Contribution of Tourist and Transit Vehicle Emissions to Air Pollution on Slovenian Roads during Summer

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REPUBLIC OF SLOVENIA
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SLOVENIAN ENVIRONMENT AGENCY

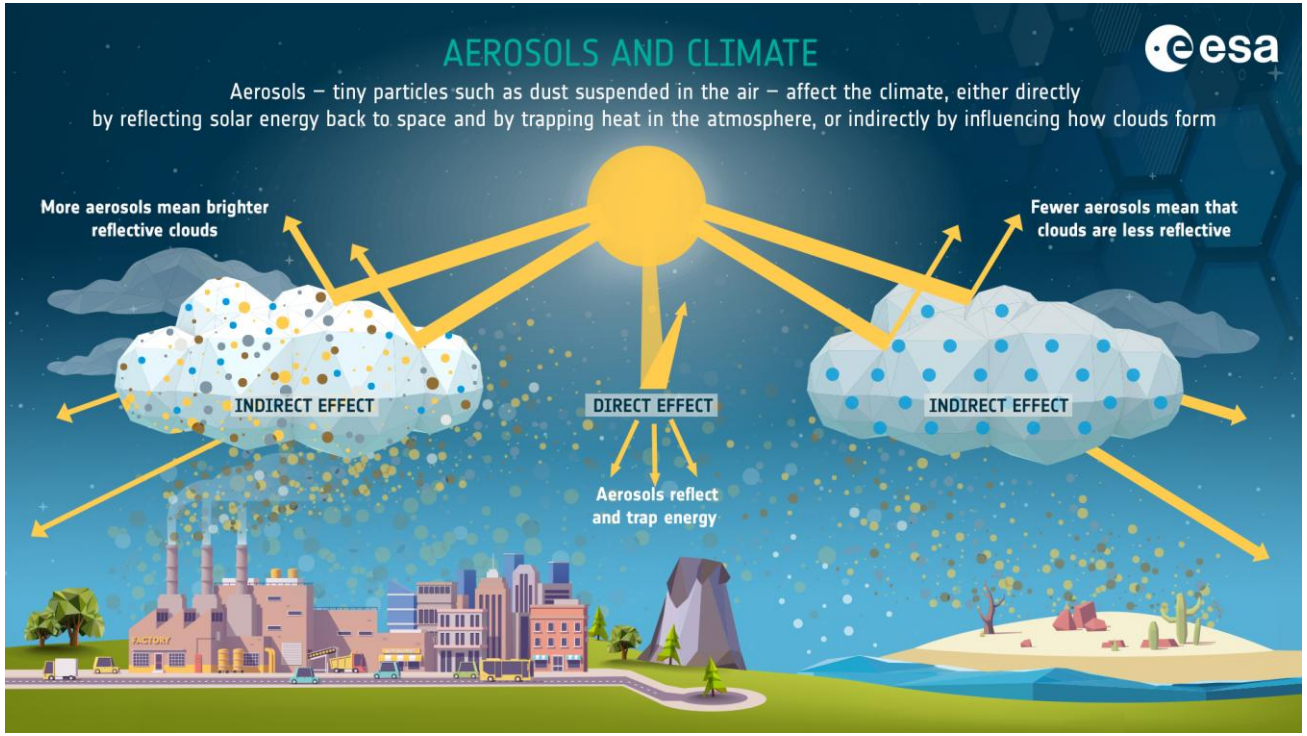
The better input, the better output

Air pollution, particular aerosols and their precursors,
has a substantial impacts on
local weather and climate
by
increasing cloud condensation nuclei and
altering how much solar energy is absorbed or reflected by the atmosphere.

To accurately model impacts of aerosol to local weather
- emissions inventories
- dispersion models, and
- receptor models

perform best when using high-resolution inputs.

Europe has adopted
Directive (EU) 2024/2881 on ambient air quality and cleaner air for Europe
aimed at improving air quality and encouraging detailed studies of emission sources.



The effects of aerosols on Earth's climate are shown in this infographic, including both their direct and indirect impacts. (Adapted from The European Space Agency, https://www.esa.int/ESA_Multimedia/Images/2024/05/Aerosols_and_climate)

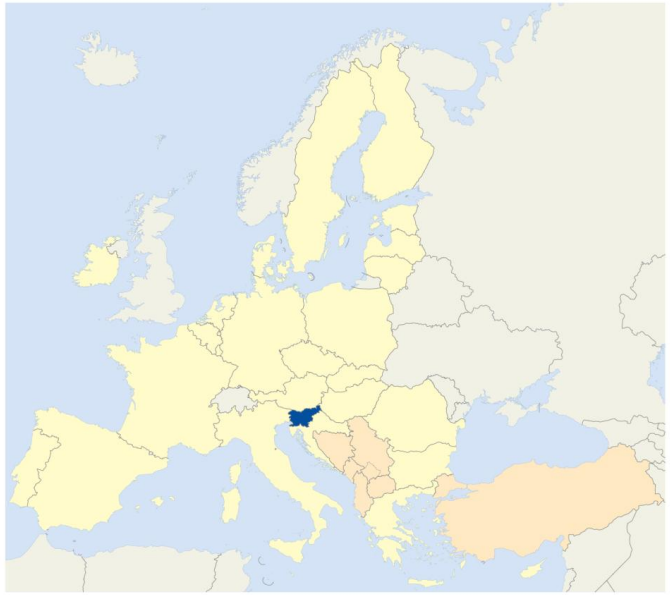
Background

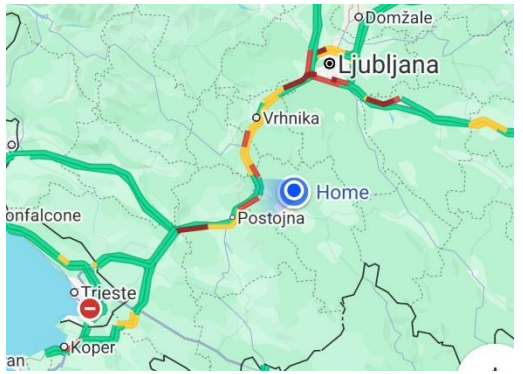
While emission records over time indicate an overall decline,
the transport sector has grown in recent decades,
mostly because an annual increase in vehicle numbers.

Southern European and Mediterranean destinations remain the most popular choices among tourists in Europe (Šulc et. al., 2021).

Slovenia, in the year 2021, the total tourist arrivals were over 4 million, and overnight stays were around 11.3 million (SURS, 2024).

A 1% increase in tourist numbers can be related to up to a 0.45% increase in PM_{10} concentration levels (Saenz-de-Miera & Rosselló, 2014).





Aim of our work

Our study identifies and evaluates the issue of vehicle congestion
on the roads during the summer,
primarily driven by
transit demands and tourism activities.

Year: 2021

Parameters: $PM_{2.5}$, NOx, and NMVOCs

Location: Ljubljana, highway ring

Air Quality in Ljubljana and source contributions

Table: Average yearly and daily concentrations of $PM_{2.5}$ and NO_x.

	Average yearly concentrations [µg/m³] – $PM_{2.5}$	Average yearly concentrations [µg/m³] - NO_x
2023	13	21
2022	14	21
2021	12	23
2020	16	20
2019	16	25

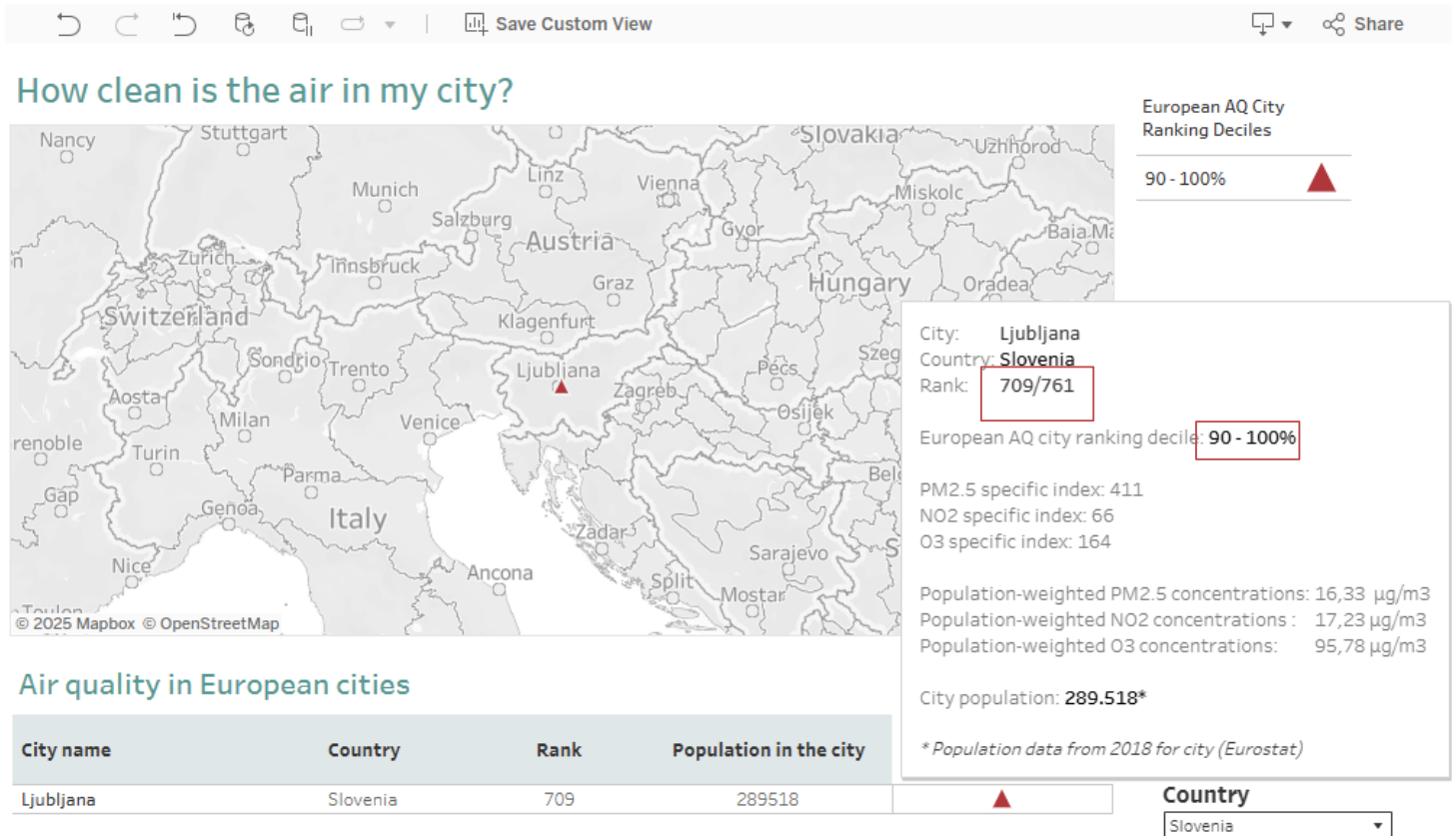


Figure: European city air quality viewer (EEA), 2025

Study Case

Slovenian highways cross-section is in 29.1 km Ljubljana ring junction.The mostly transit traffic is concentrated in the Ljubljana highway ring.

27 vehicle counters has been analyzed, owned by the Slovenian Infrastructure Agency:

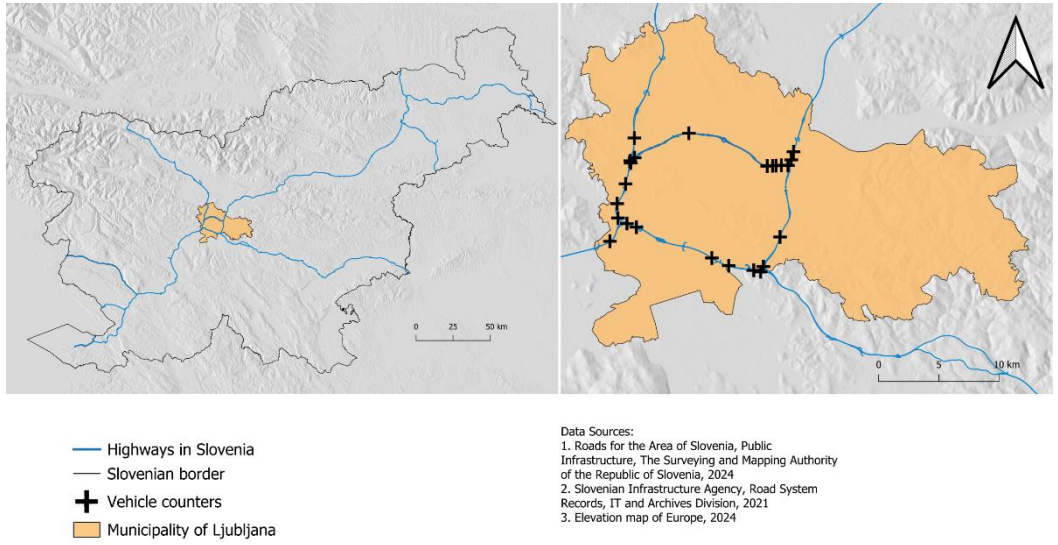
recognized the traffic in both directions

8 different vehicle categories:

- motorcycles,
- ppassenger cars,
- Buses
- light duty trucks (< 3.5 t),
- middle duty trucks (from 3.5 to 7 t),
- light duty trucks (> 7 t),
- semi-trailer trucks and
- tow trucks.

Table: Yearly and daily vehicle number statistics.

	Average	Median	Min	Max
Yearly	59,479	63,750	33,020	87,001
Daily	3654	3395	1297	7495

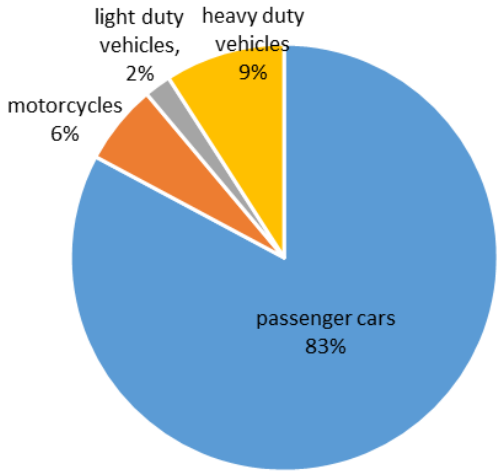


COPERT transport emissions model 5.7

Estimated emissions = hot emissions + cold-start + warming-up effects

In 2021, the Slovenian vehicle fleet comprised 1,707,488 road vehicles.

The average Slovenian passenger car is 10.9 years old, meanwhile 46% of all cars are aged between 10 and 20 years.



The g/year emissions from vehicles that passed the Ljubljana junction in 2021 were calculated according to:

$$E_{pol,v} = \sum EF_{pol,v} \times n_v \times 29.1 \text{ km} \qquad \text{Eq. (1)}$$

Table: Emissions factors for NOx, $PM_{2.5}$, and NMVOCs for 5 vehicle categories on highways, as calculated by the COPERT emission model, reported in unit g/km.

		NO_x [g/km]	$PM_{2.5}$ [g/km]	NMVOCs [g/km]
Engine Operation	Passenger Cars	0.452	0.020	0.058
	Light Commercial Vehicles	1.223	0.031	0.011
	Heavy Duty Trucks	0.587	0.058	0.026
	Buses	1.468	0.055	0.040
	Motorcycles	0.181	0.017	1.108
Tire and Brake Wear and Road Abrasion	Passenger Cars	/ [1]	0.013	/ [1]
	Light Commercial Vehicles	/ [1]	0.031	/ [1]
	Heavy Duty Trucks	/ [1]	0.020	/ [1]
	Buses	/ [1]	0.052	/ [1]
	Motorcycles	/ [1]	0.005	/ [1]
Gasoline Evaporation	Passenger Cars	/ [1]	/ [1]	0.045
	Light Commercial Vehicles	/ [1]	/ [1]	0.002
	Heavy Duty Trucks	/ [1]	/ [1]	0.00002
	Buses	/ [1]	/ [1]	0.00002
	Motorcycles	/ [1]	/ [1]	0.419

[1] The emissions factors are not available.

Traffic Analyses in the Ljubljana Ring Junction

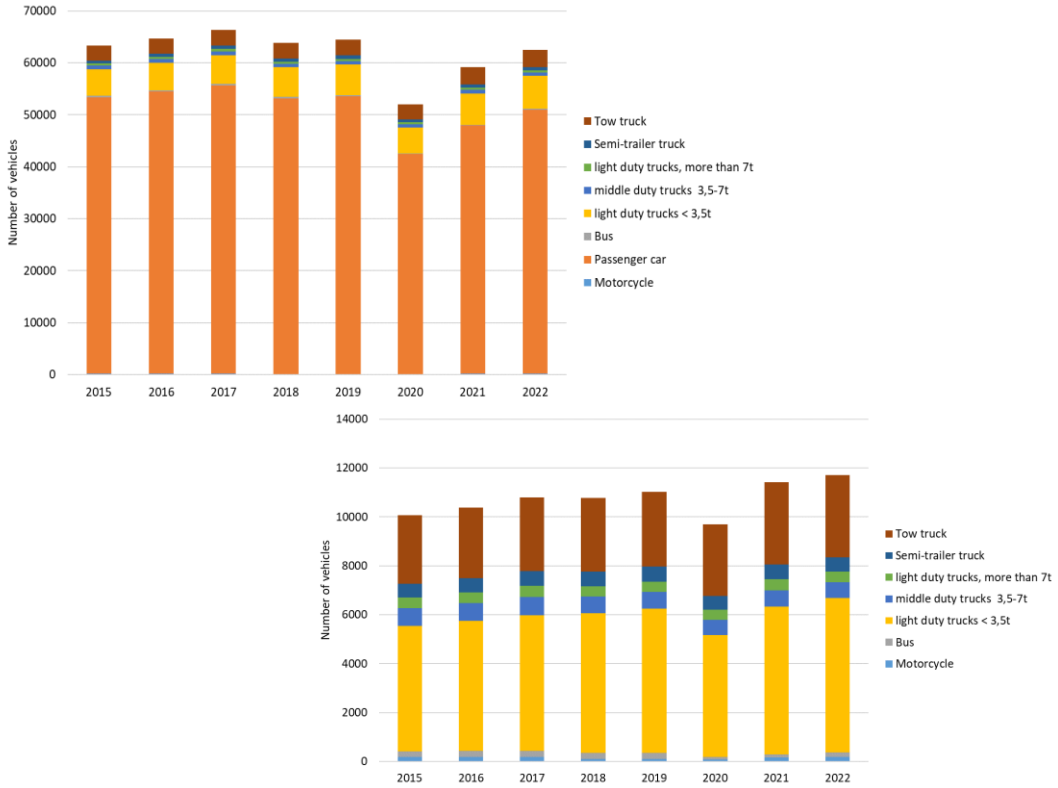


Figure: The average yearly vehicle number from counters located on Ljubljana's from the year 2015 to the year 2022 by 8 vehicle types. The upper figure includes all vehicle categories and the downer figure excludes passenger cars.

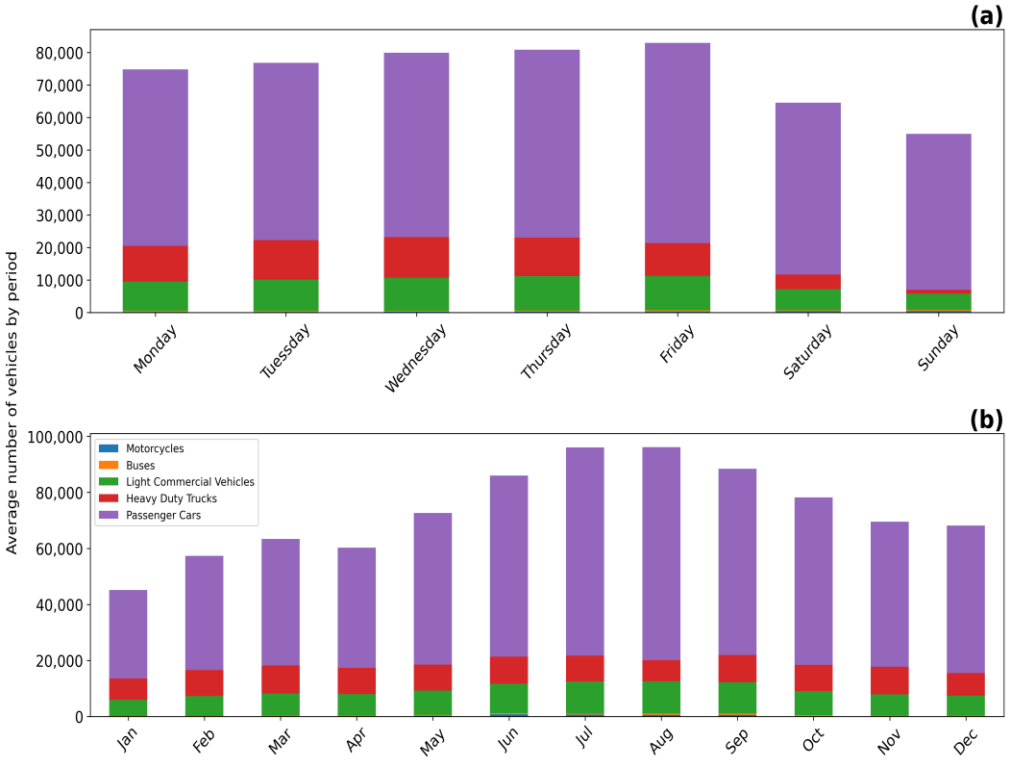


Figure: The average yearly sum of all vehicles is followed by weekly (a) and monthly (b) distributions.

Summer Traffic Peak

1. The summer traffic peak was calculated as a percentage difference $\delta_{\overline{x,v}}$

The mean concentrations of different types of vehicles during summer months (June, July, August, and September)

The mean concentrations of different types of vehicles during other months

$$\delta_{\overline{x,v}}[\%] = \frac{\overline{x}_{sum,v} - \overline{x}_{oth,v}}{\overline{x}_{sum,v}} \times 100$$

Eq. (2)

2. The difference in the number of vehicles

$$\delta_{\overline{x,v}} = \overline{x}_{sum,v} - \overline{x}_{oth,v}$$

Eq. (3)

3. Calculate the change in emissions of NOx, PM2.5, and NMVOCs

Emissions calculated according to Equation (1).

$$\delta_{E,v} = \delta_{\overline{x,v}} \times E_{pol,v} \times 122$$

Eq. (4)

the changes in the number of vehicles on the highways

122 days long summer period

Summer Traffic Peak

- Motorcycles have an increase of 85%, up to 88%.
- There is a **34% increase in buses**, with the rise reaching up to **63%**. This is associated with the rise of tourists in Slovenia during that period.
- The increase **in passenger cars** is on average **19%**, with increases up to **33%** .Due to summer holiday, the usual traffic load is lower.
- 15% fewer heavy duty vehicles.
- There is a recognized increase in **light duty vehicles** of **17% on average**, with increases up to **32%**.These could also include holiday vans weighing more than 3.5 tons.

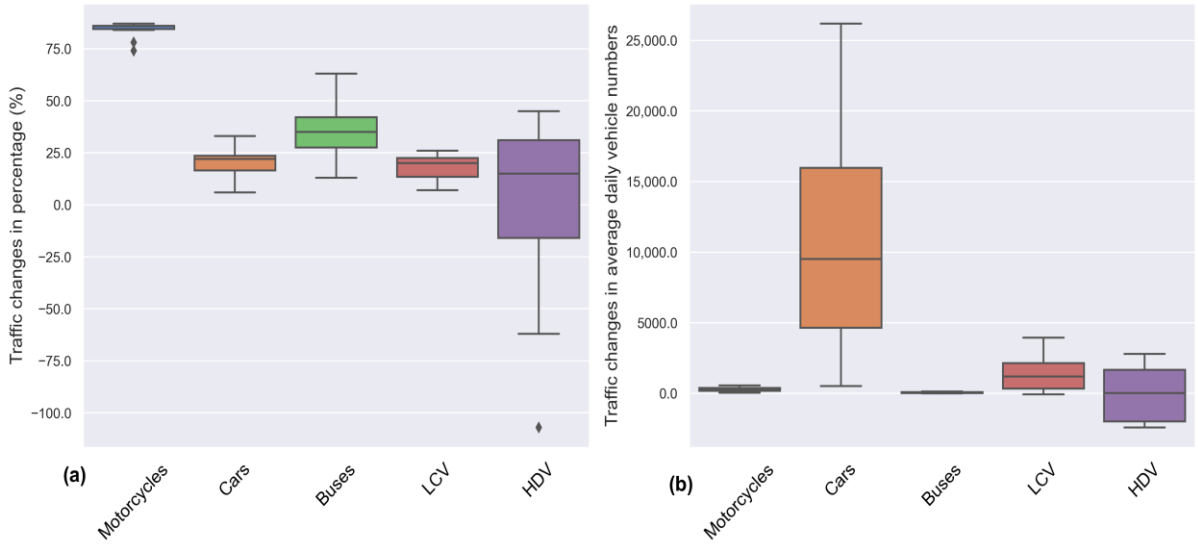


Figure: The summer traffic peak is presented in changes of percentage (a) and changes of average vehicle numbers

Emissions of NO_x, $PM_{2.5}$, and NMVOCs from the Summer Traffic Peak

- The highest emissions were NO_x emissions from passenger cars, which reach up to **41,875 kg** with an average of **15,893 kg**.
- NMVOC emissions are mainly from passenger cars, with a peak of **9542 kg** and an average of **3622 kg.**
- $PM_{2.5}$ emissions are the smallest and are also mostly contributed to by passenger cars, with a maximum of **3057 kg** and an average of **1160 kg**.

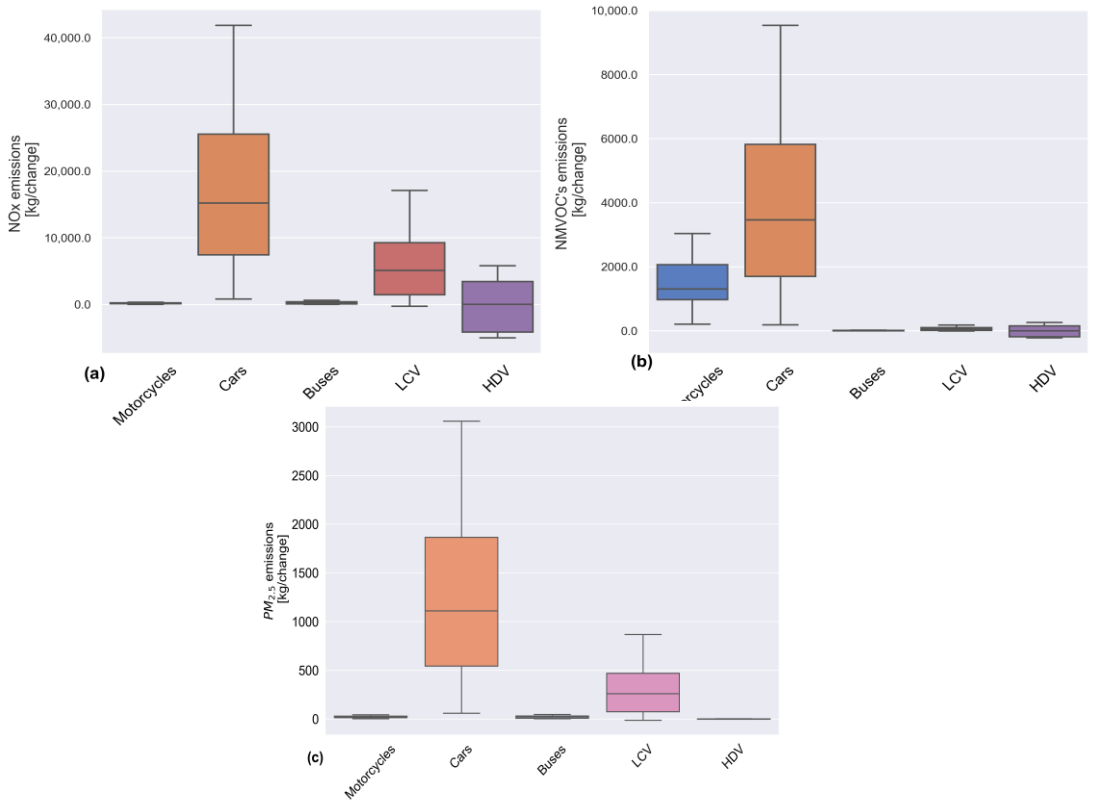


Figure: Calculation of NO_x (a), $PM_{2.5}$, (b) and NMVOC (c) emissions in units of kg

Take-home messages:

The results of this study will help understand the additional emissions sources, which indirectly affect the local weather.

The transport sector has grown an annual increase in vehicle numbers, especially the transit and tourist vehicles during summer.

On an average summer day, there are up to 11,520 additional transit and tourist vehicles which contribute:

16 tons up to 42 tons NO_x,

4 tons up to 10 tons NMVOCs,

2 tons up to 3 tons $PM_{2.5.}$

Thank you for your attention.

I‘m open to any questions.

Please, check my paper here:

Dolšak Lavrič, P.; Kukec, A. Estimating the Contribution of the Summer Traffic Peak to $PM_{2.5}$, NO_x, and NMVOCs. *Atmosphere* **2025**, *16*, 112. https://doi.org/10.3390/atmos16010112

Supplement material

Description of vehicle counters

Supplementary Material

Tabel S1: Description of vehicle counters used in the study. The table include number of counting place, naming of traffic section, locations of the counters in Slovenian coordinate system D96/TM (EPSG:3794), average number of vehicles in year 2021 and average daily vehicle number.

Number	Counting place	Traffic section	E	N	Average number of vehicles in year 2021	Average daily number of vehicles
1	1005	Razcep Zadobrava	467338	103509	33,965	2,913
2	/[1]	Ind. cona Moste - Zaloška	465948	103176	69,000	3,396
3	/[1]	Zaloška – Litijska	465947	103156	60,000	3,357
4	180	Litijska – Malence	466666	99075	57,633	3,394
5	1018	Litijska - Malence	465687	97380	37,092	2,867
6	2408	Malence - Dolenjska c.	465136	97162	69,667	5,335
7	2409	Dolenjska - Peruzijeva	463686	97438	60,607	5,318
8	178	Peruzijeva – Barjanska	462713	97888	65,000	5,273
9	/[1]	Barjanska - Vič	457256	101053	62,500	5,270
10	2403	Vič - Kozarje	458361	99691	72,724	5,510
11	1016	Razcep Kozarje	457816	99904	35,614	4,213
12	2404	Razep kozarje - Brezovica	456821	98889	73,550	7,495
13	/[1]	Šmartno - Brod	458285	103688	54,600	2,001
14	/[1]	Brod - Šentvid	458058	103384	52,000	2,066
15	832	Šentvid - Podutik	458276	104826	55,357	2,179
16	/[1]	Podutik – Koseze	458021	103512	53,500	2,106
17	2402	Koseze - Brdo	457749	102188	87,001	4,709
18	855	Brdo - Kozarje	457260	101051	73,578	4,692
19	1017	Razcep Kozarje	457298	100229	37,110	1,297
20	1019	Razcep Malence	465535	97076	33,020	2,500
21	179	Zadobrova - Leskovškova c.	466456	103180	66,505	3,416
21	891	Leskoškova c. – Šmartinska	465948	103176	48,402	2,920
22	/[1]	Šmartinska - Tomačevo	466765	103204	67,000	3,199
23	/[1]	Tomačevo - Dunajsk	467149	103194	68,500	3,469
24	/[1]	Dunajska - Savlje	466259	103175	68,000	3,384
25	174	Savlje - ind. cona Šiška	461430	105074	66,000	3,180
26	/[1]	ind. cona Šiška - Celovška	467471	103977	72,000	3,415
27	/[1]	Celovška - Vodnikova	465698	97376	65,500	3,427

[1] The Counting place is temporary.

Slovenian Vehicle Fleet Data

Supplement material

Tabel S2: Slovenian Data Fleet in year 2021, categorized by COPERT model with number of vehicles by each category and its main activities in kilometers.

Category	Fuel	Segment	Stock [n]	Mean Activity [km]
Passenger Cars	Petrol	Mini	29611	39,652
		Small	333822	74,075
		Medium	196518	85,672
		Large-SUV-Executive	37845	95,608
		2-Stroke	62	791
	Petrol Hybrid	Mini	264	13,181
		Small	4090	44,165
		Medium	5330	67,653
		Large-SUV-Executive	915	86,258
	Petrol PHEV[1]	Small	164	44,139
		Medium	775	47,203
		Large-SUV-Executive	562	39,599
	Diesel	Mini	1370	57,509
		Small	68682	111,066
		Medium	332116	132,336
	Diesel PHEV[1]	Large-SUV-Executive	243349	231,975
	LPG Bifuel	Mini	145	67,024
		Small	3030	122,773
		Medium	4236	120,293
		Large-SUV-Executive	2306	158,084
	CNG Bifuel	Mini	108	34,775
		Small	28	95,396
		Medium	193	87,542
		Large-SUV-Executive	29	62,398
Light Commercial Vehicles	Petrol	N1-I	3068	98,337
		N1-II	891	91,937
		N1-III	197	75,981
	Diesel	N1-I	6005	139,444
		N1-II	27854	138,857
		N1-III	62513	152,756
Heavy Duty Trucks	Petrol	>3,5 t	25	353
	Diesel	Rigid <=7,5 t	3429	56,655
		Rigid 7,5 - 12 t	2365	106,830
		Rigid 12 - 14 t	643	47,423
		Rigid 14 - 20 t	5744	121,710
		Rigid 20 - 26 t	4055	151,607
		Rigid 26 - 28 t	1623	166,807
		Rigid 28 - 32 t	481	93,006
		Rigid >32 t	1928	88,386
		Articulated 14 - 20 t	8	12,502
		Articulated 20 - 28 t	17	88,206
		Articulated 28 - 34 t	17	14,679
		Articulated 34 - 40 t	3687	282,032
		Articulated 40 - 50 t	12754	371,572
		Articulated 50 - 60 t	957	196,368
Buses	Diesel	Urban Buses Midi <=15 t	119	110,330
		Urban Buses Standard 15 - 18 t	251	164,736
		Urban Buses Articulated >18 t	718	188,675
		Coaches Standard <=18 t	928	127,454
		Coaches Articulated >18 t	524	147,904
	Diesel Hybrid	Urban Buses Diesel Hybrid	1	43,990
	CNG	Urban CNG Buses	113	107,799
	Biodiesel	Urban Biodiesel Buses	0	0
L-Category	Petrol	Mopeds 2-stroke <50 cm³	27786	7,741
		Mopeds 4-stroke <50 cm³	43099	6,379
		Motorcycles 2-stroke >50 cm³	1359	9,091
		Motorcycles 4-stroke >750 cm³	64629	38,859
		Quad & ATVs	7767	4,582
	Diesel	Micro-car	601	17,627

1 PHEV = Plug-in Hybrid Electric Vehicle

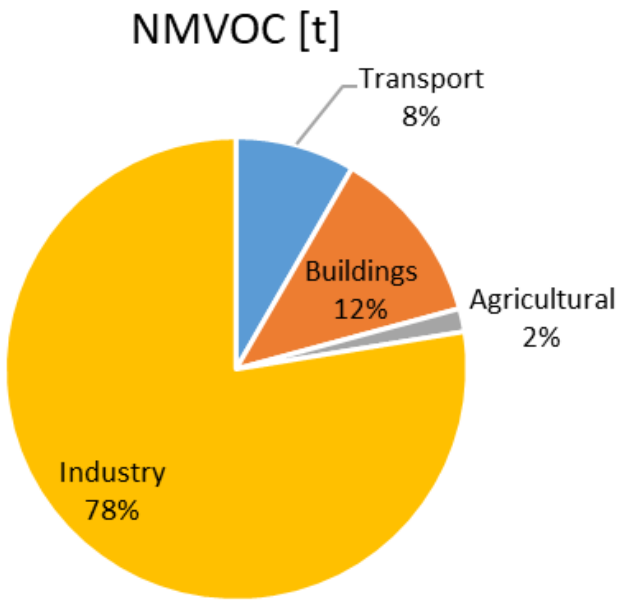
Study limitations and future improvement

1. The driving conditions were constant and smooth.
2. The driving conditions during road construction were not included.
3. During the summer break, there are fewer daily workers in the traffic, and so we expect that our methodology underestimates the emissions from the summer traffic peak.
4. Year 2021 was effected by COVID-19 period.
5. The vehicle fleet from tourist and transit transport is unknown.

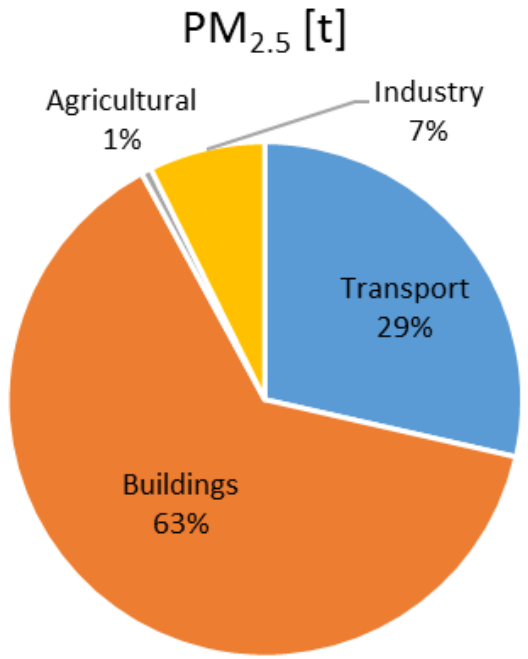
In future works:

1. more data available (traffic volume, speed, and vehicle fleet categorization),
2. greater data to go beyond the analysis of the annual emissions.

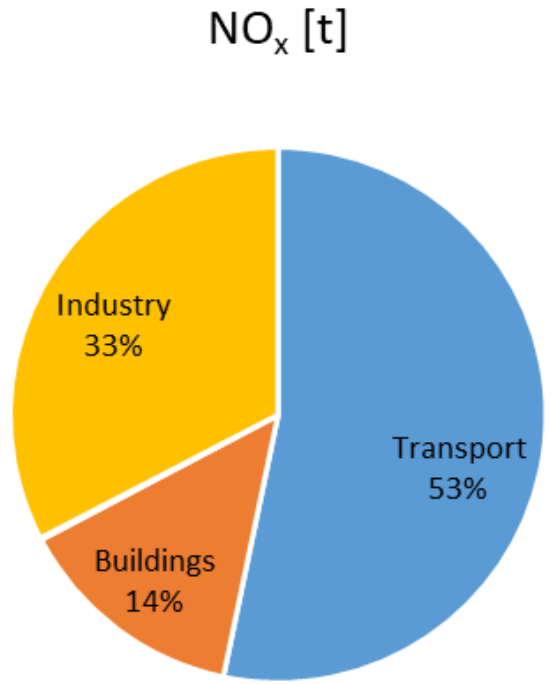
Source contributions in Ljubljana



Sum is 1,847 tons.



Sum is 315 tons.



Sum is 1,935 tons.