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How to assess influence of conventional motor fuels on natural environment?

One of the priorities of the European Union is the reduction of greenhouse gas emission. It was expressed by signing the Kyoto Protocol and also by stimulating the activities of enterprises by issuing appropriate legal acts (directives). Pro-environmental activities are effective only in the case when reduction of GHG emission at one stage or place does not cause an increase in emission at other stages. This article describes LCA – a tool for assessing the influence of conventional motor fuels on global warming. How to adopt this universal tool to carry out calculation dedicated the GHG emission in the life cycle of motor fuels was briefly discussed.

Key words: LCA, emission of GHG, motor fuels.

Jak ocenić wpływ paliw silnikowych na środowisko naturalne?

Jednym z priorytetów Unii Europejskiej jest redukcja emisji gazów cieplarnianych. Zostało to wyrażone między innymi poprzez podpisanie protokołu z Kyoto, a także stymulowanie działań przedsiębiorstw za pomocą wydawania odpowiednich aktów prawnych (dyrektyw). Proekologiczne działania są efektywne tylko w przypadku, gdy redukcja emisji GHG na danym etapie czy miejscu nie powoduje wzrostu emisji na innym. Artykuł opisuje LCA – narzędzie do oceny wpływu konwencjonalnych paliw silnikowych na globalne ocieplenie. Zostało pokrótce omówione jak zaadaptować to uniwersalne narzędzie do przeprowadzenia obliczeń dedykowanych emisji GHG w cyklu życia paliw silnikowych.

Słowa kluczowe: LCA, emisja gazów cieplarnianych, paliwa silnikowe.

Introduction

Emission in the energy sector is anticipated to fall by 85% by the year 2050 [2]. This goal can be reached by a few methods – by the intensification of power generation from renewable sources, improvement of energy efficiency and direct reduction of emitted greenhouse gases (GHG). The last method found expression in directive 2009/30/EC, commonly called the FQD Directive (Fuel Quality Directive).

One of the most essential changes introduced is increasing the maximum content of biocomponents in motor fuels and also making fuel suppliers liable for the reduction of greenhouse gases in the life cycle. According to the details contained in article 7a paragraph 2: "*Member states shall require suppliers to gradually reduce the greenhouse gas emission in the whole life cycle per unit of energy generated from fuel and energy supplied by up to 10% by 31 December 2020, compared with the fuel baseline standard referred to in paragraph 5 (b) of the FAQ directive*".

What is essential, is that the reduction of greenhouse gas emissions is referred to as emissions generated in the whole life cycle. The directive neither specifies the methodology for calculation, nor refers to standardized methods. The methodology is a subject of separate directive, being elaborated actually.

The LCA (Life Cycle Assessment) methodology

The principle of evaluation of the product in the life cycle is currently the generally applied methodology for measuring the influence of this product on the environment. The standardized methodology described in the PN-EN ISO 14040 [9] and PN-EN ISO 14044 [10] standards is used for this purpose. Life cycle includes successive and connected with one another stages of the product system: from the receiving or producing of this material from natural resources to its final disposal and the evaluation of life cycle, means collection and evaluation of inputs, outputs and the potential influence of the production system on the environment in the period of its life cycle.

In practice, when the evaluation of the life cycle of a given product is performed, its influence on the natural environment is considered in the procurement of materials for the production of the tested product, and then its production, distribution, sale, use and also – after the period of usage – during its utilisation. Calculations can be done for one or several categories of influence. As a result of such a systematic review, the amount of environmental burdens can be defined at each stage of the life cycle. Finally, this knowledge can be used to manage production in such a way as to avoid shifting of the burdens among individual stages of the life cycle. Such an approach allows to evaluate the total influence of the product on the natural environment. The above mentioned and also the universality and clearness of this methodology made it a popular tool for the evaluation of all kinds of products.

Before the research, the basic questions to be determined are: adoption of a functional unit and setting the boundaries for the calculation system. The functional unit is a quantitative effect of the product system applied as a reference unit. The purpose of determining the functional unit is to define the reference quantity to standardized input and output data.

However, the system boundaries specify which individual processes shall be included in the test and how detailed the examination of these processes should be.

When the system boundaries are set, the following should be taken into consideration, i.e.:

- materials procurement,
- inputs and outputs,
- distribution and transportation,
- production and use of fuels, electric energy and heat,
- use and service of products,
- elimination of the process wastes and residues,
- recovery of used products (including renewed use, recycling, energy recovery),
- production of supplementary materials,
- production, service and excluding the basic equipment from exploitation,
- additional operations (e.g. the lighting, heating).

When more than one product is made in a given production process, it is essential to adopt proper allocation procedure. Allocation, according to the definition given in [10], means distribution of the input and output process streams or product system among the tested product system or one or several other product systems.

Standard [9] recommends conducting LCA tests in four phases:

- goal and scope definition,
- inventory analysis,
- impact assessment,
- interpretation.

The stages of evaluation described above are presented in figure 1.

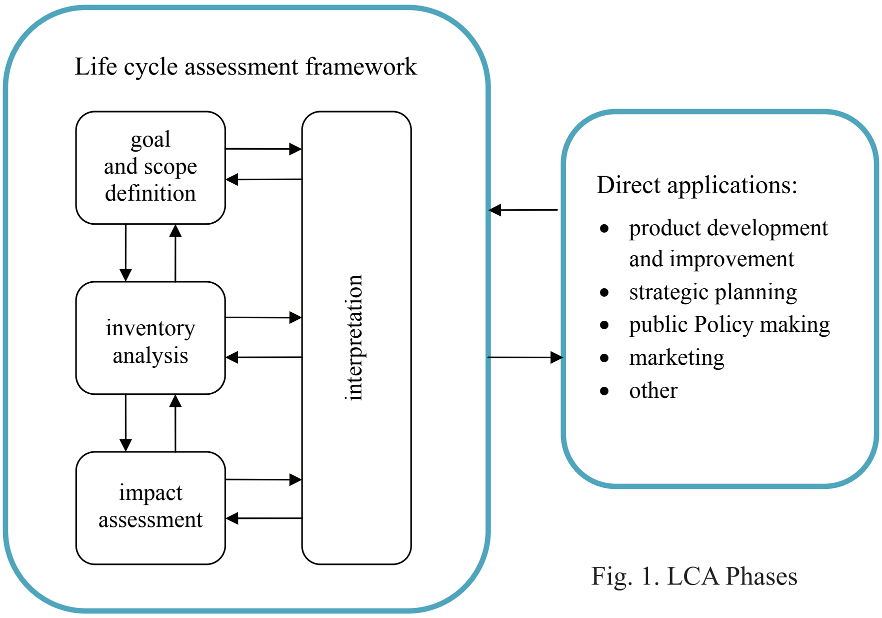

Fig. 1. LCA Phases

Life cycle of motor fuels

Methodology given in standards [9, 10] is universal and widely applied for all products. Its application for oil products requires adaptation. The life cycle of motor fuels runs according to the pattern shown in figure 2.

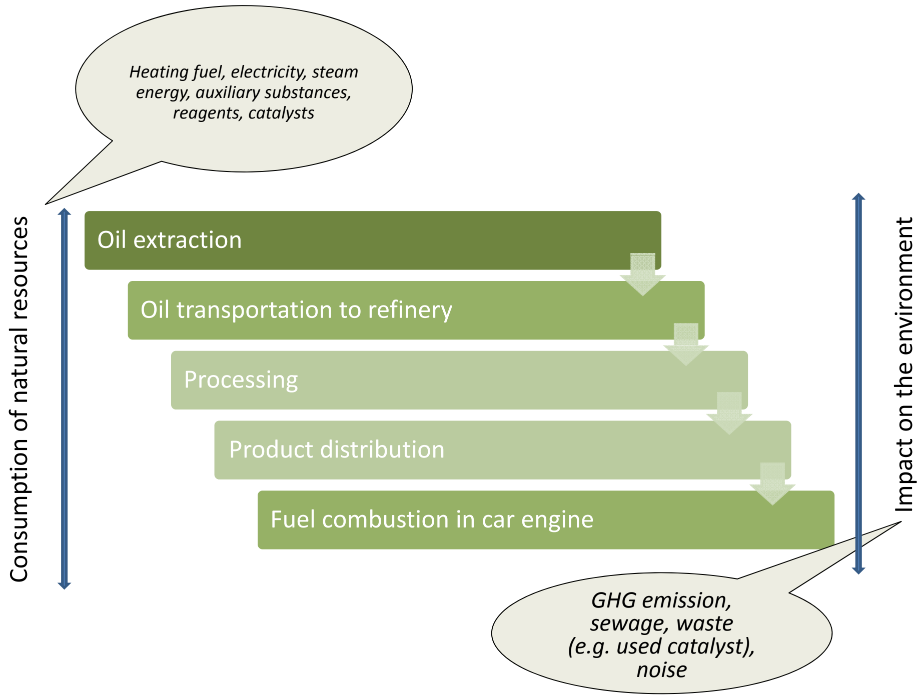

Fig. 2. Life cycle of motor fuels

Life cycle of hydrocarbon motor fuels begins at the moment of oil prospecting and exploration. The next stage is its transportation to the refinery and then processing into motor fuels. When the products are ready, they are distributed to filling stations, to the final consumer. Life cycle ends at the moment the fuel is burnt in a car engine, thanks to which there is no problem with the utilization of the used up product.

Each stage requires making use of the natural environment supplies and it also generates greenhouse gas emissions, sewage, noise etc. The FQD Directive is concentrated on one phenomenon only: global warming. Therefore, it obliges motor fuel producers to monitor and limit greenhouse gas emissions.

As shown in figure 2, the life cycle of motor fuels is composed of several separate components (oil extraction, processing in refinery, etc.). In practice, each one of these stages is treated as a separate computing system for which the GHG (greenhouse gas) emission factor is defined in reference to the energy contained in fuels. Such an approach makes it possible to compare "emissivity" of individual stages for different production pathways.

Depending on the production pathway, the emission share at individual stages can vary, however, its largest part is always attributed to the combustion stage in the vehicle engine. Figure 3 shows in a schematic way the GHG emission distribution in the life cycle of low-sulphur fuel oil [4].

The fuel combustion stage in the car engine makes up almost 80% of all the emission generated in its life cycle, while the next positions are occupied by oil processing (11%) and extraction and transportation (10% of emission). The most effective way to reduce GHG emission at the combustion stage is to use biofuel, and at the other stages: improving energy efficiency. So, this is one reason why new generations of biofuels are being developed [3].

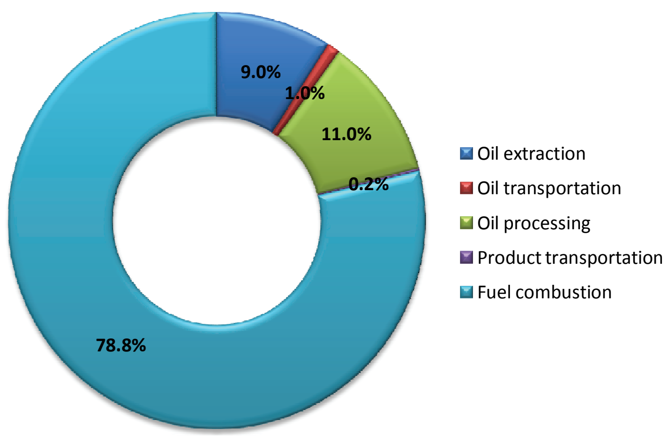

Fig. 3. The GHG emission distribution in the life cycle of low-sulphur diesel oil

Functional unit

In case of the evaluation of the influence of motor oils on global warming, the functional unit is the reference of emitted volume of greenhouse gases (expressed as equivalent of carbon dioxide – CO_{2eq}) to a fuel unit. The FQD Directive demands that these values should be referred to the energy contained in fuel. However, depending on the purposes of the LCA studies, the CO_{2eq} quantity may be referred to the fuel mass unit, volume or even energy used during production. The adoption of the $kgCO_{2eq}$/MJ unit of energy contained in fuel allows to compare greenhouse gas emissions in the life cycle of different fuels, e.g. conventional fuels and biofuels or diesel fuel and CNG (Compressed Natural Gas) LNG (Liquefied Natural Gas) used for driving trucks. So, the decision on adopting the functional unit must be justified by the purpose of the test. Due to the fact that fuels are energy carriers, calculation of greenhouse gas emissions with reference to energy contained in fuel is fully justified.

System boundaries

The extremely important element of the analysis is defining the system boundaries. The system boundaries mostly define inputs, outputs and all unit process involved in fuel production at a given stage. Inclusion of individual processes or their exclusion is conditioned by both the significance of the specific processes and the purpose for which the work is done. In case of motor fuel production, the limits of the computing system for the whole life cycle of motor fuels include:

- oil extraction,
- its transportation to the refinery,
- oil processing in the refinery,
- distribution of finished products,
- fuel use in the car engine.

Depending on the purpose of the research work, the range of individual processes at each stage should be considered. Individual model processes in the LCA motor fuel test can be e.g. oil extraction, its purification and transportation to refinery, and at the processing stage – e.g.: atmospheric distillation system, vacuum distillation system, hydrocracking or reforming system in the refinery, fuel loading at the terminal, fuel transport by railway, storage in fuel base, etc. The range of individual processes should be thoroughly considered for each of these stages; e.g. when extracting oil, the decision should be made on the inclusion or exclusion of the prospecting stage and, in each case, it should be established if the greenhouse gas emissions resulting from production of machines, devices, elements of equipment are included in the computing system.

Another essential issue is the changed volume of GHG emissions connected with the changed way of using the land on which production is conducted, especially if green areas were intended for production (forests, farmlands, wasteland, etc.). Inclusion of these processes into the computing system is important in the evaluation of new investments. In the refining industry, as well as in other production plants, supplementary services, e.g. flares, wastewater treatment plants, are indispensable for the proper functioning of the unit. Although they are not units directly producing the fuel components, their services are essential, that is why they also should be included into the computing system. Adoption of a proper allocation procedure for emission arising from oil products is a separate issue. The emission generated in connection with the production of purchased raw materials and components cannot be disregarded either, however, the emission coming from catalyst production or emission from the production of supplementary materials used in the processes remains disputable; in this case the research worker should evaluate the significance of the influence of mentioned elements on the final results. Considering the question of comparative studies for different products, it is essential that the assumptions and exclusions should be – for all evaluated products – at the same level of significance.

The system boundaries, except the individual processes, should include the set of inputs and outputs. Inputs should include input material and input energy. Input material is e.g. petroleum sent for processing or fuels designed for distribution, while the input energy is e.g. the energy used during oil extraction, transportation and product distribution.

The outputs from processes are obviously the obtained goods but also by products (sulphur, acetone on phenol installation), waste, sewage, and emitted greenhouse gases or hydrocarbons. The GHG emission sources should be identified separately for each stage of the motor fuel life cycle. During the extraction phase the essential sources of GHG comprise of: field gas combustion in turbines, burning processes in the flare and field gas discharge to the atmosphere [1]; while during oil processing in refinery it is the heating fuel combustion, electricity and heat production or regeneration of process catalysts. At the fuel distribution stage the GHG emission sources depend on the implemented logistic system.

Usually the data are aggregated in inventory tables prepared on the basis of material and energy balances of individual unit processes.

The GHG emission allocation

Except for motor fuels, many products and materials are produced from oil for further syntheses. Hence, the emission generated during oil extraction and production must be "allocated" for the received products. The allocation procedure is used for this purpose. Energy consumption allocation (and in consequence the GHG emission) in oil refineries should be done in accordance with the rules given in the ISO 14041 standard, i.e. at the level of individual refining processes, if possible. Allocation can be done based on physical quantities (mass, volume, energy content in obtained products) or economic ones (e.g. profit share in the sale of individual products). In the case of motor fuels, the recommended way is the GHG emission allocation based on the energy content in individual products. In the case of using a mass-based allocation, each stream mass is treated as the weighting factor for distributing energy (emission) among different streams. It is a rational idea, because in each refining process, energy use, is usually proportional to the mass of products processed [10]. This approach is easy to apply at the oil processing stage, but it is not an easy task, especially at the stage of distribution of finished fuels, where the filling stations – except for fuels – usually offer other goods and services (sale of goods, fast food, car wash etc.).

Selection of an appropriate allocation procedure is essential due to obtaining correct calculations results, as it was shown in the example with ethanol [5]. Depending on allocation rules, results can vary up to 28%.

In the test prepared by the Center for Transportation Research, Energy Systems Division and Argonne National Laboratory [11], the methodology was prepared based on published data on energy and mass balance for the United States refineries with a simple oil processing pattern and applied with allocation of total energy consumption in a refinery for different oil derivatives. This method consists of counting the energy use during individual refining processes, by monitoring the streams of mass and energy consumption during the production of each product in the course of refining.

Energy consumption connected with individual refining processes was distributed by way of coefficients to product streams with the help of:

- share of mass components of these products,
- amount of energy contained in them,
- market value of each product stream.

Advantages of the LCA techniques of evaluation in the case of motor fuels

Implementation of an evaluation methodology for the life cycle of motor fuels at an individual supplier allows to obtain full knowledge in the field of:

- total energy consumption in individual processes and operations of the motor fuel production cycle used for its generation,
- GHG emission generated in individual processes and operations of the motor fuel production cycle and GHG emission rates in gCO_{2eq}/MJ of energy contained in petrol (diesel fuel, LPG),
- the GHG emission value connected with production of the individual components of petrol and diesel fuels,
- the emission value connected with production of the unit amount of hydrogen.

Making calculations of the actual GHG emission in the fuel life cycle in refineries allows producers to obtain full knowledge in the field of energy consumption and the GHG emission in each process and each operation, with reference to the normalized amount of energy contained in fuel. On this basis it can be assessed, which process "brings in" the highest emissions and actions can be planned leading to the reduction of the GHG emissions.

Analysis of all the sources of GHG emissions can be done related to the production of defined fuel components and solutions can be developed for the reduction of the greenhouse gas emissions.

Calculation of the actual emissions in the field of oil extraction and transport and distribution of produced fuels allows to enable diversification of oil supplies and used refinery fuels and optimisation in the range of transportation logistics and selection of the means of transporting the finished products.

Reduction of greenhouse gas emissions is not possible in practice without incurring investment expenditures, hence the GHG emission system in the product life cycle should be integrated with the management system and system of optimisation of motor fuels in such a way as to achieve the most optimal effect, i.e. to achieve the largest reduction of greenhouse gas emissions at minimal costs.

Application of the LCA methodology is extremely profitable when introducing new products (alternative fuels) on the market. Obtained results provide knowledge about the complex influence of the product on the natural environment. Conducted studies also allow to estimate ecological advantages resulting from the replacement of one fuel with another. Such an approach was used for the assessment of biofuels. According to the 2009/28/EC directive [7], only those biofuels will be recognised as satisfying the obligatory increase in energy from renewable sources for which reduction of greenhouse gas emissions in the life cycle in relation to conventional fuels is at least 35%. This threshold will be raised to 50% in 2017 and from the year 2018 – for new biofuel production installations – to 60%.

Summary

Due to the complexity of the process of motor fuel production, the application of the LCA methodology is quite complicated as it requires the cooperation between independent economic operators acting on the fuel market, collecting detailed data for individual processes and also doing numerous calculations.

However, making such an analysis allows to identify the most emissive (which is often equivalent for the most energy consumption) processes in relation to obtained normalized energy contained in fuel. This knowledge, especially in connection with the economic data, may subsequently serve to optimise production management. At present many refineries implement integrated management systems, taking into account material purchase and product sale. Inclusion of the LCA analysis into these systems would allow to produce more ecological fuels.

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