THE EFFECT OF FUEL ON THE ENERGY CONSUMPTION AND PRODUCTION OF GREENHOUSE GASES IN TRANSPORT

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Summary

Nowadays, the environmental aspects of transport are very actual issues, mainly the energy consumption and GHG production. The priority of EU transport strategy is to decrease the negative environmental impacts of all transport modes. The article discusses the calculation of the energy consumption and production of greenhouse gases in transport from both the primary and secondary points of view. This means, that it reflects the implications on the environment not only while operating the vehicle, but also during production, refining, distribution and storage of the fuel used in transport. The calculation is done by using the methodology of the standard EN 16 258:2012. This standard is used on all cars using various types of propellants. The results of the calculation show in a non-discriminatory manner the energy effectiveness of the individual types of fuel, as well as the rate of their production of greenhouse gases expressed in a comparison unit of equivalent CO_{2e}.

Keywords: energy consumption, fuels, greenhouse gases, transport

1. Introduction

Energy consumption and the production of greenhouse gases are an increasing problem in today's society. The ecological impacts of transport on the environment are negative and in a lot of cases irreversible. For these reasons the effectiveness of transport in fuel consumption and the production of greenhouse gases is increasingly being pursued [1, 3, 8, 14]. Recently there has been a constant rise in the demand for vehicles using alternatives in the form of types of fuel not common until now [2, 10, 11, 23]. Apart from the

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conventional types of fuel, like petrol and diesel, we are seeing increasing use of CNG, electricity, or a combination of more types.

2. EN 16 258:2012

This standard is basically a methodology for calculating and declaring the energy consumption and greenhouse emissions of transport services for cargo and passenger transport. One of the legislative instruments applied to carriers and shippers with the aim of reducing energy consumption and achieving a more effective operation of motor vehicles on the market is the declaration of the energy consumption during their operation. The aim is to unify the process of declaring the energy consumption and the production of greenhouse gases. Today it's becoming a trend, that the customers choose the carrier not only on the basis of the price and the quality of the offered service, but also according to what impact the service leaves on the environment. To achieve comparable results in declaring the effects of individual carriers in different countries, the used methodology needs to be unified. This is defined in the standard STN EN 16 258:2013 (adopted EN standard). This instrument could be more effective if it was compulsory for the carrier to declare it to the customer [4].

The standard defines the methodology and the requirements for the calculation and recording of energy consumption and emissions of greenhouse gases (GHG) originating from transport services. This first edition of the standard primarily concentrates on the energy consumption and greenhouse emissions related to vehicles (used on the ground, on water and in the air) during the operational phase of their life cycle. However, when calculating the energy consumption and the emissions related to vehicles, the energy consumption and emissions related to energy processes connected to fuel and/or electricity powered vehicles (including, for example, the distribution of fuel), are considered. This ensures, that the standard uses the "well-to-wheel" approach for the calculations and for the declaration to the users of the transport services.

It specifies general principles, definitions, system boundaries, calculation methods, allocation rules (allocation, assignment) and recommendations about the data with the aim of reinforcing standardized, exact, trustworthy and verifiable declarations, as long as energy consumption and greenhouse emissions relate in any way to any quantified transport service.

It also includes examples of the use of these principles.

The potential users of this standard are all persons or organizations, which have to refer to the standardized methodology when announcing the results of the calculations of the energy consumption and greenhouse emissions related to a transport service, especially:

- operators of a transport service (cargo transport or passenger transport)
- organizers of a transport service (operators of subcontracted transport, cargo transport and travel agencies)
- the users of transport services (consignors and passengers)

The evaluation of the energy consumption and emissions of greenhouse gases of transport services must include the operational processes of the vehicle and the energy operational processes, which occur during the operational phase of its life cycle. The operational processes of a vehicle have to comprehend the operation of all the vehicle's systems including the propulsion and the complementary services [4, 6, 13].

Examples:

The main engines, auxiliary devices used for sustaining the temperature in the cargo compartment, manipulation or loading devices of a vehicle are on-board vehicle systems, the operation of which is included.

Tab. 1. Energy and gas factors of selected fuels

Fuel type	Energy factor				Gas factor					
	Tank-to-wheels (e_t)		Well-to-wheels (e_w)		Tank-to-wheels (g_t)			Well-to-wheels (g_w)		
	MJ/kg	MJ/l	MJ/kg	MJ/l	gCO_{2e}/MJ	$kgCO_{2e}$/kg	$kgCO_{2e}$/l	gCO_{2e}/MJ	$kgCO_{2e}$/kg	$kgCO_{2e}$/l
Gasoline	43.2	32.2	50.5	37.7	75.2	3.25	2.42	89.4	3.86	2.88
Gasoline/ etanol 95/5	42.4	31.7	51.4	38.4	72.6	3.08	2.30	88.4	3.74	2.80
Diesel	43.1	35.9	51.3	42.7	74.5	3.21	2.67	90.4	3.90	3.24
Biodiesel	36.8	32.8	76.9	68.5	0	0	0	58.8	2.16	1.92
LPG	46.0	25.3	51.5	28.3	67.3	3.10	1.70	75.3	3.46	1.90
CNG	45.1		50.5		59.4	2.68		68.1	3.07	
MDO	43.0	38.7	51.2	46.1	75.3	3.24	2.92	91.2	3.92	3.53

Source: [4] modified by author

The energy processes have to comprise:

- in the case of combustibles: the extraction or cultivation of primary energy, refining, transforming, transport and distribution of energy in all stages of the production of the used fuel,
- in the case of electricity: the extraction or cultivation of the primary energy, transformation, energy production, losses in the electricity distribution networks.

The calculation has to take into account:

- all vehicles used for executing the transport services including those provided by subcontractors,
- the overall fuel consumption from every energy carrier used by individual vehicles,
- all loaded and idle rides performed by every vehicle.

The calculation has to generate the four following results:

- well-to-wheels energy consumption (E_W) (primary and secondary consumption),
- well-to-wheels GHG (greenhouse gases) emissions (G_W) (primary and secondary production),

- tank-to-wheels energy consumption (Et) (secondary consumption),
- tank-to-wheels GHG (greenhouse emissions) emissions (G_t) (secondary production).

3. Equivalent CO_2, CO_{2e}

It is a universal measure of the amount of a greenhouse gas (carbon dioxide, methane, nitrous oxide and other), which has the same effect on the climate system as carbon dioxide would have on its own. It reflects the exact rate, by which it influences the greenhouse effect in the atmosphere created by individual elements of the greenhouse gases. For example, 1 ton of methane has a 21 times higher rate of the greenhouse effect, than 1 ton of CO_2 and thus 1 ton resembles the value of 21 tons of CO_{2e}. This synthetic dimension was created for the purposes of creating something with a high resemblance when comparing the production of emissions originating from various industries, sources, fuels with different composition [7, 13, 15].

It is clear from Table 1 that not only the technical perfection of a vehicle and its effectiveness in transforming the fuel energy into mechanical work influences the overall fuel consumption, but also the amount of the energy used for the production, acquisition and distribution of fuel. This is the so-called LCA factor (life cycle factor), which is included in the well-to-wheels declaration method. Table 2 shows, that when comparing vehicles' direct energy consumption, they could achieve lower e_t values if they burnt biodiesel instead of diesel, however, when comparing the e_w, biodiesel turns out significantly worse. The volume of the consumption during the vehicle's operation must obviously be taken into account when doing the comparison. It changes with regard to the amount of energy contained in the fuel and the combustion efficiency of the fuel [5, 9, 12, 26]. This means, that the energy efficiency rate of a certain transport vehicle does not have to be immediately clear from the table, it is necessary to know its real fuel consumption.

4. Practical calculation

If we want to use the methodology for calculating the energy demandingness and the production of greenhouse gases in transport specifically from cars with various types of fuel, it is appropriate to use the following example.

We will take into consideration a vehicle used frequently in Slovakia and the Czech Republic, by the lower middle class from an unnamed car manufacturer, which offers this vehicle with three types of engines – petrol, petrol/CNG and diesel, all three with approximately the same power. The brand and the type are not important in this case. The important factors are the parameters about the power, weight and fuel consumption of the given vehicle. It is a vehicle with a curb weight of 1 500 kg, engine with around 80 kW. In the case of a vehicle like this the fuel consumption can vary around 6 - 7 l of petrol per 100 km, in the case of a compression-ignition engine we can consider consumption at around 5 – 6 l/100 km and with CNG around 5 kg/100 km. When assessing and determining the fuel consumption of vehicles we must realize the following facts:

- we cannot take into account the information from the manufacturer, because they don't correspond to the real fuel consumption in real conditions,
- every single vehicle has a different consumption,
- every single driver has a different consumption,
- the consumption differs according to the load.

We could continue like this with all the operational characteristics of the vehicle. That is why these values were selected as representative for the given type of vehicle. In the first calculation the values about consumption in the combined NEDC cycle, which originated from the manufacturer, were used [17, 18, 21].

In the second calculation the values were increased by 20 %, so that they represent better the real consumption during the normal use of the vehicle [19, 20]. The real vehicle fuel consumption depends also on the traffic flow parameters and actual vehicle mass. This facts influence the vehicle drive resistances and affect the consumption [16, 22].

Tab. 2. Calculation of energy consumption and production of greenhouse gases

Fuel type	Ø fuel/energy consumption (l, kg, kWh/100km)	TtW (primary)		WtW (primary + secondary)	
		Energy consumption (MJ/km)	Production of CO_{2e} (g/km)	Energy consumption (MJ/km)	Production of CO_{2e} (g/km)
Gasoline	5.6	1.80	136	2.11	161
CNG	4.4	1.98	118	2.20	135
diesel	4.4	1.58	117	1.88	143
electric*	20	0.72	0	2.12	65/149
hybrid**	4	1.29	97	1.51	115

* applies only for used electricity produced in SK/CZ

** variable value, it depends a lot on the conditions, in which the vehicle was used (city, motorway), the type of hybrid technology applied

For comparing other propulsion systems used today in cars, vehicles of the same category were selected, but powered by alternative technologies – hybrid powered by petrol/electricity and a fully electric car. The results of the calculations of the energy intensity and of the production of greenhouse gases, which were done in accordance with the methodology of the above-mentioned standard, are displayed in the chart below.

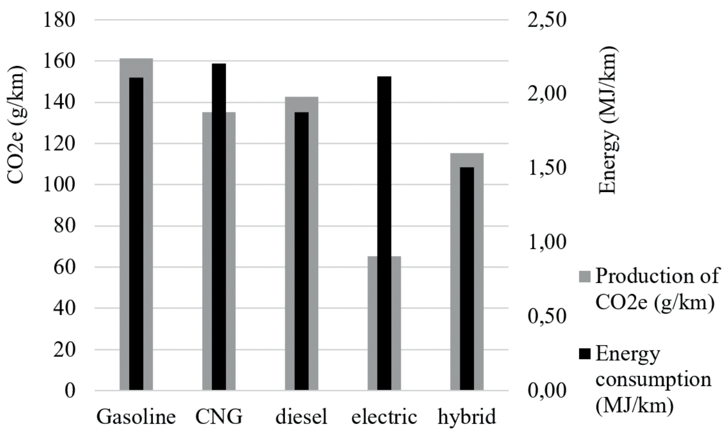

Fig. 1. Energy consumption and production of greenhouse gases

The results shown in the Figure 1 represent energy consumption and production of greenhouse gases from a global aspect, which means they include both the primary and secondary influences. CNG is the cleanest in the production of greenhouse gases among the hydrocarbon fuels, but it is the least effective in energy consumption even though it is a fuel that is not subject to the same production processes as petrol and diesel. This is because of the large amount of energy contained in 1 kg of CNG, so the engines burning CNG achieve lower efficiency than engines for petrol or diesel.

The next table together with the Figure 2 describe the situation when considering the 20 % higher values than the ones given by the manufacturer.

Tab. 3. Calculation of energy consumption and production of greenhouse gases

Fuel type	Ø fuel/energy consumption (l, kg, kWh/100km)	TtW (primary)		WtW (primary + secondary)	
		Energy consumption (MJ/km)	Production of CO_{2e} (g/km)	Energy consumption (MJ/km)	Production of CO_{2e} (g/km)
Gasoline	6.7	2.16	162	2.53	193
CNG	5.3	2.39	142	2.66	163
diesel	5.3	1.90	142	2.26	172
electric*	24	0.86	0	2.54	78/178
hybrid**	4.8	1.55	116	1.81	138

* applies only for electricity produced in SR/CZ

** variable value, it depends a lot on the conditions, in which the vehicle was used (city, motorway), the type of hybrid technology applied

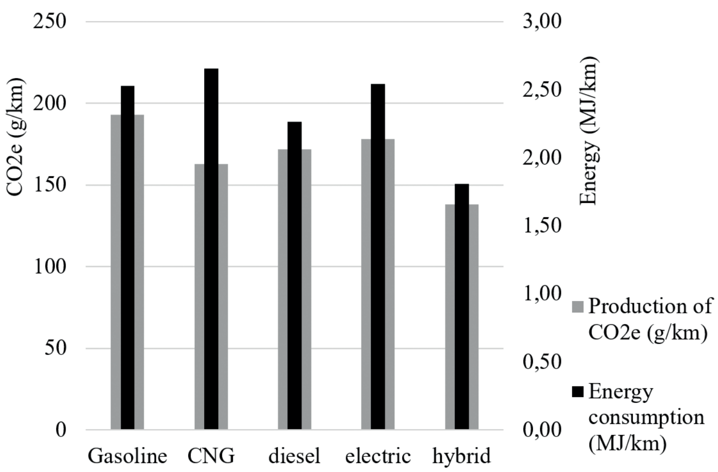

Fig. 2. Energy consumption and production of greenhouse gases

When comparing these five types of propulsion for vehicles, it is necessary to notice especially the electric cars and vehicles with a hybrid propulsion technology. In the case of electric cars, the energy consumption (primary, secondary) depends very much on which country the vehicle is driven in and which country the electricity it uses originates from [23, 24]. It is important to consider the production method of the electricity, the production effectiveness and the greenhouse gases produced in the process of generating it. This can be observed in the results depicted in both charts, where in the first case electricity produced in Slovakia was used for the calculation and in the second case electricity from the Czech Republic was used. Detailed influence of the electric energy production on the emissions is introduced in the Table 4.

Abstracting from the 20 % higher results compared with the Figure 1, the production of greenhouse gases is more than twice as high in relative values. In the case of hybrid vehicles, the final energy consumption can vary a lot and therefore also the production of emissions because this type of propulsion generates a lot more variable results depending on the conditions during its operation. The consumption can be very low when driving in the city, however, when used on the motorway, the consumption can be the same or even higher, than in comparable vehicles with conventional propulsion burning hydrocarbon fuels.

As it was mentioned above, the art and source mixture of electricity production is very important because it influences the mass of GHG produced during the electricity production [25].

The countries, which use more fossil fuels for the electricity production, reach higher values of the GHG production per kWh (Table 4).

Tab. 4. GHG production of e-drive in different countries

Country	Vehicle energy consumption (kWh/100km)	Tank-to-wheels	Well-to-wheels
		Production CO_{2e} (g/km)	Production CO_{2e} (g/km)
Estonia	20	0	318.6
Slovakia			70.6
Germany			141.2
EU - 27			115.6
Sweden			15.8

Countries like Estonia, Greece or Poland produce electricity with high mass of GHG. E-vehicles driven and charged in these countries produce more GHG than vehicles consuming petroleum products like gasoline or diesel. This is caused by the source mixture of the electricity production. Opposite them there are countries like Sweden, Austria or Slovakia where the water or nuclear energy are the most used energy sources.

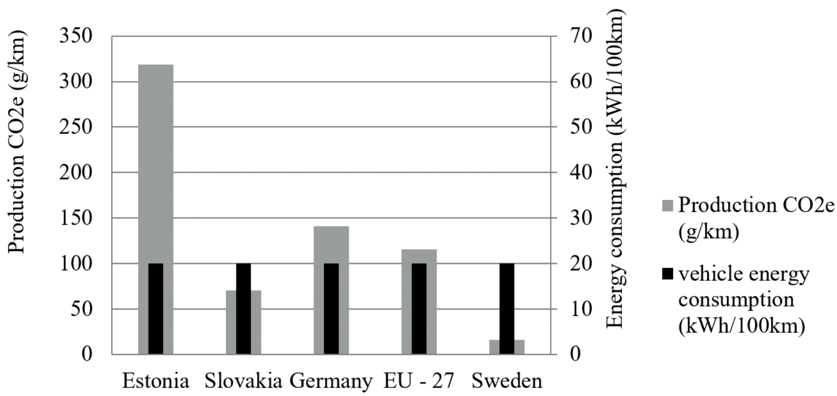

Fig. 3. GHG production of e-drive in different countries

The Figure 3 introduces the differences between operation of the same e-vehicle charged in different countries. The electric consumption is at the same level of 20 kWh/100km in all countries so differences in the GHG production are caused only by the electricity production.

5. Conclusion

The results shown in the tables and figures document the complexity of comparing the energy consumptions and production of greenhouse gases in transport when using various fuels. It is caused by the different chemical composition of the fuel, the form in which the energy is bound in the fuel, by its production, distribution, storage. This means, that not only the fuel itself and its energy transformation effectiveness in the vehicle (fuel consumption of the vehicle), but all the procedures applied for acquiring and processing it, and thus the effectiveness and ecological efficiency of these procedures determines the impacts on the environment.

Acknowledgement

This publication is the result of two project funds:

1. *Centre of excellence for systems and services of intelligent transport, ITMS 26220120028 supported by the Research Agency, Research and Development Operational Programme funded by the ERDF (European Regional Development Fund). "Podporujeme výskumné aktivity na Slovensku/Projekt je spolufinancovaný zo zdrojov EÚ." "We support research activities in Slovakia/Project is co-financed by EU sources. "*

2. *Institutional project of Department of Road and Urban Transport, University of Žilina, „Vplyv aerodynamických vlastností vozidiel v cestnej doprave na ich prevádzku" (Influence of aerodynamical characteristics on road vehicle operation, 6/KCMD/2018.*

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