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A NEW TOOL FOR THE EVALUATION OF CO$_2$ EMISSIONS FROM ROAD TRAFFIC: A CASE STUDY IN CLUJ-NAPOCA, ROMANIA

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Abstract

In the past years, there has been great interest in developing tools for an effective management including the evaluation of the impact of different policies on decreasing greenhouse gas emissions (CO$_2$) and other transport pollutant-related emissions, especially in the urban areas. This paper represents a first attempt to study a new approach to identify criticalities of pollutant emissions associated with road traffic in urban areas. The tool we propose concerns the development of an emission indicator, a proxy measure, which is useful for the assessment of emission problems, based on the use of GPS (Global Positioning System) instantaneous vehicle speed data. It can be considered an innovative and adequate solution in many cases in which the development of a valid and robust traffic simulation model, especially DTA (dynamic traffic assignment), is not available in the medium- and short-term horizon. The methodological process concerns the monitoring of road traffic conditions using GPS data from probe vehicles in combination with the use of GIS (Geographic Information System) for the estimation of an emission indicator. The tool was tested in a real case study in Romania for CO$_2$ emissions. The results show the utility of the tool in policy and decision making, due to its ease of application and consistency, especially in defining critical areas and that it can be used in any other urban contexts with GPS data availability. Further developments will deal with the computation of the emission indicator for other pollutants and validation of the approach by applying other methods and comparing the results. The analysis of the results could be focused not on the capacity to evaluate emissions but on the development of a proxy measure useful in the planning process.

Keywords: emissions, emission zones, GIS, GPS instantaneous vehicle speed, urban area

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1. Introduction

Romania is situated on the fourth place among the EU States in terms of greenhouse gas emissions per capita (EEA, 2018b). Transport-related emissions are currently less important than in other sectors (EEA, 2018a). However, over the past decade, their evolution shows significant growth, a trend which is expected to continue on the long term. In this respect the reduction of CO$_2$, the most important greenhouse gas, became the subject of a global treaty, the Paris Agreement (Santos, 2017). Until the targets set in the agreement - aimed at decarbonising the transport sector by eliminating fossil fuel - are achieved, smaller scale interventions in the urban area are already possible by implementing investments in clean infrastructure (Zhang et al., 2018).

The tool presented in this paper will help the local authorities guide the investment policy by focusing on the hot emission areas identified simply with the help of this methodology by using the large GPS data sets at their disposal.

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Romania's National Strategy on Climate Change acknowledges the impact of the urban sector given its large share of population (56%) and the highest share of economic activity (MMSC, 2015). Furthermore, 36% of the total length of national roads are situated in built areas (Mitran and Ilie, 2014) and a total share of 11% of the public roads in Romania are streets located in the urban localities (Cadar and Boitor, 2017).

Sustainable Urban Mobility Plans (SUMPs) (EC, 2013; ELTIS, 2014) have become strategic documents for transport planning in Romanian cities and towns. These promote more sustainable mobility systems and they analyse the impact of any trends or policies for urban mobility. Pollutant emissions related to transport represent one of the main parameters studied in SUMPs and their estimation is an important project indicator.

Urban regeneration models have been developed (García-Fuentes and de Torre, 2017; Kepaptsoglou et al., 2015) with the aim to reduce air pollution related to urban mobility (Transport and Environment, 2018).

Many studies provided direct estimation or models for the calculation of air pollutant emissions (COx, NOx, HC, PM2.5 PM10, etc.) using vehicle speed data in the urban area. Specifically, Zhao et al. (2017) analysed the city of Borlänge, Sweden, Mitran and Ilie (2014) the city of Pitesti, Romania, Chang and Lin (2018) Thaicung, Korea, and Tosa et al., (2015) the suburban area of Cluj-Napoca, Romania. Focas (2017) presented a comparison between the urban and exurban area. Nocera and Cavallaro (2017) studied carbon efficiency of urban freight transport in Lucca, Italy. In Xia et al. (2017), carbon metabolism in Beijing, China was reported. In Beijing, Jiang et al. (2017) also proposed the estimation of emissions based on a speed field fused from multiple source speed data on urban expressways. Gori et al. (2014) developed a model that considers the daily variations of traffic flow conditions in Brindisi, Italy. Different types of urban roads, such as expressway, arterial and collector are analysed in Li et al. (2016). Different geographic levels such as metropolitan, county and local area are considered in Choi and Zhang (2017). However, local administrations are the most appropriate units to tackle emission problems.

At the urban area level, although traffic emissions are included in background air pollution, their impact is very important (Alam et al., 2017; Banica et al., 2017; Tongwane et al., 2015). Specifically, this impact is significant for those areas where there is a large component of heavy traffic (Laña et al., 2016) or for those areas where car traffic level ranges from moderate to heavy (Matz et al., 2018). Taking into consideration this specific context, CO_2 and other pollutant emissions related to mobility are strictly correlated with the traffic dynamics such as queue, spillback and speed variation (Afotey et al., 2013; Barth and Boriboonsomsin, 2008; Zhao et al., 2017).

Over the last decade, many different road traffic emission models have been developed, depending on speed analysis. According to Wang et al. (2018), these models are classified according to the level of aggregation in space and time and the driver's behaviour. Specifically, the main classification includes a) static emission models (aggregated models, average-speed models, traffic situation models) and b) dynamic emission models (regression-based models, modal models, instantaneous models). The input data for all these is the traffic assignment model, classified according to temporal dimension: DTA, semi-dynamic traffic assignment and static traffic assignment (STA) models. Linton et al. (2015) presented a review of approaches and techniques for modelling CO_2 emissions from road transport.

Furthermore, significant advances have been made with respect to the complexity and accuracy of the emission models, in which traffic assignment models are always a key element. DTA models are more capable to represent traffic flow characteristics such as shock waves, queue dynamic phenomena etc. with respect to the STA, thereby showing high potential for improving the accuracy of emissions estimation (Nocera et al., 2018; Wang et al., 2018). However, these models present some problems due to their need of large amounts of data for robust calibration and validation and in many cases, it is very difficult to implement a satisfactory representation of the car traffic demand.

It therefore results that, there is a great interest in developing tools for an effective management and policy application in order to decrease greenhouse gas emissions (CO_2) and other transport pollutant-related emissions, especially in urban areas.

The aim of this research is to provide a simple but effective tool for the analysis of emission zones and for the evaluation of their impact in order to tackle the problem of reducing air pollutants related to road transport. The proposed methodology develops a CO_2 emission indicator, a proxy measure, based on GPS instantaneous speed data. The idea consists in using data from GPS and other environment monitoring systems providing smart data (Grote et al., 2018; Kong et al., 2018) for monitoring road traffic situations (Liu et al., 2017), in combination with the use of GIS. The use of GPS (Zhao et al., 2017), even in case of Big Data (Kan et al., 2018) collecting driving data in urban on-road conditions, can provide citywide input data for the estimation of emissions. On the other hand, GIS tools are very precise and useful in policy and decision making, especially for defining and representing the spatial distribution of pollution (Cai et al., 2015; Masood et al., 2017; Tenailleau et al., 2016). A simple visual tool would enable local administrations to gain a better insight into the assessment of the emission problems.

According to these preliminary observations, this paper is a first attempt to study a new approach in identifying the criticalities of pollutant emissions, related to road traffic in the urban area.

It can be considered an innovative and adequate solution in many cases in which the development of valid DTA model is not available in the medium- and short-term horizon. Furthermore, the visualisation function of the new tool is aiming to provide quick and sound information for the people in local administrations dealing with SUMPs projects, including non-technical staff. It would also be useful for the assessment of emission problems and the impact of different management actions including the evaluation of the impact of different policies. Such an approach can be used for any specific pollutant emissions and the first real-case study application in an urban context has dealt with the CO_2 emissions.

The proposed tool was applied in the case study of Cluj-Napoca, Romania. The urban area was divided into three different speed-emission zones: Hot emission area, Medium emission area, Cold emission area. These zones were graphically represented using only the CO_2 indicator values. GIS maps and spatial statistics were provided for the validation of the emission areas and to highlight the spatial patterns through the hot spots and cold spots within the urban area. The results may enable planners and policy makers to formulate better pollution control strategies, lay down stringent air quality standards and address the major environmental impact assessment factors.

The paper is structured as follows: Section 2 describes the methodology of the proposed tool, Section 3 presents the case study application, while Section 4 shows the results of the application. Finally, conclusions are reported in Section 5.

2. Methodology

As stated before, the methodology we propose refers to the development of an emission indicator, based on the vehicle speed detected with the use of GPS sensors. Specifically, the aim is not to estimate pollutant emissions, which implies the computation of emissions based on the knowledge of the level of traffic, but rather an indicator of these emissions. This indicator leads to the evaluation of the impact of different policies, as well as the adoption of control strategies in a simpler but nevertheless robust approach.

By analysing the well-known emission models and considering the objective of the paper, the driving vehicle mileage of travel is not the most important factor. It is more relevant to identify a possible correlation between speed and single vehicle emissions. The importance of speed – emissions relationship has already been discussed for instantaneous as well as average speed, both collected on urban roads. Instantaneous speed, along with instantaneous emissions are more accurate than average emissions (Ryu et al., 2015) for the representation of real-world situations for speeds below 20 km/h. CO_2 instantaneous emissions have been found to be more reliable for capturing congestion impact. Speed-emissions correlation is sensitive to varying real-world driving conditions in the urban context (Pathak et al., 2017), where the speed profile is a crucial parameter for emission estimation, along with other factors such as time, distance, acceleration and deceleration (Zhao et al., 2016). Therefore, instantaneous speed is used to compute instantaneous emissions.

Fig. 1 shows the 4 main steps of the procedure.

Step 1 refers to GPS data elaboration, such as visualization of the raw GPS database, namely map matching and the extraction of the GPS data for the specific area. **Step 2** focuses on GPS data filtering for the numerical application. Parking related points are separated from congestion points, both defined by zero speed (ZS). Congestion points are part of the moving process of vehicles, while parking points are excluded from the analysis. The process referring to speed filtering algorithm is shown and described in Fig. 2. **Step 3** deals with the creation and analysis of the database using a GIS application. It concerns citywide area analysis and validation of speed data and its distribution. Specifically, this step involves the analysis of speed distributions and its relationships with different levels of traffic congestion, more than specific road and environmental characteristics that can reduce traffic speed (pavements, width of section, etc.). This step allows the use of speed data as satisfactory indicators of traffic density, thus identifying the presence of congested conditions. Simple heat maps are created to visualize and check the distribution of GPS points and speed weighted points. For this, the large dataset of GPS points is aggregated using a 10m radius. For further analyses, the data points are aggregated in a hexagonal tessellated grid (10,000 square meters hexagons). GIS tools are used to identify the congestion in the road network based on speed (arithmetic mean and average speed, speed percentiles) starting from thematic maps. Using spatial distribution and weighted spatial distribution maps some general patterns were identified in the urban area. These patterns have been validated with spatial statistics indicators, such as Global Moran I and Hot Spot analysis (Getis-Ord Gi*). Moreover, 3D distributions were used for a better visualization.

Step 4 deals with the calculation and visualisation of the CO_2 emissions indicator. Speed data were used to evaluate urban emission areas starting with the computation of CO_2 instantaneous emissions. A matrix (Eq. 1) based on instant data was created for the computation of CO_2 emission. The computation of instantaneous emission is made using the Barth and Boriboonsomsin (2008) formula (Eq. 2). This formula has been chosen for the simplicity of calculation by using a robust and limited set of data (position and speed), thus reducing uncertainties that occur when a large number of variables is used.

It is a fourth order polynomial for the definition of a fleet wide average CO_2 emissions depending on the speed values collected by GPS technology, under the real-world traffic conditions, without the use of disaggregated data on specific vehicle categories (Eq. 2).

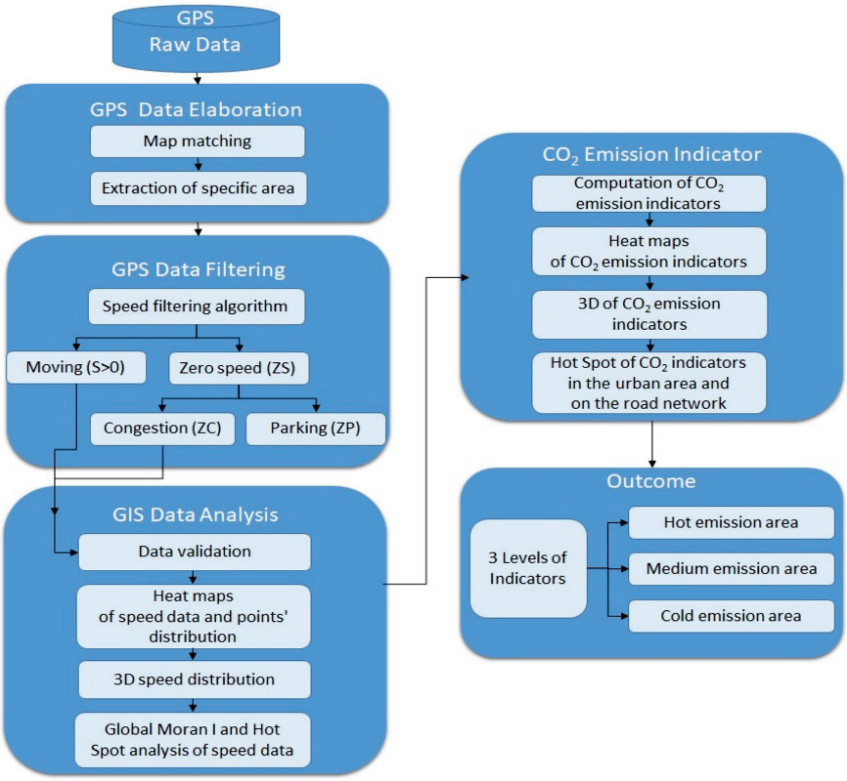

Fig. 1. General process of the new tool for the evaluation of CO_2 emissions from road traffic

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Algorithm: Speed filtering algorithm
Input: mxn Matrix MAx,
Filtering (PARKING, CONGESTION, MOVING)
  FOR all Zero speed points (ZS), v=0, PARKING OR CONGESTION
    PARKING (ZP) if
      (P1) First check: $m_{i-1}speed, m_{i-1}time \in MAx,$
          Initialization $m_{i-1}speed = 0$
          Car had Stopped if
          (I1) $(m_{i-1}time - m_i time) > TIME$ (0,2,0),
          where h =0, min =2, sec =0
      (P2) Second check: $m_{i-1}speed, m_i speed, m_{i+1}speed, m_{i+2}speed \in MAx,$
                         $m_{i-1}course, m_i course, m_{i+1}course, m_{i+2}course \in MAx,$
          Initialization $m_{i-1}speed = 0$
          Car had Stopped moving if
          (I2) $m_{i-1}speed = m_i speed$ AND $m_{i-1}course = m_i course$
          AND
          (I3) $m_i speed = m_{i+1}speed$ AND $m_i course = m_{i-1}course$
          AND
          (I4) $m_{i+1}speed = m_{i+2}speed$ AND $m_{i+1}course = m_{i+2}course$
      (P3) Third check: $m_{i-1}speed, m_i speed \in MAx,$
          Initialization $m_i speed = 0$
          Car has engine on in the parking if
          (I5) (P1) OR (P2)
    CONGESTION (ZC) if not PARKING
  FOR all other speeds, v>0, MOVING
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Fig. 2. Schematic of the speed filtering process

$$\text{MAx} = \begin{bmatrix} m_1\,time & m_1 lat & m_1 long & m_1 course & m_1 speed & \dots & m_1 emission \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ m_{i-1} time & m_{i-1} lat & m_{i-1} long & m_{i-1} course & m_{i-1} speed & \dots & m_{i-1} emission \\ m_i time & m_i lat & m_i long & m_i course & m_i speed & \dots & m_i emission \\ m_{i+1} time & m_{i+1} lat & m_{i+1} long & m_{i+1} course & m_{i+1} speed & \dots & m_{i+1} emission \\ m_{i+2} time & m_{i+2} lat & m_{i+2} long & m_{i+2} course & m_{i+2} speed & \dots & m_{i+2} emission \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ m_n time & m_n lat & m_n long & m_n course & m_n speed & \dots & m_n emission \end{bmatrix}_{mxn} \tag{1}$$

$$\ln(y) = b_0 + b_1 \cdot x + b_2 \cdot x^2 + b_3 \cdot x^3 + b_4 \cdot x^4 \tag{2}$$

where: y is the CO_2 emission in grams per mile; x is the traffic speed in mile per hour; b_0, b_1, b_2, b_3, b_4 are the parameters for the Eq. (2), given for the real-world case, considering the congestion in urban area (Barth and Boriboonsomsin, 2008).

GIS enables the emission indicator zoning process by defining the emission areas and displaying them in the form of digital maps. Finally, the result consists of a map showing the emission zones. The values of CO_2 emissions obtained for every point were aggregated and visualized in a heat map using a 10-meter radius. The patterns were highlighted using an aggregation of the CO_2 emission points in the hexagonal areas employing the spatial join in GIS. The visualization of the average emission values in the hexagonal grid was also provided by GIS thematic maps. The analysis of hot spots and cold spots was conducted using Getis-Ord Gi* statistic, by calculating a Z-score and a p-value for each feature in the dataset. For statistically significant positive Z-scores, the larger the Z-score is, the stronger the clustering of high values (hot spot). For statistically significant negative Z-scores, the smaller the Z-score is, the stronger the clustering of low values (cold spot). Mapping hot spots in this manner represents a very powerful tool taking into consideration not only the high value of a feature but, for the definition of a statistically significant hot spot, also that the feature is surrounded by other features with high values as well. Further line patterns have been obtained through interpolation with the Invert distance weighted (IDW) method and displayed on the road network. Such a representation of the emissions allows the observation of problematic/critical points and areas in terms of emission distribution and zones. Therefore, the three types of emission areas - Cold, Medium, and Hot emission areas - were validated with geo-statistical analysis. It can be noted that, using fewer classes with wider ranges of values provides data that are still robust and more responsive to visualization needs.

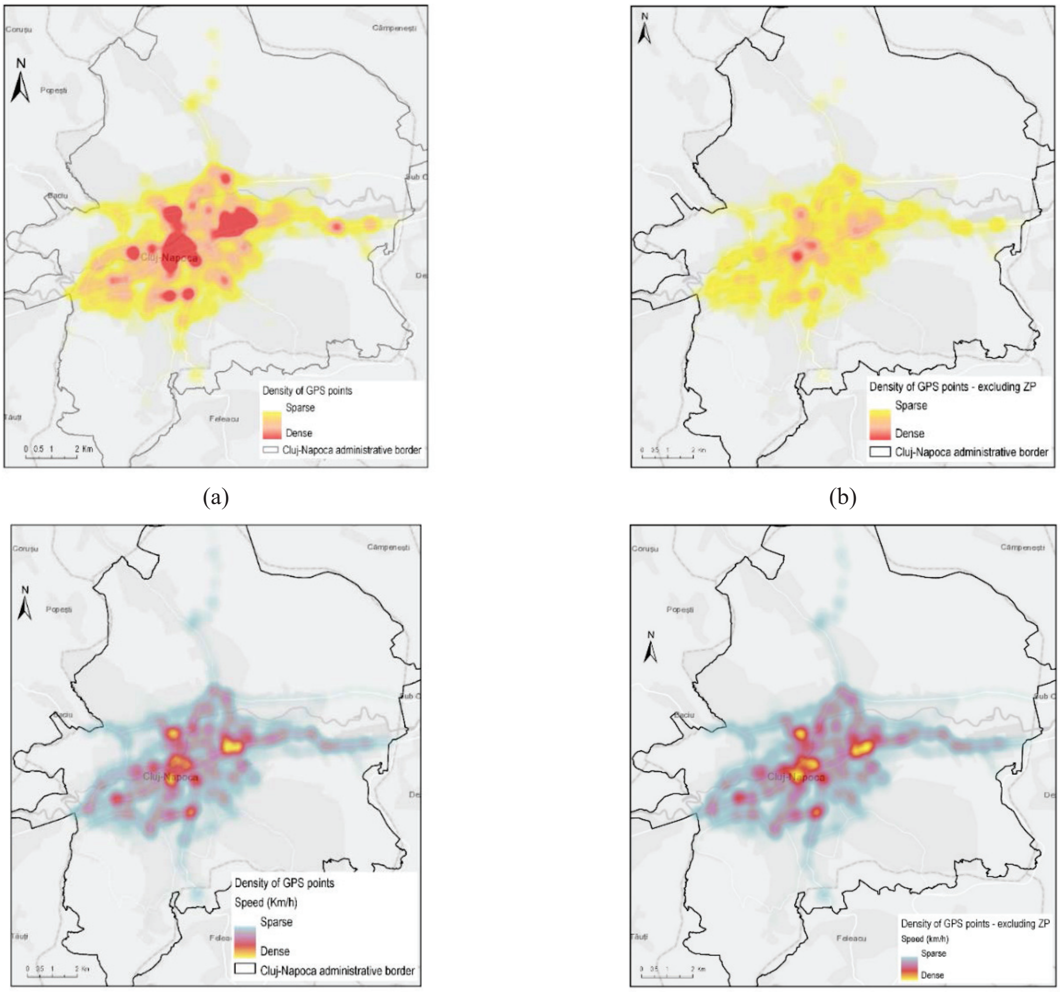
3. Case study: Cluj-Napoca, Romania

The proposed methodology was applied in a real case study in the municipality of Cluj-Napoca, Romania. Cluj-Napoca sprawls on a plateau surrounded by hills with a mononuclear and radial-shaped form. Cluj-Napoca is a mid-sized city with a population of more than 300,000 inhabitants. It has an important administrative role in the region and a strong national economic potential. The transport system relies mostly on roads for both interurban and intra-urban mobility. In the urban road network, the speed limit is 50 km/h. The detailed description of the city was discussed in previous papers and the following were presented extensively from different viewpoints: socio-demographic, geographic, weather conditions and transportation system (Ivan et al., 2015; Toșa et al., 2015; Toșa and Mitrea, 2018).

The scope of the research is to evaluate the carbon dioxide emission indicator generated by urban traffic based on instantaneous speed data. This would provide a simple but effective numerical application for further dividing the urban area into emission zones.

The primary database consists of 3,232,601 GPS points collected second-by-second between 09.02.2015 – 19.02.2018, using probe vehicles monitored with Track GPS application. Every point in the database contains information regarding time, latitude, longitude, speed and course. A subset of 1,775,477 points registered by P.C.U. probe vehicles was selected. However, only the data covering the urban area of Cluj-Napoca, consisting of 1,551,135 points, were further considered for the analysis of the emission indicator in the last part of this research. In the dataset there is a total of 376,699 zero speed (ZS) points. A closer look at the ZS points' spatial distribution revealed the necessity of dividing them into zero parking speeds (ZP) and zero congestion speed (ZC). The result was that 10% of the recorded points are ZP, 14% are ZC and 76% are moving points. A similar study (Zhao et al., 2017) presents that 87% of the recordings indicated a moving car and 13% of the recordings indicated that the car had stopped moving or the car had stopped. On the other hand, 5% of the recorded speeds have values above the posted speed.

The spatial distribution of the GPS points within the administrative boundary is illustrated in Fig. 3a and Fig. 3b. Point pattern analysis of the probe vehicles speed is inadequate for the geo-processing of the big set of data. We found that for the density of GPS points' visualization as heat maps a 10meter radius provides a good representation of data compared to other values. Considering the road network, the good coverage of the city is confirmed by the consistency of data regarding the number of observations as well as the spread locations. For the validation of the data set, the speed weighted distribution of the points is also illustrated in Fig. 3c and Fig. 3d. The distribution density of GPS detected points through the network shows a very good overlap with the arterial collectors and the main urban streets. Thus, the speed weighted points' distribution reflects traffic patterns and road traffic congestion areas better.



(a) (b)

(c) (d)

Fig. 3. Spatial distribution of the GPS points and the speed weighted points in the dataset

It can be noted that, due to the characteristics of the collection process, most of the points are within the central area of Cluj-Napoca. However, the speed weighted points' density is different, as higher density is found in congested areas. This aspect represents an additional validation of the use of these data for CO_2 emissions analysis. The spatial distribution of speed weighted points was further carried out to determine the spatial autocorrelation of speeds in the data set. The Global Moran analysis reported a value of 0.178030 for Global Moran's Index, a Z-score of 53.1 and a p-value of 0.00000001. The results indicated a strong spatial autocorrelation of the speed values. This enabled the hot spot analysis (Getis-Ord Gi*) for more complex pattern analysis.

4. Results and discussion

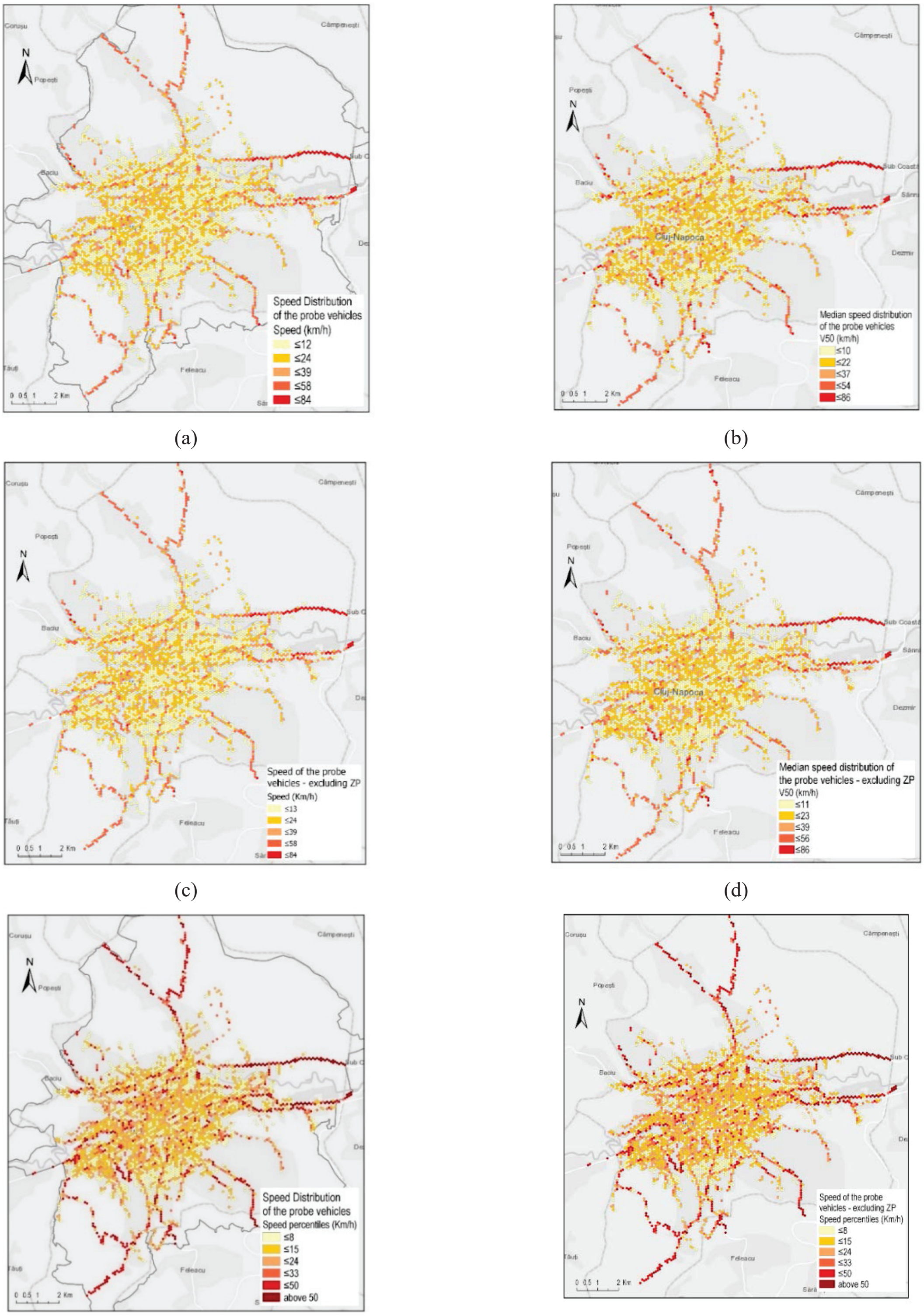
This section reports the results of the application of the tool to the real case study of Cluj-Napoca. Specifically, the first part deals with the speed results and the collected GIS analysis, while the second part deals with the analysis of the results in terms of the emissions indicator.

4.1. Spatial analysis of speed data

The analysis is carried out using GIS-based methods, such as heat maps, spatial distributions, hotspots and 3D representations, for the data visualization and the traffic pattern analysis.

GIS representation for speed visualization was conducted using the honeycomb network and different ranges for the classification of the cells. Fig. 4a uses the arithmetic mean values of the GPS speeds included while Fig. 4b the median values of speed. The ranges are GIS automatically assigned natural breaks of the data set, which are not established in accordance to the traffic speed theory and thus they are a very subjective choice. However, some traffic characteristics are highlighted. The selection of ZP and ZC was conducted according to the speed filtering algorithm (Table 1). ZP points were excluded from further analyses. Fig. 4c and Fig. 4d illustrate the spatial distribution of the new set of data. The cells are classified by the natural breaks of the arithmetic mean of the data (Fig. 4c) and the median values (Fig. 4d). The maps in Fig. 4c and Fig. 4d show more homogenized areas of speed, since they exclude ZP points, which are related to intensive parking generating objectives. Moreover, using the median value of the speed shows to be a better choice over the arithmetic mean for the identification of traffic condition. Maps in Fig. 4e and Fig. 4f present a more practical perspective of the analysis. The honeycomb network is classified using speed specific percentiles (v25, v50, v75, v85) and the posted speed (similar to v95). The outlier values, specifically the null ones and the values above the speed limit, corresponding to the 15th respectively the 98th percentile, are not considered. Fig. 4f presents the new data set, namely excluding ZP points. The speed patterns, resulting from the map can be characterized by three main aspects:

- the presence of high-speed corridors (arterial or collector street) in red, located outside the built-up area, where secondary streets give way to main traffic roads;



(a) (b)

(c) (d)

(e) (f)

Fig. 4. The honeycomb speed distribution of GPS points with and excluding ZP

- the presence of high-speed clusters (red hexagons) located within the built-up area, on high-speed streets/collectors with the right of way and near signalized intersection;
- the presence of low-speed hexagons on the main road corridors close to signalized intersections or roundabouts.

The 3D visualization of data in Fig. 5 also highlights the above-mentioned conclusions.

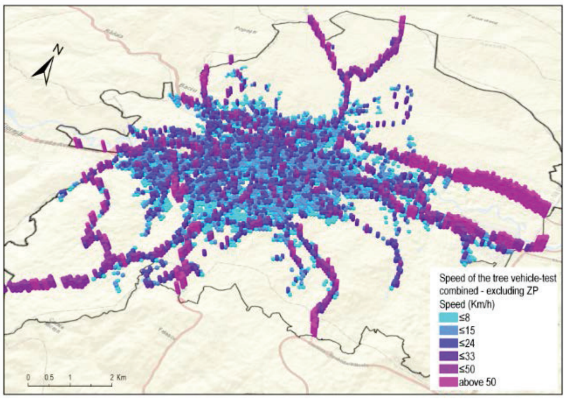


Fig. 5. 3D speed distribution of the probe vehicles, excluding ZP points

Fig. 6a and Fig. 6b present interesting results about the distribution of ZS points. The simple spatial distribution of ZS points presented in Fig. 6a, shows in detail the location of parking spaces related to specific activities (residential areas, offices, shopping malls, airport, coach station and train station, etc.). The hot spot analysis results presented in Fig. 6b show the specific areas with traffic congestion (hot spots) in the downtown area and in the other built areas of the city or free-flow areas (cold spots), respectively. Therefore, it is important to extract ZP points in the early stages of the analysis.

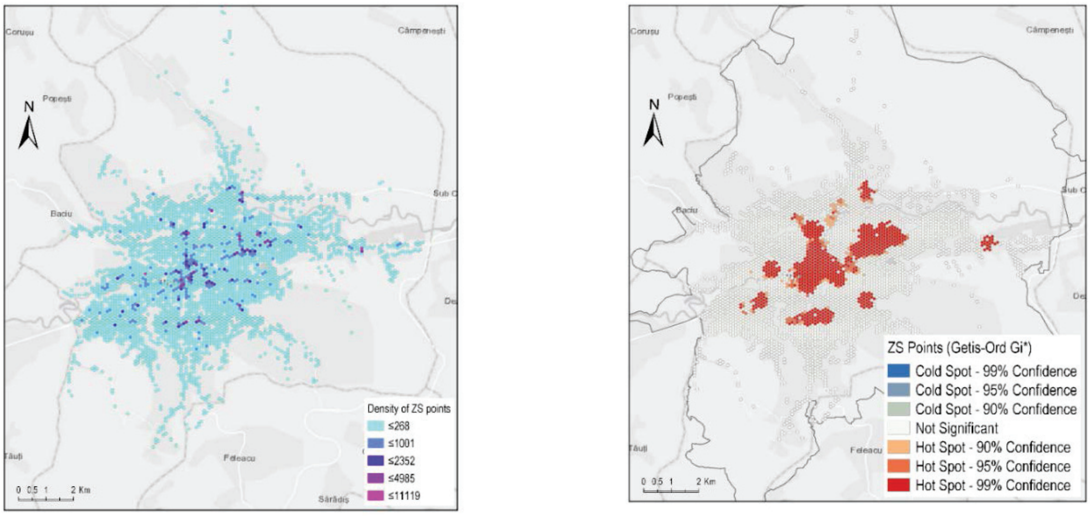
4.2. Spatial analysis of the CO_2 emission indicator

As underlined in the previous section, speed representation proved to be valid and robust, so these data are used for the last part of the computation of the CO_2 emissions indicator.

Fig. 7a presents the distribution of emissions indicator weighted points. It shows that the high concentration of emissions is found in the central area of the city, while the sparse density covering the urban areas suggest that the points are spread all over the urban built area.

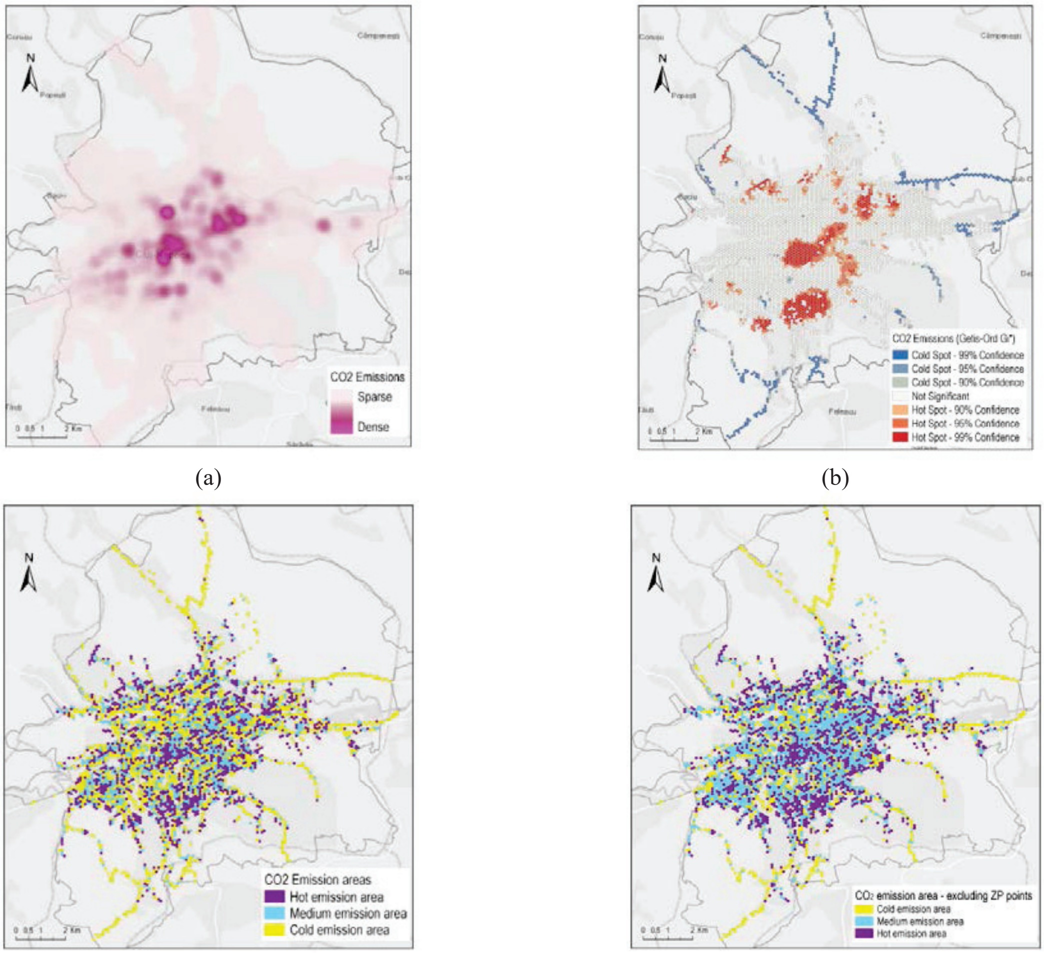
The Global Moran analysis of the CO_2 emissions reports a value of 0.117740 for Global Moran's Index, a Z-score of 35.17 and a p-value of 0.00000001. The results indicate a strong spatial autocorrelation of the CO_2 emission indicator values.

Fig. 7b shows the results of the hot-spot analysis. First, it underlines that unlike the spatial distribution of speed data, the CO_2 emission indicator presents high values, correlated to the high CO_2 emission case in many places throughout the city, not only limited to the central part of the city, where spread data show the existence of the traffic congestion case. The high emission area distribution is due to the presence of the two worst cases: slow speed for congested traffic and high-speed vehicles with increasing fuel consumption. Secondly, the use of Getis- Ord Gi* statistic underlines the presence of three different areas in which the main issues are recorded from the point of view of pollutant emissions.



(a) (b)

Fig. 6. Detailed analysis of ZP points



(a) (b)

(c) (d)

Fig. 7. Computation of CO_2 emission zones

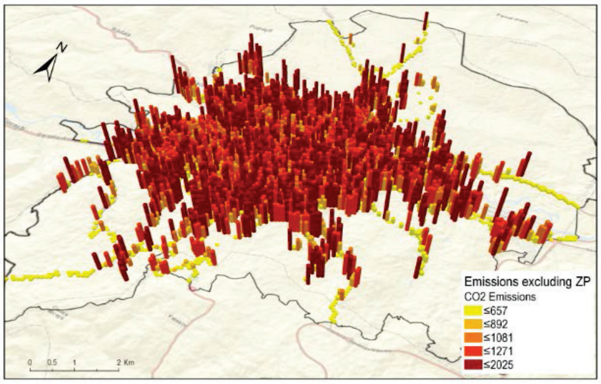


Fig. 8. 3D distribution of CO_2 emission indicator

An adjustment of the results, by filtering and excluding ZP points, enabled a more homogeneous and clear distribution of the emission areas in the urban area model, which is more consistent with real traffic conditions (Fig. 7d). Therefore, considering three types of areas based on the values of the CO_2 emission indicator (Fig. 7c), it is possible to observe that the proxy indicator allows us to obtain results similar to the ones in the classic emission models. The results are visually validated by the 3D distribution of the CO_2 emission indicator presented in Fig. 8.

5. Conclusions

New technologies allow the collection of an extensive amount of data referring to vehicle travelling. As revealed in the literature, there is a great interest in developing tools for effective management including the evaluation of the impact of various policies in decreasing greenhouse gas emissions and other transport pollutant-related emissions, especially in urban areas. Therefore, the aim of this study is to propose a simple, but effective tool for the analysis of emission zones and for the evaluation of the impact of management policies.

For this purpose, a representation framework is presented. The evaluation and visualization of CO_2 emissions indicator based on GPS speed data from several probe vehicles is conducted in four steps. The first step of the tool refers to raw data processing, namely map matching and extraction of specific area. Secondly, GPS data filtering is conducted in order to identify ZP points associated with parking, which are excluded from the emission indicator analysis. Then, the validation is carried out by means of GIS tools. At last, the emission indicator is obtained and validated. A real case study was carried out in Cluj-Napoca. The emission zones were classified based on the values of the CO_2 emission indicator and visually represented in a map. A share of 35% Hot emission areas, 40% Medium emission areas, and 25% Cold emission areas resulted. Moreover, Hot emission areas are easy to spot and further analyse.

The integration of emission data with GIS is an effective method to perform complex environmental analysis by means of pollutant spatial distribution. The results show the utility of the tool for policy and planning process of road traffic management, due to its ease of application and consistency especially for the definition of critical areas and prioritising of the improvements with mobility projects.

The input data can be dynamically updated, which implies the repetition of the numerical application. However, further developments concern the automatic processing of these data for non-technical people in the local administrations.

Particularly, further efforts should include the following aspects: (1) the study is focused on a small fleet of probe vehicles. More complete analyses, on a wider and more variate fleet of probe vehicles need be conducted; (2) the study provides a methodology that divides the urban area into smaller emission zones. The data available in the urban area can be considered sufficient for citywide-scale analysis, but additional research has to be carried out in terms of acceptability and the minimum data set required for covering areas with low traffic zones; (3) the use of the speed data is mainly focused on the spatial analysis of the zero speed from GPS points and it revealed the need for a certain classification. ZS points were divided into two different categories – parking or congestion, including signalized intersections and other obstacles; however, additional refinements are necessary in order to study the temporal changes of speed vehicles as well, for defining congested and free-flow conditions in a more robust way; (4) further development will deal with the validation of the model using two possible sets of data for comparison: the real-world data concerning pollutants emission and concentration from sensors and the emissions estimated using a detailed traffic model based on DTA. Another important step for the overall validation of the tool will test the capacity to evaluate various strategies to reduce of emissions such as the congestion mitigation actions or speed management techniques.

It is important to highlight that such an approach can be used for any specific pollutant emissions and the first real-case study application in an urban context has dealt with CO_2 emissions. Further developments will deal with the computation of the emission indicator for other pollutants and with the validation of the approach by applying other methods and comparing the results. The analysis of the results could be focused not on the capacity to evaluate emissions but on the development of a proxy measure useful in the planning process.

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