Where does the Development of Road Transport Emission Macro Modelling Lead?

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Abstract: In recent years, road transport models have developed for better estimation of road traffic emissions with higher and higher temporal and spatial resolution, to be used as a tool in air quality management for the better living. Road transport related emission models are becoming more and more complex. In this paper, the key research question is how the improvement in modelling influences the results? The authors compared three different macro emission modelling system with the dataset of Hungary for 2010. One must notice that more precise model has larger data requirement. Firstly, the consumption-based model was run with 31 needed input data secondly, EURO standard based model was run with 261 needed data and finally, speed dependent model was run with 1060 needed input data. According to the results, it can be stated that a more complex model could cause significant differences in emission compared to simpler one. The differences can be caused by old Hungarian vehicle fleet or differences in estimation error.

1 INTRODUCTION

The emission of greenhouse gases (GHGs) and the consequential climate change impacts is one of the greatest challenges facing the global community (Stern, 2007). The transport sector contributes significantly to society and the economy (Wismans et. al., 2011). It also can cause substantial adverse impacts on the environment, global climate and human health in different ways. This main source of environmental noise leads to emissions of greenhouse gases (GHG) and air pollutants, and consequently habitat fragmentation. Some air pollutants persist in the environment for long periods of time and they may accumulate in the environment and in the food chain, affecting humans and animals not only via air intake but also via water and food intake. Air pollution is, therefore, a complex problem that poses multiple challenges in terms of management and mitigation and has been studied several times in the case of air quality, emissions etc. (Brand et. al., 2012), (Samaras et al., 2012). Effective action to reduce the impacts of air pollution requires a good understanding of the sources that cause it, as well as up-to-date knowledge of air quality status and its impact on humans and on ecosystems (European Environmental Agency, 2015). The European Union has a wide range of policies of nature protection, noise and fuel quality to air quality which have resulted in some significant improvements in environmental performance. In this paper, authors have only dealt with emissions of greenhouse gases (GHG) and air pollutants. Although European air quality is projected to improve in future with a full implementation of existing legislation, further efforts to reduce emissions of air pollutants are necessary to assure full compliance with EU air quality standards set for the protection of human health and the environment.

In recent years, road transport models have developed for better estimation of road traffic emissions on macro level with higher and higher temporal and spatial resolution (PTV Group, 2015), (Liu, 2007), (Verkehr, 2011), (Axhausen and Garling, 1992), (McNally and Rindt, 2008) to be used as a tool in air quality management for the better living. It is recognised that road transport is one of the major pollution sources for urban dwellers (Ahrens, 2003), (Fenger, 1999), (Andreoni and Galmarini, 2012). In some European countries estimates of road transport emissions have been made on a national basis, and more locally as part of pollution impacts studies, since the 1970s. The methods used have been improved and developed

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since then, mainly depending on the amount, type and quality of data available (European Commission, 1999). (Figure 1):

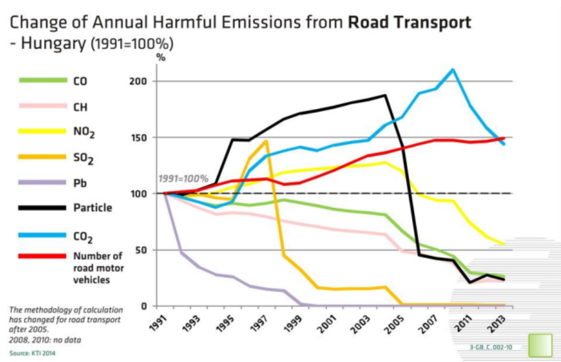

Figure 1: Change of Annual Harmful Emissions from Road Transport – Hungary. (http://www.kti.hu/uploads/images/Trends-9/3 Environment/ GT09_3-350.JPG)

To develop a consistent approach for analysing traffic-induced environmental emission, a precise quantification of pollutant amount emitted by vehicles to the atmosphere is essential (Azar et. al., 2003). One of the approaches commonly used for this purpose is emission modelling. In the literature, emission models are often placed into two broad categories: macro-scale and micro-scale models (e.g. André et al., 2006; Zachariadis and Samaras 1997). The macro-scale models estimate emissions in a large area, e.g. an urban or national network (i.e. at the vehicle fleet level) and give the average emissions for a group of vehicles, while the micro-scale models come down to the street level and predict emissions at the individual vehicle level and may involve a complete driving cycle for each vehicle. Macro-scale emission models could also produce inputs for an air quality model applied in an urban region, but additional information would be required to increase the accuracy (Zachariadis and Samaras 1997).

In this paper, three different macro emission modelling system have been compared with each other. The key research question is: **what the increasing accuracy of macro emission modelling in road transport could cause? How the models are improved?** The authors compared three different emission modelling family. Some preliminary results were already communicated (Török Ádám, 2015):

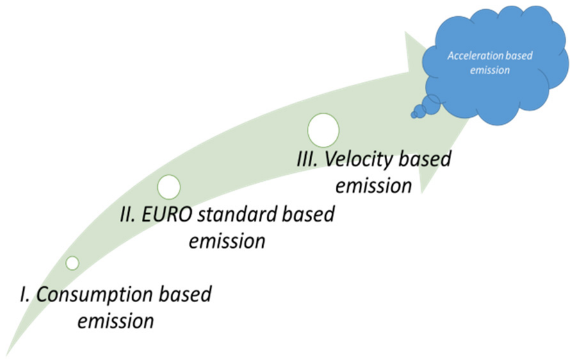

Figure 2: Evolution of emission models (Török Ádám, 2015).

2 METHODOLOGY

In order to be able to compare the three different evolutionary steps of road transport related emission modelling the same modelling environment were given (for instance, all models were run with Hungarian vehicle dataset on 1 km of straight road with the layout of double single lane road and only spark ignition (Lakatos, 2015), and compression ignition engines (Barabás, 2015), (Tutak et. al., 2015), (Zöldy and Török, 2015) were considered with the same free flow traffic conditions).

Top-down equation description is used in order to see the decomposition of emissions on each evolution stage.

At first, the consumption-based model is surveyed (Szendrő and Török, 2014), (Astarita, et. al., 2015), (1):

$$\varepsilon = \sum_{j=1}^{n}\sum_{i=1}^{p}\left(ef_{i,j}\cdot m_i\right) = \sum_{j=1}^{n}\sum_{i=1}^{p}\left(ef_{i,j}\cdot \varphi_i \cdot s_i \cdot \rho_i \cdot \beta_i\right) \quad (1)$$

where:

$ef_{i,j}$: emission factor for vehicle group i for pollutant j [kg emission/kg fuel]

m_i: mass of consumed fuel for vehicle group i [kg fuel]

φ_i: fuel consumption for vehicle group i [l/100 km]

s_i: travelled distance for vehicle group i [km]

ρ_i: fuel density for vehicle group i [kg/l]

β_i: number of vehicles in EURO group [pcs]

Secondly, the EURO emission standard based emission model is considered (Csikós, et. al., 2015) (2):

$$\varepsilon = \sum_{i=1}^{m} (ef_{i,j} \cdot s_i \cdot \beta_i) \qquad (2)$$

where:

$ef_{i,j}$: emission factor for vehicle group i for pollutant j [kg emission/kg fuel]

s_i: travelled distance for vehicle group i [km]

β_i: number of vehicles in EURO group [pcs]

Thirdly, the velocity based emission model is investigated (Toşa, et. al., 2015), (Li et. al., 2015). In this model micro level velocities were considered derived from macroscopic fundamental diagram (Stamos, et. .al., 2015), (Husnjak et. al., 2015), (3):

$$\varepsilon_{CO_2} = \sum_{i=1}^{m} (ef_{i,j}(v) \cdot s_i \cdot \beta_i) \qquad (3)$$

where:

$ef_{i,j}$: polynomial approximation of speed based emission in EURO group i for pollutant j [kg emission/kg fuel]

s_i: travelled distance for vehicle group i [km]

β_i: number of vehicles in EURO group [pcs]

3 RESULTS

Three different models were programmed in the same software environment. These three models have different complexity and data requirements (Figure 3). Firstly, the consumption-based model needed 31 data secondly, EURO standard based model needed 261 data and thirdly speed dependent model needed 1060 data. Each case data for Hungary for 2010 has been used.

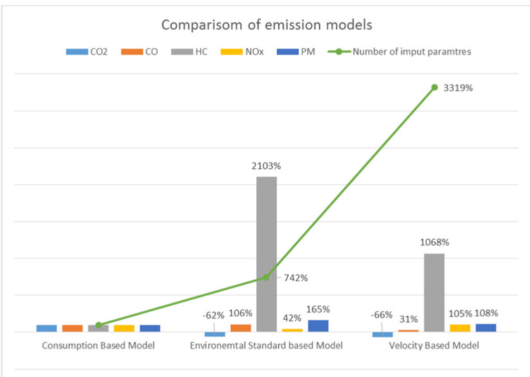

Figure 3: Comparison of input parameters (own edition).

The comparison of emission modelling shows that there is a direct relation between more detailed model and the lower amount of emitted greenhouse gases (GHG). Approximately 60 % of greenhouse gases (GHG) emission can be theoretically reduced only by using the velocity based modelling. In the case of other pollutants such as CO, HC and PM emission environmental class-based modelling had the largest result with significant differences compared to other models. This result probably could be derived from the old vehicle fleet in Hungary with the average 13.6 (2010) years. NO_x emission is continuously increasing with the increasing complexity.

Such phenomena could be derived from a more precise description of burning process in the engine. As it can be stated in these models the perfect burning was considered in terms of CO_2. With more accuracy modelling the CO_2 emission decreased while it leads to the increase of other pollutants.

Not only problem between different types of emission modelling but considerable differences were captured between laboratory tests and on-road measurements recently. European Environmental Agency reported in 2015 (European Environmental Agency, 2015) that the road transport sector emits around 40% of Europe's NO_x emissions, comprising a mixture of NO and NO_2. Although NO is not harmful to health at the concentrations typically found in the atmosphere, NO_2 is associated with a range of environmental and health problems. The emitted NO_x from vehicles, around 80 % comes from diesel-powered vehicles, for which the proportion of harmful NO_2 in the NO_x is far higher than the proportion found in the emissions from petrol vehicles. Over the past years, increasingly strict vehicle emission standards (i.e. the so-called 'Euro' standards) have been introduced in Europe in order to limit the amount of air pollution emitted by vehicles. In order to be placed on the EU market, vehicle models are first tested under laboratory conditions using a pre-defined 'test-cycle' and their emissions are measured. Recently, there has been increasing public attention on the current vehicle emissions testing regime. It is clear that both the on-road fuel consumption and emissions from European cars can be significantly higher than the official vehicle test measurements would indicate. The amount of fuel consumption by cars on the road, and subsequently the CO_2 emissions, can be 20–30 % higher than the official measurements. The differences are even higher for NO_x emissions, in particular for diesel vehicles. Real-life measurements have shown that NO_x emissions from diesel vehicles can be, on average, as much as four or five times higher under real driving conditions.

Petrol vehicles broadly meet the 'EURO' standards under real driving conditions. Such differences are attributable to a variety of factors, including the fact that the current laboratory test cycle used in Europe is not very representative of how people drive their cars in real life. Furthermore, current legislation affords manufacturers a number of flexibilities, which enable them to optimise vehicles for the testing procedure. In order to address these issues, Europe will change the test cycle used to measure vehicle emissions in the future to ensure that it better reflects real-world driving conditions and to remove many of the existing testing flexibilities. In addition, a new real driving emissions testing procedure will shortly be implemented, which will also provide a valuable assessment of the NOx levels during the on-road performance of vehicles compared with laboratory testing.

4 ANALYSIS AND DISCUSSION

Scientists using road transport related emission modelling in the last couple of decades. New methods are introduced not only in measurement but in modelling as well. In this paper, three different modelling approaches were compared to each other in order to reveal the differences between model families. According to the results, it can be stated that the different emission model could cause significant differences in emission.

European Environmental Agency stated (European Environmental Agency, 2015) that transport contribute to Europe's air pollution. Emissions of the main air pollutants in Europe have declined since 1990, resulting in generally improved air quality across the region. However, transportation has not sufficiently reduced its emissions in order to meet air quality standards or have even increased emissions of some pollutants. For example, emissions of nitrogen oxides (NO_x) from road transport have not sufficiently decreased to meet air quality standards in many urban areas.

The key question would be the way of estimation behind this statement without questioning the rightness of pollutant decreasing.

5 CONCLUSIONS

In this paper, three different road transport emission model with different complexity and data requirements were compared with each other using Top-down equation description in order to find out how the improvement in emission modelling influences the results. This comparison showed that there is a direct relation between more detailed model and the lower amount of emitted greenhouse gases (GHG). Using velocity based modelling showed that around 60 % of greenhouse gases emission can be theoretically reduced. On the other hand, using environmental class-based modelling showed the largest result with significant differences relating to CO, HC and PM compared to the other models. It should be mentioned that NO_x emission increased continuously with increasing complexity of the models.

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