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Modeling the Calculation of the Vehicles' Environmental Impact: a Case Study Regarding Planning Regional Transport

Ondrej Stopka[1], Mária Stopková[2], Branislav Šarkan[3]*
[1]*Department of Transport and Logistics, Institute of Technology and Business in České Budějovice; Czech Republic*
https://orcid.org/0000-0002-0932-4381
[2]*Department of Transport and Logistics, Institute of Technology and Business in České Budějovice; Czech Republic*
https://orcid.org/0000-0001-6436-4047
[3]*Department of Road and Urban Transport, University of Žilina; Slovak Republic*
https://orcid.org/0000-0002-5036-9223

corresponding author's e-mail: stopka@vste.cz

Abstract: This paper presents a modelling approach for assessing the environmental impacts of passenger vehicle traffic and demonstrates its application to regional transport planning using a labor mobility case study. The analysis focuses on the Strážný–Philippsreut model route, a 6.8 km regional commuter corridor linking the South Bohemian Region (Czech Republic) with Bavaria (Germany). The volume of emissions was quantified using the EEA/COPERT 5.5 methodology, based on actual traffic data collected during traffic surveys. Calculations took into consideration fuel type, Euro emission standard, route terrain characteristics, and round-trip (journey) distances. The study evaluated pollutant emissions of CO, HC, NO_x, PM, and CO_2. On the first day of data collection, total round-trip emissions reached 5.78 kg CO, 0.83 kg HC, 1.77 kg NO_x, 0.13 kg PM, and 865.5 kg CO_2, whilst lower traffic intensity on the second day of conducting the traffic survey reduced emissions' volume by more than 60%, resulting in 2.20 kg CO, 0.31 kg HC, 0.68 kg NO_x, 0.05 kg PM, and 330 kg CO_2. Approximately 61% of pollutant emissions were generated on the Czech part of the route and 39% on the German part. Vehicles equipped with spark-ignition engines were the primary source of CO and HC, whereas those with compression-ignition engines dominated NO_x and PM emissions. The designed model serves as a practical tool for evaluating the environmental impacts of regional mobility and can support evidence-based planning to reduce the transport-related emissions burden.

Keywords: planning, regional transport, mobility, environmental impact, traffic data collection

1. Introduction

Road transport is one of the principal sources of anthropogenic greenhouse gas emissions and air pollutants in Europe. Passenger cars and light-duty vehicles emit substantial quantities of carbon dioxide (CO_2), nitrogen oxides (NO_x), particulate matter (PM), carbon monoxide (CO), and unburned hydrocarbons (HC), all of which contribute to climate change and adverse public health outcomes (European Environment Agency [EEA] 2023, World Health Organization [WHO] 2021). According to the EEA (2023), the transport sector accounts for approximately one quarter of total greenhouse gas emissions in the European Union, with road transport representing the dominant source within this sector.

In recent decades, increasing labor mobility and economic integration have intensified daily commuting across national borders. This phenomenon is particularly evident in Central Europe, where residents of the Czech Republic regularly travel to Germany and Austria for employment opportunities (EC 2024). Although individual commuter trips during their mobility (Chamier-Gliszczyński & Bohdal, 2016) are often relatively short, their cumulative environmental impact may be considerable, especially when repeated daily and involving large numbers of vehicles with internal combustion engines. Such impacts are amplified in regions with older vehicle fleets and lower adoption rates of low-emission technologies (ACEA, 2025).

Short-distance journeys deserve special attention because pollutant emissions are often disproportionately high during the initial phase of engine operation. During cold-start conditions, catalytic converters and diesel after-treatment systems have not yet reached their optimal operating temperatures, leading to significantly elevated emissions of CO, HC, and PM compared with stabilized driving conditions (André et al., 2006; Bishop et al., 2019). Consequently, even routes shorter than 10 km may generate substantial pollutant burdens, particularly when repeatedly traversed by commuters.

The environmental assessment of road transport commonly relies on emission models that combine vehicle fleet composition, traffic intensity, and route characteristics with standardized emission factors (Witt, 2023). In Europe, the COPERT (Computer Programme to Calculate Emissions from Road Transport) model has become the official methodology for national emission inventories and transport-related environmental studies

(EEA 2023; Ntziachristos & Samaras, 2000). The model incorporates vehicle category, fuel type, Euro emission standard, average speed, and gradient, thereby providing a robust and transparent framework for estimating "on-road" emissions.

The present study applies the EEA/COPERT 5.5 methodology to a representative single regional labor mobility corridor between the Czech Republic and Germany (EEA 2023; Orynycz et al., 2025). The section under investigation connects Strážný and Philippsreut and constitutes a short but intensively used route linking the South Bohemian Region with Bavaria. The route is approximately 6.8 km long and features a positive elevation gain of about 84 m toward Germany, resulting in increased fuel consumption and higher specific emissions (EEA, 2023). The primary objective of this paper is to demonstrate a practical modelling framework for quantifying the environmental impacts of regional passenger vehicle traffic and to assess the extent to which a short regional commuter route contributes to local and regional emission impacts. The study further aims to provide evidence that can support transport planning, environmental policy, and the promotion of low-emission regional mobility alternatives.

2. Literature Review

As mentioned above, road transport generates a broad spectrum of pollutants with significant environmental and health consequences. Carbon dioxide is the predominant greenhouse gas associated with fossil fuel combustion, while nitrogen oxides and particulate matter are among the most harmful pollutants for local air quality (Smit et al., 2008; WHO, 2021). Numerous studies have demonstrated that transport-related emissions contribute to urban smog, acidification, eutrophication, and premature mortality, e.g., Karagulian et al. (2015) or WHO (2021).

Vehicles with spark-ignition engines (i.e., gasoline-powered vehicles) tend to emit more carbon monoxide and hydrocarbons, particularly under transient and cold-start conditions, due to incomplete combustion and delayed catalyst activation (André et al., 2006). Vehicles with compression-ignition engines (i.e., diesel-powered vehicles), by contrast, are typically the dominant source of nitrogen oxides and particulate matter, especially when equipped with older technologies lacking diesel particulate filters (DPF) and selective catalytic reduction (SCR) systems (Bishop et al., 2019; Degraeuwe et al., 2017).

The European Union's Euro emission standards have progressively reduced regulated pollutant emissions from road vehicles. Each successive standard has imposed stricter limits for CO, HC, NO_x, and PM, thereby stimulating technological development in engine design and exhaust after-treatment systems (Delgado & Muncrief, 2015; EEA, 2023). Despite these regulatory improvements, the environmental benefits depend strongly on the age structure of the vehicle fleet. In countries with relatively old passenger car fleets, such as the Czech Republic and other Central and Eastern European states, a significant proportion of vehicles still conform to Euro 3 or Euro 4 standards (ACEA 2025). Several studies have shown that older vehicles may account for a disproportionately large share of total pollutant emissions despite representing a minority of the fleet (Degraeuwe et al., 2017; Söderena et al., 2020).

As far as emission modeling is concerned, a variety of models have been developed to estimate road transport emissions, including MOVES (United States Environmental Protection Agency), HBEFA (Handbook Emission Factors for Road Transport), and COPERT (Hausberger et al., 2009; Ntziachristos & Samaras, 2000). In Europe, COPERT is the most widely applied methodology and serves as the reference tool for compiling national emission inventories submitted under international reporting obligations (EEA, 2023). COPERT calculates emissions as a function of vehicle class, fuel type, Euro standard, speed, road gradient, and ambient conditions. The model has been extensively validated and is widely used in academic studies addressing regional transport planning (Staniuk et al., 2022), policy assessment, and commuter mobility environmental analyses (Kousoulidou et al., 2008; Orynycz et al., 2025; Chamier-Gliszczyński, 2015).

Regarding regional environmental impacts related to labor mobility (Chamier-Gliszczyński & Bohdal, 2016a), commuting is a growing component of labor mobility across Europe (Perkmann, 2003). EC (2024) reports that thousands of residents in border regions travel daily between neighboring countries for employment. These movements create recurring traffic patterns that may generate concentrated pollutant burdens along specific corridors. Research on the environmental implications of regional labor (cross-border) mobility remains relatively limited compared with studies focused on urban congestion or long-distance freight transport (Decoville & Durand, 2018; EC, 2024). Nonetheless, recent investigations have emphasized the importance of incorporating commuter traffic (even electromobility) into regional sustainability assessments and transport planning (Melo et al., 2014; Turek et al., 2024).

At the same time, naturally, fuel consumption and emission rates are significantly influenced by the geometric characteristics of a regional route (Barlow et al., 2009). Uphill sections apparently require higher engine power and increase specific emissions, whereas downhill segments typically reduce energy demand (EEA, 2023; Liu et al., 2020). This effect is particularly relevant for mountainous and border regions, where relatively short routes may involve substantial gradients (Bandeira et al., 2011).

As for the regional section under investigation, the Strážný–Philippsreut route exhibits an elevation gain of approximately 84 m and includes gradients exceeding 10%. According to the EEA (2023), such conditions justify the application of correction factors to account for increased energy demand and associated emissions.

3. Methodology

3.1. Specifics of the Investigated Route Strážný–Philippsreut

The model route represents the shortest possible regional mobility scenario of the Czech-Bavarian commuters starting in Strážný (Czechia) and ending in Philippsreut (Bavaria). The total route length is approx. 6.8 km, of which around 4.2 km is located in the territory of the Czech Republic and 2.6 km in the Federal Republic of Germany. The route connects both municipalities via the I/4 road (CZ) and the B12 road (DE), which together constitute a direct regional mobility connection for commuters in the southern Šumava region. From a transport perspective, the route can be characterized as a regional border section primarily utilized for short-distance mobility. As for the Czech part, the road passes through areas with alternating velocity limits of 50 and 90 km/h, while a reduced speed limit of 50 km/h applies upon entering Strážný and at the border crossing itself.

Upon entering the German territory, the route continues along the B12 road, where the permitted velocity increases to 70–100 km/h, with a temporary reduction near the entrance to Philippsreut. The elevation profile indicates a moderately undulating but generally ascending route. The route begins at an elevation of approximately 810 m above sea level; the lowest point is near the first kilometer at approximately 790 m above sea level; and the highest point in Philippsreut reaches approximately 874 m above sea level. The overall elevation gain is approximately +84 m, while the maximum gradient ranges between 11.7% and 13.8%, with an average gradient of +3.7% along the entire route.

From an environmental perspective, the route exhibits higher energy demands towards Germany due to the ascending terrain profile. In contrast, lower specific emissions and fuel consumption may be expected in the opposite direction (DE → CZ). According to the EEA/COPERT 5.5 methodology (EEA, 2023), this route is suitable for representing short mobility trips characterized predominantly by a regional rural driving regime. In light of emission calculations, gradient correction factors of approximately +3% to +6% may be applied, while reductions of -2% to -4% may be deemed for the return direction.

Table 1. Characteristics of the Strážný–Philippsreut model route. Source: authors

Strážný–Philippsreut		
	Length of the section (km)	Cumulative length of the section (km)
Local road (CZ)	0.23	0.23
Road No. 4 (CZ)	3.94	4.17
Road No. B12 (DE)	2.63	6.80
In total	6.80	

The terrain profile and map view of the model route Strážný–Philippsreut are graphically depicted in the following Figs. 1 and 2.

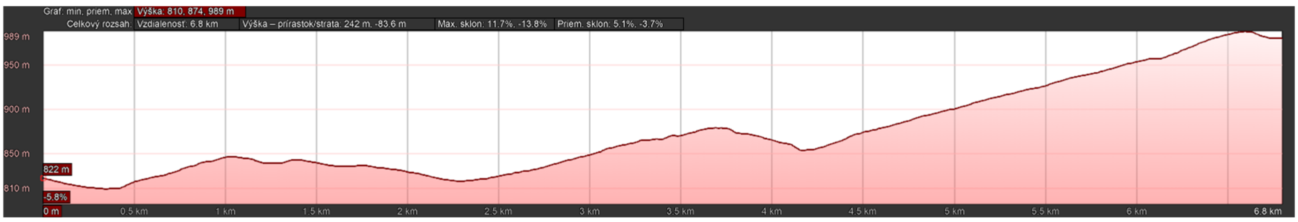

Fig. 1. Terrain profile of the model route. Source: authors

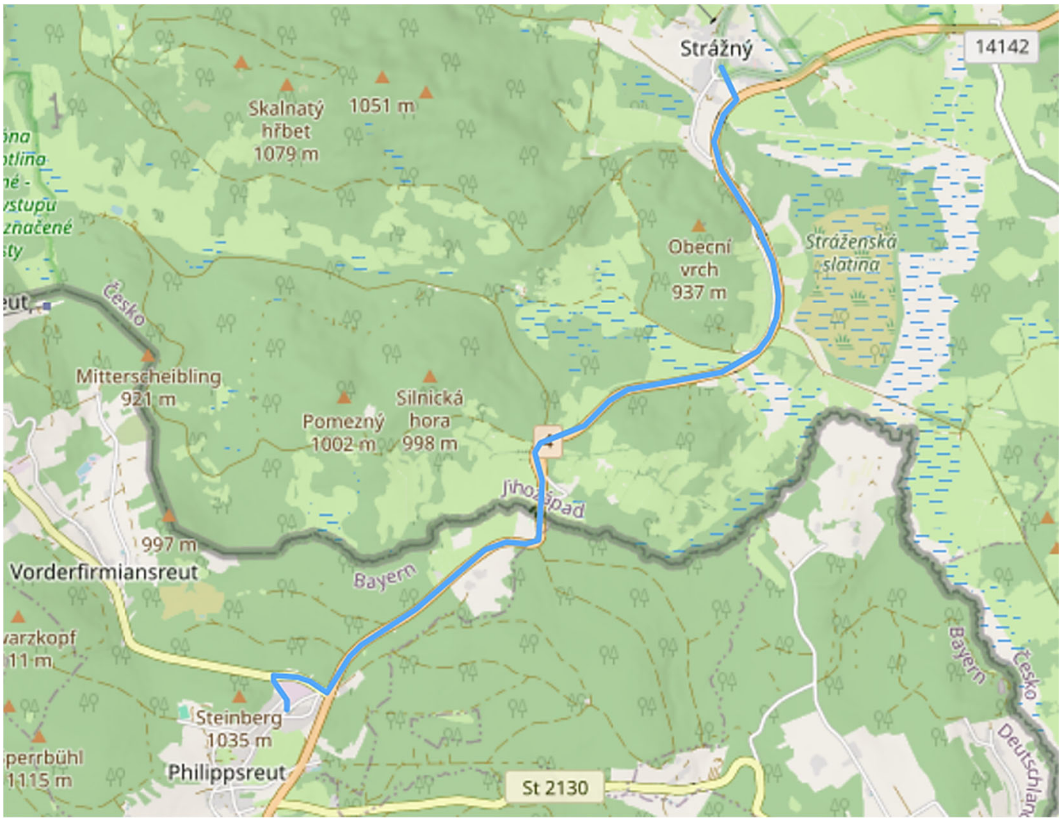

Fig. 2. Map view of the model route. Source: authors

3.2. Determination of Emission Factors and Number of Vehicles

For the sake of emission volume quantification, pollutant-specific emission factors (EFs) expressed in $g \cdot km^{-1}$ were adopted in accordance with the EEA/COPERT 5.5 methodology (EEA, 2023), as also referenced in the study conducted by Orynycz et al. (2025). The analyzed pollutants comprised carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), particulate matter (PM), and carbon dioxide (CO_2) generated by both spark-ignition and compression-ignition engines. The selected factors represent real-world exhaust emissions under normal operating conditions and account for the impact of vehicle ageing and the decline in efficiency of emission control technologies over time (Giechaskie et al., 2018).

The vehicle dataset used in the analysis was obtained from a dedicated regional traffic survey focused on traffic data collection conducted in the locality of Strážný–Philippsreut. Monitoring activities were conducted over two standard working days, taking into account the representative regional mobility of commuters between the Czech Republic and Germany. Vehicle movements were documented using video surveillance and license plate identification, enabling the tracking of traffic flows toward Germany in the morning period and in the opposite direction toward the Czech Republic in the afternoon return period (Smit et al., 2008). A vehicle was considered a mobility car for commuters if its presence was confirmed in both travel directions on at least one of the investigated days. Subsequently, the recorded vehicle fleet was evaluated according to the proportional representation of both internal-combustion-engine types, distinguishing between spark-ignition (gasoline) and compression-ignition (diesel) vehicles. The identified vehicle segments were further differentiated by corresponding EURO emission standards (Fontaras et al., 2017).

The final numbers of vehicles incorporated into the total emission volume quantification for the follow-up phases of the research conducted are summarized in the following tables (see Tables 2 and 3).

Table 2. Traffic flow volume in the direction towards Germany (data collection – 2nd day). Source: authors

Data collection – 1st day	Vehicle counts	EURO 6	EURO 5	EURO 4	EURO 3	EURO 2 and 1	EURO 0
In total	349	115	45	67	55	35	32
Spark-ignition	202	67	26	39	32	20	19
Compression-ignition	147	48	19	28	23	15	13

Table 3. Traffic flow volume in the opposite direction towards Czechia (data collection – 1st day). Source: authors

Data collection – 2nd day	Vehicle counts	EURO 6	EURO 5	EURO 4	EURO 3	EURO 2 and 1	EURO 0
In total	132	43	17	25	21	13	12
Spark-ignition	77	25	10	15	12	8	7
Compression-ignition	55	18	7	11	9	6	5

4. Results Obtained

The subsequent paragraphs provide an assessment of the volumes of major atmospheric pollutants, specifically, CO, HC, NO_x, PM, as well as CO_2, emitted by vehicles powered by gasoline (i.e., spark-ignition) and diesel (i.e., compression-ignition) engines throughout a unidirectional trip on the route Strážný–Philippsreut. The emission estimates were derived from the distribution of EURO emission categories of the monitored vehicle fleet, specifically, 349 vehicles of both engine types on the first day of data collection and 132 vehicles of both engine types on the second day of data collection, in combination with standardized emission factors ($g \cdot km^{-1}$) defined by the applicable emission standard and fuel type.

The produced emission volumes were quantified based on the following formula (1) (Caban et al., 2024):

$$E_{i,j} = EF_{i,j}.N_{i,j}.L \tag{1}$$

where:
$E_{i,j}$ – overall emission volume *i* produced according to the category of vehicle *j* [g],
$EF_{i,j}$ – pollutant emission factor *i* according to the category of vehicle *j* [$g \cdot km^{-1}$],
$N_{i,j}$ – vehicle counts according to the category of vehicle,
L – model route length [km].

The volumes of total emissions produced by vehicles, depending on the type of internal combustion engine, are the sum of all values for each individual EURO emission standard (see tables 4 and 5, relating to the first day of data collection).

Table 4. Emissions produced by vehicles with spark-ignition engines (data collection – 1st day). Source: authors

Spark-ignition engine	CO (g)	HC (g)	NO_x (g)	PM (g)	CO_2 (g)
EURO 6	251	32	27	1	77,452
EURO 5	150	18	14	1	30,940
EURO 4	371	40	27	3	49,062
EURO 3	457	44	26	3	42,432
EURO 2 and 1	422	34	20	3	27,880
EURO 0 EF	840	155	78	6	29,070
Overall (g)	2 491	322	192	17	256,836
Overall (kg)	2.49	0.32	0.19	0.02	256.84

Table 5. Emissions produced by vehicles with compression-ignition engines (data collection – 1st day). Source: authors

Compression-ignition engine	CO (g)	HC (g)	NO_x (g)	PM (g)	CO_2 (g)
EURO 6	33	7	114	1	50,592
EURO 5	26	4	58	1	21,318
EURO 4	57	11	114	5	33,320
EURO 3	78	16	125	8	28,934
EURO 2 and 1	102	20	122	14	21,420
EURO 0 EF	106	35	159	22	20,332
Overall (g)	402	93	693	50	175,916
Overall (kg)	0.40	0.09	0.69	0.05	175.92

The overall CO_2 production recorded on the first day of data collection along the model route amounted to approximately 0.43 t (for vehicles equipped with both types of internal combustion engines), reflecting the linear relationship between route length and the volume of emissions produced. The route therefore represents a local source of environmental impact, characterized by a significant share of short trips, which, due to frequent cold starts, may be more environmentally significant than the route length itself would suggest.

As a result, the following emission-related values were quantified. Vehicles with spark-ignition engines produced a total of approximately 2.49 kg of CO, 0.32 kg of HC, 0.19 kg of NO_x, 0.02 kg of PM, and 256.84 kg of CO_2, whereas diesel-powered vehicles generated about 0.40 kg of CO, 0.09 kg of HC, 0.69 kg of NO_x, 0.05 kg of PM, and 175.92 kg of CO_2.

In the following tables 6 and 7, the quantified volumes of overall emissions produced by vehicles with spark-ignition engines on the second day of data collection are summarized.

Table 6. Emissions produced by vehicles with spark-ignition engines (data collection – 2nd day). Source: authors

Spark-ignition engine	CO (g)	HC (g)	NO_x (g)	PM (g)	CO_2 (g)
EURO 6	94	12	10	0	28,900
EURO 5	58	7	5	0	11,900
EURO 4	143	15	10	1	18,870
EURO 3	171	16	10	1	15,912
EURO 2 and 1	169	14	8	1	11,152
EURO 0 EF	309	57	29	2	10,710
Overall (g)	944	121	72	6	97,444
Overall (kg)	0.944	0.121	0,072	0.006	97.444

Table 7. Emissions produced by vehicles with compression-ignition engines (data collection – 2nd day). Source: authors

Compression-ignition engine	CO (g)	HC (g)	NO_x (g)	PM (g)	CO_2 (g)
EURO 6	12	2	43	0	18,972
EURO 5	10	1	21	0	7 854
EURO 4	22	4	45	2	13,090
EURO 3	31	6	49	3	11,322
EURO 2 and 1	41	8	49	6	8 568
EURO 0 EF	41	14	61	9	7 820
Overall (g)	156	36	268	20	67,626
Overall (kg)	0.16	0.04	0.27	0.02	67.63

Regarding the second day of data collection, vehicles with spark-ignition engines generated a total of 0.944 kg of CO, 0.121 kg of HC, 0.072 kg of NO_x, 0.006 kg of PM, and 97.444 kg of CO_2. The largest share of pollutant emissions came from older vehicles in the EURO 3 to EURO 0 categories, which, even during short trips, reached considerably higher levels of CO and HC due to inefficient combustion at lower engine temperatures.

Vehicles equipped with compression-ignition engines produced approximately 0.16 kg of CO, 0.04 kg of HC, 0.27 kg of NO_x, 0.02 kg of PM, and 67.63 kg of CO_2. Vehicles classified as EURO 3–EURO 5 accounted for the majority of nitrogen oxide emissions, whereas the oldest vehicles contributed to elevated PM levels due to the absence of particulate filters.

4. Discussion

The findings presented in Table 8 below for the first day of data collection confirm that measurable volumes of emissions are generated even along such a short route segment. The total emission score for the round-trip (i.e., from the South Bohemia region to Bavaria and back) reached approximately 5.78 kg of CO, 0.83 kg of HC, 1.77 kg of NO_x, 0.13 kg of PM, and 865.5 kg of CO_2. Vehicles equipped with spark-ignition engines had the largest share of carbon monoxide (CO) and hydrocarbon (HC) emissions, whilst vehicles equipped with compression-ignition engines accounted for the majority of nitrogen oxides (NO_x) and particulate matter (PM) emissions.

The second monitored journey (see Table 9), i.e., on the 2nd day of data collection, observed lower traffic activity, resulting in a decrease in total round-trip pollutant emissions to approximately 2.20 kg of CO, 0.31 kg of HC, 0.68 kg of NO_x, 0.05 kg of PM, and 330 kg of CO_2. This depicts a reduction of more than 60% compared with the volumes recorded on the first day of data collection, reflecting the reduced mobility typically observed at the end of the working week. The territorial distribution of emissions indicates that approximately 61% of overall emissions were produced along the Czech part (4.17 km – encompassing the total length of both Czech sections combined along given types of roads), whereas the German part (2.63 km) accounted for the remaining 39%.

Table 8. Produced pollutant emissions for the model route (first day of the data collection). Source: authors

Data collection – 1st day	CO (g)	HC (g)	NO_x (g)	PM (g)	CO_2 (g)
Spark-ignition engine	2 491	322	192	17	256,836
Combustion-ignition engine	402	93	693	50	175,916
Overall emissions (journey towards Bavaria)	2 892	415	885	67	432,752
Overall emissions (round-trip)	5 785	830	1 771	134	865,504
Overall emissions (round-trip) (kg)	5.78	0.83	1.77	0.13	865.50
Czech part (4.17 km) (kg)	3.55	0.51	1.09	0.08	530.76
Bavarian part (2.63 km) (kg)	2.24	0.32	0.68	0.05	334.75

Table 9. Produced pollutant emissions for the model route (second day of the data collection). Source: authors

Data collection – 2nd day	CO (g)	HC (g)	NO_x (g)	PM (g)	CO_2 (g)
Spark-ignition engine	944	121	72	6	97,444
Combustion-ignition engine	156	36	268	20	67,626
Overall emissions (journey towards Bavaria)	1 100	157	341	26	165,070
Overall emissions (round-trip)	2 200	315	681	52	330,140
Overall emissions (round-trip) (kg)	2.20	0.31	0.68	0.05	330.14
Czech part (4.17 km) (kg)	1.35	0.19	0.42	0.03	202.45
Bavarian part (2.63 km) (kg)	0.85	0.12	0.26	0.02	127.69

For the model route (Strážný–Philippsreut), the results of exhaust gas emissions production are presented in detail in Fig. 3.

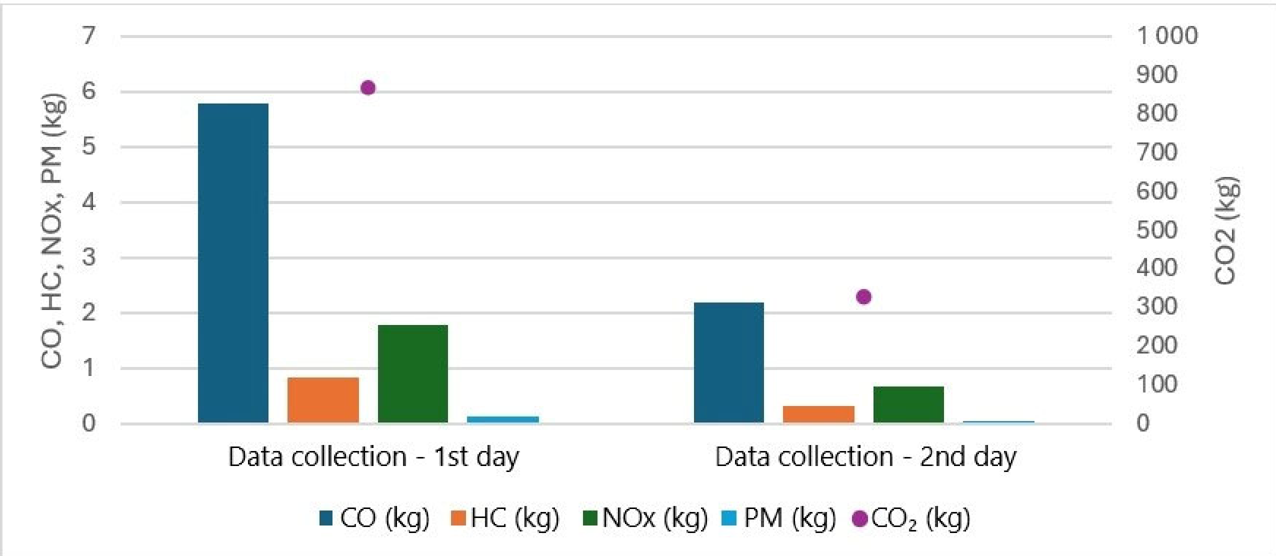

Fig. 3. Comparison of the overall emission burden (Strážný–Philippsreut route) for both days. Source: authors

5. Conclusion

This study presented a modelling framework for quantifying the environmental impacts of regional passenger vehicle traffic and demonstrated its application to the Strážný–Philippsreut border corridor between the Czech Republic and Germany. The route, although only 6.8 km long, is intensively used for daily mobility (commuting) and therefore represents an important source of regionalized or localized transport-related emissions. Using the EEA/COPERT 5.5 methodology and traffic data collected on 26 May and 30 May 2025, the study quantified emissions of carbon monoxide, hydrocarbons, nitrogen oxides, particulate matter, and carbon dioxide. On the 1st day of data collection, total round-trip emissions were 5.78 kg CO_2, 0.83 kg HC, 1.77 kg NO_x, 0.13 kg PM, and 865.5 kg CO_2. Lower traffic intensity observed on the 2nd day of the data collection reduced emissions by more than 60%, to 2.20 kg CO, 0.31 kg HC, 0.68 kg NO_x, 0.05 kg PM, and 330 kg CO_2.

The results confirmed that vehicles equipped with spark-ignition engines are the principal contributors to CO and HC emissions, whilst vehicles with compression-ignition engines dominate NO_x and PM production. Carbon dioxide represented more than 99% of the total mass of all quantified pollutants. Spatial allocation further showed that approximately 61% of emissions were generated on the Czech section of the route and 39% on the German section. These findings demonstrate that even short regional mobility corridors can produce measurable and environmentally significant pollutant impacts, particularly when traffic is dominated by internal combustion vehicles and includes a substantial share of older Euro categories. The designed methodology provides a transparent and transferable tool for supporting regional transport planning, commuter mobility environmental assessments, and policy evaluation.

As for the limitations of the study, several of them ought to be emphasized as follows:

- The analysis conducted followed the generalized COPERT "average on-road" emission factors rather than direct vehicle-specific measurements.
- Traffic surveys were conducted on only two working days, limiting the ability to capture seasonal and weekly variability.
- Cold-start effects were considered conceptually but were not modelled using detailed engine-temperature data.
- Vehicle classification relied on observed registration data and estimated Euro categories.
- The study focused exclusively on exhaust pollutants, which did not include non-exhaust sources such as tire, brake, and road wear.
- Meteorological and congestion effects were not clearly taken into consideration.

Additionally, to extend the designed methodology and modeling in other directions, the ensuing recommendations for future research are formulated:

- Use of the Portable Emissions Measurement Systems (PEMS) to acknowledge modelled emission factors under real-traffic driving conditions.
- Integration of the vehicle-specific data derived from the Worldwide Harmonised Light Vehicle Test Procedure (WLTP) and type-approval databases.
- Application of artificial intelligence and machine vision to automate vehicle classification and emission standard identification.
- Conducting long-term traffic surveys across different seasons and weekdays.
- Estimation of annual carbon footprints per journey and evaluation of mitigation scenarios.
- Comparison of the current traffic conditions with alternatives such as carpooling, electric vehicles, and public transport.
- Incorporating non-exhaust emissions and noise impacts.
- Development of GIS-based emission maps for regional planning applications.

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