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Comparison of Greenhouse Gas Emissions Associated with Reconstruction of Low-volume Road – Lithuania Case Study

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Abstract

Europe faces the ambition to drastically reduce greenhouse gas (GHG) emissions. In road sector, most of the carbon footprint emissions are generated by vehicles. The remaining emissions are generated during the different stages of road life cycle. Therefore, European and other countries use methods to calculate GHG emissions and evaluate the impact of road construction and maintenance methods, and technologies on the environment. In Lithuania there is a little experience in using such tools, but it has committed itself to reduce GHG emissions not less than 40% comparing with the level of 1990 till 2030. Different modern and innovative techniques are available in road construction and maintenance, but their contribution achieving national goals is unknown. The aim of this research is to compare GHG emissions associated with reconstruction of low-volume road using different construction techniques. Analytical analysis was performed using Highways England Carbon calculation tool. This study showed that soft asphalt and warm asphalt technologies are more efficient than hot asphalt in terms of GHG emissions, which are respectively lower by 20.3% and 5.2%.

Keywords: life cycle analysis (LCA); greenhouse gas (GHG); hot mix asphalt (HMA); warm mix asphalt (WMA); soft asphalt (SA).

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1. Introduction

One of the major global environmental issues is the climate change (Huang et al. 2013). European Union countries have committed themselves to the long-term goal of joint action to reduce their emissions by 80–95% by 2050 compared to 1990 levels (Oberthür 2011). The economy will have to become a low-carbon economy so that emissions of greenhouse gases (GHG) would be reduced significantly (Shimada et al. 2007).

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. 1). 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. 2).

Recently, GHG emissions for the construction of roads have been receiving increasing attention (Chehovits and Galehouse 2010). Emissions occur during raw materials extraction, their transportation and processing, road construction, maintenance (e.g. resurfacing) and demolition (Miliutenko et al. 2014).

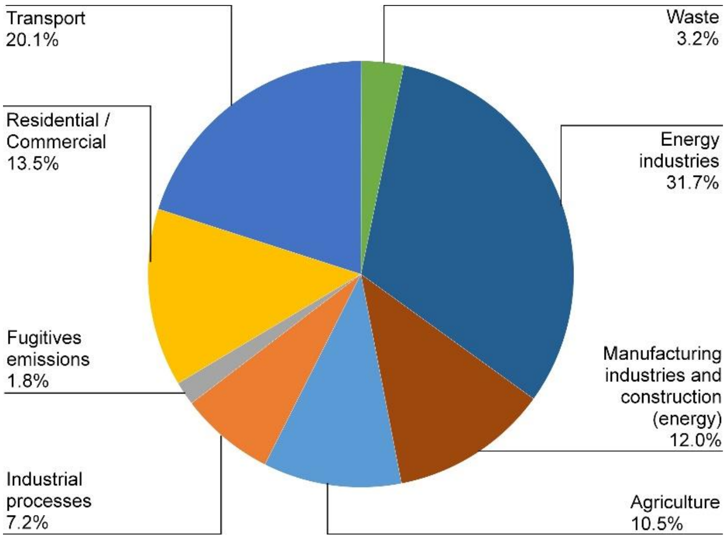

Fig. 1. EU Member States total GHG emissions from different sectors in 2012 (EC 2014)

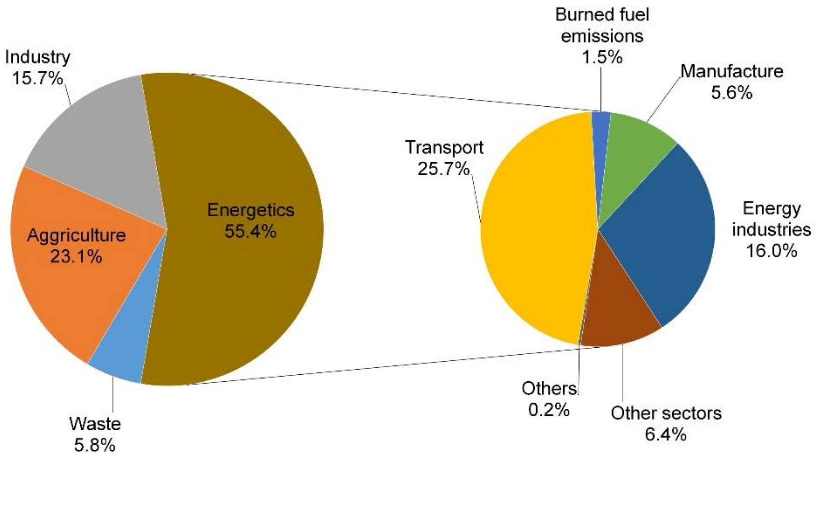

Fig. 2. Lithuanian total GHG emissions from various sectors in 2014 (EPA 2016)

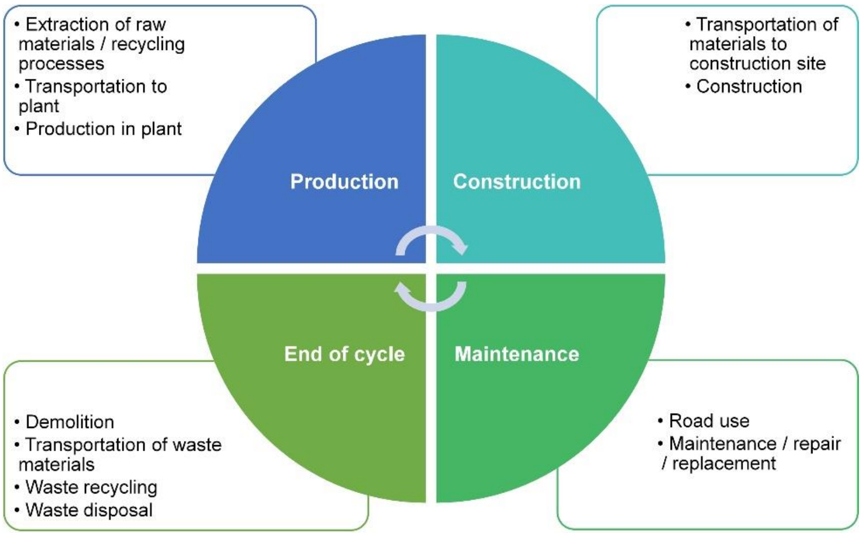

Fig. 3. Stages of road life-cycle

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 (Fig. 3).

Life Cycle Assessment (LCA) is one of the tools that can be used for assessing and estimating GHG emissions from road infrastructure. The life cycle of the road infrastructure can be divided into the stages according to the European standard EN 15643-2: A1 Raw material supply, A2 Transport to factory, A3 Manufacturing, A4 Materials transport to site, A5 Construction of the road, B1 Operation, B2 Maintenance, B3 Repair, B4 Reconstruction, C1 Deconstruction, C2 Waste transport, C3 Waste processing, C4 Disposal.

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. European and other modern countries creates and improves 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.

There are many carbon footprint calculation tools which are being used in the world to calculate emissions from roads' construction, e.g., ECORCE, DUBOCALC, asPECT, LICCER, PALATE and others (Vorobjovas et al. 2017). Previous research showed that asPECT GHG calculation tool allows assessing the benefits or losses during all road life-cycle or outside of it, but further analysis, when it was started to work with various GHG calculations tools, it was found that Highways England Carbon Tool (HECT) is a tool used to calculate CO_2e for road construction and maintenance activities. In this study it was HECT since it has very convenient structure, it is possible to introduce own emission factors. The tool has a wide range of materials needed for the road construction and maintenance. Also it is possible to calculate emissions due to the treatment of waste generated during road construction or maintenance. The disadvantage of HECT is that it does not include the end stage of road life cycle, i.e. demolition, waste transportation and waste treatment (Highways England… 2015). In addition, the materials emission factors used in the tool are general and technological data of their production cannot be introduced (e.g., different mixtures of asphalt, mixing temperature). Embodied carbon of the materials can be influenced by changing emission factors. The tool uses the Inventory of Carbon and Energy (ICE), Department for Environment Food & Rural Affairs (DEFRA), Waste & Resources Action Programme (WRAP) emission factors.

It is important to take into account the road category, as CO_2 emissions generated during the installation of the road depends on it. Different road categories have different geometrical parameters of the road track, the type of the pavement, the design and operation of the pavement. According to the World Bank data (Deng 2010) the installation of 1 km long road generates different CO_2 emissions which depend on the type of the road. Tables 1–3 shows GHG emissions of various road categories.

Table 1. Typical GHG emissions of various road categories (Deng 2010)

	Highway	National Road	Main Road	Regional Road - Gravel
Emission (CO_2e t/km)	3234	794	207	90

Table 2. Generated CO_2e emissions by work items for various roads (Deng 2010)

Generated CO_2 e emissions (CO_2e t/km)	Highway	National Road	Main Road	Regional Road - Gravel
Earthworks	161.40	15.89	12.00	2.74
Installation of pavement	1333.86	424.66	157.30	72.20
Installation of culverts	238.48	51.45	16.69	11.85
Installation of road structures	1067.99	119.39	20.57	3.03
Installation of road facilities	432.40	182.42	0.00	0.00
Total	3234.12	793.81	206.56	89.82

Table 3. Distribution of generated CO_2e emissions for various roads (Deng 2010)

CO_2 emissions (CO_2e t/km)	Transportation emissions	Material emissions	Machines emissions	Total
Highway	1003.71	2121.83	108.58	3234.12
National Road	235.00	522.62	36.19	793.81
Main Road	66.08	111.52	28.96	206.56
Regional Road - Gravel	19.83	55.51	14.48	89.82

During the construction of highways, CO_2e emissions from installation of structures and road facilities account for 46.4% of total emissions, however, during the construction of other roads, emissions from the installation of road pavement account for more than 50.0% of total CO_2e emissions. Therefore, the choice of road paving technology is very important in order to reduce GHG emissions.

The production of hot-mix asphalt (HMA) for pavements generates a significant part of GHG emissions. Emissions are caused by drying and heating mineral aggregates, and bitumen at temperatures above 140 °C. Warm mix asphalt (WMA) technology requires lower production temperature, which results in lower CO_2e emissions. The production temperature of this technology is typically 30 °C lower (Capitão et al. 2012; Vaitkus and Vorobjovas 2014).

The aim of this paper is to calculate GHG emissions evaluating low-volume road reconstruction project and using conventional and CO_2e emissions reducing road construction technologies applying Highways England Carbon Tool v1.03.

2. Low-volume road reconstruction project

33.4% of the total road network of Lithuania is composed of gravel roads (Lithuanian Road Administration… 2017). Every year it is planned to pave about 450 km of regional gravel roads until 2020 (Vaitkus et al. 2017).

Goal and scope. The goal of the study was to calculate and compare GHG emissions from three different low-volume road reconstruction technologies.

Three different asphalt pavement technologies were used in the calculations:

1) Typical (conventional) hot mix asphalt concrete AC 16 PD, which works as wearing and base layer at the same time. Asphalt pavement thickness is 10 cm.
2) Warm mix asphalt concrete AC 16 PD WMA. The type and characteristics of asphalt concrete mixture are the same as AC 16 PD, except that the mixing temperature is about 30 °C lower. Warm mix asphalt (WMA)

technology requires lower production temperature, which results in lower CO_2e emissions. The production temperature of this technology is typically 30 °C lower (Vaitkus et al. 2016).

3) Soft asphalt SA 16-d-V6000 type C. Soft asphalt (SA) is commonly made of mineral material mixture, filler aggregate and binder – soft bitumen. Thus, the mixing temperature of soft asphalt is 30–40 °C lower comparing to conventional hot mix asphalt technology and this let to reduce CO_2e emissions (Vaitkus and Vorobjovas 2014). Also, the thickness of soft asphalt layer is 4.5 cm (less material is required) and frost blanket course is not required.

Only asphalt technologies were different, the rest part of the road reconstruction was the same.

Functional unit. In this study the project "Reconstruction of regional road No. 3816 Karčrūdė–Jankai–Baltrušiai section from 7.039 km to 9.139 km" (2.1 km length, 6 m pavement width) was selected and GHG emissions were calculated using HECT tool.

System boundary. This road reconstruction project can be treated as the new road construction project. Analysis of GHG emissions consisted of the materials production, their transport to the site and construction stages, i.e. A1, A2, A3, A4, A5, B2 and B3. Maintenance of this road was not analysed because low-volume roads with SA pavement were constructed 4 years ago and there are not enough data about how this pavement works during design life.

Inventory analysis. HECT tool requires to enter data and activities for 10 categories: 1. bulk materials; 2. earthworks; 3. fencing, barriers and road restraint systems; 4. drainage; 5. road pavements; 6. street facilities and electrical equipment; 7. civil structures and retaining walls; 8. fuel, electricity and water; 9. business and employee transport; 10. waste. In the tool, categories 1–7 are considered as materials and categories 8–10 are considered as non-materials.

The tool calculates all carbon emissions from different types of the activities according to the following formula:

$$CO_2e = the\_quantity\_of\_the\_activity \times EF \times conversion\_factor \,, \qquad (1)$$

where *conversion_factor* – a value, which converts the measuring unit (and at the same time quantity) of the activity to the appropriate one; *EF* – emission factor.

Materials. HECT uses the ICE embodied carbon database for building materials. The boundaries within the ICE database are cradle-to-gate so given emission factors of the materials already include stages A1, A2 and A3. Only quantities of the materials are needed to include into the tool. The quantities of the asphalt and other materials used in the calculations are presented in Table 4 and Table 5.

Transport of materials. It was assumed that the transportation distance of all materials to the project site is 20 km.

Construction.
The analysed reconstruction project consists of the following stages:

1) Preparation works:
   - Wood felling (54 units). For wood felling chainsaw fueled by petrol is used;
   - Stump extraction (54 units). For stumps extraction excavator fueled by petrol is used;
   - Mechanized milling of old asphalt pavement (in joints); loading milled asphalt to heavy goods vehicle and transportation at 20 km distance;
   - Cutting joints in asphalt pavement;
   - Disassembly of the existing concrete culverts; loading them to vehicles and transportation at 20 km distance);
2) Earthworks:
   - Removal of gravel pavement top layer by bulldozers up to 20 m distance;
   - Excavations (4642.7 m³);
   - Embankment preparation (212.0 m³);
   - Grading of the bottom of excavations and the top of embankments using graders (20812.9 m²). Graders are fueled by diesel (20 l/h);

- Grading of the slopes and the bottom of the ditch using bulldozers (11451.3 m²). Bulldozers are fueled by diesel (11 l/h);
- Grading of areas using graders (4428.4 m²). Graders are fueled by diesel (20 l/h);
- Strengthening the bottoms of road ditches using fractional gravel (265.7 m²);

3) Road pavement construction:
   - Installation of frost blanket course (except Soft asphalt technology);
   - Installation of unbound base course;
   - Installation of asphalt pavement (13638.9 m²);
   - Installation of 8 cm thickness shoulders consisting of gravel (80%) and sand (20%) mixture;
4) Road signs installation;
5) Drainage.

The parameters of three asphalt technologies used in the calculations are presented in Table 6.

Table 4. The amount asphalt needed for different asphalt technologies

Parameter	Asphalt pavement technologies		
	Typical (conventional) hot mix asphalt concrete AC 16 PD	Warm mix asphalt concrete AC 16 PD WMA	Soft asphalt SA 16-d-V6000 type C
The amount of asphalt (4% binder content, by mass), t	3041.51	3041.51	1368.68

Table 5. The quantities of materials used in the calculation

Material	Preparation works	Earthworks	Road pavement construction	Road signs installation	Drainage
Fill / aggregate (gravel, crushed stone), t	-	4.62	5242.64	-	-
Soil, t	-	-	9340.40	-	-
Steel pillars (for traffic signs), t	-	-	-	0.072	-
Monolithic concrete (traffic signs foundations), m³	-	-	-	0.067	-
Aluminium traffic signs, m²	-	-	-	8.58	-
Plastic signal columns, ps.	-	-	-	121.00	-
Plastic road culverts, m	-	-	-	-	213.00
PVC cable protection, m	-	-	-	-	346.00
Drainage pipes with geotextile filter, m/m²	-	-	-	-	311.00 /124.09
Drainage collectors, m	-	-	-	-	33.00
Plastic inspection chambers, ps.	-	-	-	-	12.00

Table 6. The amount of fuel and asphalt production, emission factors needed for different asphalt technologies

Parameter	Asphalt pavement technologies		
	Typical (conventional) hot mix asphalt concrete AC 16 PD	Warm mix asphalt concrete AC 16 PD WMA	Soft asphalt SA 16-d-V6000 type C
Asphalt thickness, cm	10	10	4.5
Mixing temperature, °C	150–170	120–140	110–130
CO_2e emission factor, tCO_2e/t	0.071	0.062	0.062
Working time for asphalt laying, hours	3.38	3.38	1.52
Fuel (diesel) for asphalt laying, L	118.3	118.3	53.2
Working time of drum rollers, hours	1.1	1.1	1.1
Fuel (diesel) for drum rollers, L	8.36	8.36	8.36
Total fuel (diesel) for asphalt laying, L	133.42	133.42	64.82

Table 7. Fuel consumption in the analysed road project

Construction stages	Asphalt pavement technologies					
	Typical (conventional) hot mix asphalt concrete AC 16 PD		Warm mix asphalt concrete AC 16 PD WMA		Soft asphalt SA 16-d-V6000 type C	
	Petrol, l	Diesel, l	Petrol, l	Diesel, l	Petrol, l	Diesel, l
Preparation works	36.96	78.45	36.96	78.45	36.96	78.45
Earthworks	0.00	11025.25	0.00	11025.25	0.00	11025.25
Road pavement construction	7.70	220.90	7.70	220.90	7.70	152.30
Road signs installation	0.00	0.00	0.00	0.00	0.00	0.00
Drainage	0.00	18.27	0.00	18.27	0.00	18.27
The total amount of fuel, l	44.66	11342.87	44.66	11342.87	44.66	11274.27

Typical CO_2e emission factor used in the calculation tool is taken from the ICE database and is equal to 0.071 tCO_2e/t for asphalt mixture with 5% bitumen. Van der Zwan (2012) presented the carbon footprint of asphalt construction in percentage values: production and transport of raw materials – 44%, asphalt production – 31%, laying and compaction – 18%, maintenance (excluding materials) – 7%. Considering the percentage values, the ratio of production and transportation of raw materials and asphalt production is 1.42:1. It is assumed that the production of asphalt at a lower temperature reduces CO_2e emissions by 30% or 40%, respectively for WMA and SA. Thus, the ratio of production and transportation of raw materials and asphalt production is 1.42:0.7 for WMA and 1.42:0.6 for SA. Then, the CO_2e emission factor becomes 9.3% lower and equals to 0.064 tCO_2e/t for WMA, for SA – 12.4% lower and equals to 0.062 tCO_2e/t.

In Table 7 there are presented the quantities of needed petrol and diesel in the different stages of the analysed project. Total quantities of petrol and diesel were introduced in the calculation tool. Lithuanian national emission factors were calculated according to the data provided in the Lithuania's national inventory of greenhouse gas emissions report. As the HECT tool does not requires to input emission factors CO_2e, CO_2, CH_4 and N_2O separately, so these emission factors were summed. Obtained values were 75.83 $kgCO_2e/GJ$ and 81.28 $kgCO_2e/GJ$ respectively for petrol and diesel. These values were converted to 2.55 $kgCO_2e/l$ for petrol and to 3.01 $kgCO_2e/l$ for diesel by using the calorific values provided in Lithuania's national inventory of greenhouse gas emissions report and densities of 750 kg/m^3 and 860 kg/m^3 respectively.

3. Emissions associated with materials and construction equipment

The quantities of materials, fuel, waste and their transportation distance were inputted into the HECT tool and output data were calculated. The results of the road reconstruction project using three different asphalt technologies are presented in Table 8 and Table 9.

It was determined that the greatest GHG emissions are when typical hot mix asphalt concrete AC 16 PD is used and are equal to 638.81 tCO_2e. In case of using warm mix asphalt concrete AC 16 PD WMA GHG emissions are 4.5% lower and reach 609.964 tCO_2e. The lowest calculated GHG emissions are in the case of using soft asphalt mix SA 16-d-V6000 type C and are equal to 492.743 tCO_2e or 22.87% lower compared to the emissions obtained in case of using typical asphalt concrete technology. Such significant reduction in CO_2e emissions was due to the fact that the soft asphalt technology uses less asphalt (thickness is only 4.5 cm) and also less fuel was needed for laying it. In addition, emissions are lower, as the mixing temperature of soft asphalt is lower and the production of it generates less CO_2e emissions.

It was determined that production of asphalt concrete generates one of the largest part of CO_2e emissions: in the case of typical technology, it makes 120.840 tCO_2e/km (Table 8). In the case of warm mix asphalt concrete technology, CO_2e emissions are 11.3% lower, i.e. 107.162 tCO_2e/km, while using soft asphalt technology CO_2e emissions are 54.2% lower comparing to typical asphalt concrete technology and reach 55.339 tCO_2e/km.

Table 8. Results of calculation GHG emissions of the project using three different asphalt technologies (tCO_2e)

CO_2e emissions sources	Typical (conventional) hot mix asphalt concrete AC 16 PD		Warm mix asphalt concrete AC 16 PD WMA		Soft asphalt SA 16-d-V6000 type C	
	Total	1 km	Total	1 km	Total	1 km
Material and fuel transport to the site	78.228	37.092	78.228	37.092	70.509	33.432
Waste transport from site	0.158	0.075	0.158	0.075	0.158	0.075
Total emissions due to materials (includes A1, A2, A3 stages)	514.021	243.729	485.155	230.042	375.879	178.228
Bulk materials	*254.868*	*120.848*	*226.002*	*107.161*	*116.726*	*55.347*
Earthworks	*224.572*	*106.483*	*224.572*	*106.483*	*224.572*	*106.483*
Fencing, Barriers and Road Restraint Systems	*0*	*0*	*0*	*0*	*0*	*0*
Drainage	*28.416*	*13.474*	*28.416*	*13.474*	*28.416*	*13.474*
Road Pavements	*0*	*0*	*0*	*0*	*0*	*0*
Street Furniture and Electrical Equipment	*6.054*	*2.871*	*6.054*	*2.871*	*6.054*	*2.871*
Civil Structures and Retaining Walls	*0.111*	*0.053*	*0.111*	*0.053*	*0.111*	*0.053*
Fuel, Electricity and Water	34.265	16.247	34.265	16.247	34.058	16.149
Business and Employee Transport	10.925	5.180	10.925	5.180	10.925	5.180
Waste	1.213	0.575	1.213	0.575	1.213	0.575
Total:	638.810	302.897	609.964	289.220	492.743	233.638

Table 9. GHG emissions from bulk materials in different cases (tCO_2e)

Bulk materials	Typical (conventional) hot mix asphalt concrete AC 16 PD		Warm mix asphalt concrete AC 16 PD WMA		Soft asphalt SA 16-d-V6000 type C	
	Total	1 km	Total	1 km	Total	1 km
Asphalt (assigned to road pavements – 100%)	*227.565*	*107.902*	*198.719*	*94.224*	*89.423*	*42.401*
Fill/aggregate (assigned to road pavements – 100 %)	*27.286*	*12.938*	*27.286*	*12.938*	*27.286*	*12.938*
Total emissions due to road pavement	254.851	120.840	226.005	107.162	116.709	55.339
Ready mix concrete (assigned to civil structures and retaining walls – 100 %)	*0.017*	*0.008*	*0.017*	*0.008*	*0.017*	*0.008*
Note: these emissions are not duplicated in the other categories (i.e. they are not seen in road pavements and civil structures), but only included in the category of bulk materials						

The obtained value (233.638 tCO_2e/km, Table 8) of CO_2e emissions for soft asphalt technology is the closest to the emissions for 1 km of regional road provided by Word Bank (i.e. 207 tCO_2e/km, Table 1).

According to data presented in Table 3, emissions associated with extraction/production of materials are 111.52 tCO_2e/km. The difference between the obtained value for typical asphalt concrete technology (tCO_2e/km) and the World Bank's value for the regional road (Table 3) is about 130 tCO_2e/km. The largest difference is in the category of earthworks: the estimated emissions of the analysed project are 106.483 tCO_2e/km and the largest share falls on imported soil (excluding equipment and transport emissions). According to the World Bank's provided typical value of emissions is only 12.0 tCO_2e/km (including equipment and transport emissions) due to the earthworks.

GHG missions from the transport of road building materials are 66.08 tCO_2e/km while estimated project's emissions in the case of hot and warm mix asphalt technology are 37.092 tCO_2e/km (Table 3). Such a difference could be due to the relatively small material and fuel transport distance (20 km) entered into the tool.

Typical emissions from used machines in the road construction are 28.96 tCO_2e/km, while estimated project's emissions in the case of typical asphalt technology are 16.247 tCO_2e/km (Table 3).

Typical emissions from road pavement installation are 157.30 tCO_2e/km (including equipment and transport emissions), while estimated project's emissions are 120.84 tCO_2e/km (excluding equipment and transport emissions) (look at Table 2).

Typical emissions due to installation of drainage are 16.69 tCO_2e/km (including equipment and transport emissions), while estimated project's emissions are 13.474 tCO_2e/km (excluding equipment and transport emissions) (look at Table 2). And typical emissions due to installation of road structures are 20.57 tCO_2e/km (including equipment and transport emissions), while estimated project's emissions are 2.932 tCO_2e/km (excluding equipment and transport emissions).

Overall, the least amount of CO_2e emissions would be generated using soft asphalt technology for road reconstruction of low-volume road, i.e. total 618.471 tCO_2e. The generated emissions would be 20.3% lower comparing to the emissions generated using typical hot mix asphalt. 735.692 tCO_2e emissions would be generated using warm mix asphalt technology, i.e. 5.2% lower than the emissions that would be generated using hot mix asphalt technology.

4. Conclusions

1. Testing of HECT tool for calculation of GHG emissions showed that input data of selected projects should be corrected, national emission factors and coefficients should be used in order to calculate GHG emissions more accurately.
2. Analysis with HECT tool showed the lowest CO_2e emissions generated by soft asphalt technology (618.471 tCO_2e) or 20.3% lower than hot mix asphalt technology emissions (775.651 tCO_2e). The warm mix technology generates 5.2% lower CO_2e emissions (735.692 tCO_2e) than hot mix technology. The greatest impact on the reduction of emissions had the reduced thickness of asphalt (4.5 cm) in soft asphalt case.
3. Based on impact of road construction methods, technologies and innovations into generation of GHG emissions it could be stated that:
    - most significant factors causing CO2e during road construction are road geometry and track parameters, pavement structure and pavement type;
    - the largest amounts of CO2e emissions generate during materials production and construction process;
    - considerable attention should be taken to reduction of CO2e emissions during extraction of raw materials, production of materials and road construction, where innovative and modern technologies can be used;
    - sustainable road pavements, innovative construction techniques and technologies, high quality materials and the possibility of their recycling can significantly reduce carbon footprint emissions.

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