The (life cycle) environmental operational costs when selecting a motor vehicle

Abstract

When selecting a transport vehicle, contracting authority shall, within the overall assessment, prefer the vehicle with smaller operational costs during its life cycle. Operational costs, taking into account energy and environmental impacts include energy consumption, CO$_2$, NO$_x$, NMHC emissions and particulate matter.

Keywords: Operational costs, life cycle, energy consumption, CO$_2$ emission, NO$_x$ emission, NMHC emission, particulate matter, energy content of motor fuels, cost for emissions, lifetime mileage of vehicles, selection of vehicles

1. Introduction

When selecting a transport vehicle, the transport company takes into consideration several criteria – transport capacity, investment and operational costs that means those with the highest weight of importance. Vehicle showing lower operational costs during its life cycle /lifetime/ provided the expected transport performance will be preferred into the final selection.

It is important to put the attention to the need of lowering emissions originating in transport, fuel consumption and dependency on oil, alternatively affect the demand for alternative fuels and technologies when selecting a vehicle. It is important to increase the demand for ecological and energy efficient vehicles, so it is high enough to make the entire automobile industry investing in vehicles with low energy consumption, low CO$_2$ emissions and low pollution. These energy efficient vehicles have higher initial price than conventional ones, but by creating sufficient demand for these vehicles could lead to savings by their procurement that could lead to a reduction in operating costs over their lifetime.

Including the energy consumption, CO$_2$ emission and pollution particles into the procurement criteria should not result in higher total costs, because by choos-
ing of means of transport are incorporated only operational costs during the life
time. This approach will value real emission of polluting materials.

2. Life cycle of vehicle

Life expectancy of the vehicle is its ability to fulfill expected functions till reaching its threshold level when maintaining as recommended. Life expectancy of the vehicle depends on the period of use, mileage, alternatively on number of performance hours. Can be expressed in numbers as technical life in kilometers or time if use in years.

Threshold level of the vehicle is given by car’s inability to operate due to lowered effectively, cost efficiency and increased deterioration or safety of the road traffic.

Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicles states the lifetime mileage of different vehicles categories as per table.

Tab. 1. Lifetime mileage of road transport vehicles. Source: [5]

<table>
<thead>
<tr>
<th>Vehicle category</th>
<th>Lifetime mileage [LLM]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger cars (M1)</td>
<td>200 000 km</td>
</tr>
<tr>
<td>Light commercial vehicles (N1)</td>
<td>250 000 km</td>
</tr>
<tr>
<td>Heavy goods vehicles (N2, N3)</td>
<td>1 000 000 km</td>
</tr>
<tr>
<td>Busses (M2, M3)</td>
<td>800 000 km</td>
</tr>
</tbody>
</table>

3. Selection of clean and energy-efficient vehicles in road transport

When buying new vehicles, obliged subjects (public procurers, buyers and transport companies offering services in public interest) in public procurements have to consider the environmental impacts of vehicles during their lifetime. The operational energy and environmental impacts to be taken into account shall include at least the following:

a) energy consumption,
b) emissions of carbon dioxides (CO$_2$),
c) emissions of
   1. nitrogen oxides (NO$_x$),
   2. non methane hydrocarbons (NMHC),
   3. particulate matter.

In addition to the above energy and environmental impacts, incumbents may also consider other environmental impacts.
The public procurer, procurer and the contracting carrier are required by the purchase or lease of motor vehicles to account for energy requirements and environmental performance by applying any of the following:

1. Stating technical specifications for energy and environmental performance in the technical specifications to be determined in the documentation relating to the purchase or lease of motor vehicles. This means that the procurement authority and the procurer will include also requirements concerning the environmental performance of vehicles purchased in the description of the order, which is part of the tender documents.

2. Energy and environmental impacts could be included into the purchase or leasing decision by
   • using the environmental impacts as a criteria in the procurement decision as stated in the public procurement act or
   • using the methodology of calculating operating costs over the life cycle of the vehicle, if these environmental impacts are converted to monetary values to be included in the decision to purchase or lease.

4. Measuring the environmental impacts of motor vehicles

Measuring the environmental impacts of vehicle's operation is performed during the approval of a motor vehicle, when each vehicle must pass the approval test in accordance with pre-defined technical requirements, also known as regulatory acts. The consumption measurement and measurement of carbon dioxide (CO$_2$) is regulated by UNECE no. 101 [6] and to measure the emission of gas emission and particulate emissions is regulated by UNECE no. 83 [7].

All measured values (energy consumption, emissions of carbon dioxide – CO$_2$, nitrogen oxides (NO$_x$); emissions of non-methane hydrocarbons (NMHC), particulate emissions (solid particles) are available for each new vehicle. All these are reported in the certificate of conformity of the vehicle (COC) followed in the vehicle registration document (in the registration certificate), but also in the information material of the vehicle.

4.1 Measurement of energy consumption

The fuel consumption values are calculated from the emissions; from the hydrocarbons emissions (HC), carbon monoxide (CO) and carbon dioxide (CO$_2$) obtained from the measurement results according to UNECE Regulation 83 [7]. Fuel consumption is then calculated using the following formulas:

a) for vehicles with petrol engine

\[
FC = \frac{0.1155}{D} \cdot [(0,866 \cdot NMHC) + (0,429 \cdot CO) + (0,273 \cdot CO_2)]
\]
b) for vehicles with diesel engine

\[
FC = \frac{0.1154}{D} \cdot \left[\left(0.866 \cdot NMHC\right) + \left(0.429 \cdot CO\right) + \left(0.273 \cdot CO_2\right)\right]
\]

[l.100km\(^{-1}\) alebo m\(^3\).100km\(^{-1}\)]

where:

- \(FC\) = Fuel consumption [l.100km\(^{-1}\) or m3.100km\(^{-1}\) for natural gas]
- \(D\) = Density of test fuel [kg.l\(^{-1}\) or kg.m\(^3\) for natural gas]
- \(NMHC\) = Measured emission of non-methane hydrocarbons [kg.km\(^{-1}\)]
- \(CO\) = Measured emission of carbon monoxide [kg.km\(^{-1}\)]
- \(CO_2\) = Measured emission of carbon dioxide [kg.km\(^{-1}\)]

The fuel consumption calculation is based on working driving cycle, which consists of one elementary urban cycle and the two parts of the extra urban cycle. Graphical representation of such a combined driving cycle is shown in Figure 1.

![Combined driving cycle](source: [7])
4.2 Measurement of emissions of carbon dioxides (CO₂)

Weight of carbon dioxide (CO₂) is calculated according to the measurement results as described in UNECE Regulation 83 [7]. Calculating the weight of carbon dioxide (CO₂) is similarly based on fuel consumption as the working of the driving cycle, which consists of one elementary urban cycle and the two parts of the extra urban cycle (Figure 1).

4.3 Measurement of other pollutants emissions

The weights of the gaseous emissions are calculated using the following equation:

\[ M_i = \frac{V_{\text{mix}} \cdot Q_i \cdot k_h \cdot C_i \cdot 10^{-6}}{d} \quad [\text{g.km}^{-1}] \]

where:

- \( M_i \) = Mass emission of pollutant [g.km⁻¹]
- \( V_{\text{mix}} \) = Volume of diluted exhausted gas corrected to standard conditions (273.2 K a 101.33 kPa) [l]
- \( Q_i \) = Density of the pollutant agent under normal temperature and pressure (273.2 K a 101.33 kPa) [g.l⁻¹]
- \( k_h \) = Humidity correction factor for the mass emissions of nitrogen oxide (NOₓ); in the case of hydrocarbons (HC) and carbon monoxide (CO) are not the humidity factor [-]
- \( C_i \) = Corrected concentration of pollutants in the sampling bag [ppm]
- \( d \) = Actual distance corresponding to the cycle [km]

The weights of particulate emissions are calculated using the following equation:

\[ M_{PF} = \frac{(V_{\text{mix}} + V_{\text{ep}}) \cdot M_{PFF}}{V_{\text{eG}} \cdot d} \quad [\text{g.km}^{-1}] \]

where:

- \( M_{PF} \) = Particulate mass [g.km⁻¹]
- \( V_{\text{mix}} \) = Volume of diluted exhaust gas corrected to standard conditions (273.2 K a 101.33 kPa) [l]
- \( V_{\text{eG}} \) = Volume of exhaust gas flowing through the filter under standard conditions (273.2 K a 101.33 kPa) [l]
- \( M_{PFF} \) = Particulate mass collected by filters [g]
- \( d \) = Actual distance corresponding to the cycle [km]
5. Environmental operating costs during the life cycle of motor vehicles

Operating costs over the life of the vehicle are evaluated and calculated according to predetermined methodologies and are divided into operating costs:
1. energy consumption,
2. carbon dioxide (CO$_2$),
3. emissions of other pollutants (nitrogen oxides (NO$_x$), non-methane hydrocarbons (NMHC) and particulate matter).

5.1. The methodology for calculating operational lifetime costs for energy consumption

Vehicle fuel consumption per kilometer is calculated in units of energy per kilometer regardless of whether it is given directly, as in electric vehicles, or not. If fuel consumption is given in different units, it is converted to energy consumption per kilometer using a conversion coefficient of the energy content of fuel according to Table 2 for the fuel.

**Tab. 2.** Energy content of motor fuels. Source: [9]

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Energy content [E]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>36 MJ.l$^{-1}$</td>
</tr>
<tr>
<td>Petrol</td>
<td>32 MJ.l$^{-1}$</td>
</tr>
<tr>
<td>Natural gas (NG) / Biogas</td>
<td>(33-38) MJ.Nm$^{-3}$</td>
</tr>
<tr>
<td>Liquefied petroleum gas (LPG)</td>
<td>24 MJ.l$^{-1}$</td>
</tr>
<tr>
<td>Ethanol</td>
<td>21 MJ.l$^{-1}$</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>33 MJ.l$^{-1}$</td>
</tr>
<tr>
<td>Emulsion fuel</td>
<td>32 MJ.l$^{-1}$</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>11 MJ.Nm$^{-3}$</td>
</tr>
</tbody>
</table>

A unitary monetary value per unit of energy is used to reflect the cost per unit of energy. The single monetary value is the price of petrol or diesel free of customs, transportation duties and taxes.

The operational lifetime cost of energy can be expressed as:

\[ N_{p_{EC}} = L_{LM} \cdot c_e \cdot n_e \quad [€] \]

where:
- \( N_{p_{EC}} \) = operational lifetime cost of energy consumption [€]
- \( L_{LM} \) = kilometers traveled during the life of the vehicle [km]
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\[ c_e = \text{energy consumption per kilometer [MJ.km}^{-1}] \]
\[ n_e = \text{cost per unit of energy [€.MJ}^{-1}] \]

Energy consumption can be expressed by following equation:

\[ c_e = \frac{FC \cdot E}{100} \quad [\text{MJ.km}^{-1}] \]

where:
\[ c_e = \text{energy consumption per kilometer [MJ.km}^{-1}] \]
\[ FC = \text{fuel consumption [l.100km}^{-1} \text{ or m}^3.100km}^{-1} \text{ for natural gas}] \]
\[ E = \text{energy content of fuel [MJ.l}^{-1} \text{ or MJ.Nm}^{-3}] \]

5.2. Methodology of calculating operational lifetime costs of carbon dioxide \((CO_2)\)

Operational costs for carbon dioxide \((CO_2)\) during the life of the vehicle shall be calculated by multiplying the mileage during his life according to Tab 1, carbon dioxide \((CO_2)\), expressed in kilograms per kilometer and cost per kilogram of carbon dioxide \((CO_2)\) from the range given in Tab 3, if necessary, take account of mileage already.

**Tab. 3.** Cost for emissions in road transport. Source: [5]

<table>
<thead>
<tr>
<th>CO2</th>
<th>NOx</th>
<th>NMHC</th>
<th>Particulate matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.03-0.04 €.kg(^{-1})</td>
<td>0.0044 €.g(^{-1})</td>
<td>0.001 €.g(^{-1})</td>
<td>0.087 €.g(^{-1})</td>
</tr>
</tbody>
</table>

Operating costs over the lifetime of carbon dioxide \((CO_2)\) can be expressed with following equation:

\[ Np_{CO2} = L_{LM} \cdot M_{CO2} \cdot n_{CO2} \quad [\€] \]

where:
\[ Np_{CO2} = \text{carbon dioxide (CO}_2\text{) emission operating costs during the lifetime [€]} \]
\[ L_{LM} = \text{kilometers traveled during the life of the vehicle [km]} \]
\[ M_{CO2} = \text{mass of carbon dioxide (CO}_2\text{) [kg.km}^{-1}] \]
\[ n_{CO2} = \text{costs of carbon dioxide (CO}_2\text{) [€.kg}^{-1}] \]
5.3. Methodology of calculating operational lifetime costs for emissions of other pollutants

Operating costs for emissions of nitrogen oxides ($\text{NO}_x$), non-methane hydrocarbons (NMHC) and particulate emissions during the life of the vehicle shall be calculated as the sum of their operating costs. Operating costs for emissions of each individual pollutant during the life of the vehicle shall be calculated by multiplying the lifetime mileage according to Tab 1, the emissions expressed in grams per kilometer and cost per gram of the emissions from the average value of the emissions specified in Tab 3, if necessary, take account of mileage already.

Operating costs over the lifetime emissions of other pollutants can be expressed by following:

$$N_{p_{\text{emissions}}} = N_{p_{\text{NOx}}} + N_{p_{\text{NMHC}}} + N_{p_{\text{PT}}} \quad [\text{€}]$$

where:

- $N_{p_{\text{emissions}}}$ = operational costs during lifetime for other pollutant emissions [€]
- $N_{p_{\text{NOx}}}$ = operating costs over the lifetime of the vehicle for emissions of nitrogen oxides [€]
- $N_{p_{\text{NMHC}}}$ = operating costs during the lifetime emissions of non-methane hydrocarbons (NMHC) [€]
- $N_{p_{\text{PT}}}$ = operating costs during the lifetime of particulate emissions [€]

$$N_{p_{\text{NOx}}} = L_{LM} \cdot M_{\text{NOx}} \cdot n_{\text{NOx}} \quad [\text{€}]$$

where:

- $N_{p_{\text{NOx}}}$ = operating costs over the lifetime of the vehicle for emissions of nitrogen oxides ($\text{NO}_x$) [€]
- $L_{LM}$ = mileage over the life time of the vehicle [km]
- $M_{\text{NOx}}$ = mass of emissions of nitrogen oxides ($\text{NO}_x$) [kg.km$^{-1}$]
- $n_{\text{NOx}}$ = costs of emissions of nitrogen oxides ($\text{NO}_x$) [€.kg$^{-1}$]

$$N_{p_{\text{NMHC}}} = L_{LM} \cdot e_{\text{NMHC}} \cdot n_{\text{NMHC}} \quad [\text{€}]$$

where:

- $N_{p_{\text{NMHC}}}$ = operating costs over the lifetime of the vehicle for emissions of non-methane hydrocarbons (NMHC) [€]
- $L_{LM}$ = mileage over the life time of the vehicle [km]
- $M_{\text{NMHC}}$ = mass of emissions of non-methane hydrocarbons (NMHC) [kg.km$^{-1}$]
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\[ n_{NMHC} = \text{costs of emissions of non-methane hydrocarbons (NMHC)} \ [\text{€.kg}^{-1}] \]

\[ Np_{PT} = L_{LM} \cdot M_{PT} \cdot n_{PT} \ [\text{€}] \]

where:

\[ Np_{PT} = \text{operating costs over the lifetime of the vehicle for emissions of particulate matter} \ [\text{€}] \]

\[ L_{LM} = \text{mileage over the life time of the vehicle} \ [\text{km}] \]

\[ M_{PT} = \text{mass of emissions of particulate matter} \ [\text{kg.km}^{-1}] \]

\[ n_{PT} = \text{costs of emissions of particulate matter} \ [\text{€.kg}^{-1}] \]

6. Sample calculation of operating lifetime costs of vehicle, considering environmental impacts

1. The input parameters of the vehicle for SKODA FABIA 1,2 HTP 44kW:
   - Displacement: 1198 cm$^3$,
   - Maximum power: 44 kW,
   - Maximum vehicle speed: 155 km.h$^{-1}$,
   - Fuel consumption (combined): 5,9 l/100 km,
   - Emissions of carbon dioxide (CO$_2$) (combined cycle): 140 g.km$^{-1}$,
   - Emissions nitrogen oxides (NO$_x$): 0,005 g.km$^{-1}$,
   - Emissions of non-methane hydrocarbons (NMHC): 0 g.km$^{-1}$,
   - Emissions of particulate matter: 0 g.km$^{-1}$.

2. The operational lifetime cost of energy consumption:

By this calculation we first need to calculate the energy consumption per kilometer.

\[ c_e = \frac{FC}{100km} \cdot E = \frac{5,9l}{100km} \cdot 32MJ.l^{-1} = 1,888MJ.km^{-1} \]

The EU informs of the cost per energy unit on its The Market Observatory website [10], which monitors consumer prices for motor fuel free of duty and associated taxes within 7 days.

\[ n_e = \frac{price}{E} = \frac{5,354€.l^{-1}}{32MJ.l^{-1}} = 0,01673€.MJ^{-1} \]

\[ Np_{EC} = L_{LM} \cdot c_e \cdot n_e = 200000km \cdot 1,888MJ.km^{-1} \cdot 0,01673€.MJ^{-1} = 6317,25€ \]
3. Operating costs of carbon dioxide (CO$_2$) over the lifetime:

\[ Np_{CO2} = L_{LM} \cdot e_{CO2} \cdot n_{CO2} = 200000 \text{km} \cdot 0.140 \text{kg.km}^{-1} \cdot 0.03 \text{€.kg}^{-1} = 840.00 \text{€} \]

4. Operating costs of other pollutants emissions over the lifetime:

\[ Np_{NOx} = L_{LM} \cdot e_{NOx} \cdot n_{NOx} = 200000 \text{km} \cdot 0.005 \text{g.km}^{-1} \cdot 0.0044 \text{€.g}^{-1} = 4.40 \text{€} \]

Considering that this petrol engine has zero non-methane hydrocarbons (NMHC) and zero particulate matter, the final operating costs for these pollutants will be zero.

\[ Np_{emissions} = Np_{NOx} + Np_{NMHC} + Np_{PT} = 4.40 \text{€} + 0 \text{€} + 0 \text{€} = 4.40 \text{€} \]

5. Total operating costs over the life of the vehicle:

\[ Np = Np_{EC} + Np_{CO2} + Np_{emissions} = 6317.25 + 840.00 + 4.40 = 7161.65 \text{€} \]

7. Conclusion

Public procurement of motor vehicles, which will take into account energy and environmental issues during the life cycle of the vehicle, such as energy consumption, carbon dioxide (CO$_2$), nitrogen oxide (NO$_x$), non-methane hydrocarbons (NMHC) and particulate matter, will no doubt have a positive impact. It is important to continue to support the purchasing of clean and energy efficient vehicles by various incentives not only in certain member states but in the entire European Community. Another mean to help revive (restore) the vehicle fleet on the roads is the road tax as long as it takes into account the environmental issues.

Literature


3. MORAVČÍK, L.: Zákon o podpore energeticky a environmentálne úsporných motorových vozidiel (Act on the promotion of clean and energy-efficient vehi-
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6. Regulation UNECE No 101 – Uniform provisions concerning the approval of passenger cars powered by an internal combustion engine only, or powered by a hybrid electric power train with regard to the measurement of the emission of carbon dioxide and fuel consumption and/or the measurement of electric energy consumption and electric range, and of categories M1 and N1 vehicles powered by an electric power train only with regard to the measurement of electric energy consumption and electric range.

7. Regulation UNECE No 83 – Uniform provisions concerning the approval of vehicles with regard to the emission of pollutants according to engine fuel requirements.

