ROAD TRANSPORT EMISSIONS EVOLUTION IN URBAN AREAS; THE CASE OF THESSALONIKI, GREECE

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ABSTRACT

According to several EU studies, road transport is a major source of air pollution, especially in urban areas. Due to their significant contribution on local air quality, road transport emissions should be calculated as detailed and precise as possible. In an effort to understand the evolution of road transport emissions in the last three years (2012 – 2014), this study focuses on the calculation at micro/link level of carbon monoxide (CO), nitrogen oxides (NOx) and volatile organic compounds (VOC) emissions in Thessaloniki, the second largest city of Greece. The hourly volume data measured at real-time by inductive loops, cameras and radars in the greater metropolitan region of Thessaloniki were imported to a large-scale transportation model of the city, along with the vehicle fleet composition and a detailed representation of the urban and regional road network. The outputted hourly vehicle volumes, the average speed and the vehicle fleet composition of the 137.938 links of the network were then inputted to COPERT Micro for the calculation of the hourly and daily emissions. Afterwards, the emission values from COPERT Micro were imported to a GIS grid in order to visualize how the emissions are distributed throughout the city. The calculations were performed for the years 2012 to 2014. A typical weekday for each season and for every year was selected and then simulated. The results at link level revealed the local pollution hot-spots and the high-emission links, which usually lie along the main urban highways of the city. The seasonal variation of pollutants is mainly caused by the different transport activity pattern in each season. Moreover, there is a substantial drop on average annual emissions between 2012 and 2013, whereas a constant trend is observed between 2013 and 2014. This could be mainly allocated to the reduced transport activity throughout the city, mainly affected by the economic crisis.

Keywords: transport and emissions modeling, environmental pollutants, road traffic, air quality, Thessaloniki.

1. Introduction

Road transport is a significant source of air pollution, especially in urban areas. According to a review of the CLRTAP emission data by the European Environment Agency (EEA, 2013) road transport is an important contributor to NOx, Non-Methane Volatile Organic Components (NMVOCs), CO, PM_{10} and $PM_{2.5}$ emissions. In 2011, road transport alone was responsible for 40.3% of total NOx, and 16.5% of total $PM_{2.5}$ in the 27 European Union countries (EU27).

The air quality, especially in heavily populated cities, is strongly affected by road transport emissions. Thus, the latter must be calculated as detailed and precise as possible. Towards this approach, the current study presents the results of CO, NOx, and VOC hot emissions calculations at street level in Thessaloniki, the second largest city of Greece. The study focuses on years 2012 – 2014, so as to illustrate the recent situation in the city.

2. Materials and methods

2.1. Study area

The study area – Thessaloniki – is located in Northern Greece covering a land area of 138.847 km^2. The city's boundaries are delineated by Thermaikos Gulf (Aegean Sea) at the south/south-western side and the Hortiatis Mountain at the north/north-eastern side. Based on the latest transportation study conducted between 2010 and 2013, the average daily private vehicle traffic on the main roads of the city reaches 1.300.000 vehicle-trips, while the morning peak corresponds to 14% of the daily total (Mitsakis *et al*., 2013). The main streets in the central area of the city serve daily volumes of through traffic that reach 45% of traffic volumes recorded at peak periods (morning travel to work and afternoon travel back from work to home) (Stamos *et al*., 2013)

2.2. Traffic modelling

The transportation model for the metropolitan area of Thessaloniki has been developed with the PTV VISUM software (Gentile & Noekel, 2009), a traffic assignment tool for urban and regional operational planning analysis that has been used in several studies (Ayfadopoulou et. al., 2012; Mitsakis *et al*., 2013). The network used for the purpose of this study consists of a detailed representation of the urban and regional road network of the metropolitan region of Thessaloniki, based on open-source GIS, fused with traffic related parameters. The network consists of 137.938 directed links and 47.838 nodes. The links contain information about the number of lanes, the road type and its hierarchy in the network, width, length, free flow speed, design and effective capacity, direction, allowed transport systems. The link delays are calculated with the use of volume-delay functions, the parameters of which rely on previous studies and have been updated through travel time measurements for the purposes of the work presented herein. The nodes contain detailed information about the junction's geometry, allowed movements and control type of the node. The network consists of 339 traffic analysis zones connected to physical nodes of the road network via 3.508 connectors, according to their accessibility index (Friedrich & Galster, 2009), avoiding connections with nodes belonging to high hierarchy links. The demand side is comprised by 24 hourly Origin-Destination (OD) matrices and the travel demand for a typical weekday is within the range of 1.298.745 vehicle trips. The obtained OD matrices are corrected using the hourly volume data measured by inductive loop detectors, cameras and radars installed at 37 locations across the city. The OD matrix correction is performed with a fuzzy-set based matrix correction procedure (Rosinowski, 1994).

2.3. Emissions modelling

The emissions calculations were performed with COPERT Micro (Samaras *et al*., 2014), a specially developed version of COPERT 4 (Ntziachristos *et al*., 2009) for urban areas. COPERT Micro is an average speed emissions model that is able to calculate fuel consumption, as well as several important pollutants (CO, NOx, VOC, PM exhaust, CO_2 and others). It is a bottom-up model, thus, it can calculate the emissions from a single traffic link up to an entire city. COPERT Micro was developed focusing primarily on hot exhaust emissions. It includes 230 different vehicles categories and incorporates several emission factors that obtained experimentally as a function of the average vehicle speed.

The equations below summarize the main calculations conducted by COPERT Micro during hot exhaust emissions calculation. First of all, based on the average speed of each traffic link the corresponding emission factors are calculated for each vehicle category and for every pollutant:

$$EF_{i,\,k}(V) = f_{EF,\,i,\,k}(V_j)$$

Where:

- $EF_i(V)$: hot exhaust emission factor per vehicle category k, for average speed V and for pollutant i [g/km]
- i: pollutant of interest (CO, NOx, and VOC)
- $f_{EF,\,i,\,k}$: polynomial function derived from measured data (as trendline); unique for every vehicle category k and for each pollutant i
- V_j: average speed of the vehicles circulating on the traffic link j [km/h]

After calculating the emission factors for all pollutants, the hot exhaust emissions of the traffic link j are calculated by the formula:

$$Ehot_{i,\,j} = L_j \times N_j \times \sum(P_{j,\,k} \times EF_{i,\,k}(V))$$

Where:

- $Ehot_{i,\,j}$: hot emissions of pollutant i produced by N_j vehicles that circulate on the link j [g]
- L_j: length of the traffic link j [km]
- N_j: number of vehicles circulating on link j
- $P_{j,\,k}$: percentage of vehicles of the specific category k on the overall vehicle fleet that circulate on link j, e.g. passenger cars 0.8 – 1.4 l gasoline Euro 3 = 5% etc.

Finally, the total hot exhaust emissions of the pollutant i from the entire area ($Ehot_{i,\,area}$) are calculated by summing the emissions of individual traffic links j:

$$Ehot_{i,\,area} = \sum Ehot_{i,\,j}$$

Since the hourly activity data are available from the traffic model, the calculation is repeated for each hour of the day and the hourly and daily emissions are calculated for all pollutants and for all traffic links.

3. Results and discussion

The emission values from COPERT Micro were imported to a GIS grid in order to visualize how the various emissions are distributed throughout the city (figure 1). It is quite clear that the contribution of large boulevards – like Leoforos Periferiaki, Leoforos Egnatia, Leoforos Tsimiski and Lefoforos Nikis – on total CO, as well as on the other emissions is quite high (marked with red or orange colour on the GIS grid).

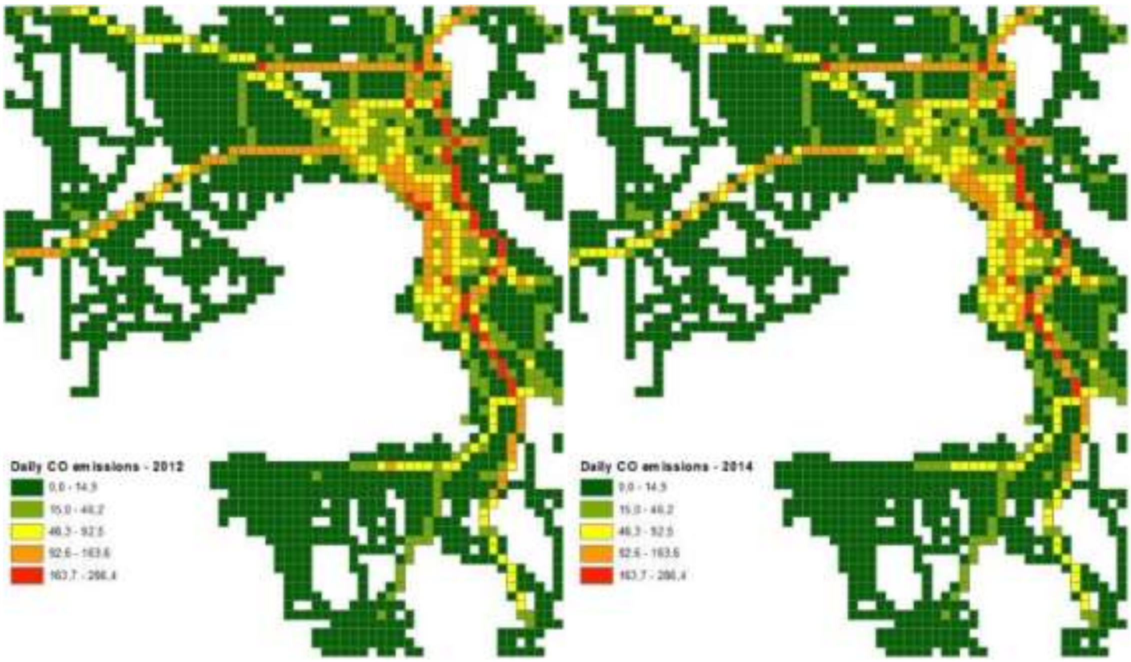

Figure 1: Daily CO hot emissions (kg) on a 100 x 100 (500 x 500 m^2) grid for a typical weekday of summer 2012 (left) and 2014 (right) in metropolitan area of Thessaloniki.

In figure 2 the seasonal variation of NOx hot emissions is presented for both 2012 and 2014. It's evident that the different transport activity pattern in each season is also reflected on emissions. Moreover, the emissions peaks for 2012 are higher than the corresponding ones for 2014, indicating that NOx emissions has been reduced.

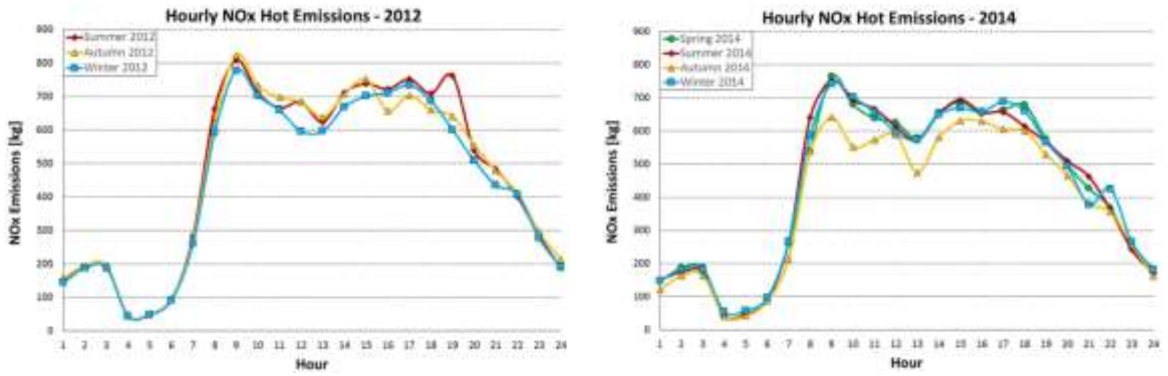

Figure 2: Hourly NOx hot emissions (kg) for a typical weekday of each season of 2012 (left) and 2014 (right) in metropolitan area of Thessaloniki.

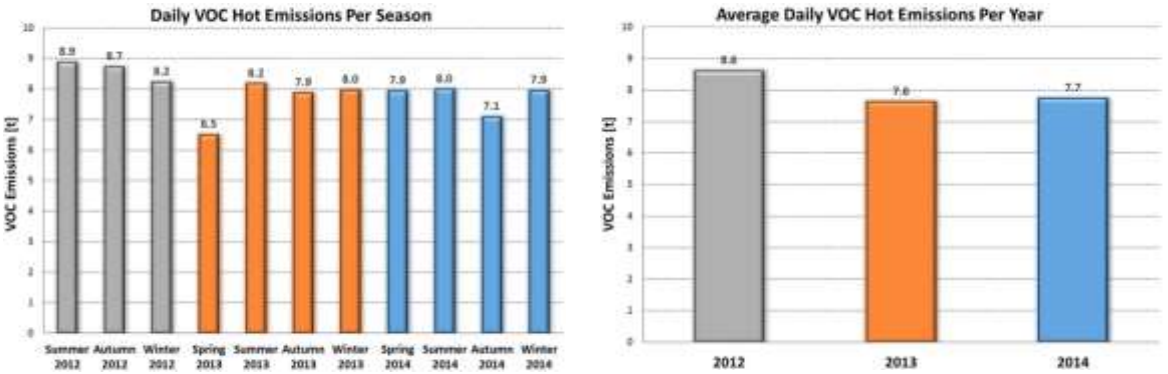

Figure 3: Daily VOC hot emissions (t) for a typical weekday of each season (left) and each year (right) of years 2012 – 2014 in metropolitan area of Thessaloniki.

The evolution of daily VOC hot emissions is shown in figure 3. On average basis, during 2013, VOC emissions were reduced about 11.4% compared with 2012. However, on 2014, there was a small increase of about 1.4%. Similar trends were observed for other pollutants, indicating that 2013 was a turning point year for Thessaloniki, in respect of transport emissions.

4. Conclusions

The results at link level revealed the local pollution hot-spots and the high-emission links, which usually lie along the main urban highways of the city. The seasonal variation of pollutants is mainly caused by the different transport activity pattern in each season. Moreover, there is a substantial drop on average annual emissions between 2012 and 2013, whereas a constant trend is observed between 2013 and 2014. This could be mainly allocated to the reduced transport activity throughout the city, mainly affected by the economic crisis.

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