

# Data-driven analysis of transport and weather impact on urban air quality

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**Abstract:** Many cities face low air quality. To better predict the exceedance of air quality limits, the traffic's contribution to air pollution was analysed in this paper. Several studies used a twin site approach to determine the impact of urban traffic; however, it requires the deployment of stations at various locations. A time variant analysis to determine traffic's contribution and regression analysis were applied to determine the weather's impact. The results were validated using actual traffic data. It was found that the traffic's contributions to CO and NO<sub>2</sub> were 22 and 30%. It was noted that the seasonal fluctuation of NO<sub>2</sub> is significantly influenced by precipitation. Long-term trends of pollutants require further research.

**Keywords:** air quality; urban; traffic; weather; sustainability

## I. INTRODUCTION

Since more and more people live in cities, the urban air quality has recently been a strong focus of researchers and media attention. Despite pollutant concentration limits set by legislation, air quality measurements show that concentrations frequently exceed the limit [1]. For example, 15, 34, and 4% of reporting stations registered exceedances of particulate matter with a diameter of 10 µm or smaller (PM<sub>10</sub>), ozone (O<sub>3</sub>) and nitrogen oxides (NO<sub>x</sub>) annual limit values. Estimates of the health impact indicated that long-term exposures to PM<sub>10</sub>, O<sub>3</sub>, and NO<sub>x</sub> in 2018 were responsible for 379 000, 19 400 and 54 000 premature deaths in EU 28, respectively [1].

Road traffic contributes to air pollution in various ways, including:

- **primary exhaust emission:** particulate matter and gases in engine exhaust,
- **secondary exhaust emission:** pollutants formed from primary exhaust emission,
- **non-exhaust emission:** wear of vehicle components, e.g., tyres [2].

In this paper, the focus is put on primary and secondary exhaust emissions. The vehicles' emission has been decreased significantly over the past decades. Despite these efforts, road transport is

still an important source of PM, CO, and NO<sub>x</sub> emission [3-5], contributing 10, 20 and 39%, respectively in 2018 in EU-28 countries [1]. Furthermore, the contribution of road transport to emission in dense urban areas may be significantly higher [6]. The sectors' contribution to O<sub>3</sub> concentrations was not calculated because O<sub>3</sub> is not emitted directly into the air but is created when volatile organic compounds and NO<sub>x</sub> combine in the presence of sunlight.

To achieve real-world emission reduction, the European Union promotes clean mobility and requires each new passenger car model to pass the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) [7]. Since local air pollution primarily affects urban areas, the identified research question are as follows: what reductions in road traffic emission can be expected from regulations and new technologies in urban areas? Furthermore, the difference between weekdays and weekends was put into focus to estimate how working from home may impact the total emission.

The structure of the paper is the following: after a brief literature review, the data and temporal twin site method are presented in Section 3. In Section 4, the results and discussion are given. Finally, the conclusions are drawn.

## II. LITERATURE REVIEW

Air pollution was studied on various levels in the scientific literature. These studies mainly focus on PM, SO<sub>2</sub> and NO<sub>x</sub>, but other components may emerge. On the atmospheric level, the transmission of air pollutants between countries was studied in several papers [8-9]. For example, a study emphasized the knowledge gaps and lack of data about the atmospheric transport of microplastics and its contribution to the worsening of air quality [10]. Other studies investigated the transmission of pollutants between cities [11-12]. For example, the effect of city-to-city air pollution transmission on COVID-19 health outcomes was investigated in [13]. It was found that PM<sub>2.5</sub>, NO<sub>2</sub> and O<sub>3</sub> increase the number of infected people.

Since local emission contributes most of the total emission in the urban regions [14] other researchers studied local air pollution on a city scale. The issue has also attracted the attention of sensor developers who combined gas sensor arrays with machine learning in the E-nose concept using different materials to better fit the requirements [15]. Recently, traffic calming measures are introduced in many cities. Therefore, the relationship between traffic's emission and air quality was put in focus to support the evaluation of measures.

The corresponding studies are summarized in **Table 1**. To estimate the contribution of road traffic to local air pollution, characteristics of traffic was used. A study estimated the CO pollution based on total travelled distance and average speed using the Versit+ micro model as a reference in a small area [16]. Microscale traffic and related NO<sub>x</sub> and PM<sub>10</sub> emissions were simulated in a hot spot [17]. The

effect of traffic characteristics on emission were analysed, but traffic's contribution to the total air pollution was not investigated. Accordingly, factors affecting air quality, such as weather, was not considered. A regional atmospheric chemistry model to quantify the NO<sub>x</sub> emission from traffic was used in [18]. Beside traffic counts, the temperature, wind speed and mixing height were considered. It was noted that the model underestimated NO<sub>x</sub> traffic emissions in urban areas on weekday between 6 AM and 5 PM. Similar underestimation of NO<sub>x</sub> was found in other studies as well (e.g., [19-20]).

Another study aimed to analyse the influence of city-scale, traffic mode, and traffic congestion on PM<sub>2.5</sub> concentration [21]. The traffic was described by the number of buses and private cars, and the total length of the urban roads. It was found that congestion significantly increase the environmental effect of private car use. Close to our aims, the relationship between traffic volume and air pollution (NO<sub>x</sub>, O<sub>3</sub>) was modelled using COPERT traffic emission and WRF-Chem atmospheric chemistry model [22]. Despite factors affecting the air pollution, such as wind and peak temperature, were considered to minimize non-traffic-related emission, the model seriously underestimated the NO<sub>x</sub> concentrations.

The contribution of road traffic to air pollution in several major cities was estimated in [23]. Data for daily pollution concentrations was 'deweathered' using a Random Forest model developed in [24] to isolate the trends. In absence of traffic volume data, measurement sites were categorized to estimate background pollution. Another study analysed the impact of traffic calming on air-quality in urban areas considering the wind [25]. It was found that

**Table 1.** Collected data in corresponding studies

<i>Study</i>	<i>Weather</i>	<i>Traffic</i>	<i>Emission</i>
[16]	-	Travelled distance, speed	CO
[17]	-	Traffic volume, composition, speed	NO <sub>x</sub> , PM <sub>10</sub>
[18]	Wind, temperature, mixing height	Traffic volume	NO <sub>x</sub>
[19]	Wind, temperature	Traffic volume	NO <sub>x</sub>
[20]	Temperature, humidity, planetary boundary layer	Traffic volume	NO <sub>x</sub> , CO <sub>2</sub> , CO
[21]	Wind, planetary boundary layer	Number of vehicles, total road length	PM <sub>2.5</sub>
[22]	Wind, temperature, cloudage	Traffic volume	NO <sub>x</sub> , O <sub>3</sub>
[23]	Wind, temperature, humidity [24]	-	mainly NO <sub>2</sub> , PM
[25]	Wind	Traffic volume	PM <sub>2.5</sub>
[26]	-	Traffic volume	NO <sub>x</sub>
[27]	Precipitation	Traffic volume	PM <sub>2.5</sub> , CO, NO <sub>2</sub> , O <sub>3</sub>

removing 100% of traffic reduces pollutants by less than 30% if the background concentration is considered. It was also shown that isolated measures have small impact on local air-quality and no impact on global emission in [26]. Besides weather and traffic data, the public perception to air-quality studies was introduced in [27] because public awareness and support are fundamental for air quality legislation and clean-air transitions [28]. It was found that public perception correlates more with traffic volume than actual air quality.

Based on the literature review, it was found that many studies investigated the relationship between weather, traffic, and air-quality. Yet, emission is often underestimated. In the literature, time variant analysis can be found, but the traffic's contribution usually not determined for various periods [29]. Furthermore, Budapest, Hungary region lacks a comprehensive study about the status and long-term trends of key air pollutants, which is also a novelty of this paper.

### III. DATA AND METHOD

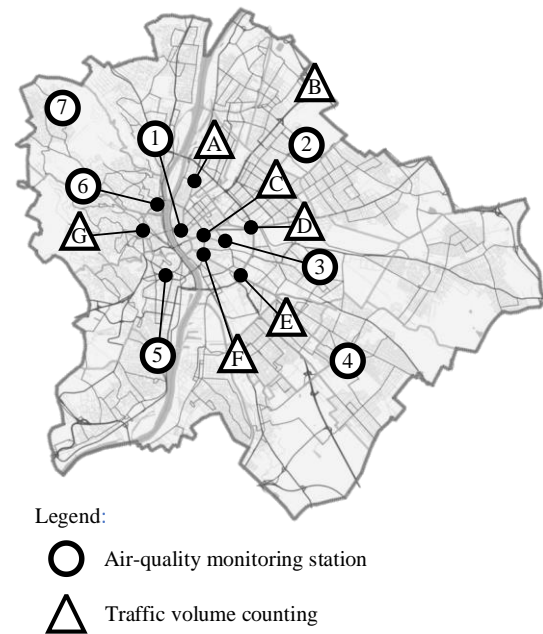
In this study, air-quality, weather, and traffic volume data were used. Publicly available data about air quality collected between 2008 and 2019 by automated air-quality monitoring stations were used. The measurements were performed in each hour. The stations are operated by the Ministry of Agriculture (levegominoseg.hu). There are 12 stations in Budapest and 7 stations were selected for analysis because of the high availability in the investigated period. The ministry categorized the stations into two groups based on the distance between the station and major roads: urban background and urban traffic. Urban traffic air-quality monitoring stations are close to the major roads. Data about the following pollutants were collected: CO, NO<sub>2</sub>, O<sub>3</sub>, and PM<sub>10</sub>.

Publicly available data about weather collected by the Hungarian Meteorological Service (met.hu) were used. Data about the lowest, median, and highest temperature and precipitation on each day between 2008 and 2019 were used. Data about sunshine duration were available until 2013, and data about wind is available from 2011.

Traffic volume data at junctions and along an urban highway were used. Data about hourly traffic volume at junctions were provided by the Centre of Budapest Transport (bkk.hu). In this study, 6 high traffic junctions were selected based on the distance between junctions and air-quality monitoring stations. Publicly available data about daily average traffic volume on urban highway were given by Hungarian Public Roads (kozut.hu) for each month. Since the organization focuses on national roads, only 1 measured section is in Budapest. Hourly and monthly traffic volume data were used to analyse the

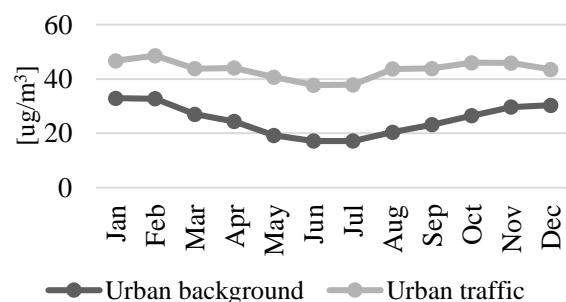
relationship between traffic and air quality on different time horizons. Publicly available data about the congestion level in Budapest were provided by tomtom (tomtom.com). Monthly congestion level values were available for 2019.

The locations of air-quality monitoring stations and traffic volume counting are given in **Fig. 1**. Stations 2, 4 and 7 are in the urban background group. The urban highway traffic volume was measured at B. In Budapest, there are no significant industrial emission sources.



**Figure 1.** Locations of air-quality monitoring stations and traffic volume counting

Several studies apply the twin site approach to determine the contribution of traffic to air pollution. In this case, one of the air quality monitoring stations is along a major road, and the other one is far away. In this study, the considered monitoring stations are close to each other, and no significant difference could be observed regarding the NO<sub>2</sub> concentration characteristics. The average monthly NO<sub>2</sub>



**Figure 2.** Average NO<sub>2</sub> concentration between 2008 and 2019

concentration at urban background and urban traffic stations are given in **Fig. 2**.

Therefore, twin site analysis was performed in time. The measurements were divided into two groups: weekdays and weekends. The hypothesis was that the difference between hourly average emission on weekdays and weekends reflects the emission of traffic. However, in this way, the emission will be underestimated by the weekend traffic. Based on traffic counting, average weekend traffic is appr. 45% of the weekday traffic. Accordingly, the weekday and weekend emissions were 180% and 80% of the difference between weekend and weekday concentration. The same rate was applied for each air-quality monitoring station group, and the subtraction was performed for each month. A strong correlation between CO and PM<sub>10</sub> was found at each station. Therefore, the two were analysed together. Namely, it was assumed that they have a common source. This is in line with the fact that heating is a significant source of CO and PM<sub>10</sub>.

#### IV. RESULTS AND DISCUSSION

The average difference between weekday and weekend emissions in December for urban traffic and urban background stations is presented in **Fig. 3**. Similar characteristics were found in each month. The difference reflects the daily traffic fluctuation, which validates the method. The higher peaks and valley between the peaks can be seen at the urban traffic stations, which is in line with Budapest's traffic characteristics. Traffic contribution to NO<sub>2</sub> concentration was determined for weekdays and weekends in each month (**Table 2**).

Our results show that traffic regulation may significantly impact air quality in August and September. According to the differences between weekdays and weekends, working from home may decrease traffic's contribution by 16%. Since the main source of O<sub>3</sub> is NO<sub>2</sub>, it was assumed that the traffic's contribution to O<sub>3</sub> emission is the same.

A similar analysis was performed to determine the traffic's impact on CO and PM<sub>10</sub> concentrations. The average difference between weekday and weekend emissions in December for urban traffic and urban background stations is presented in **Fig. 4**. Similar

**Table 2.** Contribution of traffic to NO<sub>2</sub> concentration

Month	Urban traffic station		Urban background station	
	Mo-Fr	Sa, Su	Mo-Fr	Sa, Su
Jan	34%	19%	37%	21%
Feb	34%	19%	37%	20%
Mar	22%	11%	34%	18%
Apr	34%	19%	42%	25%
May	22%	11%	32%	17%
Jun	36%	20%	42%	24%
Jul	31%	17%	43%	25%
Aug	41%	24%	56%	36%
Sep	35%	19%	49%	30%
Oct	17%	8%	26%	14%
Nov	31%	16%	44%	26%
Dec	23%	12%	26%	14%

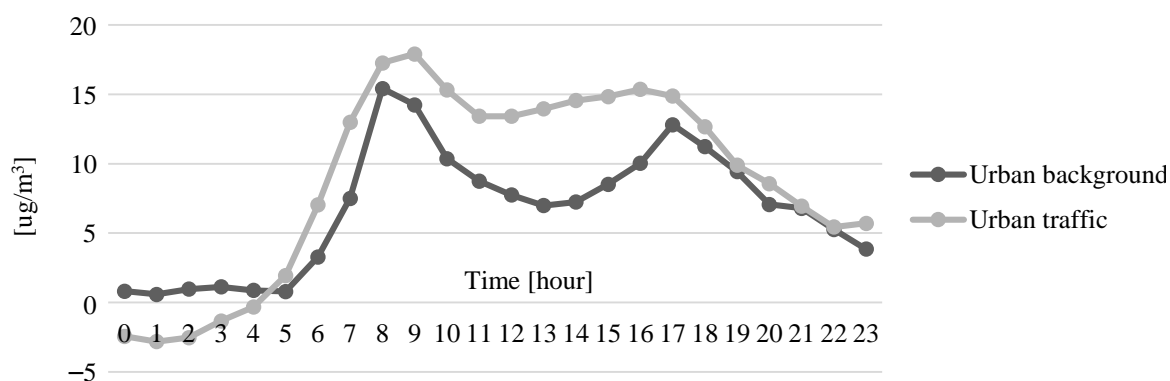
Legend:

Mo-Fr: Monday-Friday

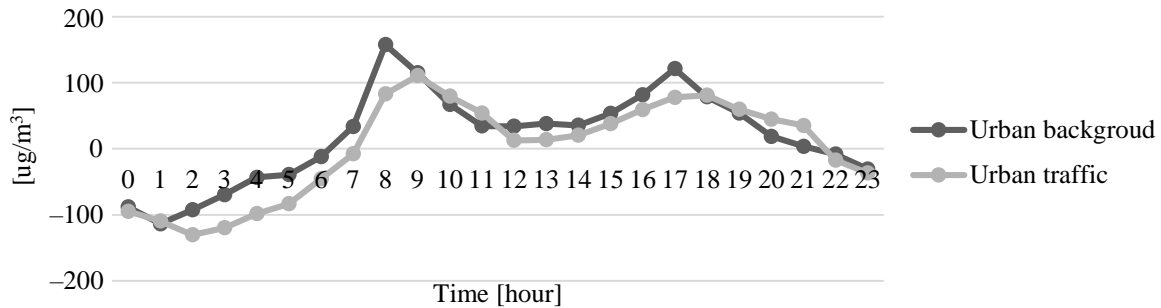
Sa, Su: Saturday and Sunday

characteristics were found in each month. It is noted that the weekend emission is significantly higher between 0 AM and 4 AM during the cold months and lower during daytime because of lower traffic. The two phenomena balance each other causing a low contribution of traffic. Accordingly, this method may be used with limitations for pollutants with low traffic contribution.

Furthermore, it indicates that home office in cold months may not decrease the total emission because the impacts of increased heating and lower traffic are roughly equal. To mitigate this effect on traffic CO emission, the lowest value was subtracted before multiplication and was added after multiplication.



**Figure 3.** The average difference between weekday and weekend NO<sub>2</sub> emissions in December



**Figure 4.** The average difference between weekday and weekend CO emissions in December

The contribution of traffic to CO emission on weekdays and weekends is summarized in **Table 3**. It is noted that the traffic's contribution on weekends is negligible. The difference between weekday and weekend emission characteristics reflects the differences in emission of other sources as well. It was assumed that the PM<sub>10</sub> contribution is similar, which is in line with the results in [5], which estimated that the traffic's contribution is between 10% and 30%.

The average monthly traffic contribution for NO<sub>2</sub> and CO are summarized in **Table 4**.

The average contribution NO<sub>2</sub> was 30%. This is significantly lower than what was found in [30], which may be because of the vehicle technology developments and the higher distance between the road and the monitoring stations. However, it is greater than the estimated traffic's contribution (21%) was in Budapest in 2012 [31]. The average contribution CO was 22%. The contribution was the lowest in January and October and low in the cold months. CO concentration usually exceeds the limit during winter when traffic regulation cannot cause a

significant decrease. Therefore, the heating system should be improved.

**Table 4.** Average contribution of traffic to NO<sub>2</sub> and CO concentration

Month	NO <sub>2</sub>	CO
Jan	31%	11%
Feb	31%	21%
Mar	24%	15%
Apr	34%	24%
May	23%	20%
Jun	34%	20%
Jul	33%	31%
Aug	44%	31%
Sep	37%	33%
Oct	19%	12%
Nov	33%	20%
Dec	21%	23%

The seasonal fluctuations of NO<sub>2</sub> and CO were analysed. A relationship between traffic volume, precipitation and NO<sub>2</sub> concentration was found and the emission using linear regression was calculated (eq.1).

$$E_{NO_2} = 28.97 + 0.362Cl - 2.808P \quad (1)$$

Where  $E_{NO_2}$  is the average NO<sub>2</sub> concentration [ug/m<sup>3</sup>],  $Cl$  is the congestion level calculated by

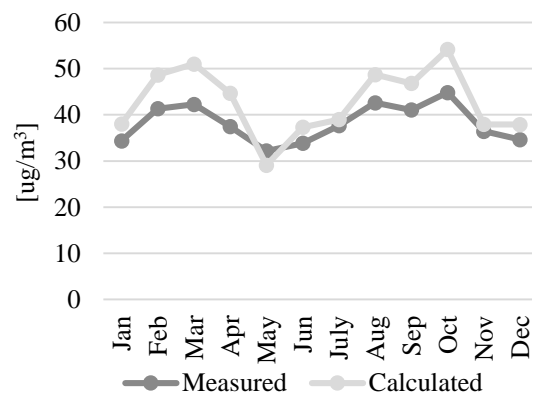
**Table 3.** Contribution of traffic to CO concentration

Month	Urban traffic station		Urban background station	
	Mo-Fr	Sa, Su	Mo-Fr	Sa, Su
Jan	14%	0%	17%	2%
Feb	28%	6%	26%	6%
Mar	20%	0%	21%	1%
Apr	32%	6%	31%	4%
May	29%	3%	26%	1%
Jun	40%	7%	31%	2%
Jul	44%	8%	37%	4%
Aug	46%	10%	36%	4%
Sep	49%	13%	35%	6%
Oct	18%	0%	17%	-1%
Nov	24%	4%	27%	6%
Dec	31%	9%	26%	6%

Legend:

Mo-Fr: Monday-Friday

Sa, Su: Saturday and Sunday



**Figure 5.** Measured and calculated NO<sub>2</sub> emissions in 2019

tomtom [%], and  $P$  is the average precipitation [mm].  $R^2$  is equal to 0.55. Therefore, further analysis is recommended, but data about monthly traffic were only available for 2019. Measured and calculated  $\text{NO}_2$  concentration values are given in Fig. 5.

In the case of CO and  $\text{PM}_{10}$ , a strong correlation was found with the median temperature: the coefficients were between  $-0.91$  and  $0.95$  at each station. Finally, the long-term trends of  $\text{NO}_2$  and CO were analysed. No significant relationship was found between  $\text{NO}_2$  and average traffic volume over the years. It may be because other factors cover the effect of higher traffic volume. Therefore, further analysis is required. In the case of CO, a correlation between CO and the median temperature was found in the cold months and between CO and precipitation during summer.

## V. CONCLUSIONS

Analysis of traffic's contribution to air pollution helps forecast air quality and determine effective measures. In this study, the traffic's contribution was calculated using time variant analysis to determine the difference between weekday and weekend emission, which is the paper's main contribution. The results were validated using real-world traffic data. The average CO and  $\text{NO}_2$  emissions contributions were 22 and 30%, respectively. According to the results, traffic regulations are the most effective during summer in the term of air

pollution. Accordingly, improving other sources, such as the heating system, helps reduce exceedances of air quality standards. Seasonal analysis revealed that  $\text{NO}_2$  concentration is strongly influenced by precipitation. It was noted that home office may not decrease the total CO pollution in cold months. It was also found that CO correlates with  $\text{PM}_{10}$  and median temperature over the year. In the case of long-term trends, it was found that CO correlates with precipitation during summer, and  $\text{NO}_2$  does not correlate with traffic. It may be because the annual traffic data was measured on a highway. Accordingly, further research about seasonal and long-term trends is necessary to predict air quality better.

## AUTHOR CONTRIBUTIONS

**B. Csonka:** Conceptualization, methodology, analysis, visualization, writing—review and editing.

## DISCLOSURE STATEMENT

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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