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Research paper

Particulate matter air pollution in the Republic of Slovenia and its national spatial emissions release

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ABSTRACT

In this work, an impact of particulate matter (PM) on air pollution and its emissions released is investigated. Concentration levels of PM10 and PM2.5 in the Republic of Slovenia (RS) were analyzed on daily, weekly, monthly, quartile, and annual data and then compared. The study was conducted from January 1, 2020 to December 31, 2020 at two monitoring stations, so-called urban traffic and urban industrial. Obtained results showed that the highest concentrations of PM in air were during the cold months of the year when the temperatures are lower (< 6%). Results from heating seasons (from October 1, 2019 and March 31, 2020 and from October 1, 2020 to March 31, 2021) showed the highest concentration levels of PM10 between 9:00 and 14:00 and between 18:00 and 22:00, with highest concentrations recorded during the winter months (January and February). Additionally, emission building inventory was built based on PM10 and PM2.5 emissions released. The study includes yearly spatial building emissions release model considering currently installed high PM emitted stoves. The building model for the Republic of Slovenia has been developed by using 500 x 500 m model grid. Obtained results showed that changing currently low efficient appliance with advanced appliance would result in significant lower PM emissions released from building sector.

1. INTRODUCTION

For the last decade, air pollution has been considered as a leading environmental problem across the world, caused by ongoing urbanization, rapid economic development, and growing population (Yushan Song et al. 2021; Pang et al. 2021; Dao et al. 2022; Pang et al. 2020; Wang et al. 2018). Air pollutants,

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including sulphur dioxide (SO2), nitrogen dioxide (NO2), carbon monoxide (CO), ozone (O3), volatile organic compounds (VOCs), and particulate matter (PM) nowadays present an urgent threat to environment and public health (Li et al. 2020; Yan et al. 2021; Dao et al. 2022). World Health Organization (WHO) found that around 7 million people die annually because of air pollution, both in the cities and rural areas (World Health Organization (WHO) 2021). In 2018, around 55% of European's population lived in areas exceeding WHO Air Quality Guidelines (according to the average annually concentration levels) (World Helath Organization (WHO) 2021), moreover, around 99% of European's citizens were exposed to levels of air pollutants WHO considers harmful to health (World Helath Organization (WHO) 2021). This share will increase to 60% by 2030 and to at least 80% by 2050 (United Nations, Department of Economic and Social Affairs 2018).

Especially prevalent are today high concentrations of PM in the air, which are considered among top 5 risk environmental and epidemiological factors (M. Yang et al. 2023), causing severe cardiovascular and respiratory problems (Hong et al. 2021; Middlebrook, Turner, and Solomon 2004; Sielski et al. 2021; Kyung and Jeong 2020). Atmospheric particulate matter is a term for ultra-fine particles that are present in an air over a specific period of time (Gjerek et al. 2021). PM10 are referred to inhalable particles, with diameters that are generally in a size 10 µm or smaller (coarse particles), while PM2.5 include fine inhalable particles, with diameters in a size 2.5 µm or smaller (fine particles) (Bec et al. 2022). The particles are complex mixtures mainly composed of chemical and bacterial components from different sources, such as organics (polycyclic aromatic hydrocarbons, PAHs), heavy metals, sulphates, nitrates, allergens, and dust (Samae et al. 2022; Dao et al. 2022). The composition of the particles depends mostly on the origin of the particles; therefore, they can vary according to particle size, source, time, and location (Zhang et al. 2021; Li et al. 2020). Also, PM usually arise as a product of fuel combustions, wood burnings, industrial discharges, or they could exist due to natural reasons of dust storms, forest fire, or volcanoes (Ryou et al. 2018).

A large number of studies on characteristics, formation mechanism, and sources of PM pollution have already been reported globally (W. Yang et al. 2021; Santoso et al. 2021; Yu et al. 2021; Yan Song et al. 2021). M. Yang et al. (2023) studied the association between components, sources, and toxicological effects in PM which were different sizes (PM10-2.5, PM2.5-1, PM1-0.2, and PM0.2). Pang et al. (2021) investigated the impact of the Chinese Clean Air Action implemented in 2013 on changes in aerosol chemistry characteristics in heating season of 2016-2017 and 2017-2018. Foret et al. (2022) presented in the study the pollution episode over Paris in December 2016 in terms of meteorological conditions and PM levels. Lacressonnière et al. (2017) evaluated in the work the future European PM concentrations under the influence of climate change and anthropogenic emission reductions. Pokorná et al. (2015) presented in the study apportion sources of PM0.15–1.15 and PM1.15–10 at residential district of Ostrava-Radvanice and Bartovice in the Czech Republic during January and February 2012. In addition, health impacts from short- and long-term exposures to PM have been widely reported (Rodriguez-Alvarez 2021; Kalisa, Kuuire, and Adams 2023; Tuomisto et al. 2008; Weinmayr et al. 2018; Bergmann et al. 2020). It has been noted that some PM components are more associated with health problems than others, therefore special attention to this must be taken into account (Zoran et al. 2020; Maftei et al. 2022; Kyung and Jeong 2020).

Recently, the Republic of Slovenia (RS) has been suffering from serious air pollution (Zoran et al. 2020; Maftei et al. 2022; Kyung and Jeong 2020). Unfavourable geographical and meteorological conditions result in the alarmingly high concentration levels of PM, especially during the winter time when heating season occurs (Dolšak Lavrič et al. 2020; Bec et al. 2022). Among all sources of heating in the country, residential and commercial biomass combustion is still popular, as small domestic heating plants (with installation power of approximately 20 KW) present around 40% of heating system in the households (MZI 2020). It has been stated by the Slovenian Statistical Biro (SURS) that in the year 2020, 44.891

TJ of energy was consumed in households, of which 16.283 TJ (37%) of wood biomass was used (SURS 2021). Also, around 50% of biomass used domestic heating plants which are currently installed are 20 years old.

Woody biomass has been recognized as one of the most important renewable sources for producing energy and synthetic fuels in the RS, as approximately 58% of the country area is covered by woods (mixed forests, leafy, or conifers forests); 76.5% of the forests are privately owned, whilst 23.5% are owned by the state and/or municipalities. Even though the combustion of woody biomass may affect the air quality in general, its usage for energy production will rise in the European Union (EU) to between 25-30% of the total by 2050 (Sikkema et al. 2021), as a results of some environmental issues, such as global warming, climate change or ozone layer depletion (Allen et al. 2019).

To mitigate the air pollution in the country (and in EU), on behalf of European Environmental Agency (EEA), the Ministry of Natural Resources and Planning in Republic of Slovenia proposed several legal acts and standards, such as "Decree on ambient air quality, Official Gazette of RS No. 9/11, 8/15 and 66/18", "Rules on assessment of ambient air quality, Official Gazette of RS No. 55/11, 6/15, and 5/17", "Decree on emissions of substances into the air from stationary sources of pollution, Official Gazette of RS No. 31/07, 70/08, 61/09, and 50/13", and "National Meteorology, Hydrology, Oceanography and Seismic Service Act" from the year 2017. In addition, the country itself has done a lot on energy structure optimization, transportation optimization, mobile sources emission control ((ARSO) 2020; Elektroinštitut Milan Vdimar 2023; Bec et al. 2022; MZI 2020). Regarding this, a decrease in concentration levels of NO2/NOX (55%), PM10 (48%), and PM2.5 (38%), VOCs (41%), CO (49%) could be observed during 2005-2020 (Bec et al. 2022).

This paper presents an insight into PM concentration levels between the heating seasons in the Republic of Slovenia during the year 2020 covering two monitoring stations from two different regions in the country. This year was chosen as it was globally marked with COVID-19 pandemic and several measures were set by the Slovenian government, such as remote schooling and working, while the chosen monitoring stations were selected as they present typical urban and traffic location in the country with severe air pollution. Additionally, Slovenian building emissions spatial release is presented for the observation year 2018. The findings of this paper can be useful to provide scientific evidence to support the prevention and control of regional air pollution.

2. MATERIALS AND METHODS

2.1. Monitoring stations

Based on the wide variety of the sources for air pollution, geographical and meteorological environment (e.g. background, traffic, industrial or urban, suburban, rural, near city, regional), social, and economic characteristics (e.g. industry, population density, traffic intensity), two nation-based monitoring stations (I. and II.) from two different regions were selected (Fig. 1). Table 1 shows the information about studied monitoring stations, including altitude, coordinates, area type, and measurement type. The air quality samplers were placed inside the monitoring stations, which is approximately 1 m above ground level.

The observation campaign was conducted from January 1, 2020 to December 31, 2020, with special attention to heating seasons, which took place from October 1, 2019 and March 31, 2020 and from October 1, 2020 to March 31, 2021, respectively.

2.2. Sample collection and evaluation method

Real-time hourly concentrations of PM10 and PM2.5 were continuously monitored by the Milan Vidmar

Electric Power Research Institute (EIMV), Department for the Environment, and the Slovenian Environment Agency (ARSO) and are available on open access to the public on the following platform: https://www.arso.gov.si/zrak/kakovost%20zraka/podatki/ (accessed on March 22, 2023). The PM10 and PM2.5 were analyzed using an automatic gravimetric instrument (Sven Leckel, model SEQ47/50). Pre-weighed (WhatmanTM, diameter 47 mm, porosity 8.0 and 0.4 µm) and prebaked (850 °C, 3 h) fiber filters have been used. Before and after the sampling filters stay in a room with controlled humidity 50±5% and temperature 25±2 °C, at least 48 h before being weighted. A Mettler Toledo analytical balance, model AG 245 with a resolution of 0.01 mg was used. The mass concentration of particles in the air was expressed in µg/m3. The sampling procedure was strictly quality controlled to avoid any possible contamination (Shi et al. 2023). PM measurements were performed according to the standard gravimetric method SIST EN 12341: 2014.

The daily average concentrations of PM10 and PM2.5 were only calculated when there were more than 16 h of valid data (Wang et al. 2018). All of the monitoring data was then subdivided into average weekly, monthly, yearly, and quartile average concentrations. For each pollutant, the average data are discussed based on location (traffic and industrial, respectively) during the study year. Besides entire study period was divided into “heating” seasons to recognize the effect of anthropogenic activities on the air pollution in the country.

In addition, meteorological data on daily average temperature (T), relative humidity (RH), wind direction (WD), and wind speed (WS) during the study period were obtained from the EIMV and ARSO meteorological stations as described in our previous works (Ivanovski et al. 2021; Dolšak Lavrič et al. 2020; Ivanovski et al. 2022).

Table 1. Characteristics of monitoring stations.

Sampling site	Altitude (m)	G_{KKY}	G_{KKX}	Area type	Measurement type	Characteristic of the area
I.	299	461919.00	101581.00	Urban	Traffic	Residential, Commercial
II.	362	504504.00	137017.00	Urban	Industrial	Residential, Industrial

2.3 Emission inventory

The emission evidence (EE) is defined as a comprehensive record of pollutants from all sources in a certain area over a certain period of time Jiang et al. (2020). It is defined as a list of pollutants from all resources, entering in the air during a given period of time. Its constant update with actual data and analysing the different future projections is important, specifically for governments, to accept the law with the most suitable air quality measurements and in the long run improve the air quality in the country (Bang and Khue 2019). It also represents a tool for choosing the location of measuring points and choosing the pollutants to be measured. The basic equation to establish EE is (Eq. 1):

$$E = A \times T \times E_F \times \left(\frac{1 - E_R}{100}\right) \tag{1}$$

where, E = emissions; A = activity rate; T = technology; E_F = emission factor; E_R = overall emission reduction efficiency (%).

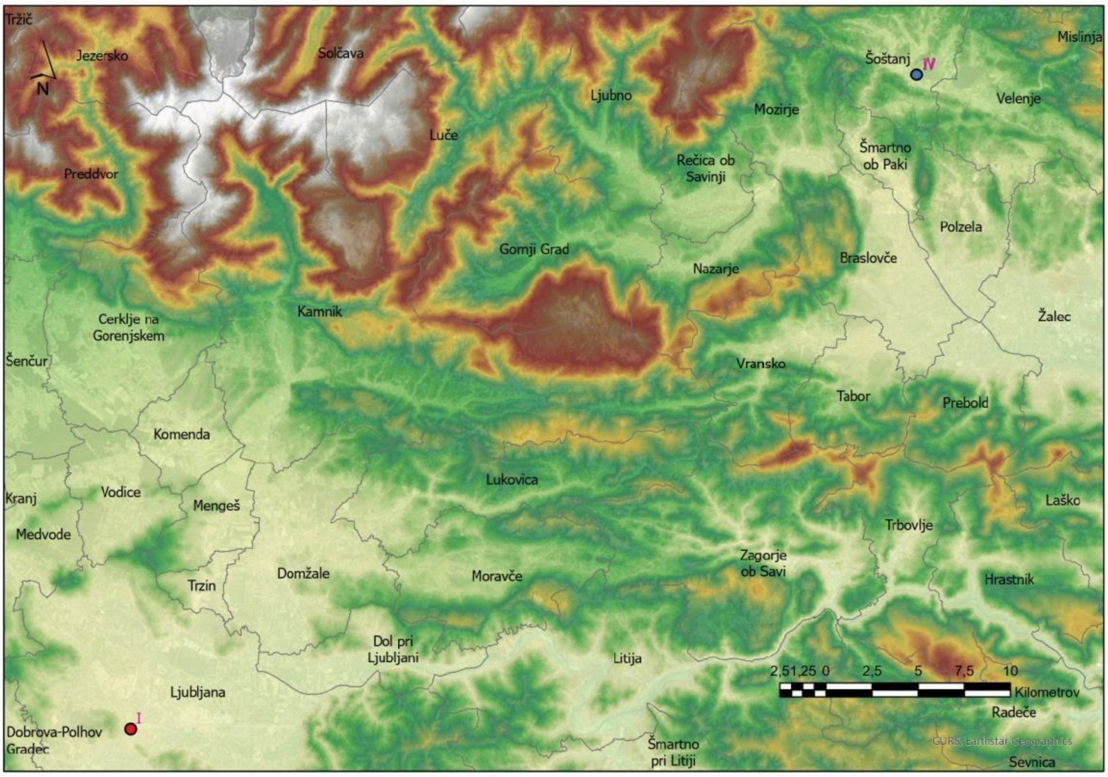


Fig. 1. Location of the monitoring stations in the RS.

EMEP/EEA emission inventory guidebook (European Environment Agency 2019) provides the unified methodology to calculate national emissions release, throughout the National Emission Ceilings Directive (NEC 2001/81/EC) and is based on the Convention on Long-Range Transboundary Air Pollution (CLRTAP 1979). The EMEP/EEA guidance on reporting national emissions provides 3 different complex approaches to reporting national emissions. Tier 1 (TIER 1) refers to statistical activities and basic emission factors; Tier 2 (TIER 2) takes into account more precise data on activity, emission factors and selected technology; and Tier 3 (TIER 3) takes into account the highest level of disaggregation of input data (European Environment Agency 2019). When choosing different levels of reporting, the accesses of input data and the importance of a particular source are taken into account. Emission records are therefore built on two different approaches: “bottom-up” or “top-down” approach. The selection of a specific approach depends mainly on the available data on the activity and the emission factor (EF, i.e. emission factor is necessary for updating emission inventories, which are an essential input for emission evidence and, additionally, to the mathematical models that estimate air quality). The biggest difference between the two is in the spatial distribution of resources. In a »top-down« approach, activity data is obtained at a national or regional level and then distributed to a national area, whereas in the »bottom-up« approach, activity data is obtained at a much more precise spatial unit (e.g. point sources, road network, etc.) and then aggregated to the desired spatial resolution (European Environment Agency 2019). The following pollutants are reported under (CLRTAP 1979): five basic pollutants (NOX, NMVOCs, SO2, NH3 and PM2.5 and additionally (CO) dust emissions: PM10 and PM2.5, black carbon (BC) and total particulate matter (TSP); heavy metals: cadmium (Cd), lead (Pb) and mercury (Hg) and, if available, arsenic (As), chromium (Cr), copper (Cu), nickel (Ni), selenium (Se) and zinc (Zn); and finally, persistent organic compounds (POPs) including PAHs, dioxins and furans, polychlorinated biphenyls (PCBs), and hexachlorobenzenes (HCBs).

Such a model was built in this work by using the official and currently only available data from the year 2018. The model on how to calculate the PM emissions released from the buildings was prepared based on the energy demand for heating and preparing warm sanitary water for each house in the RS (Slovenian Environment Agency 2020). The building model for RS has been developed by using 500 x 500 m model grid. The basic data for the model was the Slovenian National Register of Buildings, whereas the residential use was recognized from the Slovenian Population register (Slovenian Environment Agency 2020), which holds information about the number and address of the habitants. Based on the daily hourly temperature and measures from the meteorological stations the temperature deficit was calculated, which is important to recognize the days when the heating system was used. The information about the type of appliances and the fuel used in particular buildings is held in the Evidim base. The buildings near by the location of the district heating and natural gas network, without the information about the heating system and fuel noted in the Evidim database, were recognizedas the use of gas or district heating. Some improvements on the quality of house such as changing of rooftops, type of isolation, appliances and fuels are noted in the Eco fund base.

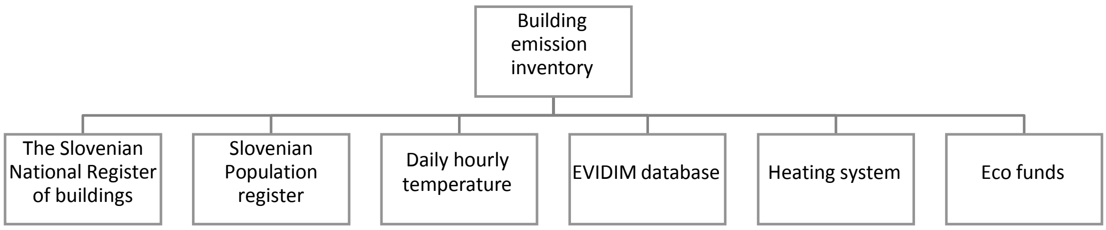


Fig. 2: The input data used in the building emission inventory

3. RESULTS AND DISCUSSION

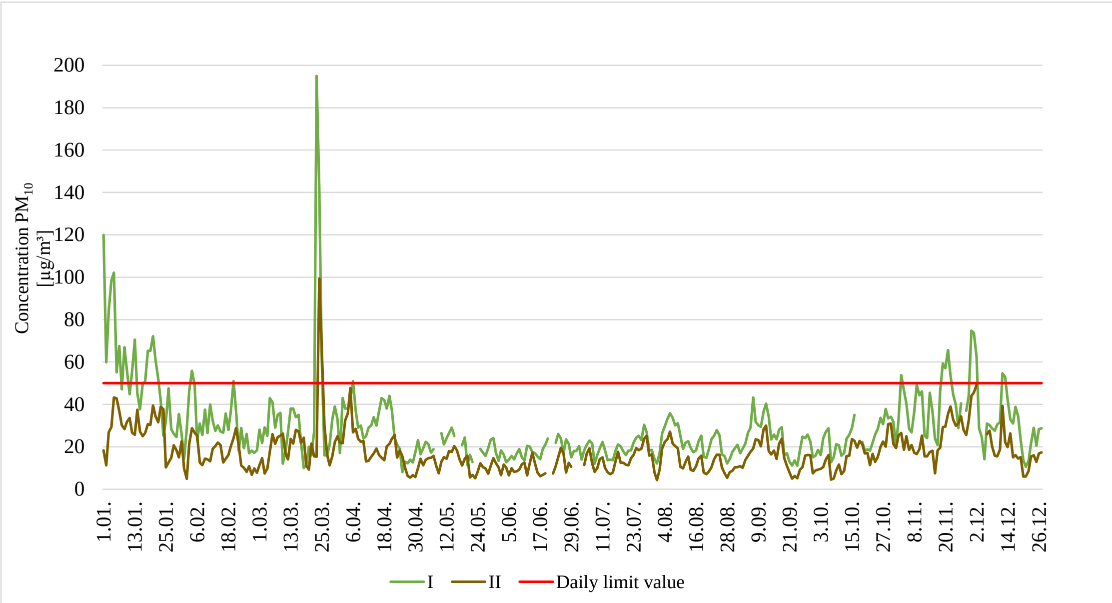
3.1. Overview of air pollutant concentration during the year 2020

Fig. 3a and 3b shows the daily average concentrations of PM10 and PM2.5 at traffic and industrial (I. and II.) monitoring stations during the entire studied period. Fig. 4 furthermore shows average, minimum, and maximum values with Standard Deviations for each study air pollutant at each monitoring station, respectively. At traffic monitoring station, the daily average concentrations of PM10 and PM2.5 in the year 2020 were 30.31±0.91 µg/m3 and 18.35±0.55 µg/m3, respectively, whereas the concentration level of PM10 was 17.82±0.53 µg/m3 at the industrial monitoring station. In that year, concentration levels of PM2.5 were not detected due to the error in the measuring system. The weekly average concentrations of PM10, and PM2.5 in the year 2020 at the traffic monitoring station were 16.86±0.51 µg/m3 and 13.96±0.41 µg/m3, while at the industrial monitoring station, the weekly average concentration of PM10 was 21.43±0.64 µg/m3. The monthly average concentrations varied from 20.00±0.60 µg/m3 to 64.00±1.92 µg/m3 and 20.00±0.60 µg/m3 to 43.00±1.29 µg/m3 for each studied pollutant respectively at the traffic monitoring station; meanwhile at the industrial monitoring station the concentration from 1.00±0.33 µg/m3 to 29.00±0.87 µg/m3 was detected. The daily limit value of 50 µg/m3 for PM10 at the traffic monitoring station was exceeded 21 times in January, 2 times in February, 3 times in March, 1 time in April, 5 times in November, and 5 times in December; at the industrial monitoring station the value exceeded 1 time in February, 3 times in March, 1 time in April, and 5 times in November and December, respectively (Gjerek et al. 2020). The average quartile concentrations for each studied pollutant are presented in the Fig. 5. The year 2020 was divided into four quartiles I. (January – March), II. (April - June), III. (July – September), and IV. (October – December). For the PM10 parameter, the highest average quartile value at the traffic monitoring station was obtained at the

II. and III. quartile (50.00±1.00 µg/m3), whereas at the industrial monitoring station the highest average quartile value for PM10 parameter was detected at the I. quartile.

From the obtained results it can be concluded that the highest concentrations of particulate matter in the air were especially during the cold months of the year when the temperatures are lower (I., IV. quartile). This also leads to creation of temperature inversions at both monitoring stations. Moreover, it is believed that the points where the pollutant concentration increased dramatically is result of unique events, such as unexpected Saharan dust, blooming time (in spring), forest fires (in summer), or any other unforeseen event.

a)



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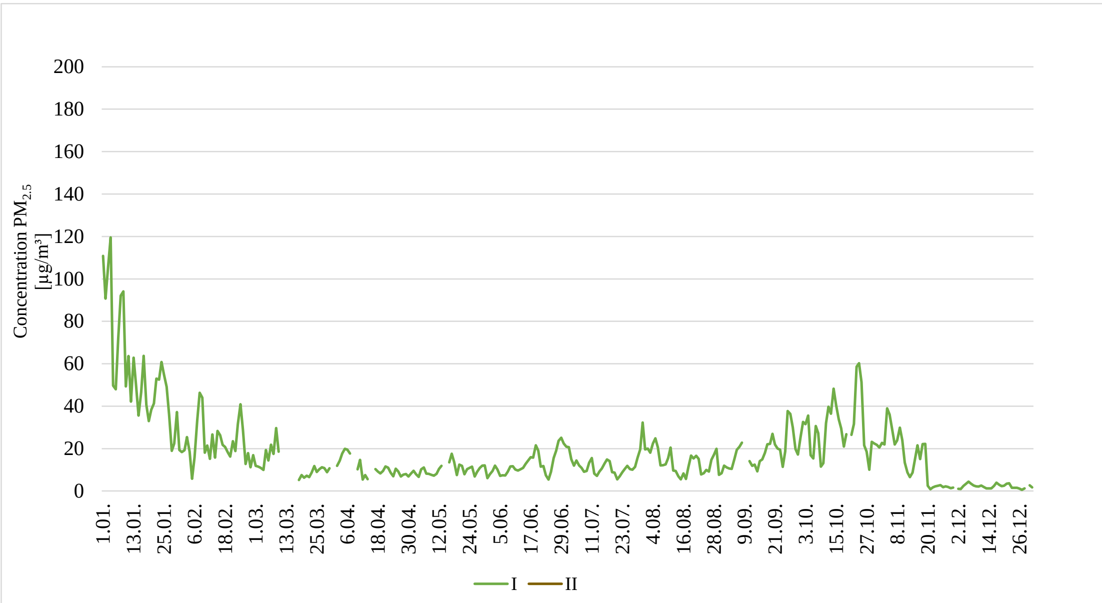


Fig. 3: The daily average concentration levels of PM_{10} and $PM_{2.5}$ at traffic (I.) and industrial location (II.) during the year 2020.

A look across the Slovenian geographical borders shows that the exceedances of the European daily limit value for PM10 in year 2020 have been seen for example in Italy, particularly in Po valley, and some other eastern EU countries (Croatia, Bulgaria, and Poland) ("Directive on Ambient Air Quality and Cleaner Air for Europe (EC/50/2008)" 2008). For instance, in Croatia, the exceedance of PM10 daily concentration levels were found in the town of Kutina (70 µg/m3) and Osijek (67 µg/m3), both are urban traffic locations. In Bulgaria, the exceedance of PM10 daily concentration levels was found at location AMS Trakia – Plovdiv Sarajevo (62 µg/m3), whereas in Poland, the exceedance of PM10 daily concentration levels were found at location Nowa Ruda (76 µg/m3), Pszcyna (76 µg/m3), and Nowi Targ (89 µg/m3). All are urban background locations. It is believed that this is mostly the consequence of widely used solid fuels such as wood or coal for heating the households, industrial facilities, and power plants. Annual calendar report on status of air quality in Europe (European Environment Agency 2023b) recognized that in 2020, the annual calendar limit value of 40 µg/m3 was not exceeded. Additionally, 10 reporting countries, including 6 EU Member States, registered concentrations of PM10 above the European annual limit value of 25 µg/m3 (Croatia, Italy, Poland, Turkey, Kosovo, and Bosnia and Herzegovina). All studied monitoring stations were located mostly in the urban area (European Environment Agency 2023b). Moreover, in year 2020 the impact of COVID-19 lockdown restrictions across the Europe was limited and no greater than a median reduction of 4% across all stations. The main reason for that could be the fact that increased emissions from residential heating compensated for emission reductions in other sectors. But decreases in annual mean PM10 concentrations were measured predominantly at traffic stations. On the other hand, some other monitoring stations measured a clear increase. Clear geographical pattern across Europe could not been recognized (European Environment Agency 2023a).

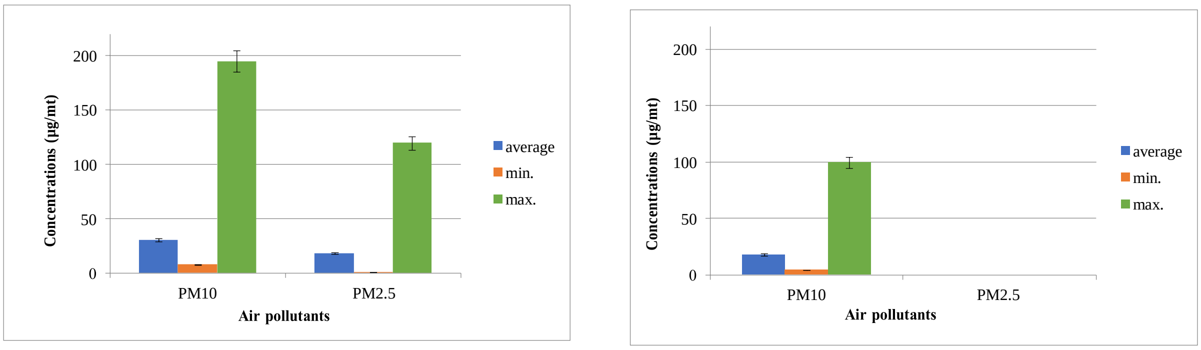


Fig. 4: The average, minimum, and maximum values for PM_{10} and $PM_{2.5}$ at the traffic (left) and industrial (right) monitoring stations during the entire year 2020.

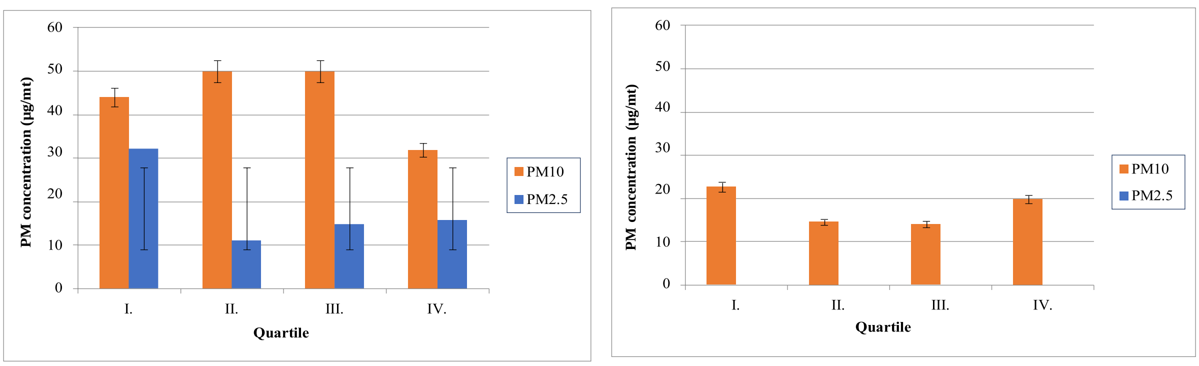


Fig. 5: The average, minimum, and maximum values for PM10 and PM2.5 at the traffic (left) and industrial (right) monitoring stations during the entire year 2020

Furthermore, local meteorology and relief variability of the surface are closely related to the concentration of emissions in air (Ivanovski M., Dolšak Lavrič P., Miklavčič N., Kovačič D. 2021). Studied meteorological parameters (wind speed, ambient air temperature, relative humidity, and precipitation) during the year 2020 are presented in the Table 2. Average annual temperature at the traffic monitoring station was 12.00±0.60 °C, at the industrial monitoring station average annual temperature was 11 10.00±0.50 °C. Detected wind speeds were 1.30±0.07 m/s at the traffic monitoring station and 6.00±0.30 m/s at the industrial monitoring station. At traffic location north-east wind dominated during both years, while at the industrial location north- west and south-east winds dominated (Agencija Republike Slovenije za Okolje 2020). The relative humidity was 65.00±3.25 % at the traffic monitoring station, whereas at the industrial monitoring stations it was 82.00±4.10%. Lastly, precipitations were 105.18±5.30 and 115.20±5.80 mm, respectively at each monitoring station.

Based on these findings, we can conclude that changes in ambient air temperature, wind speeds, relative humidity, and rainfall were similar at both locations.

Table 2: Meteorological parameters during the entire study year at both monitoring stations.

		Traffic monitoring station		
	T (°C)	**WS (m/s)**	**RH (%)**	**Rainfall (mm)**
average	12.00±0.60	1.30±0.07	65.00±3.25	105.18±5.30
min.	-2.00±0.10	0.70±0.04	28.00±1.40	13.90±0.70
max.	26.00±1.30	1.80±0.09	87.00±4.40	202.60±10.10
		Industrial monitoring station		
average	10.00±0.50	1.00±0.05	82.00±4.10	115.20±5.80
min.	-6.00±0.30	0.00±0.00	46.00±2.30	22.30±1.10
max.	26.00±1.30	5.00±0.30	10000±5.00	247.30±12.40

3.2. Overview of air pollutant concentration during the heating seasons

Figs. 6a, 6b, and 6c show the concentrations of PM10 at both studied monitoring stations during the heating seasons (1 October 2019-31 March 2020 and 1 October 2020-31 March 2021). Because the PM2.5 concentration levels were not detected at the industrial location during the year 2020, comparisons between hearing seasons for this parameter were not possible. At the traffic monitoring station, the PM10 concentrations during the heating seasons were 42.03±2.10 µg/m3, 48.54±2.43 µg/m3, and 50.44±2.52 µg/m3, respectively. At the industrial monitoring station, the PM10 concentrations during the heating seasons were 23.38±1.17 µg/m3, 28.56±1.43 µg/m3, and 30.15±1.51 µg/m3, respectively. At the industrial monitoring station, the PM10 concentrations were lower (< 60 wt.%), which may be the result of the geographical location of the monitoring stations; traffic monitoring station lies in the capital city of Ljubljana, very close to a road with significant daily vehicle traffic (10 m distant), a junction of international motorways running in four directions (crossing two corridors-directions) and railway lines (five to six directions). Central district heating and wood heating precedence. Industrial monitoring station is located in the north-east of the RS, in the valley along the Paka river, close to the thermal power plant (500 m distant).

Based on the local standard time, variations of PM10 concentrations at both locations were higher between 9:00 and 14:00 and between 18:00 and 22:00, with highest concentrations recorded during the winter months (January and February). It is believed that such results are a consequence of home schooling, remote working, and in general staying at home.

3.3. Slovenian building Emissions Inventory

The Republic of Slovenia has a typical spatially dispersed settlement, where to conduct district and gas heating system are not always possible. As already stated, citizens in the country still use woody biomass as a primary fuel source, especially in the winter time, and consequently, high amount of PM10 are released in that period. In the current work, installed domestic heating stoves built on average 20 years old low-efficiency were evaluated, together with emissions released (PM10, PM2.5) by using woody biomass as the main source. The emission inventory is built on the year 2018 data. Obtained results showed that domestic buildings released approximately 8.51 kt of PM2.5 and 8.69 kt of PM10 emissions in the Slovenian territory, respectively. The validation of this data was made in two steps. Firstly, emissions released were compared to the ones stated in the National Energy report published in year 2018 (European Environment Agency 2019); secondly, the whole emissions released in tons per year were compared by the official national emissions evidence conducted mostly by TIER 1 and 2 methods (Slovenian Environment Agency 2020), which currently presents the only official national emissions evidence. First validation showed that data in this work is higher for 20% compared to those in the National Energy report. It is assumed that those anomalies are result of different human heating activities. For example, in the building inventory it is estimated that each room is heating up to 23 °C, whereas in real life this is not always possible. Besides, all buildings do not heat their rooms through the whole heating seasons. Second validation of our data showed 10% higher emissions released (PM10 and PM2.5) than those calculated through »top-down« approach. Such small discrepancy could be the result of the using the same data activity validation and the same PM emissions factories. The »top-down« emissions showed the spatial distribution of building heating PM emissions. The same validation process of bottom-up national emissions evidence was reported in study of Terrenoire et al. (2015) and Pallavidino et al. (2014).

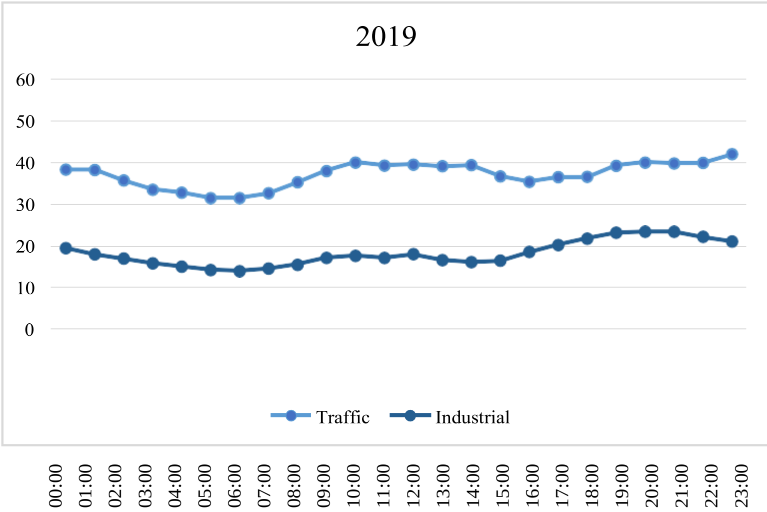
Based on these results it is believed that the finest solution of successfully decrease emissions from biomass burning is to develop heating stoves that are more efficient and using biomass that release less emissions. Besides, emission inventory showed that emissions released in the country are more related on the efficiency of the installations stoves than on the number of people actually living in the country (Fig. 7).

4. CONCLUSIONS

This study investigated concentration levels of PM10, and PM2.5 in the Republic of Slovenia and their emissions released. The air pollutants were observed at two monitoring stations, urban traffic and urban industrial location, between January 1, 2020 and December 31, 2020. From the average data it can be observed that PM10 and PM2.5 average concentrations were higher at urban traffic location compared to the ones at industrial location. Results from heating seasons showed that the variations of PM10 concentrations at both locations were higher between 9:00 and 14:00 and between 18:00 and 22:00, with highest concentrations recorded during the winter months (January and February). It is believed that such results are a consequence of home schooling, remote working, and in general staying at home. Furthermore, yearly spatial emission release from buildings is presented in the study, built on the »bottom-up« approach. From the obtained results, it is clear, that emissions released are not depended on the population, but on the type of installed appliances.

In the future work, we would like to continue with the experimental part using and comparing different appliances, such as domestic wood stove or fireplace, as well as using different type of equipment for measuring PM particles.

a)



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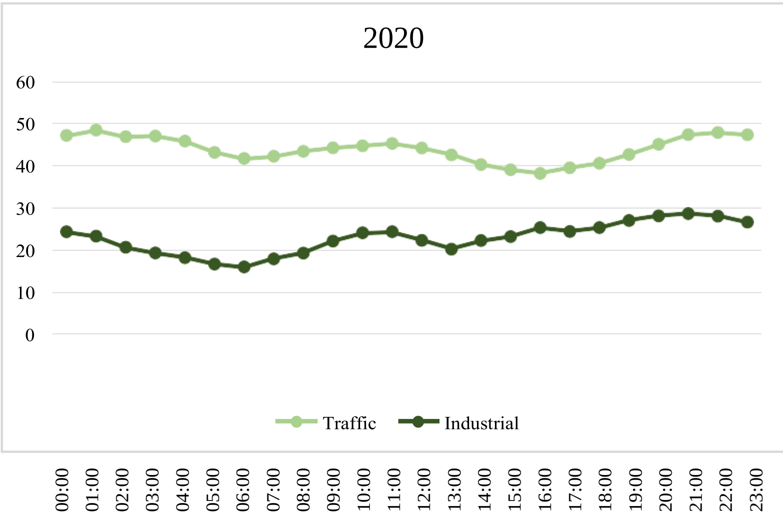

c)

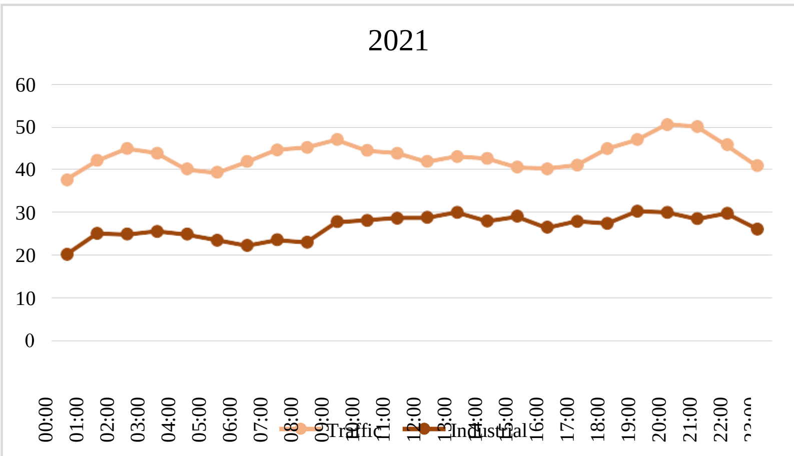

Fig. 6: Daily variations of PM10 concentrations during the heating seasons at both locations, respectively (from October to December and from January to March)

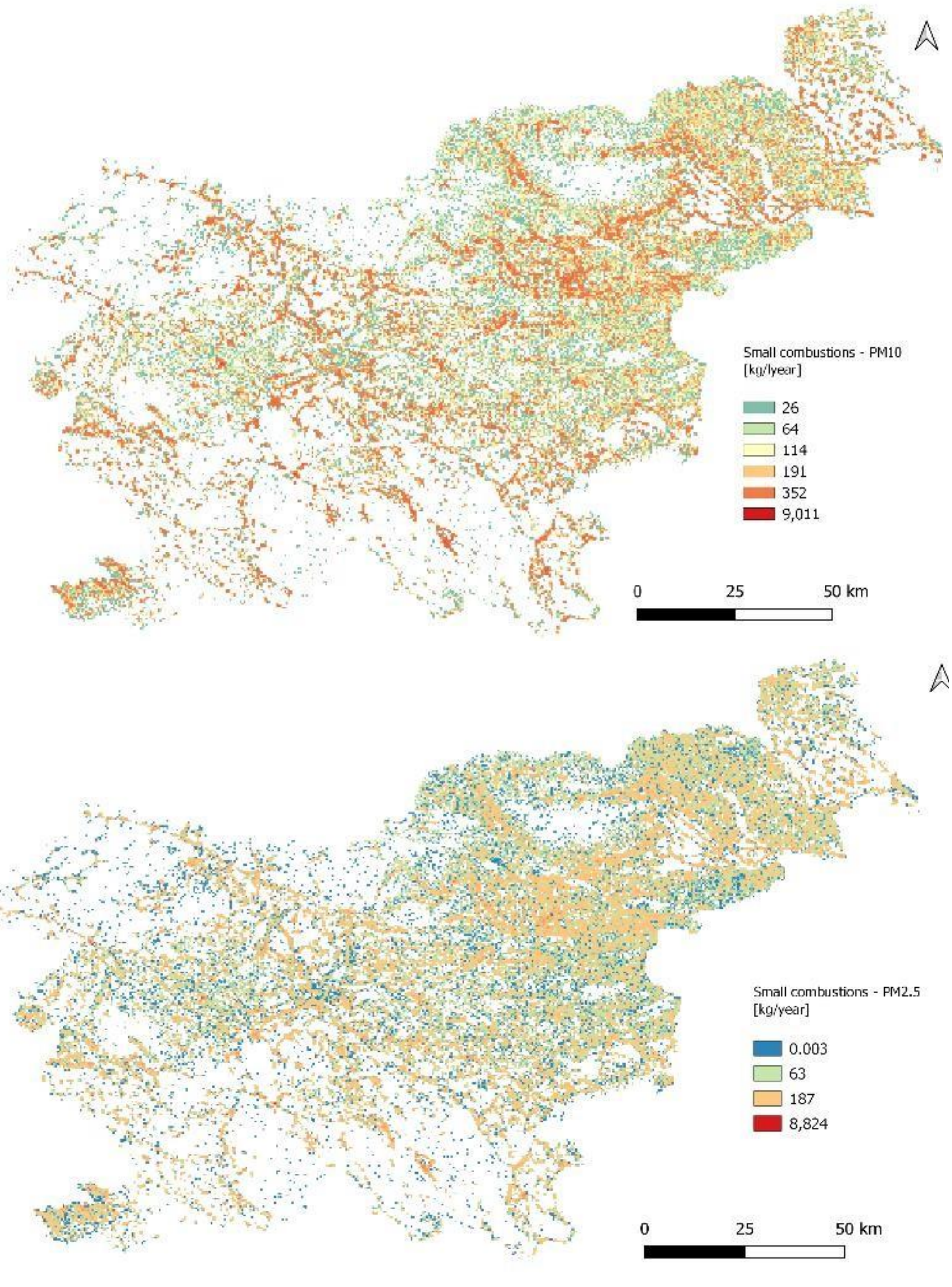

Fig. 7: Spatial release of yearly PM_{10} (left) and $PM_{2.5}$ (right) emissions on 500×500 meters grid

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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ABBREVIATIONS

ARSO	Slovenian Environment Agency
CLRTAP	Convention on Long-Range Transboundary Air Pollution
EEA	European Environment Agency
EE	Emission evidence
EF	Emission factor
EU	European Union
EIMV	Elektroinštitut Milan Vidmar
PM	Particulate matter
RS	Republic of Slovenia
RH	Relative humidity
SURS	Slovenian Statistical biro
WHO	World Health organization

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