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DERLEME / REVIEW

Scenario – Based Approach to Determine Exhaust Pollutant Emissions From Heavy Duty Road Traffic Along a Segment of the Pan-European Corridor 10

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Abstract

Heavy duty vehicles (HDV) play a significant role in the urban and extra-urban pollution derived from mobile sources. Due to their dynamic nature and complex pollution processes and mechanisms, quantifying such emissions is often lacking from national inventories. This paper aims to provide an insight into the extra-urban exhaust pollutant emission quantities that are a direct result from HDVs traversing the Pan-European Corridor 10. To achieve this, the paper uses publicly available and on-site testing data, and further it devises two scenarios that take account of the border passing and pay-toll waiting period for these types of vehicles. The motive behind writing this paper is that creating suitable and applicable scenarios may help in devising policies that will lead to decreasing the emission of pollutants from mobile sources, which will also decrease the overall pollutant concentration and improve the overall air quality.

Keywords: Pollution Sources, International Transport, Impact, Scenarios, Policies.

Özet

Ağır yük taşıtları (AYT), hareketli kaynaklardan kaynaklanan kentsel ve kentsel dışı kirlilikte önemli bir rol oynamaktadır. Dinamik yapıları ve karmaşık kirlilik süreçleri ve mekanizmaları nedeniyle, bu tür emisyonların nicelendirilmesi genellikle ulusal envanterlerde eksik kalmaktadır. Bu makale, Pan-Avrupa Koridor 10'u geçen AYT'lerin doğrudan bir sonucu olan kentsel dışı egzoz kirletici emisyon miktarlarına bir bakış sunmayı amaçlamaktadır. Bu amaçla, makale kamuoyunda bulunan ve yerinde yapılan test verilerini kullanmaktadır ve ayrıca bu tür araçlar için sınır geçişi ve ücret bekleme süresini dikkate alan iki senaryo geliştirmektedir. Bu makaleyi yazma nedeni, uygun ve uygulanabilir senaryolar oluşturmanın, hareketli kaynaklardan gelen kirletici emisyonlarını azaltacak politikaların oluşturulmasına yardımcı olabileceğidir, bu da genel kirletici konsantrasyonunu azaltacak ve genel hava kalitesini iyileştirecektir.

Anahtar Kelimeler: Kirlilik Kaynakları, Uluslararası Taşımacılık, Etki, Senaryolar, Politikalar.

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1. INTRODUCTION

The degradation of air quality in urban regions to a significant degree is associated with mobile sources of emissions (Qu et al., 2021; Ventura et al., 2021). These emissions adversely affect human health and lead to respiratory, cardiovascular and neurodegenerative diseases (Cassee et al., 2014). However, there is also growing evidence of freshly emitted air pollutants in the vicinity of major highways, motorways, and freeways that include: particulate matter (PM), nitrogen oxides (NOx), and carbon monoxide (CO) (Brugge et al., 2007).

Considerable attention has been paid in research toward diesel vehicles since they traditionally have the highest emission rates of these exhaust pollutants (Al-Thani et al., 2020;). At the same time, diesel engines dominate heavy-duty applications because of their greater fuel efficiency and torque output. This means that the presence of the abovementioned pollutants and their contribution to air pollution, overall negative impact to the environment and general quality of life have been exacerbated by the presence of heavy freight vehicles, otherwise known as heavy duty vehicles (HDVs) (Jin et al., 2021, Manev et al., 2021).

Although HDVs play a significant role in the urban and particularly extra-urban pollution from mobile sources due to their dynamic nature and complex pollution processes and mechanisms, quantifying such emissions has been somewhat complicated and this data is often lacking from national inventories. That is why, the aim of this paper is through the collection of on-site testing data and publicly available data on the number of vehicles to calculate the air pollution impact of heavy-duty road traffic along the road segment of the Pan-European Corridor 10, running through North Macedonia. EMEP/EEA's methodology is the primary means for the calculation of the exhaust pollutant emissions (EEA, 2019a; EEA, 2019b), however, this paper provides a scenario-based insight into the pollutant emissions quantities when taking into account idling periods due to border processing and pay-toll stoppage.

2. METHODOLOGY

2.1 EMEP/EEA models

This part will outline the different models that are put forward by the European Environment Agency which are suitable for calculating the HDV pollution across different scenarios, traffic characteristics and conditions.

The EMEP/EEA models related to the mobile sources of pollution consider different vehicles, different technologies, different categories across different EURO emission models. In essence, there are three different models put forward by the EEA, based on the level of the details they contain. In fact, these methods or approaches are: Tier 1, Tier 2 and, Tier 3. The following part of this paper will present these three distinctive approaches, with their specific characteristics and calculation variables.

Tier 1 Approach

The Tier 1 approach of the EMEP/EEA model relates to the fuel consumption and the specific vehicle category when deriving the emission of pollutants. More generally, the Tier 1 approach is based on the following equation:

$$E_i = \sum_j \left(\sum_m \left(FC_{j,m} \times EF_{i,j,m} \right) \right)$$

Where:

E_i = emission of pollutant I [g],

$FC_{j,m}$= fuel consumption of vehicle category j using fuel m [kg],

$EF_{i,j,m}$= fuel consumption-specific emission factor of pollutant i for vehicle category j and fuel m [g/kg].

The emission factors are derived from more complex approaches and methodologies which enables an easier calculation of the emission of different pollutants. In fact, these factors are given in the form of a mean value accompanied by the minimum and maximum values retrieved from the more complex approaches. The following tables 1 and 2 provide an overview of such emission factors for HDV.

Table 1. Tier 1 NOx and PM Emission Factors for HDVs

Fuel	NOx [g/kg fuel]			PM [g/kg fuel]		
	Mean	Min	Max	Mean	Min	Max
Diesel	33.37	28.34	38.29	0.94	0.61	1.57
CNG	13.00	5.50	30.00	0.02	0.01	0.04

Table 2. Tier 1 CO and NMVOC Emission Factors for HDVs

Fuel	NOx [g/kg fuel]			PM [g/kg fuel]		
	Mean	Min	Max	Mean	Min	Max
Diesel	7.58	5.73	10.57	1.92	1.33	3.77
CNG	5.70	2.20	15.00	0.26	0.10	0.67

The Tier 1 approach also considers other pollutants, providing the derived emission factors that relate not only with the fuel combustion, but also with the combustion of lubricant oil. Table 3 provides the emission coefficients for the lubricant oil combustion.

Table 3 – Tier 1 Lubricant Oil Emission Factors for HDVs

Fuel	CO_2 from lubricant oil [g/kg fuel]		
	Mean	Min	Max
Diesel	2.54	1.99	3.32
CNG	3.31	3.09	3.50

Aside of these emission factors, another important input in the Tier 1 approach stands to be the fuel consumption of vehicle categories and the related type of fuel. Table 4 provides the typical fuel consumption for HDVs.

Table 4 – Typical Fuel Consumption of HDVs (Tier 1)

Fuel Category	Typical fuel consumption [g/km]
Diesel	240
CNG (Buses)	500

Considering the characteristics of this approach, Tier 1 stands to be most useful when applied for the determination an conducting an aggregate analysis of pollution within a certain area where the fuel consumption/sales along with the number of vehicles from the analysed categories are known.

Tier 2 Approach

The Tier 2 approach expands on the Tier 1 method, as the vehicles' emission standards are considered. More specifically, for each vehicle category and type of fuel, the Tier 2 approach considers the EURO emission standard technology adopted, providing more specificities and calculation elements. The following equation represents the Tier 2 approach:

$$E_{i,k} = \sum_{k} (N_{j,k} \times M_{j,k} \times EF_{i,j,k})$$

Where:

$N_{j,k}$ = number of analysed vehicles of category j and technology k,

$M_{j,k}$= average annual distance driver per vehicle of category j and technology k [km/veh],

$EF_{i,j,k}$= technology-specific emission factor of pollutant i for vehicle category j and technology k [g/veh-km].

What stands to be the most important aspect of the Tier 2 approach is the fact that it extends the emission factors of the category of analysed vehicles according to their technology to include emission factors that are specific to the emission standard. Table 5 provides the emission factors for HDVs for different pollutants according to their emission standard.

Table 5 – Tier 2 CO, NMVOC, NOx and PM Emission Factors for HDVs

Type	Technology (EURO Standard)	CO	NMVOC	NOx	PM
Units		g/km	g/km	g/km	g/km
Diesel <= 7.5 t	Conventional	1.85	1.07	4.70	0.333
	Euro 1	0.657	0.193	3.37	0.129
	Euro 2	0.537	0.123	3.49	0.061
	Euro 3	0.584	0.115	2.63	0.0566
	Euro 4	0.047	0.005	1.64	0.0106
	Euro 5	0.047	0.005	0.933	0.0106
	Euro 6	0.047	0.005	0.180	0.0005
Diesel <= 7.5 - 16 t	Conventional	2.13	0.776	8.92	0.3344
	Euro 1	1.02	0.326	5.31	0.201
	Euro 2	0.902	0.207	5.50	0.104
	Euro 3	0.972	0.189	4.30	0.0881
	Euro 4	0.071	0.008	2.65	0.0161
	Euro 5	0.071	0.008	1.51	0.0161
	Euro 6	0.071	0.008	0.291	0.0008
Diesel <= 16 - 32 t	Conventional	1.93	0.486	10.7	0.418
	Euro 1	1.55	0.449	7.52	0.297
	Euro 2	1.38	0.29	7.91	0.155
	Euro 3	1.49	0.278	6.27	0.13
	Euro 4	0.105	0.010	3.83	0.0239
	Euro 5	0.105	0.010	2.18	0.0239
	Euro 6	0.105	0.10	0.422	0.0012
Diesel > 32 t	Conventional	2.25	0.534	12.8	0.491
	Euro 1	1.90	0.510	9.04	0.358
	Euro 2	1.69	0.326	9.36	0.194
	Euro 3	1.79	0.308	7.43	0.151
	Euro 4	0.121	0.012	4.61	0.0268
	Euro 5	0.121	0.012	2.63	0.0268
	Euro 6	0.121	0.012	0.507	0.0013

Moreover, the Tier 2 approach also considers the fuel consumption of the vehicles in question, providing typical fuel consumption for HDVs as seen in table 6.

Table 6 – Typical Fuel Consumption of HDVs (Tier 2, Euro 1 and later)

Weight Category	Typical fuel consumption [g/km]
<= 7.5 t	101
7.5 – 16 t	155
16 – 32 t	210
> 32 t	251

Tier 3 Approach

The Tier 3 method is the most complex approach for calculating the pollution emission from mobile sources. The approach includes a combination of technical data such as emission factors and activity data, including total kilometres travelled. The Tier 3 approach includes both hot (emissions during stabilized or hot engine operation) and cold (emissions during transient thermal engine operation, also known as cold start). Moreover, this approach includes the activity data and characteristics of the mobile sources in three distinctive scenarios: i) the urban, ii) the rural and iii) the highway driving profiles. This makes this approach suitable for analysing these distinct driving conditions. Figure 1 presents the application of the baseline methodology.

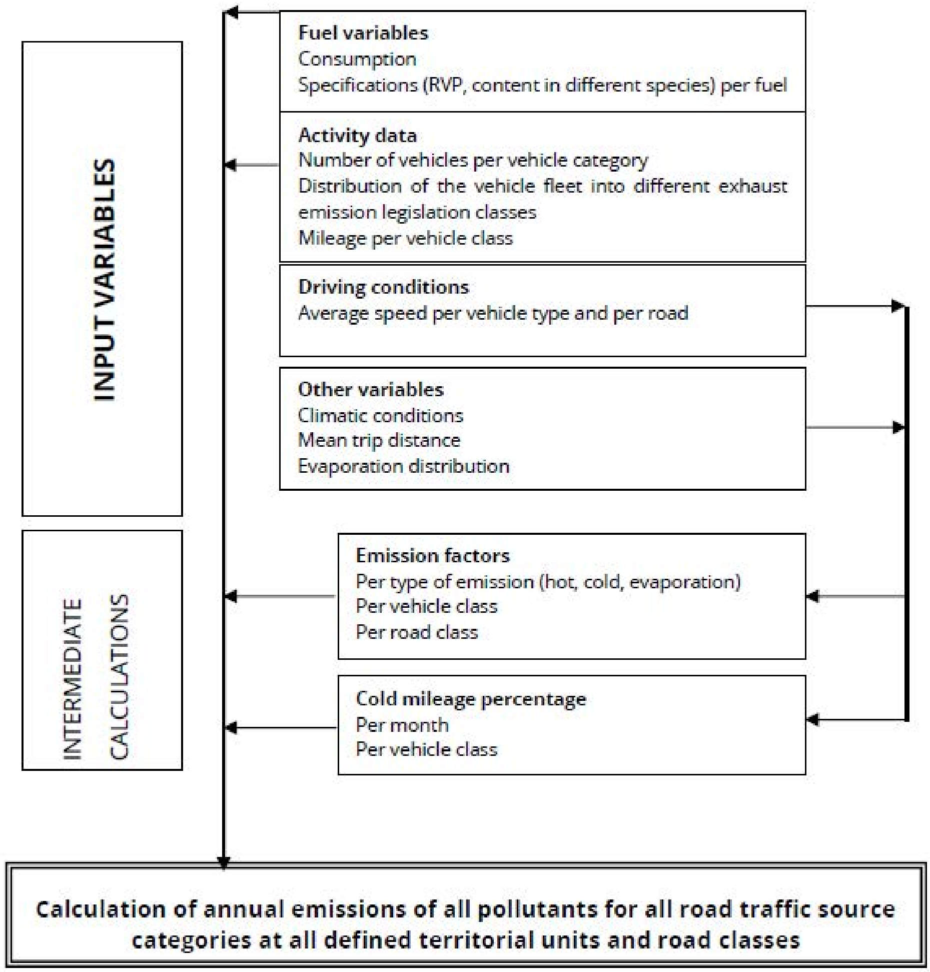

Figure 1 – Flow Chart of the Application of the Baseline Methodology

The application of the Tier 3 method for calculating the hot emissions includes the following equation:

$$E_{HOT;i,k,r} = N_k \times M_{k,r} \times e_{HOT;i,k,r}$$

Where:

$E_{HOT;i,k,r}$ = hot exhaust emissions of pollutant i [g] generated by vehicles with technology k that are driven on roads type r,

N_k = number of vehicles [veh] of technology k

$M_{k,r}$ = mileage per vehicle [km/veh] driven on road type r by vehicles with technology k,

$e_{HOT;i,k,r}$ = emission factor [g/km] for pollutant i, for technology k, driven on road type r.

Moreover, the driving modes in the three distinctive scenarios pose the challenge of determining the average speed that corresponds to each of these scenarios. More specifically, the driving modes that are velocity-dependent yield different results in terms of pollution, as the specified emission factors that are determined through different approaches are in fact velocity-dependent.

As the Tier 3 approach is the most detailed way of calculating emission pollution from mobile sources across different scenarios and for different vehicle categories and EURO emission standards, the EMEP/EEA guidebook provides the emission factor function for each of these different variables across different weight categories and different EURO emission standards.

2.2 Calculation models selection

The emission of pollutants from mobile sources includes not only the two general aspects covered by the EMEP/EEA's Tier 3 approach, but also other relevant determinants. More specifically, mobile sources emissions are also related with both the active driving cycle (that includes the hot and cold emissions) and from the idling cycle (where vehicles are stationary). Due to these complexities, the approach taken within this research addresses both the active emissions (hereinafter hot emissions) and the idling emissions. To calculate the active emissions, the EMEP/EEA model is considered. By following the decision tree presented in figure 2, the appropriate Tier approach is selected.

The calculation of the hot and the idling emissions from heavy duty vehicles is performed by combining the EMEP/EEA Tier 3 hot emissions methodology along with the idling emission factors suggested by CAFEE and adjusted according to the emissions' decrease realised through the implementation of higher EURO emission standards.

When it comes to the EMEP/EEA methodology selection, the approach considers all of the relevant input variables for the purpose of achieving the detailed calculation provided by the Tier 3 approach. Figure 3 outlines all input variables needed to successfully apply the Tier 3 approach.

As seen from the figure, the hot emissions from HDV according to EMEP/EEA's Tier 3 methodology are both vehicle and route specific. This means that aside of the vehicle characteristics such as the EURO emission standard, velocity, the curb weight and the load, the slope of the terrain and consequently the length of the analysed route also impacts the HDV's hot emissions. Having said this, it is important for the route to be analysed and different height segments to be determined, which will ease the calculation of hot emissions according to the height and length segments of the analysed route, creating a route profile that grasps the slope, the length, and the average velocity of the HDVs in that segment.

On the other hand, the idling emissions calculation approach is only time- and EURO emission standard specific, as it provides the idling emissions of HDVs per hour. In short, the only input variables of the idling emission calculation approach stand to be the time spent idling and the EURO emission standard of the HDVs, in order to obtain the emission factors.

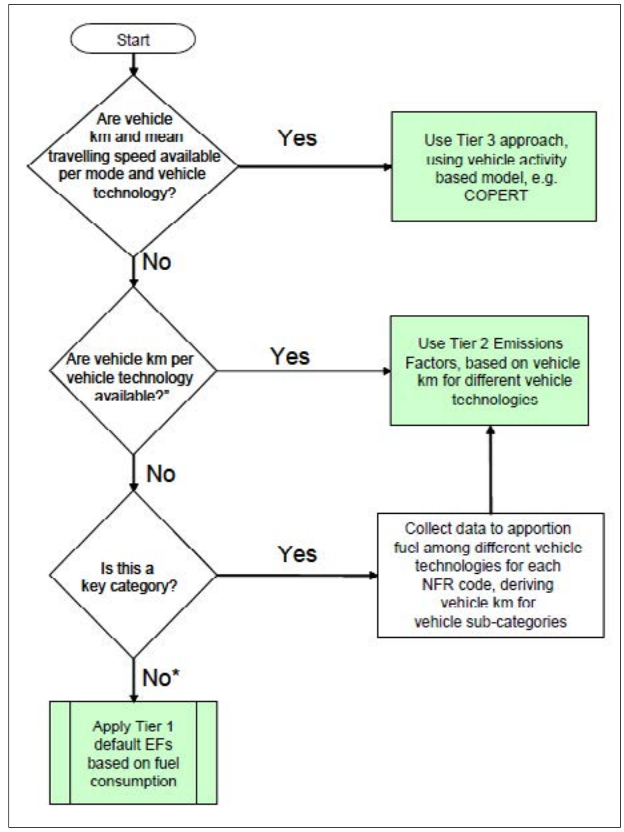

Figure 2 – EMEP/EEA Decision Tree for HDVs' Exhaust Emissions

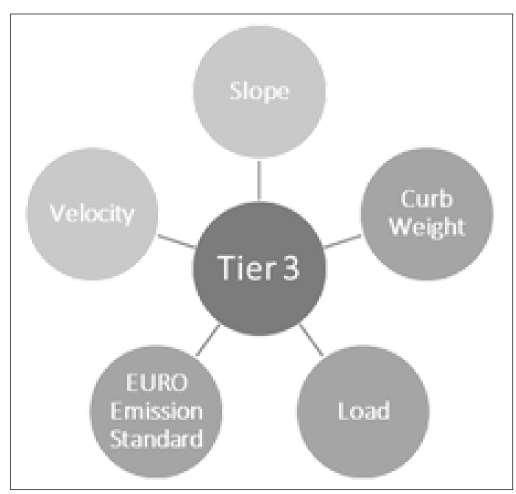

Figure 3 – Input Variables of the EMEP/EEA's HDV Tier 3 Approach

2.2.1. EMEP/EEA Tier 3 Hot Emission Calculation Functions

The applicability of the Tier 3 emission calculation approach is further justified by the lower and upper velocity calculation limits with which high coefficients of determinations are guaranteed. In this case, the lower limit is 12 km/h while the upper velocity limit is 86 km/h, making these functions highly applicable within this analysis. Moreover, the Tier 3 approach considers four pollutants which are mostly at the centre of analysis in environmental and transportation engineering. These four pollutants are carbon monoxide (CO), nitrous oxides (NOx), hydrocarbons (HC) and particulate matter (PM).

The calculation functions for different weight HDV categories with different EURO emission standards were taken from EMEP/EEA's methodology and adjusted by considering a 50% HDV load and a 0% terrain slope. The emission functions are based on different models including the Hoerl, the two power fits, the reciprocal quadratic, the Harris as well as the reciprocal exponential model. All these functions are velocity dependent and contain constants provided in the methodology application manual.

2.2.2. Adjusted CAFEE Idling Emission Coefficients

The CAFEE idling emission coefficients provide the emission of the hereinbefore mentioned pollutants according to the EURO emission standard, but up to EURO 4. To satisfy the requirements of calculating the idling emissions for the later EURO emission standards, the following approach was followed. Namely, the idling emission coefficients for EURO 5 and EURO 6 emission standards were decreased by the same percentage as are the mean hot emission coefficients compared to EURO 4. By doing this, the carbon monoxide (CO) emissions remained the same, but decreases in the idling emission coefficients was achieved in the following pollutants:

- Nitrous oxides (NOx): 53% reduction for EURO 5 and 89% reduction for EURO 6 as compared to EURO 4,
- Hydrocarbons (HC): no reduction for EURO 5 and 72% reduction for EURO 6 as compared to EURO 4 and,
- Particulate matter (PM): no reduction for EURO 5 and 50% reduction for EURO 6 as compared to EURO 4.

By taking this approach, the following emission coefficients were obtained as presented in table 7, expressed as grams per hour according to the different EURO emission standards for the same pollutants. The idling emission coefficients presented in the table above provide for an easy calculation of the idling emission of heavy-duty vehicles, as the needed inputs are only the number of vehicles per EURO emission standard and the waiting time in hours.

2.3. Route Specification

The HDV emission analysis is focused on a road segment of the Pan-European Corridor 10 (the E-75 highway). Specifically, the road segment starts from "Bogorodica" border crossing on the border with Greece and ends north at the "Petrovec" pay toll. This segment has a total length of 136 kilometres and contains several pay tolls, which are important points in terms of the velocity segment characterization. To determine the altitude of the route as well as determine the velocity profile, the route was driven with a passenger car and the data was recorded by using a GPS-enabled recording device with an integrated speedometer. The results of this measurement approach and the obtained crude data is presented in the following figure.

Table 7 – Idling Emission Coefficients per EURO Emission Standard

Pollutant Emission [g/h]	EURO 4		EURO 5	EURO 6
CO	27		27	27
NOx	60		28.2	6.6
HC	4		4	1.12
PM	1		1	0.5

The recorded data were afterwards cleaned, removing any outliers in both the velocity and altitude profiles due to route-specific elements such as tunnels, elements that negatively influence the measuring and the recording of the needed data. Moreover, the changes in the altitude within the identified segments will enable the determination of terrain slopes, as one of the main input variables in the HDVs' hot emission calculation. The results obtained across 80,000 measuring points from the crude data in figure 4 resulted in the following speed and altitude profiles, shown in figure 5. These profiles are related to the passenger vehicle with which the measurements were made, considering the speed limits on the different segments on the route.

2.3.1. Characteristic Segments

The determination of the characteristic segments with their corresponding terrain slope, velocity and length was done based upon the recorded GPS and velocity data presented in figure 3 and adjusted according to the country's upper velocity limitations for HDVs on highways. The identified characteristic segments for HDVs are presented in table 8 and figure 5 below, including their average velocity, slope and length. These results provide the needed route specific inputs for determining the hot emissions from HDVs according to the Tier 3 approach. As there are no positive/negative slope variations, the calculation of the hot and the idling emissions are independent from the direction.

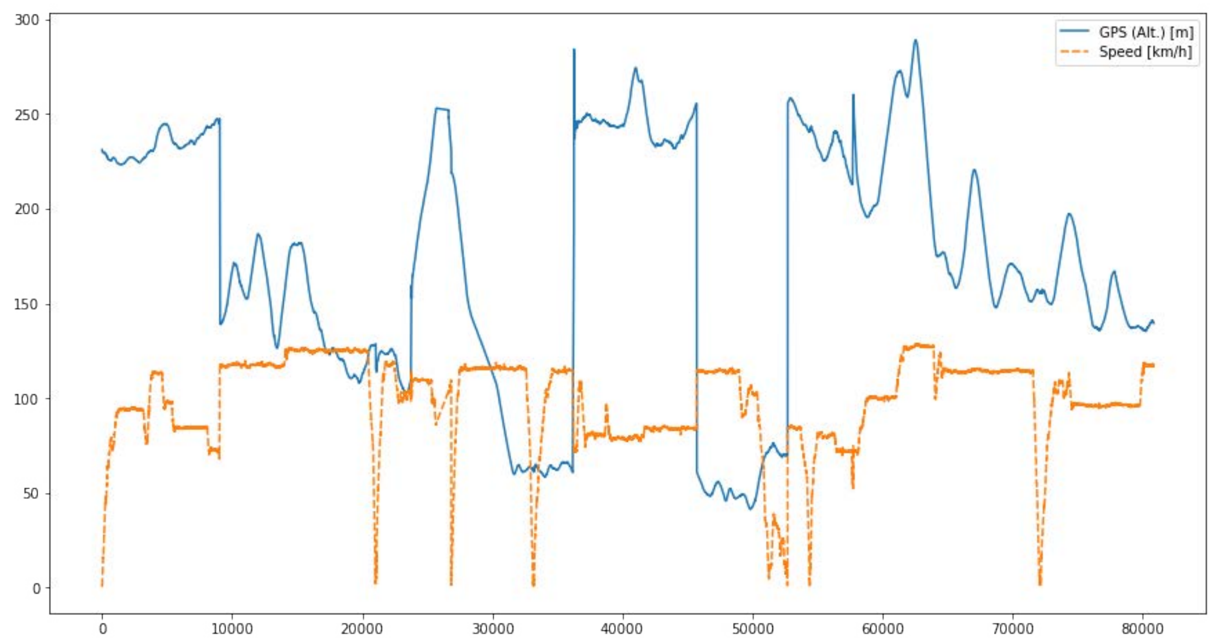

Figure 4 – Altitude and Velocity Profile of the Analysed Segment

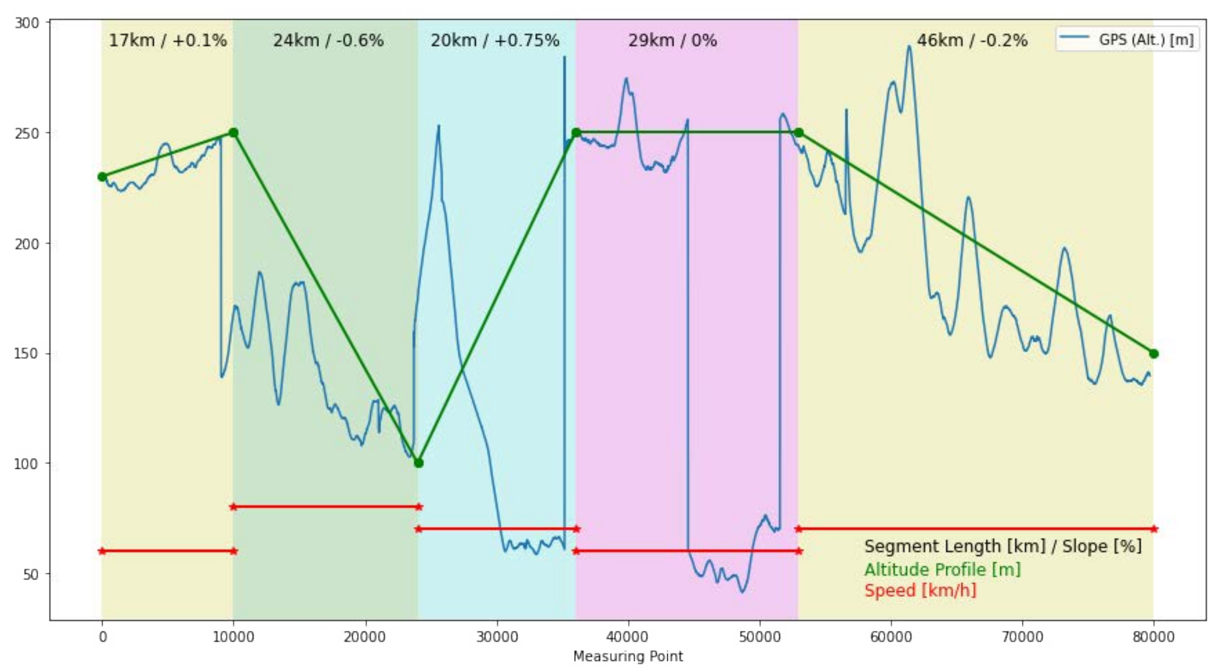

Figure 5 – Characteristic Segments for HDVs

Table 8 – Characteristic Segments Data

Segment	Average Velocity [km/h]	Length [km]	Slope [%]
1	60	17	0.1
2	80	24	-0.6
3	70	20	0.75
4	60	29	0
5	70	46	-0.2

2.4. HDV Characteristics

The required HDV characteristics as inputs in the Tier 3 approach relate to the number of such vehicles according to their EURO emission standard, curb weight and load. The load is defined to be 50%, while the main HDVs characteristics are derived from the Public enterprise for state roads data on the number of HDVs across various segments on the selected route. The selection of HDVs to be considered in this research was performed by comparing the number of HDVs in two segments (the Gevgelija - "Bogorodica" border crossing and the Petrovec - Veles segment) and selecting the smaller number. When this approach is applied on the data obtained from the Public enterprise for state roads by different segments, the following average daily traffic per vehicle category per year is obtained, as presented in figure 7. The vehicle category designations used by the Public enterprise for state roads corresponds to the Tier 3 categorization of HDVs according to the curb weight, resulting in K4 (14-20 tonnes), K5 (20-28 tonnes) and K6 (28-34 tonnes).

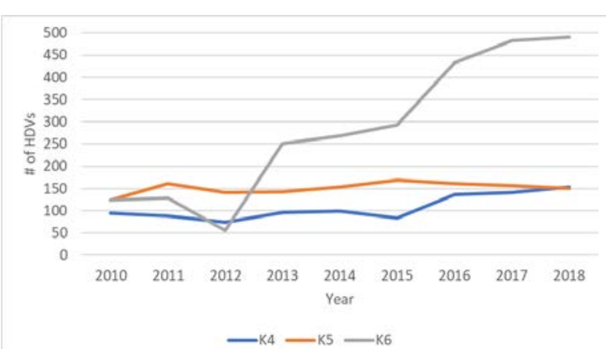

Figure 7 – Average Daily Traffic per Vehicle Category

After obtaining the number of HDVs according to their curb weight category, the EURO emission standard should be derived to fulfil all of the input data requirements for the Tier 3 approach. Due to the lack of such data, the following assumption is made in terms of dividing the selected number of HDVs according to an emission standard:

- 20% of the HDVs satisfy the EURO 4 emission standard,
- 50% of the HDVs satisfy the EURO 5 emission standard and,
- 30% of the HDVs satisfy the EURO 6 emission standard.

In order to apply this assumption to a specific year, the data from the year 2018 is taken into account in order to avoid the implemented vehicle categorization changes adopted by the Public enterprise for state roads. When the EURO emission standards assumptions are applied to the 2018 data, the following results are obtained, as presented in table 9.

The analysis shows that in 2018, most of the HDVs that used the selected route belonged to the K6 category and satisfied the EURO 5 emission standard, followed by the same category with EURO 6 emission standard.

Table 9 – Average Daily Traffic per Vehicle Category and EURO Emission Standard

Vehicle category/ EURO emission standard	EURO 4	EURO 5	EURO 6
K4	31	77	46
K5	31	76	46
K6	99	246	148

2.5. Scenarios - Idling Periods

To grasp the importance of decreasing the idling times of HDVs and outline the difference between short and long idling times on the production of pollutants, the following two scenarios are developed taking into account the border processing or layover times at the "Bogorodica" border crossing and the waiting times at the five pay-tolls in the analysed segment.

- **Scenario 1**: 50 minutes waiting at the border crossing and 5 minutes waiting at each pay toll in the specified segment, resulting in 75 minutes idling periods and,
- **Scenario 2**: 20 minutes waiting at the border crossing and no waiting times at pay tolls in the specified segment, resulting in 20 minutes idling periods.

3. RESULTS

3.1. Hot Emissions

These emissions constitute the larger of the two parts of the total emissions from HDV on the analysed route. Aside of the specific results per the vehicle category and the EURO emission standard, an important aspect must be drawn in terms of the total pollution per the analysed pollutants. In order to provide these findings, table 10 below shows the total hot emissions of CO, NOx, HC and PM from the HDVs on the selected route.

Table 10 – Total Hot Emissions from HDVs

Pollutant	Emission [kg/year]	Emission [ton/year]
CO	25682.34	25.68
NOx	79231.75	79.23
HC	1239.44	1.24
PM	820.73	0.82

The results show that nitrous oxides (NOx) are the largest emitted pollutants from HDVs on this route, when the driving (hot) emissions are considered, with more than 79 tonnes per year. These emissions are followed by the carbon monoxide emissions (CO), with more than 25 tonnes per year. The hydrocarbons (HC) and the particulate matter (PM) emissions, despite being vastly lower, are still present as pollutants on the route, with 1.24 and 0.82 tonnes per year respectively.

3.2. Idling Emissions

When it comes to the idling emissions, two different results were obtained depending on the selected scenario. For example, the difference between the two scenarios is 55 minutes, from which it becomes immediately evident that the longer idling times will have higher idling emissions. The results from Scenario 1 are provided in table 11 while the results from Scenario 2 are provided in table 12 below. The results show that the idling emissions are only a small part of the total emissions from HDVs on the selected route.

The idling emission results suggest that by decreasing the idling periods of HDVs on the selected route, the decrease of more than 6 tonnes of carbon monoxide (CO) emissions may be achieved, as well as the decrease of more than 7 tonnes of nitrous oxides (NOx) emissions. The decrease of the idling periods also leads to a decrease in the hydrocarbon (HC) and the particulate matter (PM) emissions.

Table 11 – Idling Emissions from Scenario 1 (75 minutes idling period)

Pollutant	Emission [kg/year]	Emission [ton/year]
CO	9263.70	9.26
NOx	10119.17	10.12
HC	1120.11	1.12
PM	299.30	0.30

Table 12 – Idling Emissions from Scenario 2 (20 minutes idling period)

Pollutant	Emission [kg/year]	Emission [ton/year]
CO	2628.00	2.63
NOx	2736.99	2.74
HC	305.24	0.31
PM	82.73	0.08

These results also point to the need of adopting different practices and systems for decreasing the idling periods of HDVs. Aside of the vehicle-specific technologies that control these idling emissions, certain modifications and innovations along the route may be adopted in order to decrease the idling periods and thus the idling emissions. Such innovations are suitable to be adopted in the border crossing and across the different pay tolls on the route.

3.3. Total Emissions

The total emissions from HDVs on the analysed route include both the hot and the idling emissions. Moreover, the calculation of the total emissions according to this methodology also addresses the route reversibility issue, and as there are no slope variations, the route with its segments should not be altered to grasp such variations.

In other words, the summation of the hot and idling emissions will provide the result of the emission of pollutants on the route from heavy duty vehicles according to the data from 2018. The results from the two analysed scenarios that are idling period dependent are presented in the following table 13 and table 14.

Table 13 – Total Yearly Emissions for Scenario 1

Pollutant	Emission (kg/year)	Emission (ton/year)
CO	34946.04	34.95
NOx	89350.92	89.35
HC	2359.56	2.36
PM	1120.03	1.12

Table 14 – Total Yearly Emissions for Scenario 2

Pollutant	Emission (kg/year)	Emission (ton/year)
CO	28310.34	28.31
NOx	81968.74	81.97
HC	1544.68	1.54
PM	903.46	0.90

4. CONCLUSION

Increasing awareness of the urban air pollution impacts from mobile sources has slowly, but surely been shifting to include extra-urban sources as well.

Due to the emphasis being primarily put on urban air pollution however, national inventories often lack the data that considers the impact of exhaust pollutants emissions in the vicinity of major highways. The aim of this paper was a thorough scenario-based analysis of the quantities of pollutant emissions resulting from diesel HDVs traversing a road segment of the Pan-European Corridor 10, crossing North Macedonia. Furthermore, on-site data measurements and publicly available data on the number of vehicles crossing multiple counting points along the E-75 highway provided by the Public enterprise for state roads added to the credibility of this study.

Devising the two scenarios (despite their simplicity) had a purpose of quantifying the impact of "waiting" or idling periods from trucks and considers border layover and processing times and pay-toll waiting times. The analysis of the results from both scenarios shows that the decrease of the idling period for 55 minutes on the selected route will result in a yearly decrease of HDVs' carbon monoxide (CO) emissions for more than 6 tonnes, the nitrous oxides (NOx) emissions for more than 7 tonnes, the hydrocarbon (HC) emissions for more than 500 kilograms and the particulate matter (PM) emissions for more than 200 kilograms. As such, the decrease of the waiting times across the border crossing and the pay tolls for heavy duty vehicles is justified by the vast decrease of the related pollution emissions.

A major point of discussion as well as a point for future work is to analyse the impact of the automated pass by "M-card" or "M-TAG" on reducing pay-toll waiting times especially for HDVs. This system was set up during 2019 and had a test period on the existing 5 pay-toll locations, while by the end of 2019, 2 more pay-toll locations were put in function. The automatization of the pay-tolls strongly relates to the second scenario, so future research should be aimed at proving or disproving if the automatization reduces waiting times, and how does this affect the exhaust emissions pollutant quantities along the Pan-European Corridor 10.

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