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Dorota BURCHART-KOROL*, **Piotr FOLĘGA**
Silesian University of Technology, Faculty of Transport,
Krasińskiego 8, 40-019 Katowice, Poland
**Corresponding author*. E-mail: dorota.burchart-korol@polsl.pl

COMPARATIVE LIFE CYCLE IMPACT ASSESSMENT OF CHOSEN PASSENGER CARS WITH INTERNAL COMBUSTION ENGINES

Summary. The purpose of this paper is to provide a comparative environmental life cycle assessment (LCA) of chosen internal combustion engine vehicles (ICEVs). It addresses an LCA of both petrol-fuelled and diesel-fuelled passenger cars. The analyses pertained to the carbon footprint and respiratory inorganics related to the cars in question, considered against the relevant system from cradle to grave. The comparative analysis has shown that the carbon footprint of a diesel-fuelled car is lower than that of a petrol-fuelled car. However, the environmental indicators of respiratory inorganics induced by diesel-fuelled cars are higher than those attributable to petrol-fuelled cars. The main determinant of carbon footprint for the life cycle of these ICEVs is the direct atmospheric emission of carbon dioxide associated with their operation. The main determinants of respiratory inorganics for the diesel passenger cars' life cycle are nitrogen oxide emission and car production. As for the life cycle of petrol-fuelled passenger cars, the largest share of the respiratory inorganics indicator is attributable to the car production and petrol production.

1. INTRODUCTION

According to the European Automobile Manufacturers' Association, more than a half of all European passenger cars (55.6%) run on petrol [1]. Fig. 1 provides a breakdown of passenger cars used in the European Union into fuel types. Passenger cars with small petrol engines are more common than medium-sized and large engines in the majority of Member States [1].

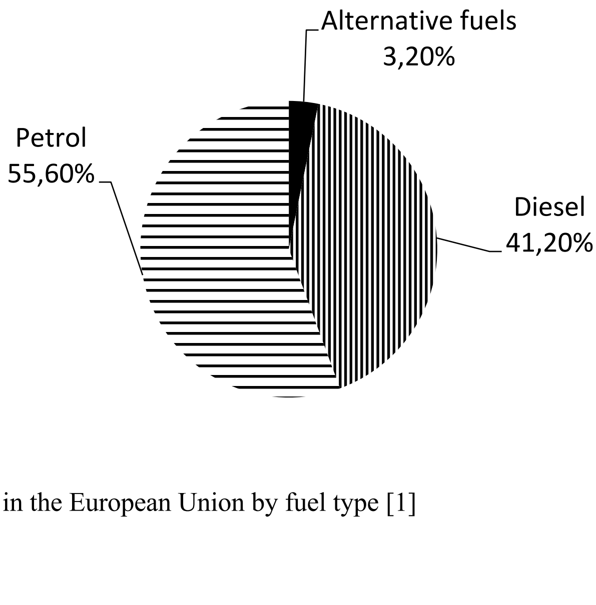

Fig. 1. Passenger cars used in the European Union by fuel type [1]

Petrol vehicles are currently the most frequently sold cars in the European Union countries, accounting for almost a half of new passenger car sales (Fig. 2). Hybrid electric vehicles (HEV) accounted for 2.9% of the car market in 2017, alternatively powered vehicles (APV) accounted for 1.4%, whereas electrically chargeable vehicles (ECV) made up for only 1.5% of all cars sold in the year 2017 [2].

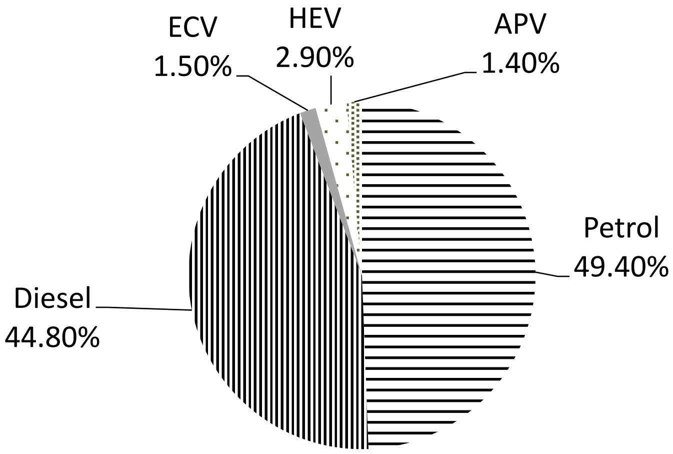

Fig. 2. Breakdown of new passenger cars in the European Union according to fuel types (ECV – Electrically chargeable vehicles, HEV – Hybrid electric vehicles, APV – Alternatively powered vehicles other than electric)

Transport accounts for approximately one-third of all final energy consumption in the European Environment Agency member countries and for more than one-fifth of greenhouse gas (GHG) emission [3]. It is also responsible for a large portion of urban air pollution. It is the main cause of negative impact on human health and it is associated with global warming. An important factor in reducing GHG emissions is the type of fuel used in transport [4]. Reducing GHG emission is one of the European Commission's priorities. It is required that GHG emission should drop by approximately two-thirds by 2050, compared to the 1990 levels, in order to meet the long-term 60% GHG emission reduction target established in the paper [5]. The literature of the subject mentions individual methods used for assessment of environmental aspects, which can also be applied to the automotive industry. The transport sector has been using the Well-To-Wheel (WTW) fuel life cycle analysis increasingly often, as it enables assessment of energy consumption and of GHG emission resulting from fuel production and consumption [6,7]. The WTW focuses only on the greenhouse gas (GHG) emission from consumption of transport fuels, and it does not comprise other stages of the vehicle life cycle and other damage categories, for example, respiratory inorganics. A more comprehensive method for environmental impact assessment is the life cycle assessment (LCA). The LCA accounts for the environmental impacts throughout the vehicle life cycle, starting from the vehicle production phase (including manufacture of materials for vehicle production, vehicle assembly and fuel production), through the operation phase (including the fuel combustion phase and vehicle servicing), up to the life cycle end (waste management, including recycling and scrapping) [8-11].

Earlier papers comprising the literature addressing environmental assessments of transport mainly included the WTW analysis and greenhouse gas emission.

The goal behind this study was to assess the potential environmental impacts of petrol-fuelled and diesel-fuelled passenger cars by taking the life cycle of these cars into account. For this purpose, a number of comparative analyses of carbon footprint and respiratory inorganics of passenger cars were performed. The authors of this paper have outlined the main sources of impact with reference to the life cycle of ICEVs subject to analysis.

2. MATERIALS AND METHODS

The LCA is a new approach to assessment of environmental aspects, which allows identification of environmental aspects related to the life cycle, both directly and indirectly, taking the construction, operation and decommissioning phases into account. The LCA method was chosen for purposes of comparative assessment because it enables an environmental assessment, considering the life cycle of cars. The LCA was conducted in accordance with the ISO 14040:2006 [12] guidelines using the SimaPro v. 8.5 package with the Ecoinvent v.3 database [13]. Environmental assessment of petrol and diesel passenger cars was performed on the basis of the life cycle assessment method in four phases: defining the goal and scope, defining the life cycle inventory, life cycle impact assessment, and interpretation [14]. The main sources of environmental burden of these ICEVs were identified for two impact categories: carbon footprint and respiratory inorganics. The scope of the LCA analyses included comparisons between the environmental impacts of petrol-fuelled ICEVs and those of diesel-fuelled ICEVs. For comparative purposes, all the analyses were referred to the same functional unit, which was determined as 100 kilometres driven by a passenger car. The system boundaries for the analysed passenger car life cycle have been shown in Fig. 3.

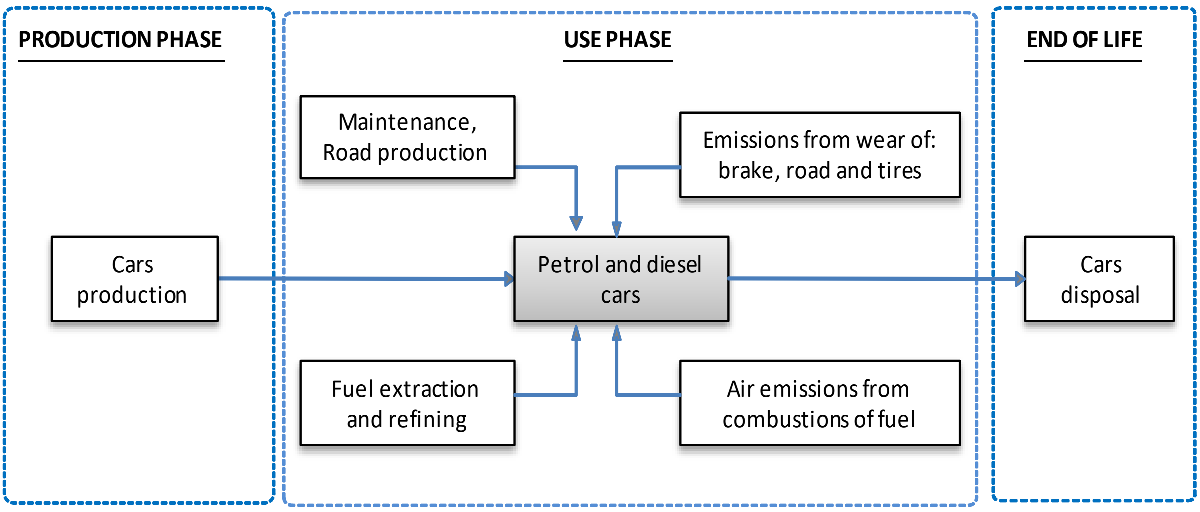

Fig. 3. System boundaries of the analysed passenger car life cycle

The system boundaries extend over a cradle-to-grave range: production of passenger cars, fuel production (diesel and petrol), car operation phase (including car maintenance), emissions related to the operation of cars, road construction, disposal of cars, and maintenance (Fig. 3). For the LCA, transport using small passenger cars with internal combustion engines, both petrol and diesel fuelled, was analysed. Small cars were chosen for the analysis because small engines are more common than medium-sized and large engines in the European Union countries. The average weight of small cars was estimated at 1,200 kg. The assumed engine size was up to 1.4 dm^3. The analysis comprised small passenger cars of the Euro 5 class.

The second phase consisted of analysing the inputs and outputs, which formed an inventory of all the data necessary for the assessment of the car life cycle. The data included the construction, operation, maintenance and disposal of cars. The operation of the cars subject to analysis comprised all the direct emissions caused by fuel combustion and non-exhaust emissions, such as those generated by tyre consumption, brakes and road wear. The basic assumptions and the sets of input and output data used against each phase of the passenger car life cycle (production, operation and end of life) were based on the Ecoinvent v. 3 database [13]. The data set was parameterised with respect to the small car size, fuel consumption and car lifetime. The size of passenger cars affected the amount of both exhaust and non-exhaust emissions. The exhaust emissions caused by fuel combustion were divided into two groups: fuel-dependent emissions (dependent on fuel type and quantity) and Euro class-dependent emissions, which reflected the emission standards satisfied by the car.

The input data came from ecoinvent 3 datasets [13]. The results of the inventory analysis can be applied in Europe. Ecoinvent v3 covers datasets for petrol- and diesel-fuelled vehicles in Europe (small <1.4 litre engine displacement, medium 1.4–2.0 litre engine displacement and large <2.0 litre engine displacement vehicles) and for the Euro 3, 4 and 5 emissions standards. The description of the datasets for the operation of fossil-fuelled passenger cars was presented in paper [15].

The next phase, namely the LCIA, enabled calculation of values of the environmental impact categories according to the selected assessment methods. The instrument used for the sake of the carbon footprint assessment was the IPCC method, developed by the Intergovernmental Panel on Climate Change (IPCC). The IPCC publishes Global Warming Potentials (GWP). IPCC 2013 GWP 100a covers a time frame of 100 years. The total amount of greenhouse gases produced to support human activities directly and indirectly was expressed using the reference unit of kg of CO_2. The carbon footprint factor was calculated on the basis of the GWP. The respiratory inorganics element was assessed using the IMPACT 2002+ method. The respiratory inorganics impact category included inorganic compounds whose presence in the air increase the likelihood of respiratory diseases.

Carbon footprint impact category refers to greenhouse gas emission. Carbon footprint is expressed in kg CO_2, which is reference substance. A carbon footprint is defined as the total emissions expressed as carbon dioxide equivalent (CO_2 eq).

Respiratory inorganics impact category refers to respiratory effects that are caused by inorganic substances. Respiratory effects caused by inorganics are expressed in kg PM2.5 into air, which is reference substance. Particulate matter (PM) is classified on the basis of its particle size. PM2.5 covers all the fraction of particles < 2.5 μm. Respiratory inorganics are defined as the total emissions expressed as particulate matter equivalent (PM eq).

3. RESULTS

3.1. Comparative analysis of carbon footprint

The results of the LCA performed for purposes of the comparative analysis of carbon footprint have been presented in Figure 4. To establish the determinants of carbon footprint, the environmental impacts of the elements enveloped by the system boundaries were analysed (Table 1).

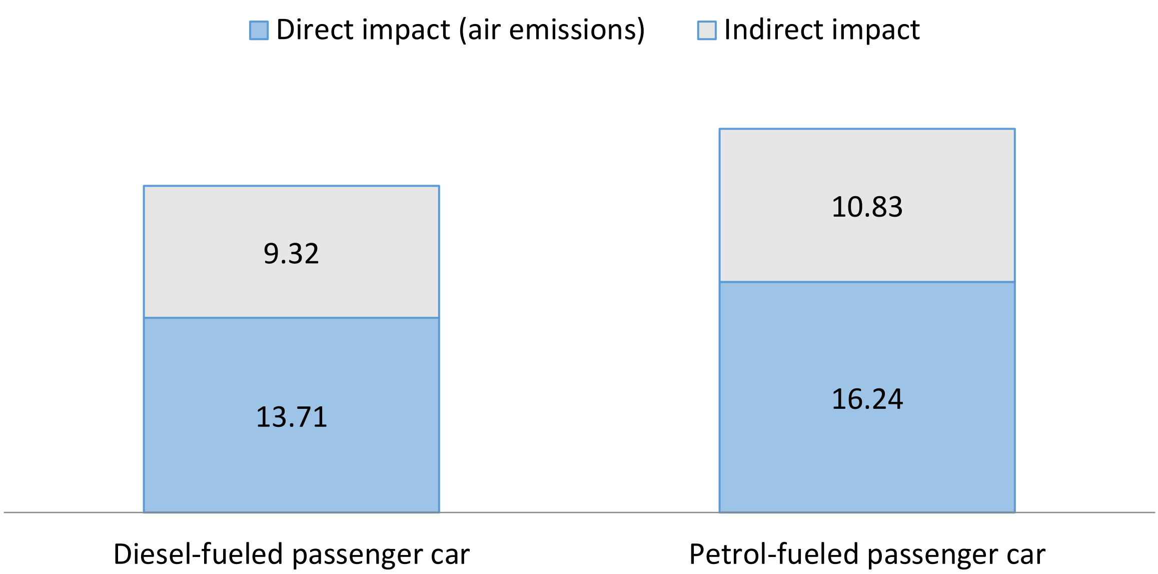

Fig. 4. Carbon footprint due to the life cycle of diesel- and petrol-fuelled passenger cars, kg CO_2 eq/FU

Table 1

Main determinants of carbon footprint due to the life cycle of diesel- and petrol-fuelled passenger cars

Carbon footprint	Diesel-fuelled passenger car		Petrol-fuelled passenger car	
Unit	kg CO_2 eq/FU	%	kg CO_2 eq/FU	%
Direct impact – emissions, including:	13.71	59.51	16.24	59.99
Carbon dioxide	13.64	59.20	16.01	59.14
Dinitrogen monoxide	0.06	0.26	0.20	0.74
Methane	0.00	0.00	0.03	0.11
Indirect impact, including:	**9.32**	40.45	**10.83**	40.01
Passenger car production	5.44	23.61	5.38	19.87
Fuel production	2.54	11.02	4.11	15.18
Road	0.59	2.56	0.59	2.18
Passenger car maintenance	0.75	3.26	0.75	2.77
Total	**23.04**	100.00	**27.07**	100.00

With reference to the comparative analysis based on the LCAs of petrol-fuelled car and diesel-fuelled cars, it was found that the carbon footprint of a diesel-fuelled car is lower than that of a petrol-fuelled car, which is primarily attributable to the higher carbon footprint caused by petrol production as well as the direct air emissions caused by the operation of petrol-fuelled car (Figure 4).

With regard to diesel-fuelled passenger cars, the carbon footprint factor is 23.04 kg CO_2eq, and as much as 59.51% of the emission is attributable to direct atmospheric emission at the stage of the car operation. With respect to the carbon footprint, 23.6% share in the carbon footprint can be attributed to the passenger car production and the 11.02% share is associated with the production of diesel fuel.

As for petrol-fuelled cars, the carbon footprint factor is 27.07 kg CO_2eq, whereas as much as 60% of the emission is due to direct atmospheric emission (particularly of CO_2) at the stage of the car operation. In the total carbon footprint, 19.87% share is attributable to the production of passenger cars and the 15.18% share is connected with production of petrol.

Based on the analysis, it was established that the main determinant of carbon footprint for the life cycle of diesel- and petrol-fuelled passenger cars is the direct atmospheric emission of carbon dioxide associated with the operation of these cars.

3.2. Comparative analysis of respiratory inorganics

The results of the comparative analysis of respiratory inorganics attributable to the life cycle of diesel-fuelled and petrol-fuelled passenger cars have been presented in Figure 5. Results of the analysis of the impact category for each element within the system boundaries have been shown in Table 2.

Based on the LCA analyses performed by the authors, it was shown that the environmental indicators in the respiratory inorganics impact category were higher for the life cycle of diesel-fuelled passenger cars than of petrol-fuelled passenger cars.

With regard to diesel-fuelled passenger car, the respiratory inorganics factor is 0.0253 kg PM2.5 eq/FU wherein 38.34% of this factor is attributable to the production of passenger cars and 34.39% of this factor is due to direct atmospheric emission at the car operation stage, and 14.62% share is associated with the production of diesel fuel.

As for petrol-fuelled cars, the respiratory inorganics factor is 0.0184 kg PM2.5 eq/FU, and 51.63% of this factor is due to the passenger car production, whereas 28.26% share is connected with production of petrol. Only 2.72% of this factor is due to the direct emission into air at the car operation stage.

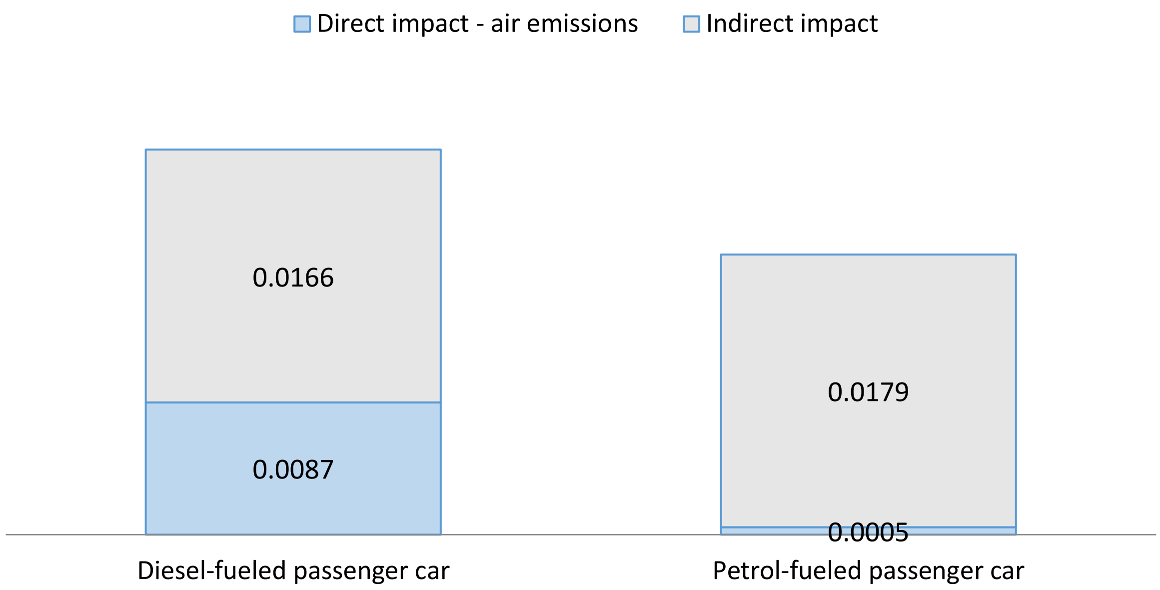

Fig. 5. Respiratory inorganics attributable to the life cycle of diesel-fuelled and petrol-fuelled passenger cars, kg PM2.5 eq/FU

Table 2

Main determinants of respiratory inorganics attributable to the life cycle of diesel-fuelled and petrol-fuelled passenger cars

Respiratory inorganics	Diesel-fuelled passenger car		Petrol-fuelled passenger car	
Unit	kg PM2.5 eq/FU	%	kg PM2.5 eq/FU	%
Direct impact – emissions, including:	**0.0087**	34.39	**0.0005**	2.72
Nitrogen oxides	0.0085	33.60	0.0004	2.17
Particulates	0.0002	0.79	0.0001	0.54
Indirect impact, including:	**0.0166**	65.61	**0.0179**	97.28
Passenger car production	0.0097	38.34	0.0095	51.63
Fuel production	0.0037	14.62	0.0052	28.26
Road	0.0011	4.35	0.0011	5.98
Passenger car maintenance	0.0011	4.35	0.0011	5.98
Road wear emission	0.0003	1.19	0.0003	1.63
Brake wear emissions	0.0002	0.79	0.0002	1.09
Tyre wear emissions	0.0004	1.58	0.0004	2.17
TOTAL	**0.0253**	100.00	**0.0184**	100.00

The analyses performed in the research process imply that the main determinant of respiratory inorganics for diesel passenger cars is the emission of nitrogen oxides at the stages of car operation and car production. As for petrol-fuelled passenger cars, the largest fraction of the respiratory inorganics impact category is related to the indirect impact associated with production of passenger cars and petrol.

4. CONCLUSIONS

The article comments upon results of a comparative life cycle assessment of petrol-fuelled and diesel-fuelled passenger cars performed by adopting a life cycle approach. The comparative analysis has revealed that the carbon footprint attributable to diesel-fuelled passenger cars is lower than that of petrol-fuelled passenger cars, which is primarily affected by the higher carbon footprint caused by petrol production as well as direct CO_2 emission related to the operation of petrol-fuelled cars. However, the environmental indicators of respiratory inorganics caused by diesel-fuelled cars are higher than those caused by petrol-fuelled cars.

The main carbon footprint determinant for these ICEVs is the direct atmospheric emission of carbon dioxide associated with operation of cars. The main determinant of respiratory inorganics for diesel passenger cars is nitrogen oxide emission at the stages of car operation and car production. As for the petrol-fuelled passenger cars, the largest fraction of the respiratory inorganics impact category is related to the indirect impact associated with the production of passenger cars and of petrol.

The carbon footprint of petrol- and diesel-fuelled passenger cars is primarily attributable to the operation of these vehicles. Therefore, in order to reduce their impact on the environment, one should undertake specific efforts aimed at increasing the share of alternative fuels in the mix of fuels powering passenger cars.

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