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PASSENGER CAR DEPENDENCY AND CONSEQUENT AIR POLLUTANTS EMISSIONS IN IASI METROPOLITAN AREA (ROMANIA)

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Abstract

Urban expansion, often seen as an indicator of economic growth and a possible response to housing crisis in big cities, is the main driver for carbon emissions in the metropolitan area due to higher values of household income, vehicle ownership and home size. The transport related pollution includes over 200 different compounds: besides CO_2 emissions, CO, NOx, BTX and dust resulting from exhausting processes, from abrasive wear of brakes, tires and road surfaces. The expansion of the urban areas in Romania has faced similar patterns in all major cities in Eastern Europe. Traffic congestion and increasing pollution became common aspects of urban life, as most big cities were not prepared for this fast change in urban land use. The present paper proposes to highlight which communes from the Iasi metropolitan area contribute the most to air pollution due to car commuting. The results highlight the negative effects of urban sprawl upon air pollution and the challenges raised by residential mobility. The above-mentioned aspects were analyzed using surveys, statistical data, pollutants inventory and GIS related simulations for commuting in order to highlight patterns of peri-urban air pollution due to car commuting. The results suggest that the Iasi metropolitan area is confronted with an important sprawl which results in high values of different air pollutant emissions originating from extensive passenger car use in the peri-urban area.

Key words: commuting, Iasi pollutants emissions inventory, urban sprawl

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1. Introduction

Urban sprawl is a multifaceted concept which has been intensely researched in the last decades mainly because of the issues associated with ecological stress in fast-changing patterns of land use due to the accelerated growth of liberal economies (Fina and Siedentop, 2008; Gonzalez, 2005; Muñiz and Galindo, 2005; Mironiuc and Huian, 2017). Analysing air pollution expressed by the expansion of the built-up area and car dependency has an increasing role as the effects of air pollution on public health are being observed worldwide. Road traffic emissions represent an increasingly major part of air pollutants emissions in Romanian urban areas, a fact that is enhanced by peri-urbanisation/sprawl processes within the Metropolitan areas.

Besides fragmentation of natural landscape (Park et al., 2014), diminution of natural habitats (Alberti and Marzluff, 2004; Su et al., 2010) or biodiversity, other major problems are associated with this concept and are highly researched. Urban expansion has a direct negative impact on traffic congestion (Ciobanu and Benedek, 2015), high oil consumption (Aftabuzzaman and Mazloumi, 2011; Novelli et al., 2017), increased level of automobile travel (Petrescu et al., 2015) or car dependency (Newman and Kenworthy, 2011), air pollution

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(Stankovic et al., 2015; Stefan et al., 2015) and related health problems (Frumkin, 2002), thus affecting the human condition.

Urban automobile transport has become the dominant source of air pollution in larger urban cities (Jensen, 1998; Takucev et al., 2014). Moreover, peri-urban areas are responsible for more than 50 % of all household emission (Jones and Kammen, 2014). Intense traffic air pollution is usually considered to result from high population density (Stankovic et al., 2015), which makes urban areas to gather the largest number of population subject to automobile pollution exposure (Banica et al., 2016). Meanwhile, it is often stated that compact urban areas address better environmental issues related to air emissions (Wang et al., 2016), while more dispersed development of cities is beneficial in terms of reducing the impact of localized pollution (De Ridder et al., 2008; Martins, 2012; Schindler et al., 2017; Schindler and Caruso, 2014). Nevertheless, both urban and peri-urban traffic (Kim, 2016) contribute to harmful effects on both human health and environment (WHO, 2016). One of the reasons of urban sprawl is represented by the choice of the population to leave the crowded urban centre in order to look for less polluted neighbourhoods (Lera-López et al., 2012). Meanwhile, this relocation is in itself creating additional pollution, by longer commuting trips to their workplaces and to service areas, which modifies the spatial patterns of urban pollution (Schindler et al., 2017). The fact is reflected by transport performance and accessibility which were debated by many studies focusing on the impact of mode choice on energy efficiency and atmospheric emissions. Some of these studies focus on the structure of vehicles (sizes and ages of engines) and travel behaviour, concluding that there is an obvious need to integrate urban development and transport systems in order to reduce pollution (Ambarwati et al., 2016; Chiou et al., 2009; Chiou and Chen, 2010). There is even a study that proposes numerical simulations of an urban model where residents are homogeneously harmed by the 'total pollution' generated by commuters (Verhoef and Nijkamp, 2004). Other different approaches assess the vehicular contribution to higher concentrations of nitrogen dioxide (NO_2) and suspended particles (PM10) in traffic-related areas (Oprea et al., 2017; Vasilescu et al., 2017), especially referring to diesel vehicles in spite of the fact that more stringent emission standards had already been implemented (Borken-Kleefeld and Chen, 2015; Carslaw et al., 2011; Carslaw and Rhys-Tyler, 2013; Franco et al., 2014; Stefan et al., 2015; Zhang et al., 2016). Eastern Europe has been facing an important extension of functional urban areas in the last decade and is expected to go through the same pollution problems (Sailer-Fliege, 1999), as the highest values for air pollutants are recorded in the major cities across Eastern Europe (EEA, 2016; Manolache et al., 2017). The issue of sustainability of human-environment interaction represents a priority research topic, especially in the areas where urban expansion has recorded important changes, as it is the case of the Iasi Metropolitan Area, in the North-Eastern Region of Romania.

The aim of the research is to investigate the relation between the urban sprawl, commuting and air pollution using a GIS integrative approach, based on network analysis, qualitative and quantitative surveys and official statistical data, in order to evaluate the impact of the urban expansion in the Metropolitan Area of Iasi on air pollution. Several objectives create the guidelines of the research in order to determine the degree of air pollution in the Metropolitan Area of Iasi Municipality. The first objective is to determine the extent of the urban sprawl based on accessibility measures, thus highlighting the existing pattern of the peri-urbanization process. The second objective aim is to determine the degree of car dependency using a survey applied for each settlement from the Metropolitan Area. The third objective targets to estimate the quantity of different pollutants generated by the daily use of personal cars on a detailed level, based on commuting data and the results of the survey.

2. Material and methods

2.1. Study area

Urban sprawl, a phenomenon with different levels of intensity and generated by different factors, has its beginnings during the post-Fordism period (Iatu and Eva, 2016). Romania (Grigorescu et al., 2012) and most of Eastern European (Brade et al., 2009) countries have experienced the process of urban expansion while changing the political and economic ideology from socialist to capitalist economies. The spatial frame of urban sprawl of the Iasi Municipality falls under these characteristics which are different from the western or American models and different from one city to another located in Eastern Europe.

The present research takes into consideration the Metropolitan Area of the Iasi Municipality, the first entity of this kind established in Romania in 2004 (Clipa, 2012). Located in the North-Eastern Romania, the study area comprises the Iasi Municipality (the second largest city in Romania) and 76 settlements grouped in 13 communes (Cimpianu and Corodescu, 2013) (Fig. 1). The entire area has a population of more than 400.000 inhabitants on a relatively small area (800 km^2), forming one the densest, most active and complex functional urban area in Romania and on the Eastern border of the European Union. The positive effect of this urban agglomeration is represented by being considered the main economic engine of the entire North-East Development Region, clustering important IT&C services, high educational services, retail and industrial platforms.

The Iasi Municipality had a compact form until the late ´90s. Even though the city faced a rapid urbanization, the extension was mainly vertical, densifying and creating compact districts, which are now seen as a sustainable urban form (Burton et al., 2013).

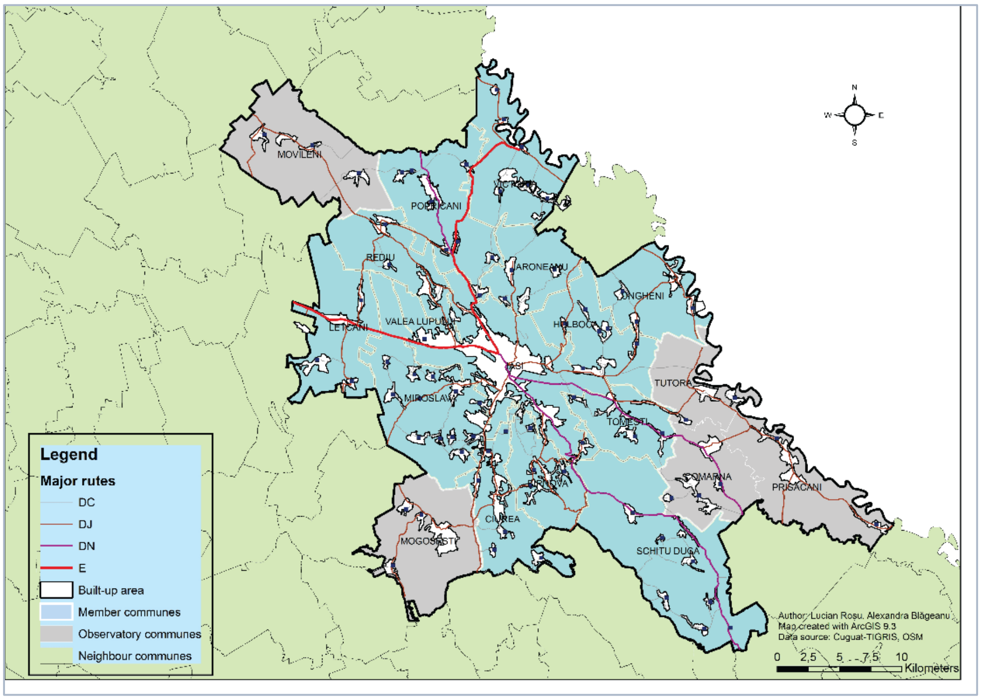

Fig. 1. Iasi Metropolitan Area

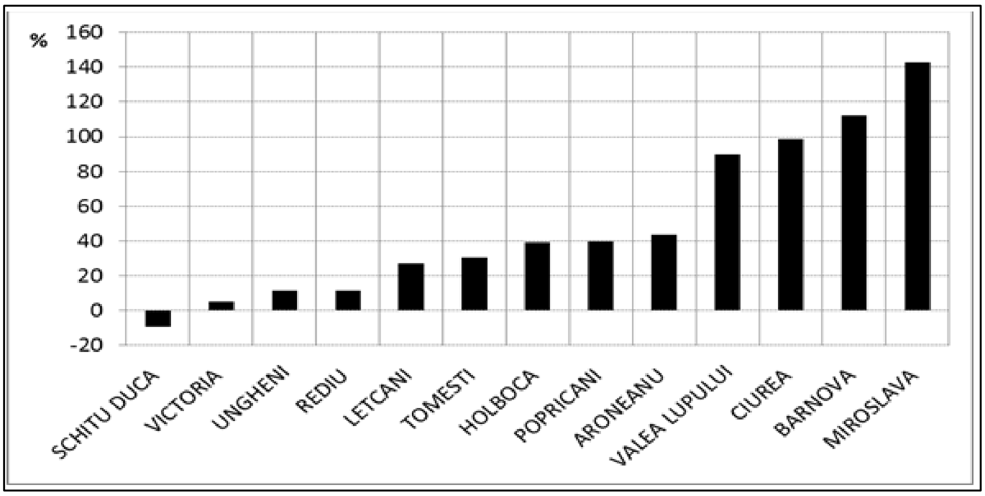

Fig. 1. Population growth rate (%) of the communes from Iasi Metropolitan Area (1992 – 2016)

The entire functional urban area faces a slow process of post-communist transition (Rosu and Blageanu, 2015). The actual form of the city and its surroundings has been influenced by rapid and visible changes in the last two decades, mainly due to the relocation of industry and housing in the peri-urban areas, where the new industry and retail economy are located.

During the last 25 years, the city has ceased growing (from a demographical perspective) even though its polarization force attracts more and more people from the surrounding areas (Blageanu et al., 2012). On the other hand, the fast growth of the peri-urban areas determined the local administration to create the Metropolitan Area of Iasi in order to fill the gap between the compact city and the undeveloped rural regions. As a consequence 12 of the 13 communes which are part of the Metropolitan Area experienced significant population growth, some of them doubling their population in the last 14 years, while the only commune showing a decrease (Schitu-Duca) is also the most remote from the city (Fig. 2 and Fig. 3). The constant movement towards the fringe of the city resulted in the occurrence of residential districts outside the city limits. On the other hand, most of the services are being clustered in the city centre, the economic integration leading to a dramatic increase in the geographic concentration of facilities via self-reinforcing agglomeration process (Forslid and Ottaviano, 2003).

Therefore a rather obvious monocentric development model can be observed (Mihai, 2015), resulting in planning problems such as a chaotic urban sprawl which generates, inter alia, massive traffic jams

(Ursu et al., 2016), especially at the main entrances towards the urban core, high values for air pollutants (Banica et al., 2017; Luca and Ioan, 2012), and other specific problems. These issues are also generated by the lack of an integrated metropolitan public transport and an obvious car-dependency model (Rosu and Blageanu, 2015).

2.2. Data and methods

In order to evaluate the interaction between car dependency, urban sprawl and air pollutants, a comprehensive methodology based on integrative approach was applied. There are three phases of the methodological path: evaluating urban sprawl by using GIS-based accessibility assessment, applying a survey in order to estimate car dependency and, finally, making an inventory of the main air pollutants that result from the use of cars for commuting.

2.2.1. Evaluating urban sprawl using GIS accessibility assessment

The concept of accessibility is used to determine different levels of peri-urban development (Frenkel and Ashkenazi, 2008). Accessibility represents the main outcome derived from the spatial analysis of a transport system. It creates the main location advantage of an area in relation to other areas it is linked to. Accessibility indicators point out the returns of an actor in his location from the use of the transport infrastructure relevant in its hinterland (Spiekermann and Neubauer, 2002). In order to establish the degree of urban sprawl a time-travel model based on network analyses has been performed using GIS specific methods.

The model takes into account the road network, classified by type, speed limits and length, built up areas of settlements inside the Metropolitan Area and the communes' administrative limits.

Using this method, each settlement from the Metropolitan Area obtained a value of duration-distance to the city centre, according to the road network type. The results were clustered into three categories of settlements, according to different levels of accessibility to the city centre (high, medium and low).

2.2.2. Using surveys for estimating car dependency

In order to evaluate different characteristics of travel pattern and car dependence during commuting, a qualitative approach was used by applying questionnaires. The use of questionnaires was a requisite for linking official statistics of commuters with car travel patterns and its characteristics. The items of the survey covered the dimensions of the researched field, according to the objective mentioned afore (Table 1). Most of the questions used were factual ones, adding filtered and identification questions. For establishing the questions, several items such as importance, responsiveness, clarity, comprehensiveness, validity and policy relevance were taken into account (Fowler Jr, 2014)

The information was collected using questionnaire-based surveys applied between August 2016 and October 2016 for approximately 30 settlements from all 13 communes which are part of the Iasi Metropolitan Area using a random sampling technique. Surveys were conducted both on weekdays and weekends and were worked out both directly and via online platforms. The sample size for data collecting was estimated using the methodology offered by National Statistical Services (NSS, 2017). With a confidence level of 95 %, population size of 17,000 commuters (according to official statistics) and a sample size of 255 surveys, the relative standard error is 6.23% which is considered admissible and stands at the bases of our further analysis.

2.2.3. Estimating air pollutants generated by car-commuting

For estimating the quantity of each pollutant, average European emission factors, stated in units of grams per vehicle-kilometre, were taken into account for each given vehicle technology. Five pollutants that are relevant for traffic related impact were chosen (CO, NMVOC, NO_x, N_2O and $PM_{2.5}$) and estimated using the estimations from Guidebook inventory of atmospheric air pollutants 2016 in g/km (EEA, 2016) These average emission factors were determined by European Environment Agency taking into account the typical values for ambient temperatures, driving speeds, rural-urban-expressway mode mix, trip length, etc.

Table 1. Questions used in the survey

Subject of interest	***Type of question***	***Ex. of answer***
Place of living	Identification Question	Valea Lupului
Work place	Identification Question	Iasi, City Centre
Commuting frequency	Factual Question	Daily
Distance (time and km) covered	Factual Question	50 km / 60 minutes
Means of transportation	Filtered question	Personal car
Number of passengers (by car)	Factual Question	Two passengers
Displacement for the car (cc)	Factual Question	1500-2000 cc
Fuel Type	Factual Question	Diesel
Pollution norm	Factual Question	Euro 4
Family income	Factual Question	4,000 RON
Age	Identification Question	45
Sex	Identification Question	M

The input data also included the estimated vehicle stock involved in commuting by vehicle type/technology (Non-EURO, EURO 1 to 6), fuel type (gasoline, diesel, LPG, hybrid) and vehicle size, broken down by cylinder capacity.

The results of the above mentioned applied questionnaires were used in order to obtain the profile of each commune from the Metropolitan Area not only in what concerns the mobility behaviour, but also the passenger cars fleet structure. The data obtained from questionaries' were extrapolated to the total number of commuters. Finally joining the commuting profile data (frequency, distance, no. of passengers, displacement for the car) and the emission factors for each type of car there was identified a raw assessment of the annual quantities of the main air pollutants (CO, NMVOC, NO_x, N_2O, $PM_{2.5}$).

3. Results and discussions

3.1. GIS Assessment of Urban Sprawl in Iasi Metropolitan Area

The process of expanding the urban influence area, while concentrating the facilities inside the city centre, leads to a strong core-periphery model based on the assessment of accessibility that was calculated for each settlement from the Metropolitan Area (Fig. 3) and then averaged at communes level (Table 2). Applying the GIS accessibility model taking into account the existing configuration and quality of road network resulted in the delineation of three rings of settlements. The first ring includes localities accessible in less than 15 minutes by car from the city centre: the suburban localities such as Valea Lupului, Miroslava, Barnova, Aroneanu, Letcani etc.). The second ring mainly encloses localities with medium accessibility within 15 - 25 minutes from the urban chore that are also emitters (and sometimes receivers) of commuters towards (and from) the city (secondary settlements from Popricani Aroneanu, Holboca, Miroslava communes). Finally, the third ring delineates localities with lower accessibility outside the 25 minutes isochrone (Schitu Duca, Ungheni, Victoria etc.).

The ease of accessing the city (and its facilities) is also correlated to the degree of development which explains the fact that several settlements bounded to the city (with a high degree of accessibility) have also a high degree of development. In the same time, localities positioned between main transportation axes have, generally, a lower degree of development caused by higher values of duration-distances.

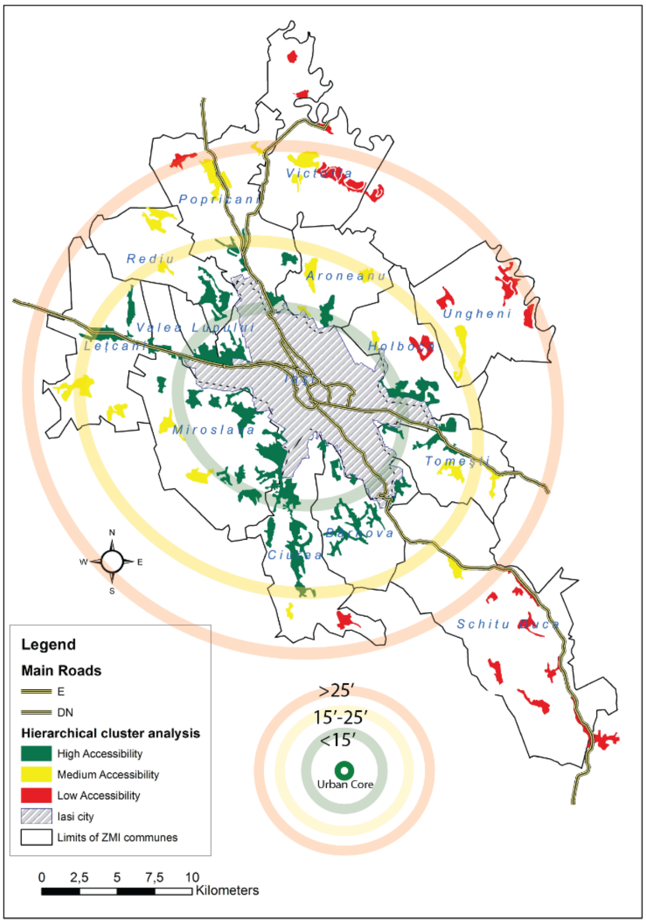

Fig. 3. Accessibility by duration-distance values in Iasi Metropolitan Area

Table 2. The relation between commuters and commuting distance to Iasi Municipality

Commune	***No. of commuters***	***Commuters out of total employees (%)***	***Distance (km)***	***Time travel to city centre (min.)***
Aroneanu	603	47.2	8	12
Barnova	1315	52.9	10	11
Ciurea	2256	49.3	13	10
Holboca	2962	58.2	11	12
Letcani	753	24.6	15	13
Miroslava	2117	51.7	5	10
Popricani	1089	39.2	19	14
Rediu	931	53.5	10	12
Schitu Duca	272	15.0	24	23
Tomesti	2674	52.6	11	12
Ungheni	453	24.9	21	20
Valea Lupului	1460	62.5	7	8
Victoria	190	12.0	25	22

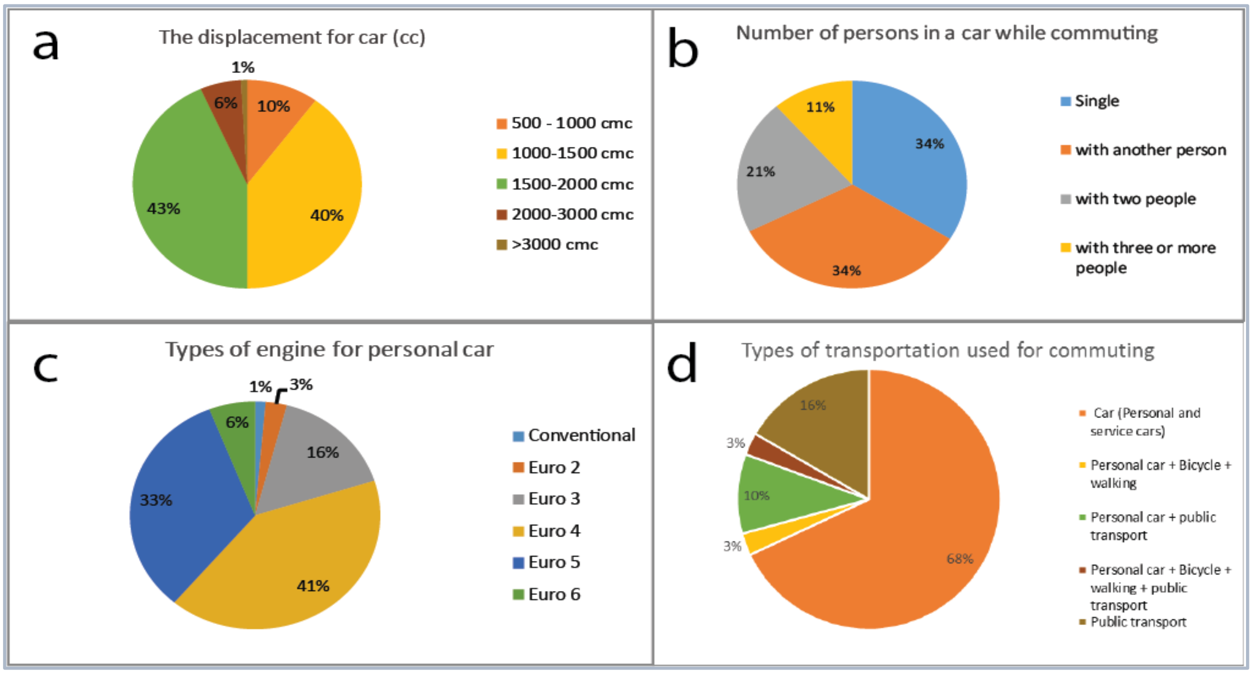

Fig. 2. Indicators of car dependency estimation using survey results

Therefore, these areas are considered peripheral and rural (even if they are 10 km away from the core), presenting typical characteristics and behaviours (lower frequency of commuting, less mobility, lower development). The accessibility model highlights a strong relation between the percentage of commuters working in Iasi and the time travel to city centre (R^2 = 0.82) (Table 2). It can be noticed that the longer the distance from the outskirts of the city, the lower the degree of mobility and usage of personal cars.

Nevertheless, there are cases of communes that are emitting fewer commuters even though they are relatively close to the city. For example in Letcani, local development absorbs a higher number of employees and the share of the commuters out of the total number or employees is at the same level with as the one in Ungheni, which is more than 21 km far from the city.

The negative effects are mainly caused by traffic agglomeration and longer trips which induce car dependency and generate increased air pollution. Therefore the relation discussed above, between the length of the trips and the number of commuters is highly important in order to understand and estimate car dependency in Iasi Metropolitan Area.

3.2. Estimating car dependency

Analysing the survey, the results highlighted that most commuters (68 %) are using their personal car, no matter their earnings, showing a car-dependency pattern which has its bases on the socialist regime, when having a car was considered a privilege (Fig. 4d). Most of the cars used by the commuters (83 %) have their displacement lower than 2,000 cc, emphasising a lower consumption of fuel (Fig. 4a). On the other hand, a reduced average income determines most of the commuters to buy used cars with a moderate ecological footprint (Euro 5 – 33 % and Euro 4 – 41 %), resulting in negative effects upon traffic environment. Also, most of the respondents (34 %) are travelling alone or with another person (34%). The results of the survey demonstrate a high dependency on commuting by personal car. Most of the respondents possess a car (50 %) and 41 % possess two cars. Another reason for this dependency is related to a weak connectivity of the public transportation services to the suburbs (Rosu and Blageanu, 2015; Ursu et al., 2015) and within the Metropolitan Area.

The rapid growth of the income determines purchasing a car and locating in the peri-urban areas, thus establishing the car dependency no matter the time or distance. However, the accessibility model and the official statistics highlight a decrease in the number of commuters along with the increase in the distance to city centre.

To conclude, one can emphasise that the Metropolitan Area of Iasi city has known a strong increase in population, and, together with this, a high level of mobility by using their private cars. These behaviours are related to and have direct consequences on environmental pollution and the degradation or air quality.

3.3. Pollution resulted from using passenger cars for commuting

According to the previous assessment, a high number of commuters are located in the very proximity of the city (Valea Lupului, Miroslava, Ciurea), but fewer in the Northern and Eastern area. Nevertheless, the highest number of commuters are located in the Eastern part of the Metropolitan Area (Tomesti and Holboca) that are, in fact, neighbourhoods of Iasi city. The issue is reflected in the estimated annual emissions of exhausted gases from passenger cars, which are higher in the nearby communes also because of the high number of displacements per day except for the communes efficiently linked to the city by public transport and those with commuters owning new cars of high quality technology (EURO 5 and 6- for example in Valea Lupului). The second ring of communes around Iasi has lower emissions, except for Schitu Duca ($PM_{2.5}$). There are differentiations that appear when it comes to communes where commuters usually use Diesel cars or cars with older and lower technology (Schitu Duca, Popricani, Holboca). For CO, the highest estimated emissions are originating from the peri-urban communes that are the closest to the city due to the high number of cars and daily trips: Ciurea (28.85 % of the total metropolitan rural areas), followed by Valea Lupului (18.08 %) and Tomesti (15.55 %). They are also the main emitters of NMVOC compounds (Table 3). If one refers to the main pollutant from transport activities – NOx, the highest emitted quantities are caused by commuters from Tomesti (about 18 %), Ciurea and Valea Lupului (about 14 % each), followed by Barnova, Holboca and Popricani, which are farther from the city and, therefore, the travel distances are longer.

An important greenhouse gas, N_2O is emitted mainly by passenger cars from Ciurea (about 24 %) while other communes have a rather similar contribution of about 10% (Tomesti, Barnova, Valea Lupului, Holboca). In the case of fine particulate matter ($PM_{2.5}$), the higher values are from Ciurea and Holboca (about 33% from the total amount) because of high usage of diesel engines, followed by Barnova and Valea Lupului (large number of cars – different types). The lowest values for all analysed pollutants come from Aroneanu (smaller number of cars, predominantly with gasoline engines), Victoria and Ungheni (lower flows of commuters).

One can assess that the urban sprawl itself is mainly induced by the wealthiest people who can afford to commute by using their personal cars. They are, at the same time, the main contributors to the alteration of the air quality by using personal cars and having car-dependency behaviour. Meanwhile the results of our calculations indicate that even though the highest numbers of cars per family are in Valea Lupului and Barnova, there are also the newest types of cars that pollute less (Euro 5 and EURO 6).

Table 3. The estimated annual amount of pollutants by rural communes of Iasi Metropolitan Area

Commune	***CO (kg/year)***	***NMVOC (kg/year)***	***NOx (kg/year)***	***N_2O (kg/year)***	***PM2.5 (kg/year)***
Aroneanu	356.49	27.19	456.78	3.24	1.71
Barnova	2766.49	237.19	1013.98	16.85	42.17
Ciurea	6671.86	610.45	1398.40	36.49	59.39
Holboca	147.61	22.46	930.56	16.04	50.38
Letcani	477.86	59.97	272.47	2.67	23.51
Miroslava	2076.13	160.45	299.70	8.05	4.42
Popricani	1142.23	62.99	922.51	12.90	32.73
Rediu	1503.14	127.68	712.68	10.60	32.21
Schitu Duca	65.78	12.36	491.70	6.18	25.62
Tomesti	3595.46	425.12	1718.58	19.45	12.32
Ungheni	31.96	3.78	77.30	0.54	5.92
Valea Lupului	4182.05	307.81	1363.49	16.28	38.01
Victoria	111.79	9.76	118.97	1.29	5.77

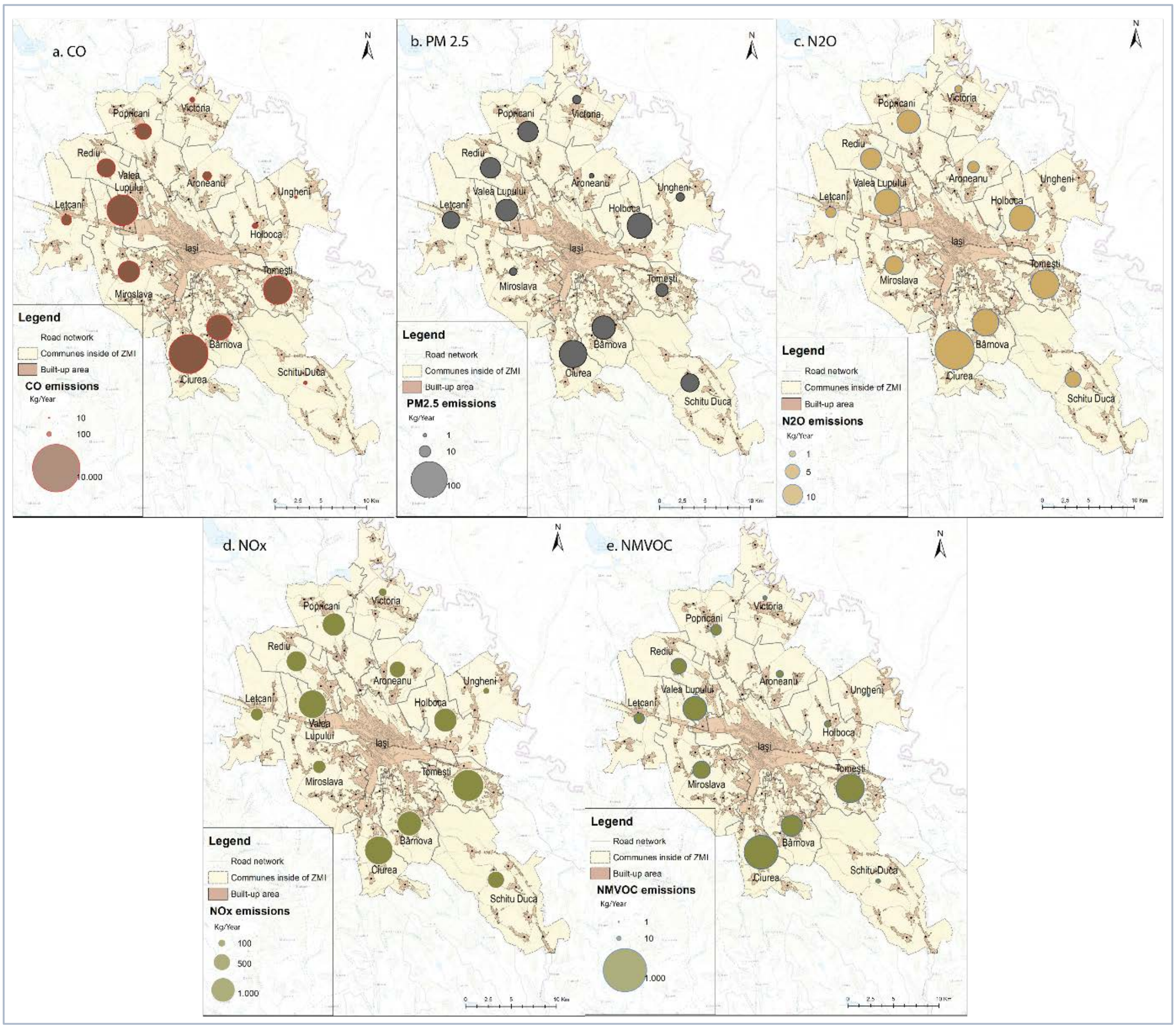

Fig. 3. The estimated annual emmisions of CO(a), PM2.5(b), N_2O (c), NOx (d), NMVOC (e) resulting from the use of personal car for commuting in Metropolitan Area of Iasi

On the other hand, there are rural areas with fewer commuters, but using older cars which pollute more (Ungheni, Victoria, Schitu Duca). Therefore, no direct correlation can be made between the number of cars and the relative atmospheric emissions.

The daily displacements of peri-urban population from Iasi Metropolitan area are an important cause of air pollution especially at peak hours, when it comes to more than 2,000 commuters (Holboca, Tomesti, Ciurea and Miroslava). The pollution is reduced if the commuters associate in using fewer cars for travelling to work, when the public transport has an acceptable quality and frequency or when commuters use new cars with environmentally friendly technology and fuel. The local policies are very important, stimulation of using public transport, smoothing the traffic flow or renewing the car fleet are to be considered by the local stakeholders in order to reduce the effects upon the quality of local environment.

Overall, without planning the areas of present urban sprawl, the Metropolitan Area of Iasi cannot face a farther extension of urban built area, the explosion of commuting surpassing the real possibilities of the infrastructure and environment to bear the consequences.

The current assessment of spatial distribution of estimated air pollution in Iasi peri-urban metropolitan area does not comprise an actual modelling of pollution or an assessment of its actual impact, but the results do indicate the main directions (axis) that contribute to general pollution (Southern, Eastern and Western). The emissions inventory is a preliminary but useful tool in assessing car dependency environmental impact by increased air pollution. It is only a raw assessment that has to be integrated in larger studies. Unfortunately, the lack of monitoring stations in the peri-urban area – except for IS-5, Tomesti station - makes it impossible, at this phase, to perform the validation of data or finding a clear relation between air pollutant emissions and the corresponding air pollutants levels.

Nevertheless, it estimates the passenger cars used for commuting in each administrative unit and the annual amount of emissions that cumulate and contribute to background pollution in the metropolitan area. It gives opportunity for further studies to evaluate the actual concentration of pollutants, the need for monitoring and implementing strategies for pollution abatement.

The resulting assessment should be completed by adding more precise and detailed long term data from traffic monitoring in the car-commuting areas. In practice, the decision-making process of obtaining these data is stopped by budget constraints (Vlachokostas et al., 2011).

4. Conclusions

The fast extension of the built-up area and uncontrolled peri-urbanization lead to specific issues of urban sprawl. The relation between this process, on the one hand, and car dependency and air pollution, on the other hand, was examined in the present study by using official statistical data and the results of our own survey for evaluating the commuter's flows and consequent atmospheric emissions.

It was observed that communes located in the proximity of urban core contribute the most to the air pollution caused by the usage of personal cars for commuting as their inhabitants have the highest number of cars per family, the highest number of daily trips to and from the city, therefore the highest car dependency. Meanwhile, the fact that they have newer cars reduces their overall contribution to general pollution. Contrary to this trend, the rural areas that are more remote from the city centre – more than 25 minutes car travel distance from the city – have a lower number of commuters, a higher use of public transport, while having fewer cars per family and a lower car dependency. However, their contribution to air pollution is increased by longer travel distances and the use of older and more polluting cars.

The results of this integrative approach estimate the quantities of air pollutants generated by the daily use of cars for commuting by each commune from Iasi Metropolitan Aria, creating a spatial image of the air pollution footprint caused by car commuting.

The present study has several implications for policy analysis. It represents a starting point for further studies that could also imply measurements, dispersion modelling and public health assessments that could have in view the actual transformations in urban sprawl in order to ground coherent strategies for an effective air pollution abatement strategy in Iasi City, one of the most polluted urban areas in Romania.

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Author Contributions

All three authors equally contributed to the development of the framework and writing of the manuscript.

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