ACTA TECHNICA JAURINENSIS
Vol. 16, No. 3, pp. 99-106, 2023
10.14513/actatechjaur.00698

Research Article

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

Bálint Csonka[1,*]

[1]Department of Transport Technology and Economics, Faculty of Transportation Engineering and Vehicle Engineering, Budapest University of Technology and Economics
Műegyetem rkp. 3., H-1111 Budapest, Hungary
*e-mail: csonka.balint@kjk.bme.hu

Submitted: 07/05/2023 Accepted: 22/05/2023

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_2 were 22 and 30%. It was noted that the seasonal fluctuation of NO_2 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_{10}), ozone (O_3) and nitrogen oxides (NO_X) annual limit values. Estimates of the health impact indicated that long-term exposures to PM_{10}, O_3, and NO_X 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_X 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_3 concentrations was not calculated because O_3 is not emitted directly into the air but is created when volatile organic compounds and NO_X 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_2 and NO_X, 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 $PM_{2.5}$, NO_2 and O_3 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_X and PM_{10} 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_X 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_X traffic emissions in urban areas on weekday between 6 AM and 5 PM. Similar underestimation of NO_X 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 $PM_{2.5}$ 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_X, O_3) 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_X 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*

Study	***Weather***	***Traffic***	***Emission***
[16]	-	Travelled distance, speed	CO
[17]	-	Traffic volume, composition, speed	NO_X, PM_{10}
[18]	Wind, temperature, mixing height	Traffic volume	NO_X
[19]	Wind, temperature	Traffic volume	NO_X
[20]	Temperature, humidity, planetary boundary layer	Traffic volume	NO_X, CO_2, CO
[21]	Wind, planetary boundary layer	Number of vehicles, total road length	$PM_{2.5}$
[22]	Wind, temperature, cloudage	Traffic volume	NO_X, O_3
[23]	Wind, temperature, humidity [24]	-	mainly NO_2, PM
[25]	Wind	Traffic volume	$PM_{2.5}$
[26]	-	Traffic volume	NO_X
[27]	Precipitation	Traffic volume	$PM_{2.5}$, CO, NO_2, O_3

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_2, O_3, and PM_{10}.

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.

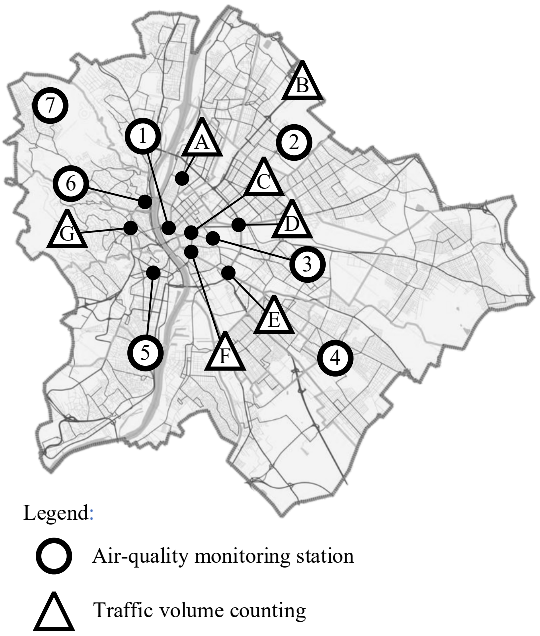

***Figure 1.** Locations of air-quality monitoring stations and traffic volume counting*

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_2 concentration characteristics. The average monthly NO_2

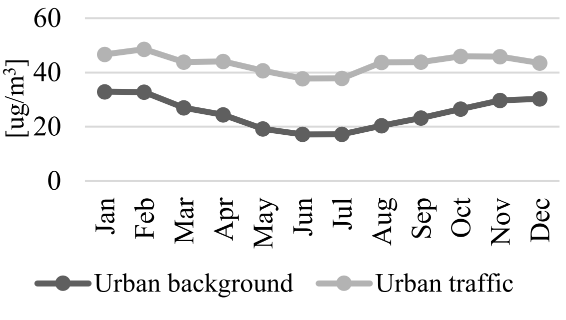

***Figure 2.** Average NO_2 concentration between 2008 and 2019*

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_{10} 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_{10}.

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_2 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_3 is NO_2, it was assumed that the traffic's contribution to O_3 emission is the same.

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

Table 2. *Contribution of traffic to* NO_2 *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

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.

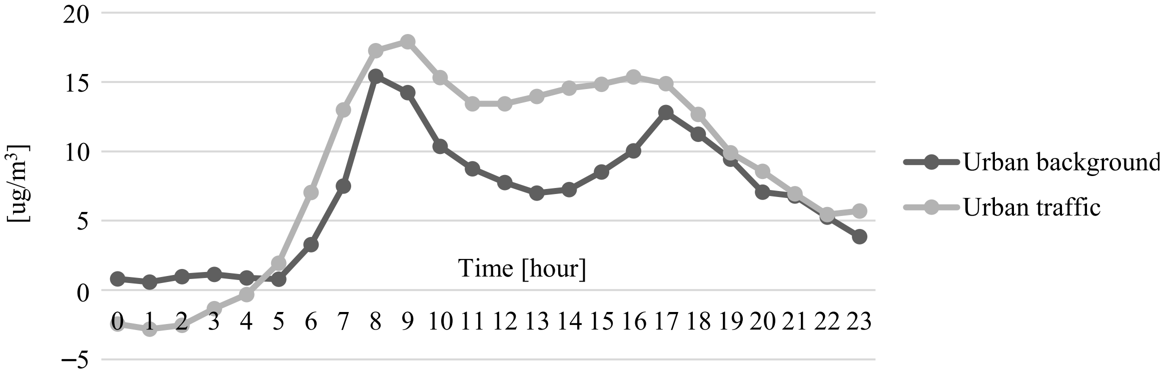

Figure 3. *The average difference between weekday and weekend* NO_2 *emissions in December*

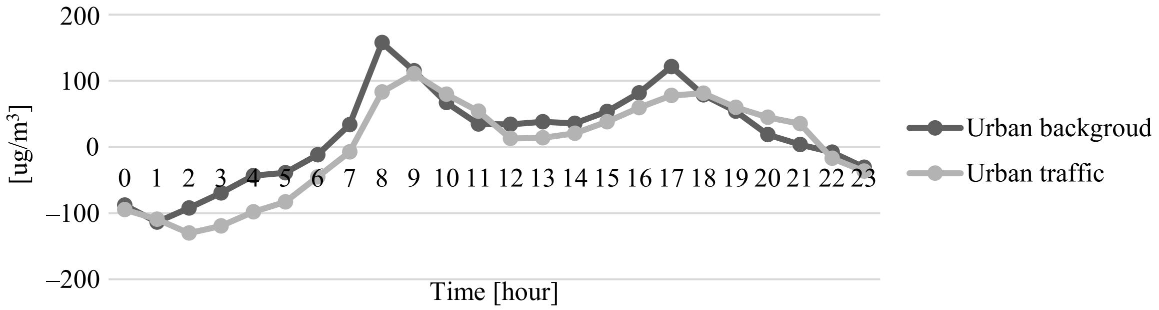

Figure 4. *The average difference between weekday and weekend CO emissions in December*

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_{10} 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_2 and CO are summarized in **Table 4**.

The average contribution NO_2 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 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

Table 4. *Average contribution of traffic to NO_2 and CO concentration*

Month	***NO_2***	***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_2 and CO were analysed. A relationship between traffic volume, precipitation and NO_2 concentration was found and the emission using linear regression was calculated (eq.1).

$$E_{NO2} = 28.97 + 0.362Cl - 2.808P \qquad (1)$$

Where E_{NO2} is the average NO_2 concentration [ug/m^3], *Cl* is the congestion level calculated by

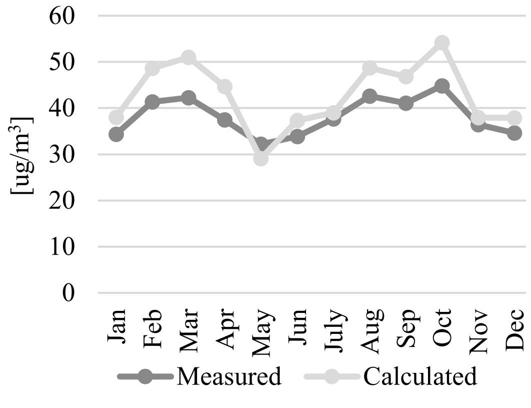

Figure 5. *Measured and calculated NO_2 emissions in 2019*

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 NO_2 concentration values are given in **Fig. 5**.

In the case of CO and 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 NO_2 and CO were analysed. No significant relationship was found between 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 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 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 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 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.

ORCID

B. Csonka https://orcid.org/0000-0002-4976-8294

REFERENCES

[1] EEA, Air quality in Europe – 2020 report (2020) https://doi.org/10.2800/786656

[2] F. Amato, F.R. Cassee et al., Urban air quality: The challenge of traffic non-exhaust emissions, Journal of Hazardous Materials 275 (2014) pp. 31-36. https://doi.org/10.1016/j.jhazmat.2014.04.053

[3] M. Guarnieri, J.R. Balmes, Outdoor air pollution and asthma, The Lancet 383 (2014) pp. 1581-1592. https://doi.org/10.1016/S0140-6736(14)60617-6

[4] W. Chen, A. Li, F. Zhang, Roadside atmospheric pollution: still a serious environmental problem in Beijing, China, Air Quality, Atmosphere & Health 11 (2018) pp. 1203-1216. https://doi.org/10.1007/s11869-018-0620-2

[5] S. Paraschiv, L.S. Paraschiv, Analysis of traffic and industrial source contributions to ambient air pollution with nitrogen dioxide in two urban areas in Romania, Energy Procedia 157 (2019) pp. 1553-1560. https://doi.org/10.1016/j.egypro.2018.11.321

[6] C. A. Belis, F. Karagulian et al., Critical review and meta-analysis of ambient particulate matter source apportionment using receptor models in Europe, Atmospheric Environment 69 (2013) pp. 94-108. https://doi.org/10.1016/j.atmosenv.2012.11.009

[7] ICCT Briefing, On the Way to "Real-World" CO_2 Values: The European Passenger Car Market in its First Year After Introducing the WLTP (2020).

[8] S. Itahashi, I. Uno et al., Nitrate transboundary heavy pollution over East Asia in winter. Atmospheric Chemistry and Physics 17 (2017) pp. 383-3843. https://doi.org/10.5194/acp-17-3823-2017

[9] S. Chen, T. Yuan et al., Dust modeling over East Asia during the summer of 2010 using the WRF-Chem model, Journal of Quantitative Spectroscopy and Radiative Transfer 213 (2018) pp. 1-12. https://doi.org/10.1016/j.jqsrt.2018.04.013

[10] S. Sridharan, M. Kumar et al., Microplastics as an emerging source of particulate air pollution: A critical review, Journal of Hazardous Materials 418 (2021) p. 126245. https://doi.org/10.1016/j.jhazmat.2021.126245

[11] X. Fu, Z. Cheng et al., Local and Regional Contributions to Fine Particle Pollution in Winter of the Yangtze River Delta, China, Aerosol and Air Quality Research 16 (2016) pp. 1067-1080. https://doi.org/10.4209/aaqr.2015.08.0496

[12] Y. Wang, Y. Li et al., Inter-city air pollutant transport in The Beijing-Tianjin-Hebei urban agglomeration: Comparison between the winters of 2012 and 2016, Journal of Environmental Management 250 (2019) p. 109520. https://doi.org/10.1016/j.jenvman.2019.109520

[13] S.A. Sarkodie, P.A. Owusu, Global effect of city-to-city air pollution, health conditions, climatic & socio-economic factors on COVID-19 pandemic, Science of The Total Environment 778 (2021) p. 146394. https://doi.org/10.1016/j.scitotenv.2021.146394

[14] Y. Wang, S. Bao, Local and regional contributions to fine particulate matter in Beijing during heavy haze episodes, Science of The Total Environment 580 (2017) pp. 283-296. https://doi.org/10.1016/j.scitotenv.2016.12.127

[15] L. Mahmood, M. Ghommem, Z. Bahroun, Smart Gas Sensors: Materials, Technologies, Practical Applications, and Use of Machine Learning – A Review, Journal of Applied and Computational Mechanics 9 (3) (2023) pp. 775-803. https://doi.org/10.22055/JACM.2023.41985.3851

[16] A. Csikós, T. Tettamanti, I. Varga, Macroscopic Modeling and Control of Emission in Urban Road Traffic Networks, Transport 30 (2015) pp. 152-161. https://doi.org/10.3846/16484142.2015.1046137

[17] C. Quaassdorff, R. Borge et al., Microscale traffic simulation and emission estimation in a heavily trafficked roundabout in Madrid (Spain), Science of the Total Environment 566–567 (2016) pp. 416-427. https://doi.org/10.1016/j.scitotenv.2016.05.051

[18] F. Kuik, A. Kerschbaumer et al., Top–down quantification of NO_X emissions from traffic in an urban area using a high-resolution regional atmospheric chemistry model, Atmospheric Chemistry and Physics 18 (2018) pp. 8203-8225. https://doi.org/10.5194/acp-18-8203-2018

[19] J.D. Lee, C. Helfter et al., Measurement of NO_X Fluxes from a Tall Tower in Central London, UK and Comparison with Emissions Inventories, Environmental Science & Technology 49 (2015) pp. 1025-1034. https://doi.org/10.1021/es5049072

[20] T. Karl, M. Graus et al., Urban eddy covariance measurements reveal significant missing NO_X emissions in Central Europe, Scientific Reports 7 (2017) p. 2536. https://doi.org/10.1038/s41598-017-02699-9

[21] J. Lu, B. Li et al., Expansion of city scale, traffic modes, traffic congestion, and air pollution, Cities 108 (2021) p. 102974. https://doi.org/10.1016/j.cities.2020.102974

[22] A. Kovács, Á. Leelőssy et al., Coupling traffic originated urban air pollution estimation with an atmospheric chemistry model. Urban Climate 37 (2021) p. 100868. https://doi.org/10.1016/j.uclim.2021.100868

[23] R.M. Harrison, T. Vu et al., More mileage in reducing urban air pollution from road traffic, Environment International 149 (2021) p. 106329. https://doi.org/10.1016/j.envint.2020.106329

[24] T.V. Vu, Z. Shi et al., Assessing the impact of clean air action on air quality trends in Beijing using a machine learning technique, Atmospheric Chemistry and Physics 19 (2019) pp. 11303-11314. https://doi.org/10.5194/acp-19-11303-2019

[25] H. Wang, P. Brimblecombe, K. Ngan, A numerical study of local traffic volume and air quality within urban street canyons, Science of the Total Environment 791 (2021) p. 148138. https://doi.org/10.1016/j.scitotenv.2021.148138

[26] D. Rodriguez-Rey, M. Guevara et al., To what extent the traffic restriction policies applied in Barcelona city can improve its air quality? Science of the Total Environment 807 (2) (2022) p. 150743. https://doi.org/10.1016/j.scitotenv.2021.150743

[27] H. O’Leary, S. Parr, M. M.H. El-Sayed, The breathing human infrastructure: Integrating air quality, traffic, and social media indicators, Science of The Total Environment 827 (2022) p. 154209. https://doi.org/10.1016/j.scitotenv.2022.154209

[28] J. Liang, P. He, Y. Qiu, Energy transition, public expressions, and local officials’ incentives: Social media evidence from the coal-to-gas transition in China, Journal of Cleaner Production 298 (2021) p. 126771. https://doi.org/10.1016/j.jclepro.2021.126771

[29] L. Makra, H. Mayer et al., Variations of traffic related air pollution on different time scales in Szeged, Hungary and Freiburg, Germany, Physics and Chemistry of the Earth 35 (2010) pp. 85-94. https://doi.org/10.1016/j.pce.2010.03.005

[30] S. R. Gadsdon, S. A. Power, Quantifying local traffic contributions to NO_2 and NH_3 concentrations in natural habitats, Environmental Pollution 157 (10) (2009) pp. 2845-2852. https://doi.org/10.1016/j.envpol.2009.04.010

[31] I. Sundvor, N.C. Balaguer et al., Road traffic's contribution to air quality in European cities, ETC/ACM (2012)