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ENVIRONMENTAL ASSESSMENT OF ROAD TRANSPORT IN A PASSENGER CAR USING THE LIFE CYCLE APPROACH

Summary. Environmental issues are an increasingly important aspect of management in the transport sector; new methods have been developed for assessment of the environment in the transport sector using the life cycle approach. The paper presents the application of Well to Wheel (WTW) and Life Cycle Assessment (LCA) in the transport sector. The WTW method focuses on energy analysis and greenhouse gas emissions during the life cycle of fuels. WTW is used to support decision-making on the environmental aspects of transport, particularly with regard to fuel life cycle management, but this method omits important stages in the life cycle, particularly the ones regarding important circular economy guidelines such as reduction of natural resource consumption, impact on human health, etc. The LCA method provides a much broader approach to environmental assessment than WTW. LCA takes into consideration environmental impact in the whole life cycle of the vehicle, from the stage of production, through the period of exploitation, and finally its disposal.

1. INTRODUCTION

Automotive companies are paying more attention to environmental issues and are increasingly using the WTW (Well to Wheel) environmental analysis method, which allows for an assessment of energy consumption and greenhouse gas emission generated as a result of production, transport and distribution of fuel, and fuel consumption during the life of the vehicle.

In the literature, emphasis was placed on the limitations connected with the application of WTW in comparison with LCA (Life Cycle Assessment); therefore, this article suggests the development of the LCA method [1]. The LCA method enables the assessment of the potential impact on the environment during the entire life cycle of the product: from the acquisition of raw materials, through the period of exploitation, and finally its disposal. LCA facilitates the comparison of the environmental impact of various products and technological solutions to reduce deleterious effects and aids in the choice of products and solutions with the least impact on the environment during the product's entire life cycle. Life cycle assessment is the subject of international standards for environmental assessment – ISO 14040:2006 [2] and ISO 14044:2006 [3].

In paper [4], the authors propose a hybrid WTW-LCA system to conduct greenhouse gas emission assessments for electric vehicles. The LCA analyses can affect, apart from fuels or the construction of the body structure, the life cycle of tyres, which was presented in papers [5,6], in which the impact of tyres on the environment was shown from the moment of their production to their management after they have come to the end of their useful life. The WorldAutoSteel organization conducts comparative analyses of greenhouse gas emissions by concentrating on the construction of the body [7]. At present, there are some studies in the literature enumerating ways to reduce energy expenditure in transport. The results presented in paper [8] show reducing energy consumption in road transport through hybrid vehicles. Developing methods taking into account the life cycle approach are becoming increasingly important in the new circular economy. Previous results of LCA assessments for road transport presented in the literature mainly included WTW analysis and mainly focused on greenhouse gas emissions.

In this paper, environmental assessment of road transport with a life cycle approach is presented.

2. SCOPE OF WTW AND LCA IN THE TRANSPORT SECTOR

Environmental analyses according to the WTW method comprise the phases connected with extraction of raw materials, refining and distribution of fuels, and fuel exploitation [4]. Fuel life cycle according to the WTW method covers two phases (Fig. 1):

- Well to Tank (WTT) - this phase includes the environmental impact connected with raw material extraction, from which fuel is produced, fuel production, and its transportation and distribution
- Tank to Wheel (TTW) - this phase includes the environmental impact connected with the exploitation and consumption of fuels in vehicles.

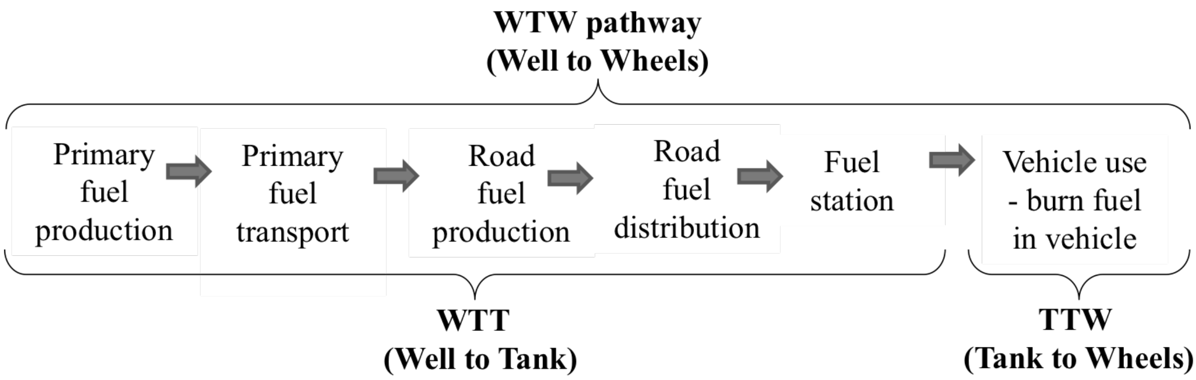

Fig. 1. Phases included in the WTW analysis

The WTW method focuses only on greenhouse gas emissions from road transport fuels and does not include other important damage-causing factors and other stages of a vehicle's life cycle. The WTW method can be seen as a quite simplified LCA; therefore, WTW results are different from LCA results [4]. An updated WTW study on automotive fuels and power trains has been developed by the Joint Research Centre [9].

Fig. 2 shows the range of WTW and LCA analyses during the life cycle of a vehicle (covering WTW and LCA with the system boundaries 'from cradle to grave'). The range of the WTW analyses covers the entire process from extraction of raw materials to production and, finally, consumption of fuels. LCA also comprises the various stages of a vehicle manufacturing process (including the entire cycle of the production as well as the manufacture of vehicle components and assembly), maintenance during the exploitation stage, and the end of the life cycle connected with waste management.

In comparison with the LCA method, the WTW method takes into account only greenhouse gas emissions. Life Cycle Assessment additionally takes into account the materials used in the process of vehicle manufacture, as well as many other stages in the life cycle of vehicles, in addition to the other factors that have an environmental impact, like human health, the ecosystem, and resources. LCA takes into consideration the environmental impact during the life cycle of the vehicle, from the stage of production (together with the production of materials and assembly), through the stage of exploitation (together with the fuel production stage and its consumption), until the end of the life cycle (waste management, recycling, and disposal) for comparison purposes depending on the assumed system boundary. The LCA method offers a variety of opportunities, which makes it indispensable to many industries for performing environmental assessments. Environmental life cycle analysis can be applied to design and to select materials in the production of vehicles; it also facilitates the analysis of various fuels. It also allows for a comparative analysis of various alternative variants of transport to choose a vehicle that is more friendly for the environment. The LCA method allows to assess many environmental impact categories such as greenhouse gases emissions, acidification, eutrophication, the consumption of fossil fuels, consumption of minerals etc. This method allows for benchmarking the environmental impact on each stage of the life cycle. Life cycle assessment integrated with economic analyses promotes eco-efficiency, thanks to which it is a useful tool for the choice of the most eco-efficient solutions, and can be a helpful device in decision-making. The application of LCA can also help fulfil the guidelines of the Circular Economy (CE). Further, in the case of the automotive industry, the guidelines of the European Commission concerning environmental footprints, as well as economic guidelines of the Circular Economy, present new challenges connected with environmental impacts. A good example of a practice connected with the development of environmental analysis methods in the automotive industry is the Green Clean and Lean concept, which was developed by Toyota Motor Manufacturing France (TMMF), and, recently, they have been associated with the end of the vehicle's life cycle [10].

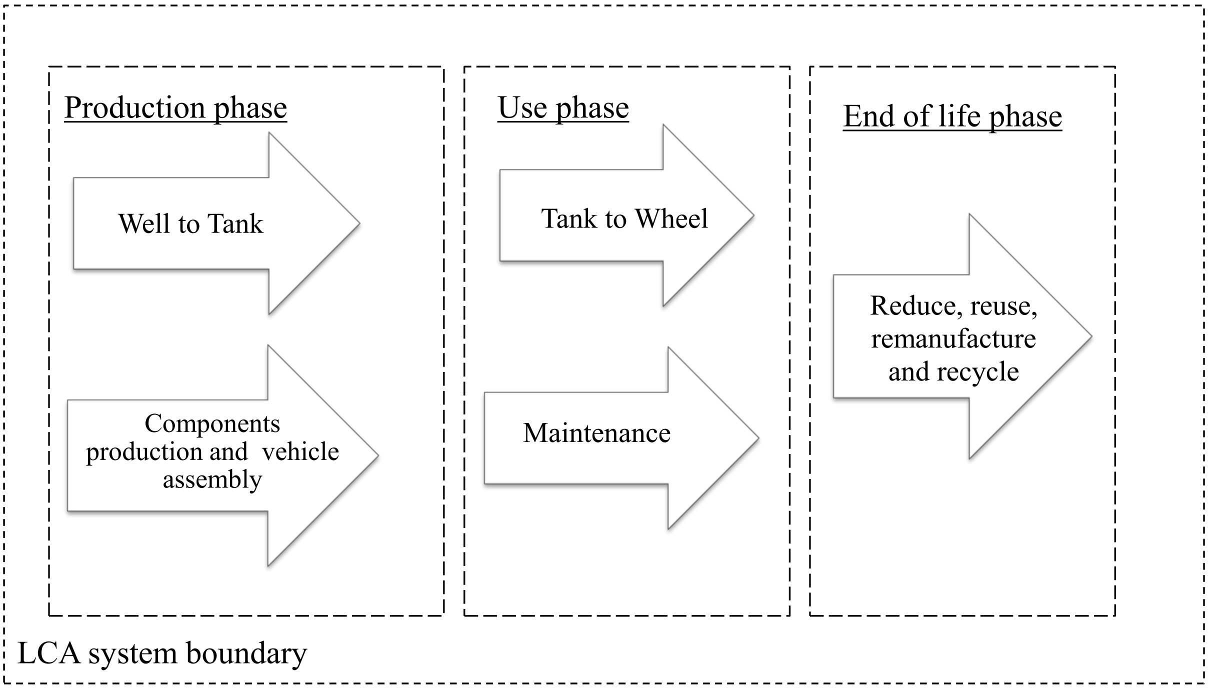

Fig. 2. The scope of WTW and LCA analyses in the life cycle of the vehicle

On the basis of our analyses, the application of LCA to the analysis of the environmental impact of transport is presented. Paper [11] shows the results of LCA analyses for the transport of steel products, and paper [12] shows a comparative analysis of various forms of transport (freight trains and trucks) to choose the ones that are more friendly for the environment. It was proved that the LCA method can be widely applied to vehicle life cycle assessment. On the basis of the conducted analyses it was concluded that the LCA method is suitable and should be developed for life cycle assessment in the automotive industry.

3. METHODS AND MATERIALS

The LCA of road transport in a passenger car was performed following standard ISO 14040:2006 in four phases: specifying the aim and scope of the analysis, collecting data, conducting Life Cycle Impact Assessment, and interpreting the obtained results (Fig. 3) [3].

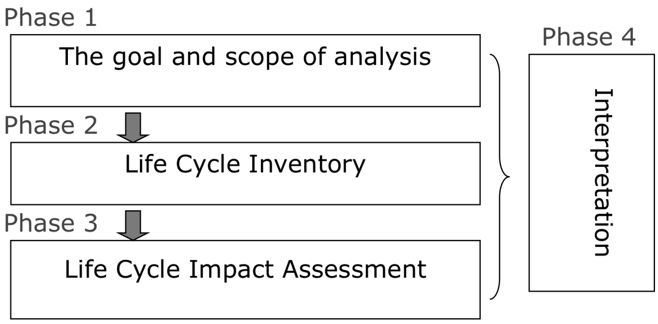

Fig. 3. Phases of Life Cycle Assessment

The aim and scope of research is determined on the basis of the recipient of the research and its range, which should be closely connected with the range of decisions made on the basis of the received results. The aim of the analysis was to assess the potential environmental impact of an exemplary passenger car that uses a traditional drive (petrol; Front Wheel Drive). In this phase, a functional unit was determined. It is the unit used for research constituting a quantitative effect of the system. The main task of the functional unit is the provision of a reference plane to normalize the input and output data. The functional unit of the analysis is 100 kilometers driven by a passenger car. This analysis considers a medium petrol passenger car of Euro 5 class. The category medium size includes passenger cars with an engine size between 1.4 and 2.0 liters. The average weight for this category is estimated to be 1600 kg. The data set that was used in the work represents the service of transport in a passenger car for a journey length of 100 km and is valid for Europe. Fuel consumption and emissions are for average car use and not representative of a specific driving cycle. The data set is parametrized with respect to car size, fuel consumption, and car lifetime. The average fuel consumption estimated for this analysis is 7.9 liters per 100 km. The passenger car size influences the amount of both exhaust and non-exhaust emissions. The exhaust emissions caused by the burning of fuel are divided into two groups: fuel-dependent emissions (dependent on fuel type and quantity) and Euro class-dependent emissions, which reflect the emission standards the car complies with. Also included within the direct exchanges to the environment are the fuel evaporation emissions from the fuel tank, relevant to petrol cars only [13].

System boundaries included fuel production, combustion of fuel in the engine, the infrastructure of the car and road network, the materials and efforts needed for maintenance of these, and the fuel consumed in the car for the journey. The data set includes the construction, operation, maintenance, and disposal of the car and road infrastructure. Operation of the car includes all the direct emissions produced by fuel combustion and evaporation as well as from tyre, brake, and road wear. System boundaries included activity ends with the transport over 100vkm and the emissions of exhaust and non-exhaust emissions into air, water, and soil [13].

The data used for LCA were collected from catalogues made available by manufacturers from the automotive industry included in the Ecoinvent 3 database of SimaPro 8 software.

LCIA is the third phase of the LCA, after goal and scope definition and LCI. LCIA is associated with evaluating potential environmental impacts. Many life cycle assessment methods are used to perform life cycle analyses: among others, the ILCD Midpoint method (which is recommended by the European Commission as representative for European conditions), the IPCC (the method developed by the Intergovernmental Panel on Climate Change, which serves to assess the impact of greenhouse gas emissions), the CED method (Cumulative Energy Demand) (which allows the determination of cumulative energy demand), the IMPACT2002+ (the method enables data inventory and rating in several indirect categories assigned to four categories of damage) and the ReCiPe 2008 method (one of the most comprehensive assessment models). According to the new edition of ISO 14001: 2015, for the first time, the life cycle approach has been taken into account in environmental analyses.

The transport sector is associated with negative health effects and greenhouse gas emissions. Currently, there is a need to further understand the health impacts and ecosystem damage caused by transport. To assess the environmental potential of road transport in a passenger car, the IPCC method and the ReCiPe Endpoint method were selected. IPCC 2013 was developed by the Intergovernmental Panel on Climate Change (IPCC). The IPCC publishes Global Warming Potentials (GWPs). IPCC 2013 GWP 100a has a time frame of 100 years.

To assess various damage categories, the ReCiPe life cycle assessment method was applied. The primary objective of the ReCiPe method is to transform the long list of life cycle inventory results into endpoint indicators of damage: human health, ecosystem and resources. To assess various damage categories, the life cycle assessment method was applied, referring to the normalized values of Europe [14]. LCA enables assessing material and energy use as well as influence on the environment throughout the life cycle. On the basis of LCA, it is possible to assess the influence of transport on given categories of damage to human health, ecosystem quality, and resource use. It is also possible to determine which elements and stages have the largest impact on the environment.

Following the ReCiPe 2008 method, one aggregated environmental indicator, covering all the damage categories, expressed in Pt/100 km, was obtained. A result expressed in ecopoints covers such categories of damage as influence on human health, ecosystem quality and resources use. Results of the LCA according to the ReCiPe Endpoint for a given road transport were expressed in ecopoints (Pt). One ecopoint represents one thousandth fraction of yearly damage to the environment caused by one European.

Attributional Life Cycle Assessment (LCA) was used to assess the potential environmental impact of the analyzed road transport in a passenger car. The life cycle assessment was carried out using the LCA software package SimaPro v.8.0 and the Ecoinvent 3.2 database within the program.

4. RESULTS

Greenhouse gas emissions of road transport in a passenger car is presented in Table 1. The greenhouse gases emission of the analyzed road transport in a passenger car is 34,2 kg CO_2 eq/FU and includes the impact of the fuel life cycle (WTW analysis) as well as other components. The results of the WTW analysis relate to petrol production (petrol, low-sulfur) as well as to the emissions caused by the burning of petrol during car use (direct-impact emissions). The greenhouse gas emissions from petrol production and consumption during a journey length of 100vkm are 25,05 kg CO_2 eq/FU. Production of petrol causes GHG emissions of 5,04 kg CO_2eq/FU, whereas petrol consumption in the use phase accounts for as much as 80% of the impact on greenhouse gas emissions. The use of the LCA method has also made it possible to show the environmental impact of components such as passenger car, passenger car maintenance, road wear, brake-wear emissions, tyre-wear emissions and road-wear emissions in various impact categories. The results of the LCA using the ReCiPe method in all damage categories are presented in Table 2.

It was found that the indicator for all damage categories is 3,44 Pt/FU, 40% of which is the resources category and almost 40% is the human health category; the remaining 20% is the ecosystem category. The analysis showed that the most significant impact on human health (42%) and also on the ecosystem (49%) is caused by the car's fuel emissions. Human health is affected 32% by car production and 16% by fuel production. The remaining elements represent only 10%. The ecosystem also has the same impact elements as human health. The biggest consumption of natural resources has been showed in the petrol production process and accounts for 66%. The consumption of resources is also influenced by car production by 26%.

5. CONCLUSIONS

The paper presents the results of the environmental assessment of road transport in a passenger car based on life cycle approach methods. The Well to Wheel (WTW) method is used to support decision-making on environmental aspects of transport, particularly with regard to fuel life cycle management. This method focuses on greenhouse gas emissions during the stages related to the life cycle of fuels, but it omits important life cycle stages, particularly the ones regarding important circular economy guidelines. The WTW analysis is a simplified LCA analysis and is connected with many limitations. This is why a different method of environmental assessment is presented in the paper, taking into account life cycle approaches. The LCA method allows the assessment of the environmental impact of components such as WTW (the petrol production and greenhouse gas emissions caused by petrol burning during car use) as well as other components like passenger car, passenger car maintenance, road wear, brake-wear emissions, tyre-wear emissions and road-wear emissions in various impact categories. The LCA method provides a much wider approach to environmental assessment than WTW. Methods for environmental assessments taking into account the life cycle approach are being developed in the transport sector.

Table 1
Environmental assessment of road transport in a passenger car according to the IPCC 2013 GWP 100a method

GHG emissions	kg CO_2 q/FU
Direct impact - emissions, including:	**20,017**
Carbon dioxide	19,737
Dinitrogen monoxide	0,240
Methane	0,040
Indirect impact, including:	**14,212**
Passenger car, petrol	7,055
Petrol, low-sulfur	5,055
Road	1,164
Passenger car maintenance	0,938
Total	**34,230**

Table 2
Environmental assessment of road transport in a passenger car according to the ReCiPe Endpoint method

Damage category, Pt/FU	Human Health	Ecosystems	Resources	Total
Petrol, low-sulfur	0,2154	0,1310	0,9128	1,2592
Passenger car, petrol	0,4287	0,1493	0,3555	0,9335
Direct impact - emissions	0,5600	0,3513	0,0000	0,9112
Road	0,0677	0,0598	0,0738	0,2013
Passenger car maintenance	0,0438	0,0191	0,0468	0,1097
Brake wear emissions, passenger car	0,0160	0,0007	0,0000	0,0167
Tyre wear emissions, passenger car	0,0044	0,0001	0,0000	0,0044
Road wear emissions, passenger car	0,0043	0,0000	0,0000	0,0043
Total	1,3402	0,7112	1,3889	3,4404

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