“Environmental Engineering” 10th International Conference
Vilnius Gediminas Technical University
Lithuania, 27–28 April 2017
http://enviro.vgtu.lt

eISSN 2029-7092 / eISBN 978-609-476-044-0

Article ID: enviro.2017.156
DOI: https://doi.org/10.3846/enviro.2017.156

Analysis of Calculation Methods for Life Cycle Greenhouse Gas Emissions for Road Sector

Viktoras Vorobjovas[1], Algirdas Motiejūnas[2], Tomas Ratkevičius[3], Alvydas Zagorskis[4], Vaidotas Danila[5]

[1, 2, 3]Road Research Institute of Faculty of Environmental Engineering, Vilnius Gediminas Technical University, Vilnius, Lithuania
[4, 5]Research Institute of Environmental Protection, Faculty of Environmental Engineering, Vilnius Gediminas Technical University, Vilnius, Lithuania
E-mails: [1]viktoras.vorobjovas@vgtu.lt (corresponding author); [2]algirdas.motiejunas@vgtu.lt; [3]tomas.ratkevicius@vgtu.lt; [4]alvydas.zagorskis@vgtu.lt; [5]vaidotas.danila@vgtu.lt

Abstract. Climate change is one of the main nowadays problem in the world. The politics and strategies for climate change and tools for reduction of greenhouse gas (GHG) emissions and green technologies are created and implemented. Mainly it is focused on energy, transport and construction sectors, which are related and plays a significant role in the roads life cycle. Most of the carbon footprint emissions are generated by transport. The remaining emissions are generated during the road life cycle. Therefore, European and other countries use methods to calculate GHG emissions and evaluate the impact of road construction methods and technologies on the environment. Software tools for calculation GHG emissions are complicated, and it is not entirely clear what GHG emission amounts generate during different stages of road life cycle. Thus, the precision of the obtained results are often dependent on the sources and quantities of data, assumptions, and hypothesis. The use of more accurate and efficient calculation-evaluation methods could let to determine in which stages of road life cycle the largest carbon footprint emissions are generated, what advanced road construction methods and technologies could be used. Also, the road service life could be extended, the consumption of raw materials, repair, and maintenance costs could be reduced. Therefore the time-savings could be improved, and the impact on the environment could be reduced using these GHG calculation-evaluation methods.

Keywords: life cycle analysis (LCA), greenhouse gas (GHG), carbon footprint, emission calculator.

Conference topic: Roads and railways.

Introduction

In all civilized world countries, climate change seems like a global problem that needs to be solved immediately in all human activities. Suitable solutions can be adopted only in cooperation with countries on a global scale. Also, the efficiency of energy use should be increased, the clean technologies expanded and stimulated and greenhouse gas (GHG) emissions reduced.

In period 2021–2050 the EU Member States, including Lithuania, has committed itself to reduce GHG emissions not less than 80% comparing with the level of 1990 (Fig. 1). The reduction of GHG emissions should be based on a low-carbon economy (EC 2014). In EU countries, about 30% of total GHG emission is generated from the energy sector, 20% – from transport and 12% – from manufacturing industries and construction according to 2014 data (Fig. 2). For comparison, in Lithuania energy industries amounted about 55.4% of total GHG emission, agriculture – 23.1%, industry – 15.7% and waste sector – 5.8% during 2014 (EPA 2016). The main sectors of energy consumption are energy production and transport, which in 2014 accounted 16.0% and 25.7% of the total GHG emissions respectively (Fig. 3).

In 2014 the total GHG emission in Lithuania amounted to 19.690 kt CO_2 eq. The emission has decreased by 58.8% comparing with 1990. GHG consists predominantly of carbon dioxide (CO_2), the amount of which accounted for 65.1% in 2013, followed by methane (CH_4) – 17.6% and nitrous oxide (N_2O) – 15.7%. Fluorinated gases (HFCs, SF_6, and NF_3) together accounted for only 1.6% of total Lithuania GHG emissions (EPA 2016) (Fig. 4).

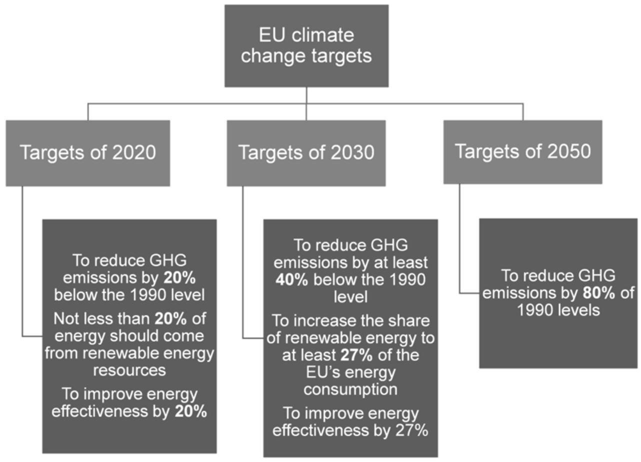

Fig. 1. Targets of EU climate change of 2020, 2030, and 2050 (EC 2014)

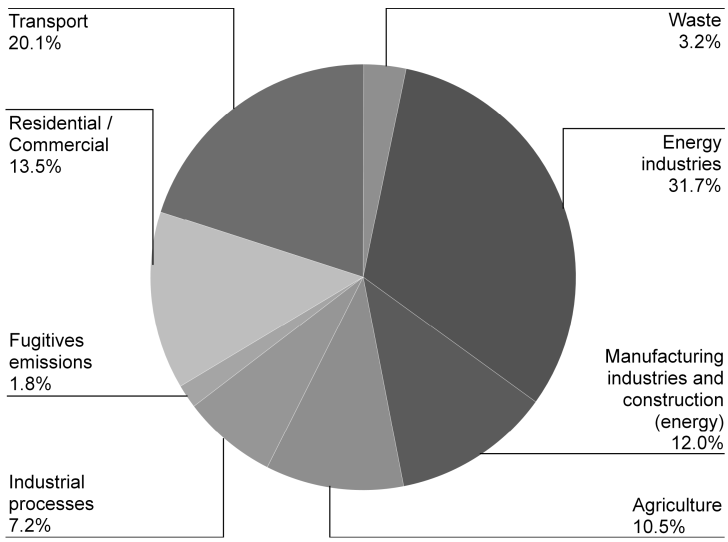

Fig. 2. EU Member States total GHG emissions from different sectors in 2012 (EC 2014)

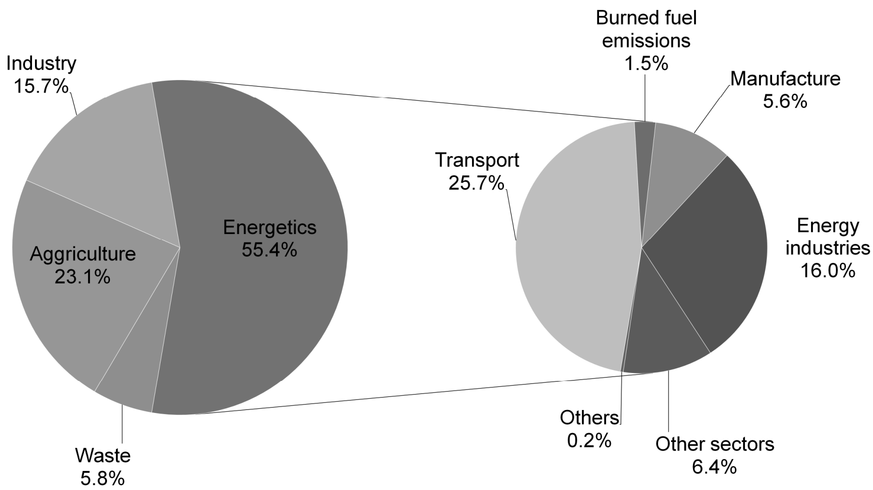

Fig. 3. Lithuanian total GHG emissions from various sectors in 2014 (EPA 2016)

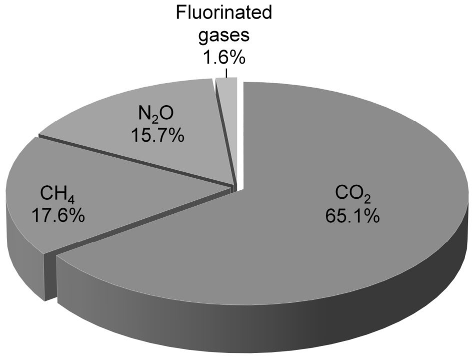

Fig. 4. The composition of Lithuanian GHG in 2013 (EPA 2016)

GHG emissions in road life-cycle

In the road transport sector, the major part of the carbon footprint emissions is generated by vehicles. Road transport accounts about 20% of the CO_2 emissions of GHG. These emissions, like carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other GHG, which contribute directly to climate change, generates during combustion of different fuel types. Other emissions are generated during various stages of road pavement life-cycle: extraction of raw materials and transportation to plant, production of materials and asphalt mixtures, and their transportation to the construction site, construction process, maintenance and repair of the road, demolition and transportation of waste materials, waste recycling and disposal (Fig. 5).

At the moment it is not clear what amount of CO_2 and GHG emission is generated during different stages of road pavement life-cycle. Therefore, EU countries and other advanced countries of the world develops CO_2 or carbon footprint calculation and evaluation methods/tools. These methods allow evaluating the impact of the different road building materials and technologies on the environment taking into account CO_2 and GHG emissions in total road life-cycle.

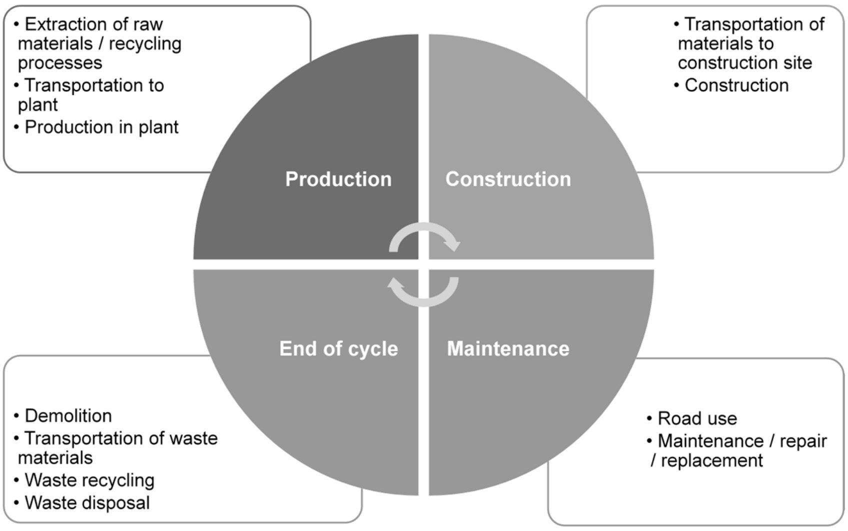

Fig. 5. Stages of road life-cycle

GHG emissions calculation methods for road sector

In the modern world, many tools for assessment of road design sustainability are used regarding ecology balance. According to European standard EN 15804:2012 *Sustainability of Construction Works, Environmental Product Declarations, Core Rules for the Product Category of Construction Products* the life-cycle of construction product is divided into stages. However, this distribution is generic and applies to all construction products. Nowadays there are some doubts about these steps. There are no clear agreements between Europe and other modern world countries, e.g. in some countries, the life-cycle of concrete pavement is divided into ten stages, while in the others the life-cycle of asphalt concrete pavement consists of four stages including maintenance. In 2015 National Centre for Sustainable Transportation (USA) carried out the research "*The Role of Life Cycle Assessment in Reducing Greenhouse Gas Emissions from Road Construction and Maintenance*", in which the role of each road life-cycle stages was determined in reducing GHG emissions. Therefore, the scheme of different road life-cycle stages was prepared, which has been divided into four major parts (Harvey *et al.* 2015):

– material production;
– construction, preservation, maintenance, rehabilitation;
– use phase;
– end-of-life.

Each process and technology used in material production and applied from road construction till end-of-life must be accurately assessed for calculation of carbon footprint emissions which generates during road life-cycle. Currently, a lot of carbon footprint calculation tools are being used in the world. In this paper, the analysed carbon footprint calculation tools are presented in Table 1.

Table 1. Carbon footprint calculation tools selected for analysis

Abbreviation	Name	Year	Developer
ECORCE	ECOcomparateur Route Con-	2013	IFSTTAR, France
GHGC	GreenHouse Gas Calculator	2012	NAPA, USA
DUBOCALC	DUurzaam BOuwen CALCulator	2014	RWS (Dutch Ministry of Infra-structure and Environment), Netherlands
asPECT	Asphalt Pavement Embodied Carbon Tool	2014	TRL, UK
HACCT	Highway Agency Carbon Calculator Tool	2013	UK Highway Agency
PALATE	Pavement Life-cycle Assessment Tool for Environmental and economic effects	2011	University of California, USA
LICCER	Life Cycle Considerations in EIA of Road Infrastructure	2016	Norway

Each carbon footprint calculation tool is different according to applicability regarding road life-cycle. These tools differ regarding (Gallivan *et al.* 2010; Highways England 2015; Hu *et al.* 2015; De Lange *et al.* 2016; Miliutenko *et al.* 2014; Mukherjee, Cass 2011, 2012; Potting *et al.* 2013; Virtanen 2011):

1. The goal and purpose of the application, e. g.:
   – ECORCE, design oriented;
   – GHGC, asphalt plant oriented;
   – DUBOCALC, construction process oriented;
   – asPECT, life cycle oriented.
2. The output data. CO_2 is one of the GHG components. Commonly all amounts of GHG components emissions (CO_2, CH_4, N_2O, HFCs, SF_6, and NF_3) are assessed, and these GHG emissions are usually expressed in CO_{2e}, as CO_2 equivalent emissions, e. g.:
   – HACCT, output CO_2;
   – asPECT, output CO_{2e};
   – GHGC, output CO_{2e}.
3. Adaptation options, e. g.:
   – DUBOCALC. By using this tool the environmental cost indicator (ECI) is obtained, that shows the impact of the civil engineering activities on the environment. DUBOCALC program allows to choose the mode of materials transportation, modify asphalt type, characteristics of materials and energy consumption during asphalt production. The advantages of DUBOCALC calculation tool are that it allows to quantitatively evaluate the different road construction designs and the ecological balance of the project alternatives; allows objectively, within limits set by the database, to assess the environmental sustainability of the planned project. The disadvantages of DUBOCALC calculation tool are that selected materials are restricted to standard formulas used in the Netherlands. The program is adapted only for the Dutch market. Calculations in the tool can only be made using the existing materials. The impact of innovative techniques and products cannot be calculated (Keijzer *et al.* 2015).
   – GHGC. It focuses on energy use in the plant but is not suitable to compare different asphalt mixes along their lifetime.

- asPECT. It is limited to asphalt pavements. asPECT customisable approach to recycling/recyclability is also available. Users can specify an allocation between the recycled method and the recyclability method, or somewhere in between.
- PALATE. Having a quantitative part within a project sustainability evaluation tool as GreenRoads PALATE has as drawbacks or inconveniences.
- LICCER. The tool is based on standard ISO 14040, Figure 6. The life-cycle of the road in LICCER includes GHG emissions and environmental impact from raw materials stage to its demolition (waste disposal) stage (Huang *et al.* 2015). LICCER model is specifically designed for use from the road planning stage. In this stage, planning decisions can be changed according to the model results. The LICCER model can be used to calculate the choice of route selection and the choice between different construction types (e. g. bridges, road, tunnel) (Huang *et al*. 2015). The model is developed on Excel basis. Using LICCER model it is possible to calculate GHG emissions (CO_{2e}) in all life cycle stages of the road. The model includes the contribution of the vehicles and road engineering facilities to GHG emissions. The model evaluates the chosen length of road section within a specified number of years. LICCER model can calculate annual generation of GHG emissions. The model can assess the impact of the traffic flow not through the entire user-specified period (for example, 30 years), but through smaller one-year periods, and the impact of the final result can be summed up. Default values of greenhouse gas emissions are taken directly from EFFEKT database. According to the obtained calculations using LICCER model, it is possible to make necessary decisions on possible construction alternatives in the planning stage. The model provides the opportunity to look how the different types of raw materials will result in some emissions and to evaluate what alternative would be more friendly to the environment (Miliutenko *et al.* 2014). The advantages of this calculation tool are that LICCER model is complex and quite simple to use, easily adapted to different types of roads, provides the opportunity to compare GHG emissions and energy consumptions of various alternatives. The disadvantage of the tool is that LICCER model does not include emissions due to waste recycling and waste disposal. The model is more adapted for the Scandinavian market (Potting *et al.* 2013).

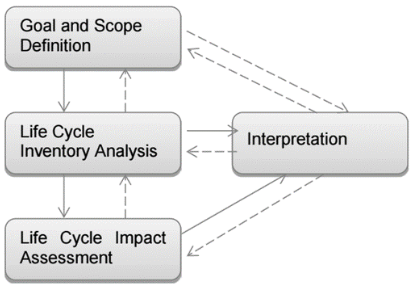

Fig. 6. LICCER model structure (Potting *et al.* 2013)

Many GHG calculation tools used for the calculation of emissions during life-cycle of the road are based on Excel spreadsheet. In this way, it is possible to introduce a large amount of data, which will help to calculate GHG emissions in the whole road life-cycle or at individual stages.

The precision of obtained results depends on the amount of uploaded data, their accuracy and made assumptions. When analyzing selected different software tools, it is necessary to evaluate data sources used in calculation tools and chosen default values. It is important because even if same data were entered to the calculation tools, obtained results would be different. It can be partly explained by the fact, that in the carbon footprint calculation tools different carbon factors are used. Also, the stages of road life cycle and relation between them are not the same. Carbon footprint calculation tools provide different output results because different methodologies, as well as parameters of used materials and with them related carbon factors, are used.

Although the quantity of GHG emission estimation methodologies of all road life-cycle stages is large enough, the simplified method is most commonly used: to assess the overall emissions of the greenhouse gases accurately; it is necessary to evaluate these factors: fuel used, materials, transportation distance, and waste treatment. Conversion factors (carbon factors) are used adding these factors to the overall calculations. Carbon factors are determined by various institutions (DEFRA, BATH, ECOINVENT), which help to estimate the amount of GHG and at the same enables to assess an impact to the environment by knowing which type of the activities have the biggest contribution to the overall carbon footprint.

The general formula applied in the calculation tools and used to estimate CO_2e emissions:

$$CO_2e = the\_quantity\_of\_the\_activity \times EF, \quad (1)$$

where CO_2e – carbon dioxide equivalent for the type of the activity, tCO_2e/the given period; EF – emission factor.

Calculation tools include *CO_2e* emissions from different type of sources: 1) materials (the units depend on the type of used material – t, kg, m, m²), 2) fuel used (l; kg) in the construction process, 3) electricity used (kWh), 4) transportation of the materials and waste (tkm). The unit of emission factors depend on the type of activity: tCO2e/t – for the use of materials, kgCO_2e/km – for personal travel, kgCO_2e/kg – for the use of the fuel, kgCO_2e/kWh – for the use of electricity, tCO_2e/tkm – for the transportation of materials.

Conclusions

1. Analysis of the GHG calculation tools and methods that evaluate carbon footprint during the road life-cycle suggests that carbon calculation tools are sophisticated. The precision of the obtained results depends on the range of data uploaded into the tool, their values, made assumptions and hypotheses.
2. When selecting and evaluating the GHG calculation tools, it is necessary to compare the sources of data used in the tool, the possibility to change them and for which country the tool is adapted.
3. GHG calculation tools differ regarding the goal and purpose of the application, the output data, their adaptation options, and procedures.
4. All GHG calculation tools have deficiencies, like:
   - none of the analysed tools does connect the use of road phase with transport impact on road pavement;
   - it is known that road parameters, pavement condition or driving speed limits impacts on the generation of GHG emission, but it is not accounted in GHG calculation tools.
   - only one of analysed GHG calculation tools (asPECT) allows assessing the benefits or losses during all road life-cycle or outside of it.
5. Sustainable road pavements, innovative road construction technologies, high-quality materials and their processing for reuse, and efficient GHG calculation tools are the main issues which would allow significantly reduce amounts of GHG emissions.

References

De Lange, G.; Van Meerten, H.; Lelieveld, C.; De Vries, B.; Van Zomeren, A.; Rover, V.; Visser, J.; De Vos, S. 2016. *Climate Resilience and Circularity in Construction assignments* [online]. Part of report in work package 4 "Construction assignments" in the Adaptive Circular City project. Netherlands [cited 11 June 2016]. Available from Internet: ftp://ftp.ecn.nl/pub/www/library/report/2016/o16018.pdf

EPA. 2016. *Lithuania's national inventory report 2016. Greenhouse gas emissions 1990–2014* [online]. The Environmental Protection Agency [cited 29 December 2016]. Available from Internet: http://klimatas.gamta.lt/files/NIR_2016_04_15_FINAL.pdf

EC. 2014. *Climate Change* [online]. European Commission [cited 11 October 2015]. Available from Internet: http://ec.europa.eu/clima/publications/docs/factsheet_climate_change_2014_en.pdf

EN 15804:2012. *Sustainability of Construction Works, Environmental Product Declarations, Core Rules for the Product Category of Construction Products.*

Gallivan, F.; Ang-Olson, J.; Papson, A.; Venner, M. 2010. *Greenhouse gas mitigation measures for transportation construction, maintenance, and operations activities*. Part of NCHRP Project 25-25, Task 58, National Cooperative Highway Research Program, Transportation Research Board, San Francisco, CA.

Harvey, J.; Kendall, A.; Saboori, A. 2015. *The role of life cycle assessment in reducing greenhouse gas emissions from road construction and maintenance* [online]. Institute of Transportation Studies of University of California [cited 11 June 2016]. Available from Internet: https://ncst.ucdavis.edu/wp-content/uploads/2014/08/07-07-2015-NCST-Pavement-LCA-Policy-Brief-FINAL.pdf

Highways England. 2015. *Highways England Carbon Tool Guidance* [online]. UK Government [cited 22 December 2016]. Available from Internet: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/453177/Task_446_Guidance_Document.pdf

Huang, L.; Bohne, R. A.; Bruland, A.; Jakobsen, P. D., Lohne, J. 2015. Life cycle assessment of Norwegian road tunnel, *The International Journal of Life Cycle Assessment* 20(2): 174–184. https://doi.org/10.1007/s11367-014-0823-1

Hu, H.; Baek, J.; Lee, G.; Noh, K. 2015. Feasibility Check for Carbon Emissions Estimation Method of G-TIES, *International Journal of Environmental Science and Development* 6(10): 750–754. https://doi.org/10.7763/IJESD.2015.V6.693

Keijzer, E. E.; Leegwater, G. A.; de Vos-Effting, S. E.; de Wit, M. S. 2015. Carbon footprint comparison of innovative techniques in the construction and maintenance of road infrastructure in The Netherlands, *Environmental Science & Policy* 54: 218–225. https://doi.org/10.1016/j.envsci.2015.06.010

Miliutenko, S.; Kluts, I.; Lundberg, K.; Toller, S.; Brattebø, H.; Birgisdóttir, H.; Potting, J. 2014. Consideration of life cycle energy use and greenhouse gas emissions in road infrastructure planning processes: examples of Sweden, Norway, Denmark and The Netherlands, *Journal of Environmental Assessment Policy and Management* 16(04). 26 p. https://doi.org/10.1142/S1464333214500380

Mukherjee, A; Cass, D. 2011. *Carbon footprint for HMA and PCC pavements*. Michigan Tech Transportation Institute of Civil and Environmental Engineering Department of Michigan Technological University. Report for Michigan Department for Transportation [online], [cited 11 June 2016]. Available from Internet: https://www.michigan.gov/documents/mdot/MDOT_Research__Report_RC-1553_363800_7.pdf

Mukherjee, A.; Cass, D. 2012. Project emissions estimator: implementation of a project-based framework for monitoring the greenhouse gas emissions of pavement, *Transportation Research Record: Journal of the Transportation Research Board* 2282: 91–99. https://doi.org/10.3141/2282-10

Potting, J.; Brattebo, H.; Birgisdottir, H.; Lundberg, K. 2013. *LICCER Model Case Study Report* [online]. Conference of European Directors of Roads [cited 11 June 2016]. Available from Internet:http://www.cedr.eu/download/other_public_files/research_programme/eranet_road/call_2011/energy/liccer/04_liccer_d4.1_guideline-report.pdf

Virtanen, M. 2011. *Choosing the optimal energy system for buildings and districts*: Master's thesis. Lappeenranta University of Technology.