). Thus, it becomes evident that to better characterize the use of biofuels in vehicles, it is imperative to jointly evaluate the results obtained in the laboratory and the results in normal vehicle use. In making this joint analysis, the present work reveals the main contribution to the scientific knowledge development in this field.

Using the results of the tests made laboratory, considering the past related work of the authors (Serrano et al., 2021) (Serrano et al., 2015), and (Serrano et al., 2021) the methodology considered in this work aims to a better awareness about the evaluation of vehicles consuming different percentage of biodiesel fuel blends, mainly the blend with 15 (B15), that revels a promising possibility of this mixture to be efficiently used in vehicles. Thus, the present study defines as an objective to analyze and recognise the effects in the fuel consumption of using B15 on fleets of road vehicles in real road and traffic conditions, reinforced with the results obtained in laboratory. To achieve this purpose, two fleets of different companies, made up of vehicles of different categories (cars and trucks), were parameterised and analysed.

The use of B15 represents a significative reduction in fossil fuels consumption, since actually the incorporation of biodiesel in commercial diesel remains below 7%, which means that the use of 15% of biodiesel more than doubles the actual scenario. The B15 presents good properties to be used in vehicles as referred by (Lahane, and Subramanian, 2015), considering that for unmodified diesel engine, the optimum biodiesel–diesel is up to B15 blend, based on no wall impingement and increase in NOx emissions. Also, the work of V. B. Borugadda et al. (2018) reveal that waste cocking oil blends (B10 and B15) produce lower exhaust emissions promoting a small compromise in the performance of the engine.

To accomplish this objective, biodiesel obtained from waste cooking oil was used, both in laboratorial and in road tests. This was considered as a viable source, since it presents a significative reduction on Greenhouse Gases and pollutant emissions, but has revealed by (Azad et al., 2016), more study is required.

2. Methods

The methodology considered the analysis about the results obtained in chassis dynamometer, both for light duty vehicles and for heavy duty vehicles. The measured parameters in both cases are fuel consumption and engine performance, which were possible to compare with the real road conditions.

2.1. Laboratory tests

The chassis dynamometer tests considered the use of the dynamometer and a real time fuel measurement system. For this fuel consumption measurement an external deposit was used from where the fuel was supplied, and the return fuel was drained for. Each time there was a need to perform a fuel change, the management of both suction fuel line from the external tank and the return one to the truck's own fuel tank, allowed to ensure the complete removal of all the previous fuel from the supply line and preventing any test fuel contamination.

A data acquisition was also used to compile all the information allowing to gather all the data of the equipment used, including external sensors for temperature and pressure measurements, and to acquire the information obtained from the vehicle ECU, through the OBDII.

In the case of the Heavy-duty vehicles two types of tests were done. One cycle that allows to simulate the normal use of the vehicle, which experimental procedure was developed considering the homologation cycles and processes of heavy-duty trucks, which are the WHSC (World Harmonized Stationary Cycle) and the WHTC (World Harmonized Transient Cycle). (Shahir et al., 2015).

The other type of test was the performance test, where the measurement of the maximum developed power and torque for all the engine rotation range.

In the light duty vehicles, the process was similar, also using the performance tests and a normal road test simulation. This simulation was as well based in the homologation cycles, that for these vehicles is the WLTP cycle. This cycle tries to simulate the conditions of urban, extra urban and motorway routes.

The fuels considered in both vehicle types, was B7 and B15. These fuels were obtained by the mixture of 7 and 15% of biodiesel obtained from waste cocking vegetable oil in diesel. The properties of this fuels

Table 1
The properties of the fuels used to conduct the tests (adapted from (Azad et al., 2016) - A (Shahir et al., 2015), - B).

	Units	FUEL		
		Test Method	B7	B15
Cetane number		IP 617	52,1 [A]	52,2[a]
Density at 15 °C	kg/m^3	EN ISO 12185	837,6 [A]	840,6[a]
Viscosity at 40 °C	mm^2/s	EN ISO 3104	2,8 [A]	3,0[a]
Lower Heating Value (LHV)	MJ/kg	ASTM D240	42,6 [B]	41,9 [B]

[a] Obtained by interpolation.

are presented in Table 1.

Biofuel must be created from feedstocks that shouldn't have been directly or indirectly utilized for food due to the issue of food supply, and instead should take into account alternative sources, primarily from biomass.

The simplest way to do this is to think about making biofuels from biomass that is now regarded as waste or as a by-product of other manufacturing processes with very little or no current economic value.

Municipal waste, crop residues, wood, and forest residues, and used vegetable oils from eateries and households are a few examples of materials that can be utilized to make biofuels.

The biodiesel was produced in Portugal and was obtained from UCO (used cooking oil). This biodiesel considered the transesterification of used vegetable oils. There are two key benefits to this. One is the energetic exploitation of a residue rather than the use of other beneficial sources, which can represent an efficient way to reduce carbon emissions. The other is that it gives value to a resource that, if delivered to sewage conducts, would pose a problem for the wastewater treatment process.

Through a transesterification procedure, the fatty components of vegetable or animal products are converted into biodiesel, an organic molecule. Nearly all nations are putting together a policy for the production and use of biodiesel in their transportation sector since it is thought to be a solution for today's fleets (Shahir et al., 2015) and (Abed et al., 2019).

One of the key benefits of biodiesel is that it may be utilized in IC engines like those found in fleet vehicles, avoiding the need to update the technology of present vehicles. However, it also has the drawback of still having some pollutant emissions. Although it allows for a large decrease in CO_2, the remaining pollutants can only be partially reduced and so cannot be completely eradicated (Coronado et al., 2019) and (Lopes et al., 2013).

Biofuel must be produced from feedstocks that shouldn't have been directly or indirectly utilized for food due to the impact of food supply, and instead should consider alternative sources, primarily from biomass. The simplest way to do this is to think about making biofuels from biomass that is now regarded as waste or as a byproduct of other manufacturing processes with very little or no current economic value. Municipal waste, crop residues, wood, and forest residues, and used vegetable oils from eateries and households are a few examples of materials that can be utilized to make biofuels.

The present project's biodiesel considers the transesterification of used vegetable oils. There are two key benefits to this. One is the energetic exploitation of a residue rather than the use of other beneficial sources, which can represent an efficient way to reduce carbon emissions. The other is that it gives value to a resource that, if delivered to sewage conducts, would pose a problem for the wastewater treatment process. To ensure compliance with the EN14124 standard and subsequent usage in internal combustion engines, waste cooking oils are subjected to a transesterification process and a quality control program before being converted into biodiesel and mixed in a fifteen percentage in diesel fuel.

Biofuels can contribute to reduce Carbon dioxide emissions, but the pollutant emissions are not completely eliminated because a combustion reaction is still required to produce energy in the form of work. The amount of CO_2 emissions from this process will be directly correlated to the amount of carbon present in the fuel. However, the usage of biofuels, like biodiesel, enables the removal of CO_2 from the atmosphere through the development of plants from which oil is then taken, which then permits the creation of biodiesel. Because it extracts the CO_2 molecules that will be released after burning, using biodiesel allows for a greater amount of CO_2 to not be collected in the environment. It was feasible to quantify the CO2 emissions reduction provided by the utilization of B100 in research conducted by the US Departments of Agriculture and Energy (Sheehan et al., 1998) which, when compared to fossil fuel, reached 78.45%. According to the same study, using B20 resulted in a 15.66% reduction in CO_2 emissions.

This information will be applied to evaluate that the use of B15 will reduce CO_2 emissions by 11,74%.

2.2. Real road tests

For the present case-study 2 companies were considered. Company one, that owns and uses 3 heavy duty trucks consuming B15 and company 2 that uses 13 light commercial cars also using B15. Both companies start fuelling their vehicles with B15 since 2019, so the study for this company compares the use commercial diesel (B7) which is available in all the fuel stations in Portugal and the use of B15 that is available in some fuel stations in the country. The present work analyses the comparative consumption results of 6 months using B7 and other 6 months using B15. The process of changing the fuel was made only by just draining all the previous product and start fuelling with B15. No other cleaning agents our any kind of dismounting was done, since the amount of fuel used in this period was so great that the possible influence of residual fuel could have a small influence in the first 2–3 days but can be considered irrelevant for the final results which account for 6 months of the study duration in which the vehicles used B15 (oct 2019 to mar 2020).

The heavy vehicles are from 2008 and propulsion was provided by internal combustion engines with Euro 4 and Euro 5 technology. The drivers always remained the same and the journeys were very repetitive since the operation to which they were subjected was always the same and through the same route with very similar loads. In this way, apart from the differences in atmospheric conditions, it was possible to ensure the comparability of the results obtained in a route which incorporates some part in motorway and other part in extra urban roads.

The fleet of light-duty vehicles are from 2014 and the propulsion was ensured by internal combustion engines with a cylinder capacity of 1400 cm^3 direct injection and compression ignition, with Euro 6 technology. The drivers always remained the same and the routes, despite having greater diversity than that presented by the heavy vehicles, still had a very defined pattern, since they always made routes to the same clients and, despite there being daily differences, when a longer period was analysed, whether considering a week or a month, it was possible to verify the existence of the vehicle behaviour similarity. This situation becomes evident when analysing the graph in Fig. 1, where it is possible to see that the use of vehicles follows a very analogous pattern. This information was taken from the monitoring tool used in each vehicle and that allow to have the GPS tracking of the vehicles and also a lot of information obtained from the ECU of each vehicle through the OBD II connection (speed, engine rotation, braking and accelerator actuation, and several other parameters). Thus, in addition to the differences related to atmospheric conditions, it was also possible to ensure the comparability of the results between the periods under analysis, when monitoring the light vehicle fleet.

The analysis regarding the amount of fuel consumed allows assessing whether the impact of biodiesel production, corresponding to a reduction of CO_2 emissions, is effectively reflected after the use of the fuel in the vehicles when used in real circulation. The extent of the consumption analysis varies according to the data provided by the company itself. In this context, two situations may occur: the company only provides information on refuelling performed by employees and the respective mileage; the company allows access to the vehicle management platform used by itself, thus enabling the acquisition of a much more varied range of information. For each company and to obtain an adequate comparison of results, the data collected was divided into equivalent time intervals, defined according to the availability of the data itself.

In the first case, where there is only access to information on kilometres travelled and refuelling, the consumptions (average and instantaneous) for each time interval are calculated and the results compared.

The organization of the received data, by registration plates and by

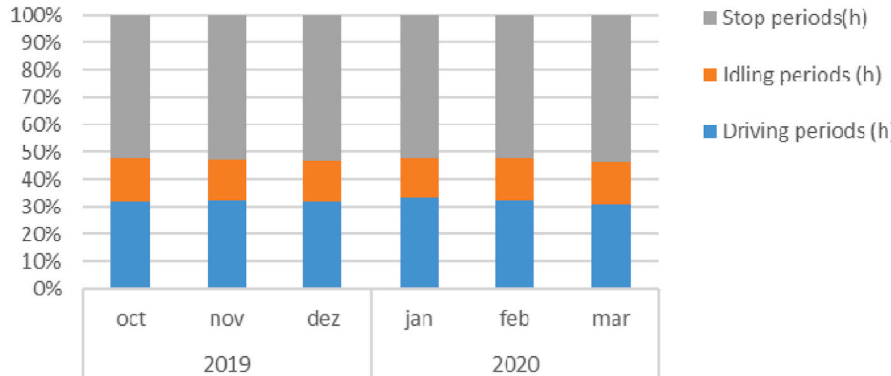

Fig. 1. Light duty vehicles use pattern.

dates, allowed to identify some inconsistencies, which need to be resolved. The average consumption for each supply was calculated and its analysis makes it possible to see that there are mismatched values, and it was necessary to understand the causes of these divergences. Three origins of error were identified: no refuelling record, small and corrigible mistake in the mileage registration and some gross errors in the mileage registration, some of them irremediable.

Taking into consideration the several influences of different factors in fuel consumption, like errors in records, driver behaviour, weather and traffic conditions, load and so one, the major effort was made to assure that the data was comparable, and some erratic or misleading results were detected and corrected or annulled.

3. Results

Results are separated into two sections for presentation. A subchapter (3.2) that presents the findings from case studies looking at the use of vehicles in actual operating conditions, evaluating the fuel consumption and the potential evaluation of the use of these vehicles, follows a first subchapter (3.1) that presents the values obtained in prior experimental work considering the performance of laboratory tests.

The work presented is naturally limited by the difficulty in controlling driver behaviour very precisely, and by atmospheric and traffic conditions that introduce variables that make it difficult to compare different vehicles consumption results. However, it is important to introduce this variability that is characteristic of the real use of vehicles and that allows to extrapolate and validate, or not, the results obtained in a controlled laboratory environment that is more accurate but that may or may not be representative of the effective use of vehicles, whether light or heavy.

3.1. Laboratory tests

The obtained results from the heavy-duty vehicles reveal a small increase in average fuel consumption (1%), considering the results of B15 relatively to B7. Considering that the uncertainty of the method is also around 2%, this can indicate a light trend to a small increase in fuel consumption, that is visible in Fig. 2, but not with a significant relevance. The results obtained in the performance test with one EURO 6 Heavy-duty in chassis dynamometer reveal that the use of B15 does not introduce visible differences or any king of penalty in the performance of the engine comparatively with B7, corresponding to maximum power of 372,8cv (274,2 kW) for B7 and 372,1cv (273,7 kW) for B15. The experimental details and other results can be found in the work done by the authors in previous research (Serrano et al., 2021).

The tests with light-duty vehicles reveal similar results as the obtained for heavy-duty ones, with a small increase in mass fuel consumption also about 2% for B15 considering B7 as a reference. In fact, the higher density of B15 allows attaining a even smaller among the fuel consumption when a volumetric analysis was done, representing a value slightly above 1% (Serrano et al., 2021).

Comparing the engine performance, when the two fuels B7 and B15 were considered, it also becomes clear a small decrease in power of the engine for B15, but it only represents around 1% reduction considering B7 as reference. This is completely unnoticeable for a common driver. These tests also allow to analyze the specific fuel consumption, which is

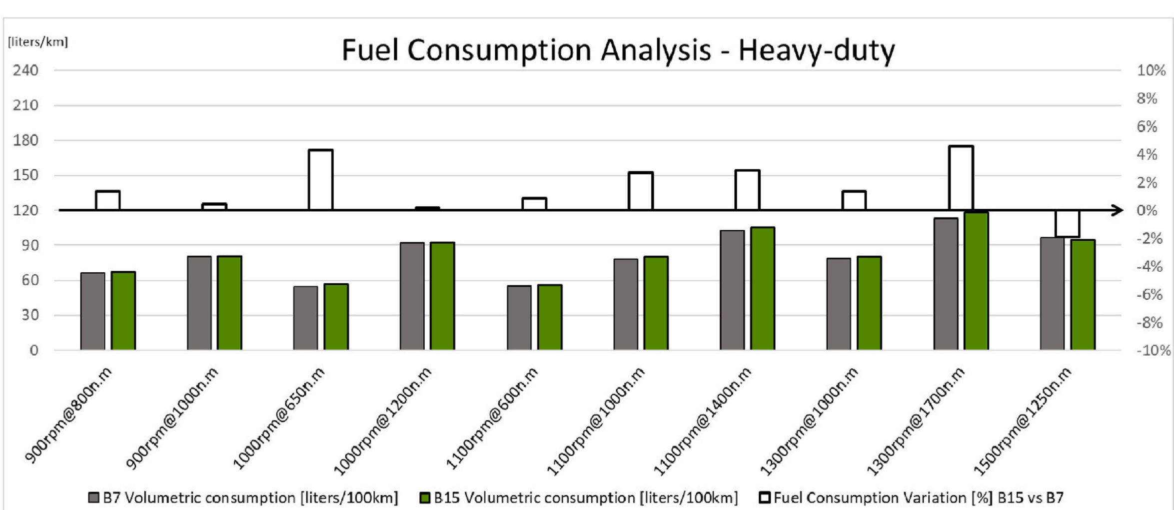

Fig. 2. Fuel consumption results for Heavy-duty vehicles in laboratory tests.

a clear form to understand the efficiency of the engine with that fuel to convert the energy supplied by the fuel in useful work. The results demonstrate that the specific fuel consumption of the engine when fuelled by B15 is very close the value obtained for B7, which means that the overall efficiency remains very similar between the two fuels. These can be observed in Fig. 3, where the different shades of grey/green represent the 3 tests made for each fuel (B7 in grey and B15 in green, considering the 4 different parts of the WLTP cycle (low speed, medium speed, high speed and very-high speed).

3.2. Road tests

The two companies' available data were not exactly the same. For the company 1, the one that uses heavy-duty trucks, the only information available was the mileage and fuel consumption. For the company 2, besides the information gathered from mileage and consumption, it was also possible to include GPS tracking data, which allow to a deeper analysis about the use of the cars and take some conclusions about the possible external influences that can affect the results.

3.2.1. Company 1

The trucks were used in the same route everyday making the same service and with similar loads. Also, the drivers for each car does not change. The fuel consumption results are present in Table 2.

Considering the difficulties referred earlier in this document about the way how records were made, there were some problems detected in the values of refuelling and mileage. To avoid the interferences of this errors, some of the data obtained was not considered, and it was chosen for each vehicle the periods that allow to have confidence that the results reflect what was the fuel consumption of each vehicle. Even so, it is easily confirmed that the distance travelled considered for this analysis is consistent and representative of the use of each one of the vehicles (distances using each of fuels between 10.000 and 30.000 km).

It is possible to verify that the use of B15 does not affect consumption, once the variations detected are very small, ranging 2% which is inside the variation expected if no change in fuel were considered. This means that the fuel does not represent any influence in the obtained consumption values.

These range variations are very common for the vehicles and were easily observed between different periods of the vehicle use when they were fuelled by the same fuel.

3.2.2. Company 2

The cars belonging to company 2 considered for this study were all light duty commercial vehicles, making similar routes during this period. They were used in normal circumstances and the drivers are always driving the same car. The vehicles have similar ages and are equipped with turbo-compressor direct injection engines with 1400 cc but from 2 different manufactures.

The obtained data for those 13 light duty vehicles fleets are presented in Table 3 and in the image of Fig. 4. Previously the cars were fuelled with commercial diesel (B7), and after September 2019 they start using B15. From that time until 28 February 2020 the cars run more than 200.000 km. The results reveal that, even considering the existence of small differences in individual consumption between B15 and commercial diesel, the overall analysis allows to get the conclusion that the difference in the average consumption of all the fleet of 13 vehicles is completely negligible (0,01%).

For the vehicles of the study there were no problems in terms of maintenance, performance, or abnormal failures.

The consumption of diesel fuel in Portugal in 2021 was 4192056 tons (DGEG 2021). Given that 3.16 kg of CO_2 are released into the atmosphere for every kg of diesel and that the conversion from B7 to B15 results in at least a 6% reduction in these emissions, this change would allow for the annual reduction of about 800,000 tons of CO_2 emissions, provided that the percentage of biodiesel in the diesel used is increased from 7% to 15%.

4. Discussion

Globally, it is possible to state that the use of 15% of biodiesel in the consumed fuel mixture does not promote any influence in fuel consumption. This makes sense at a theoretical level due to the physical properties of biodiesel. By one side, the introduction of a higher level of in the fuel mixture promotes a small deficit in lower heat value, i.e. less energy stored in the fuel. By other side, the introduction of biodiesel emphasizes other properties that favour combustion, such as oxygenation of the fuel, increase of cetane number, density, and viscosity.

The balance results in an insignificant difference in terms of energy, what is justified by the expected trend observed in laboratorial tests, which reveals that B15 presents a small increase in energy conversion efficiency resulting in a non-penalized effect in the combustion process (Serrano et al., 2021) (Serrano et al., 2015). Therefore, it is possible to verify that fuel blends with relatively low proportions of biodiesel are more efficient than pure biodiesel. Consequently, it must be considered hat the fleets analysed fuelled with a fuel blend with 15% biodiesel, are not penalized in terms of fuel consumption. This reveals a clear advantage associated to the increase of replacement of fossil fuel by a renewable fuel source and the consequences in terms of CO_2 reduction. The effect of this result is that the CO_2 emissions differences are the ones resulting from the production of the biodiesel, which is clearly favourable to this renewable energy source.

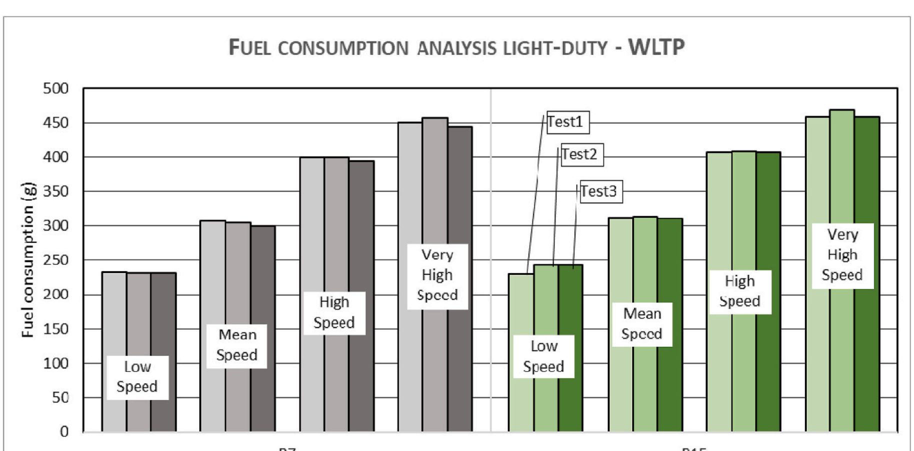

Fig. 3. Fuel consumption results for Light-duty vehicles in laboratory tests.

Table 2
Comparison between fuel consumption from vehicles Company 1 (HDV).

		HDV1			HDV2			HDV3		
		km	litres	l/100 km	km	litres	l/100 km	km	litres	l/100 km
Commercial Diesel (B7)	**at 2018**	10316	4554,98	44,15	13828	5908	42,72	22226	9988	44,94
B15	**at 2019**	30009	12873,1	42,90	23492	10253	43,64	20920	9149	43,73
Difference B15 to B7	**litres/100 km**	**−1,26**			**0,92**			**−1,21**		
	%	**−2,85**			**2,16**			**−2,69**		

Table 3
Comparison between fuel consumption from vehicles Company 2 (LDV).

VEHICLE	Distance	Fuel Consumption		
		B15	B7	Difference
	Km	Litres/100 km	Litres/100 km	%
LDV1	30146	5,89	5,57	6
LDV2	24653	5,22	5,36	−3
LDV3	22632	5,51	5,19	6
LDV4	22440	5,53	5,30	4
LDV5	13996	5,47	5,76	−5
LDV6	15803	5,97	5,59	7
LDV7	13817	5,62	5,73	−2
LDV8	24214	6,01	5,64	7
LDV9	21961	5,43	5,58	−3
LDV10	18488	5,11	5,66	−10
LDV11	8710	5,31	5,08	5
LDV12	14855	8,13	8,26	−2
LDV13	6140	5,43	5,32	2
Average Consumption		**5,74**	**5,70**	
Difference	**Litres/100 km**	**0,05**		
	%	**0,01**		

In addition, considering the access to additional travel information, namely on driving styles, reveal that, even more than the fuel itself, behavioural factors affect fuel consumption. Examples of this were the almost unanimous increases in fuel consumption when longer idling times were encountered.

The data processing made it possible to detect some problems in the records provided directly by the companies, referring to fuel fill-ups and corresponding mileage. It was clear that the compilation of data without any platform or auxiliary computer software, possibly even through human recording, implies a much higher margin of error. Two major errors were detected in the registration of data: a considerable distance records showed completely mismatched values and the refuel process records correspondent to certain period did not match the available files and there were some blanks where should be presented some amount of fuel. This becomes a serious problem and a great difficulty on the analysis of consumption, causing a serious question in the entire credibility of the results. Only with the profound and detailed analysis made possible to get the required information to construct solid arguments that allow to fundament the obtained results.

Its is also important to notice that the absence of problems in the vehicles, considering the number of kilometres travelled reinforces the option of using higher biodiesel blends in vehicles, namely B15 or even B20.

Biofuels are an alternative to fossil fuels that show both potential and controversy. Many questions have already been raised about their sustainability, particularly for some raw materials used as an energy source; however, the versatility that biofuels demonstrate, both in terms of production and applicability, means that even today it is the most widely used renewable energy in the transport sector.

It is true that biofuels, like any other energy source, have limitations, however, their evolution tends to achieve the main objective: to find the best relationship between efficiency, viability, and sustainability, to achieve valid and promising fuels, which involve lower emissions of pollutant gases in their life cycle, without jeopardizing the integrity of the engine and its fuel consumption; all this, through a careful selection of raw materials and manufacturing processes. Moreover, the use of this kind of blends has a relevant advantage compared to other alternative fuels: they are fully compatible with the rolling fleet and the existing infrastructure. Complementary, access to additional information on the driving behaviour of drivers, obtained through fleet management platforms, has made it clear that factors such as idling time or the occurrence of inappropriate vehicle use affect fuel consumption more than the fuel itself. This type of platform has become an enormous advantage in terms of work, as it helps the manager to administer his fleet, for example through alerts generated such as maintenance times, and to optimise costs by controlling driving parameters. This is clearly an advantage in terms of energetic efficiency and in terms of economy.

The current work demonstrates that a more realistic and adequate

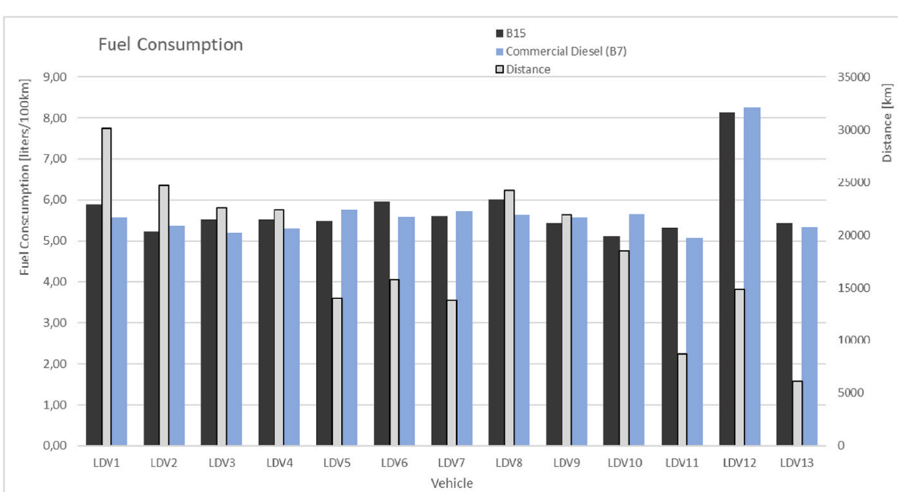

Fig. 4. Fuel consumption results considering the use of B15 and commercial diesel (B7) and the distance considered for the results.

assessment of using biofuels in automobiles is attainable through a dedicated fleet management data analysis.

Fleet managers can better understand the sustainable options for their fleets, decrease CO_2 emissions, and make better financial decisions thanks to the approach given in this study. To conclude, it should be noted that all the types of energy considered so far as viable for the transport sector have inherent benefits and limitations. The key will be to adapt the different energy options to the conditions in which they prove most favourable. Furthermore, knowledge is constantly evolving and updating, data considered to be certain and irrefutable “today” will no longer be like that “tomorrow” and therefore no definitive and decisive position should be taken about any energy source. By the contrary, a continuous effort should be done to choose the best and most efficient energetic solution for each transport requirements and conditions.

5. Conclusion

The use of biofuels in road vehicles is a theme developed in numerous studies and investigations, both in terms of production and applicability. The present work analyses the fuel consumption and vehicle behaviour when an incorporation of 15% biodiesel in pure diesel (B15), compared with the previous use of commercial diesel (B7). This allows to preview the consequences of achieving the target of increasing the incorporation of biodiesel aimed by the European regulation.

Considering the two fleets of the two different companies, one with heavy-duty trucks and other with light-duty commercial cars, it was possible to conclude that the average variation in fuel consumption is insignificant, corresponding to values completely from small increases and decreases associated with external factors than the fuel itself. Nevertheless, the use of B15 reinforces the advantages that the application of a renewable fuel offers, namely in terms of pollutant gas emissions, global warming, and replacement of fossil fuel by renewable sources. The change to B15 can represent a reduction of several tones of CO_2 emissions, since for each vehicle it is possible to detect a decrease of CO_2 emissions in almost 6%. If Portugal were the example, this could correspond to a decrease in atmospheric CO_2 emissions from about 800 thousand tonnes in 2021.

It is also possible to mention the enormous advantage of being able to use as an energy resource something that is waste, such as used cooking oil, which presents significant environmental problems if it is not treated properly.

The fact that there were no anomalies or breakdowns in the vehicles because of the usage of B15 during the research period is another extremely encouraging conclusion of the work done, indicating that B15 may be used by the vehicles without any mechanical modifications. There will be the need to continue this work, complementing it with an already prepared maintenance surveillance, including engine oil analysis, filters observation and state evaluation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Nomenclature

B15	15% biodiesel incorporation in fossil diesel
B7	7% biodiesel incorporation in fossil diesel (commercial diesel in fuel stations in Portugal)
CO_2	Carbon dioxide (non-pollutant and natural element that contributes for global warming)
UCO	Used Cooking Oil
EU	European Union
RED	Renewable Energy Directive
GHG	Green House Gases

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