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EXTERNAL COSTS DUE TO CONGESTION, ACCIDENTS, ENERGY CONSUMPTION AND EMISSIONS BEFORE AND INTO THE ECONOMIC CRISIS: PILOT STUDY ALONG SELECTED ROADWAYS OF THESSALONIKI, GREECE

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Prior to the economic crisis, forecasts indicated a continuous increase of traffic in European cities, highlighting the need of a policy to alleviate the external impacts of transport. The crisis, however, generated pressures on all sectors of activity, with transport being an indicative example. The reduction of income and employment, the increased vehicle maintenance and renewal costs and the transport related taxation seem to affect the transport system and its external impacts. Thus, taking for granted that Europe will eventually achieve "sustainable recovery" from the crisis, the current period presents an opportunity for promoting sustainable mobility policies and interventions in the most affected by the crisis European cities. Towards this goal, it is essential to capitalise on contemporary techniques for the monitoring of changes in transport external costs. The purpose of the paper is the development of a methodology for the estimation of external costs due to congestion, air pollution, climate change and accidents, based on road traffic data. The methodology is applied along road arteries in Thessaloniki for the period "before and after" the emergence of the crisis. As a result, an overall decrease in external costs is observed, creating an unforeseen "surplus" for the society during the crisis.

Key words: **Economic crisis, external costs, urban road transport, methodology, sustainable mobility.**

INTRODUCTION

During the industrialisation era, the major cities of the "Western World" attracted the main socio-economic activities and played a major role in the development of national economies. This role is further enhanced in the globalisation era, as the contemporary metropolitan areas turn into international landmarks (Maki, 2002). The urban transport system is a crucial component towards this direction due to the provision of connectivity among activity poles and accessibility to the national and international transport networks which link the city to its surroundings (Pozoukidou, 2014). Taking into account that the private car is the prevailing urban transport mode over the last six decades, it can be concluded that the ongoing intensification of socio-economic activity is related to the increase of urban transport demand, which leads to the uncontrolled development of road transport (Newman and Kenworthy, 1999). As a result, the efficiency of the transport system is compromised by negative impacts on congestion, road safety and unbalanced competitiveness in the transport market. Moreover, pressures are imposed on the built and natural environment, such as urban sprawl, segregation, social exclusion, noise, visual disturbance and pollutant emissions, with their significance being proportional to the development rate of the city. For example, according to data of 2008 for the European Union (EU), the exposure of the urban population to particulate matter (PM), mainly deriving from diesel-engined road vehicles, diverged from the corresponding target value by 5.5%. On the other hand, a significant decrease was observed in NO_x emissions from transport in the period 2000 – 2008, without however eliminating the air quality problems which affect the public health, especially in densely populated urban areas (Eurostat, 2011). During the same period, a large increase of the motorisation rate regarding passenger cars, i.e. number

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of passenger cars per 1,000 inhabitants, was observed in the 18 out of the 22 EU member states with available data, with the highest rates referring to Luxembourg in Western Europe as well as to the new member states in South East and Eastern Europe (Eurostat, 2012). In the 2001 White Paper on transport and in several policy documents afterwards, such as the 2007 Green Paper on urban mobility, the 2008 Communication on greening transport and the 2011 White Paper on transport, the European Commission sets a comprehensive framework of strategies and measures in order to alleviate the situation and promote the concept of sustainable urban mobility (European Commission, 2001; 2007; 2008; 2011).

The globalisation of the economic crisis, which was initiated in 2008 and continues to affect the European economies, emerged as a major obstacle in the implementation of the aforementioned strategies and measures. Taking into account that the urban transport system affects the development of cities, which are the main driving forces for the development of the national and global economy, it can be concluded that the impact of the crisis on the global and national economy affect the conditions of urban development with major consequences on urban mobility. More specifically, the crisis diminishes the available resources for the operation and upgrade of transport infrastructure and services, while it increases the transport operating costs due to the high fuel prices and taxes and the degraded income level, which leads to the reduction of transport demand.

On the other hand, the reduction of demand due to the decrease in the conduction of activities which act as major trip purposes, such as commerce, work, recreation etc., and the avoidance of private car use due to the relatively high personal cost, lead to lower pressures on the urban and natural environment. In the European Union, for example, the crisis led to a drop of energy consumption, fatal road accidents, greenhouse gas emissions, NO_x emissions and Particulate Matter at faster rates than in the pre-crisis period (Eurostat, 2011). Thus, the reduction in energy consumption, accidents and pollutant emissions does not derive solely from the successful implementation of sustainable mobility policies and the overall shifting of societies towards sustainability, but also from the effort of the households to reduce their daily transport costs. It is worth mentioning that the number of passenger trips by public transport. i.e. bus, tram and metro, economic crisis, in Europe was increased by approximately 7.6% in the decade 2002-2012, accompanied by a relative decrease in the use of private cars. However, an overall drop in the overall number of passenger trips was observed in the year 2009, i.e. immediately after the emergence of the economic crisis, which was followed by a steady increase in the following years (UITP, 2014).

Nowadays, it is considered crucial by transport stakeholders at the international level to continue the pursuit for sustainable mobility by taking advantage of the aforementioned effects of the global economic crisis as an opportunity to prepare for the post-crisis period (OECD/ITF, 2009). Furthermore, the efforts for the analysis of the environmental and socio-economic impacts, i.e. the external impacts, of the transport system are enhanced. In this context, research activities are directed towards the assessment of the external cost of urban transportation, which is the cost on society from the external impacts that are generated but not borne by the user of the transport system. According to this approach, the scope of the research presented in the current paper is the formulation of a methodology for the estimation of the main elements of external cost related to urban transport and the comparative analysis "before and after" the emergence of the global economic crisis. The proposed methodology is based on the combination of the methodologies for external cost assessment suggested by the IMPACT Handbook (Maibach *et al.,* 2008; Korzhenevych *et al.*, 2014), the analysis of the speed-flow function according to empirical and theoretical relations (Transportation Research Board, 2010), the application of COPERT 4 model for the estimation of pollutant and climate change emissions (EMISIA S.A. et al., 2006) and the calculation of congestion cost according to Goodwin's function (Goodwin, 2004).

More specifically, the following section of the paper involves a brief discussion of the impacts of the economic crisis on Greece's road transport system in order to allocate the parameters which lead to the changes in urban mobility conditions from the period before the crisis to the period into the crisis. Next, there is a description of the proposed methodology in a way that allows its adaptation to the characteristics of any city and its implementation by planners and/or local authorities for the analysis of the external costs generated by their city's road transport system. The next section refers to the application of the methodology for selected road segments of Thessaloniki, Greece for the period before and after the emergence of the crisis and the discussion of the results. The final section includes the conclusive remarks as well as a series of suggestions and directions for future research.

IMPACTS OF THE ECONOMIC CRISIS ON GREECE'S ROAD TRANSPORT SYSTEM

In Greece, which is one of the European countries most affected by the economic crisis, a series of negative impacts were imposed on all sectors of the transport system. Regarding the regional transport system, a decrease of approximately 30% in the freight volume transported by the trucks registered in the country was observed in the period 2011-2012 (El.STAT, 2014). Regarding the urban transport system, reductions were made by the government in the investment and subsidies for public transport as one of the measures for the repayment of loans provided by the International Monetary Fund, the European Central Bank and the Eurozone governments, which resulted in the reduction and merging of existing bus lines and in the raising of Public Transport fares (Christoforou and Karlaftis, 2011). Furthermore, a fuel price increase of 50% in combination to a raise of the transport related taxation, as opposed to a 25 – 40% reduction of gross income, is estimated for Thessaloniki due to the crisis (Papaioannou and Konstadinidou, 2011). As a result, it is estimated that the duration of peak-traffic periods in the Greek cities was reduced by approximately 60% (Hellenic Institute of Transportation Engineers, 2014).

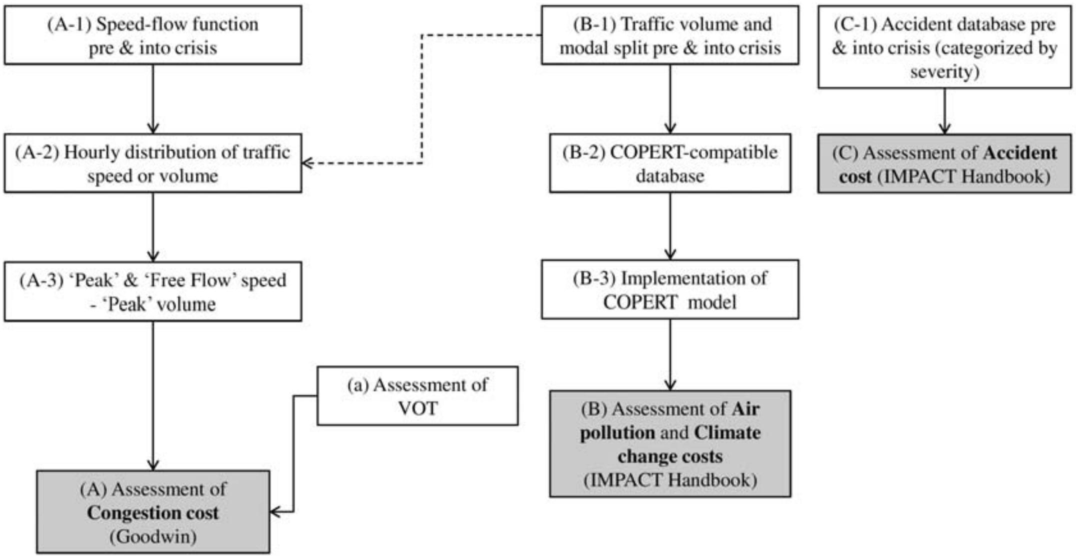

Figure 1. Proposed methodology for the assessment of external cost [own elaboration]

PROPOSED METHODOLOGY FOR THE ASSESSMENT OF EXTERNAL COST

The proposed methodology comprises a series of interrelated steps in order to assess the cost of the following external impacts: A) Congestion (in terms of delay), B) Air pollution and greenhouse gas (GHG) and C) Accidents. The step-by-step methodology is illustrated in Figure 1.

According to the figure, the main features of the methodology are described below:

- Concerning Step "A-1", a speed-flow function is developed for each examined road by conducting a regression analysis based on the available speed and volume data. The speed-flow function enables the estimation of the traffic speed from traffic volume counts or the estimation of the traffic volume from Floating Car Data (FCD), i.e. real-time vehicle speed and location collected by locating the vehicle via mobile phones or GPS over the entire road network (Leduc, 2008). The values of traffic volume and speed are necessary for the assessment of the external costs, as described in the following steps.
- Concerning Step "A-2", the external cost is assessed for the "free flow" and "peak" traffic conditions, so it is possible to compare the external costs resulting from the transition from free flow to congestion. The selection of the "free flow" and "peak" periods is based on empirical data and, more specifically, on the hourly distribution of traffic speed or volume during a typical workday.
- The calculation of "Congestion cost" is based on Goodwin's function (Goodwin, 2004):

$$EC_i = D_i \cdot VOT$$
$$D_i = (t_i - t_0) \cdot V_i$$

Where,

EC_i= Additional congestion cost during the "peak traffic hour" (i) compared to the "free flow hour" (0) (€).
VOT= Weighted average value of time (€).
D_i= Overall delay in the "peak traffic hour" (hours).
V_i= Hourly traffic volume in the "peak traffic hour" (vehicles or PCU/hour).
t_i= Travel time in the "peak traffic hour" (hours).
t_0= Travel time in the "free flow hour" (hours).

It should be highlighted that, taking into account the length of the examined segment, the traffic speed can be used for the estimation of travel time.

- Concerning Steps "B-2" and "B-3", the COPERT model is used for the estimation of emissions, i.e. $PM_{2,5}$, NO_x and NMVOC for "Air pollution cost" and CO_2 for "Climate change cost" (EMISIA S.A. *et al.*, 2006). In specific, the COPERT-compatible database requires the following data: a) Average hourly traffic volume and speed, b) Distribution of vehicle fleet by engine technology and c) Length of roadway segment.
- Concerning Step "C-1", a categorisation according accident severity is proposed, such as: Slight injury, severe injury and fatality.
- The Air pollution, Climate change and Accident costs, i.e. the external cost due to the air pollutants, the main GHG and the road accidents respectively, is based on the corresponding methods and the average unit values provided by the IMPACT Handbook (Maibach et al., 2008; Korzhenevych *et al.*, 2014).

THE CASE STUDY OF THESSALONIKI

Description of the study area

Thessaloniki is the second largest city in Greece, after Athens - the capital, and one of the largest urban centres in the wider Balkan region (Thoidou, 2013). According to the Hellenic Statistical Service (http://www.statistics.gr/portal/page/portal/ESYE), the regional unit of Thessaloniki has a population of approximately $880 \cdot 10^3$ inhabitants. The main commercial and administrative activities take place in the city centre, sharing the same space with dense residential uses and many historical monuments scattered between the mountainous terrain at the north and the gulf of Thermaikos at the south. New residential and commercial areas are nowadays being developed at the urban areas and suburbs at the east, as well as at the northwest, a part of the city which was underdeveloped until recently. At the western edge of the city an industrial zone and agricultural land uses are located in the wider region of the rivers Axios, Aliakmon, Loudias and Gallikos.

Regarding the transport infrastructure and the mobility conditions, it should be highlighted that the only available public transport network in the city is the public bus network, while the private car and the motorcycle are the dominant modes of daily travel. According to the latest General Transport Study (Organization for the Master Plan and Environmental Protection of Thessaloniki, 2000), half of the personal trips in Thessaloniki was conducted by car or motorcycle, i.e. 44% by car and 6% by motorcycle, while the 27% of personal trips was conducted by the public bus, the 12% by walking and the 10% by taxis and coaches. The aforementioned study also highlights that the Thessaloniki's city centre was the origin or destination of approximately 25% of the total daily trips within the metropolitan area. Despite the fact that these data refer to the year 1999 and should be treated as historical, they are indicative of the role of the road transport network and the attractiveness of the city centre, which often result to the congestion of the central road network as well as the main road axes that lead towards or pass through the city centre.

In order to cope with the problem, a series of measures and interventions are in the stage of implementation, planning or debate. Recently, a bicycle network and a public bicycle sharing system were developed, while a metro system and a seaborne transport system are under development. At the meantime, there are several urban regeneration schemes gradually implemented mainly within the city centre, including traffic calming measures and the pedestrianisation of roadway segments. Moreover, other alternatives are being examined such as the expansion of the orbital road network and the development of a tramway system. Nonetheless, the lack of resources due to the economic crisis affects the progress of the aforementioned interventions.

Implementation of the methodology

The methodology proposed in Section 3 of the current paper was adjusted to the available data sources and the specific requirements of the case study. More specifically, according to data availability and taking into account that the economic crisis emerged in 2008, the years 2004 (before crisis) and 2013 (in crisis) are used as milestones of the study. A set of representative segments of the following roadways were examined (Figure 2):

a) Egnatia St. from Aggelaki St. to Agia Sofia St.

b) Tsimiski St. from Agia Sofia St. to Aristotelous Sq.

c) Aggelaki St. from Tsimiski St. to Svolou St.

d) Botsari St. from Olgas St. to Delphon St.

e) Plastira St. from Papanastasiou St. to Anaximandrou St.

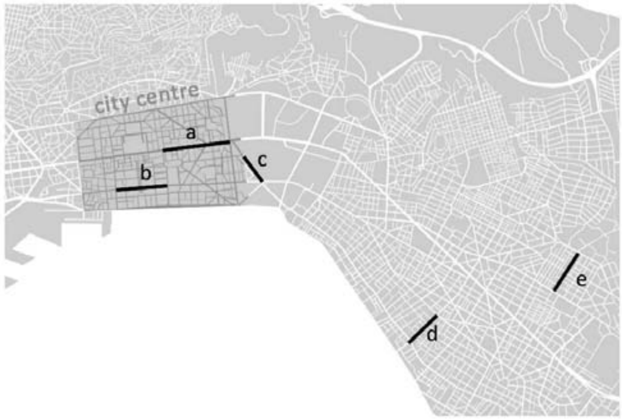

Figure 2. Examined roadway segments in the study area [own elaboration]

Moreover, the following assumptions were made:

- The hourly traffic volumes for 2004 derive from the Traffic Flow Factsheets of the Regional Administration of Central Macedonia while the corresponding volumes as well as the traffic speeds for 2013 derive from the Research Project: "Development of a system of traffic, environmental and energy consumption data for the road network of Thessaloniki's wider urban area", funded by the Programme: "Synergasia" of the Hellenic Ministry of Education, Lifelong Learning and Religious Affairs (Gavanas *et al.*, 2014) (Table 1). The road accident data derive from the Traffic Police, Division of Thessaloniki (Table 2).
- The available speed-flow functions of 2013, developed in the context of the aforementioned Research Project, refer to a set of selected road segments of different functional and geometrical characteristics (Table 3). Taking into account that these characteristics remain unchanged since 2004, it is assumed that the speed-flow functions of 2013 may represent the traffic conditions of 2004.
- According to the hourly distribution of traffic speed, cross-checked by the corresponding traffic volume, the "peak" period corresponds to the hour: 15.00 - 16.00 and the "free flow" period corresponds to the hour: 04.00 - 05.00.

Table 1. Cumulative traffic volume data

Street	Traffic volume (Private Car Units, PCU/hour)	
	2004	**2013**
Egnatia	59860	54345
Tsimiski	54855	51709
Aggelaki	22384	28935
Botsari	15880	11352
Plastira	20744	12321

Source: Traffic Flow Factsheets of the Regional Administration of Central Macedonia; Research Project: "Development of a system of traffic, environmental and energy consumption data for the road network of Thessaloniki's wider urban area"

Table 2. Accident data

Street	Number of persons involved in road accidents per year					
	2004			2013		
	Fatality	*Severe injury*	*Slight injury*	*Fatality*	*Severe injury*	*Slight injury*
Egnatia	1	12	98	0	2	78
Tsimiski	1	4	22	0	0	33
Aggelaki	0	0	0	0	0	9
Botsari	0	1	18	0	0	6
Plastira	1	2	12	0	0	24
Total	**3**	**19**	**150**	**0**	**2**	**150**

Source: Road Accident Factsheets of the Traffic Police, Division of Thessaloniki

Table 3. Speed-flow functions

Street	*Length (m)*	*Classification*	*Direction*	*Location*	*Speed-flow function (2004, 2013)*
Egnatia	650	main artery	2-way	city centre	$y=189{,}747 \cdot x^{-0{,}256}$
Tsimiski	280	main artery	1-way		$y=\exp[3{,}204+(395{,}791/x)]$
Aggelaki	300	main collector	1-way		$y=132{,}955 \cdot x^{-0{,}200}$
Botsari	350	main collector	2-way	outside the city centre	$y=42{,}088 \cdot x^{-0{,}080}$
Plastira	450	secondary collector	2-way		$y=38{,}479 \cdot x^{-0{,}069}$

Source: Pitsiava-Latinopoulou et al., 2013

- The data collected along the Streets: Egnatia, Botsari and Plastira show that the hourly average speed during the day does not exceed the speed limit (40 km/h). This is due to the fact that during the off-peak hours of the day, the traffic flow is controlled by the signing system. Thus, in order to select a value for the free-flow speed, the lowest value of free-flow speed for the road category: "Urban IV", i.e. 40km/h (according to the "2010 Highway Capacity Manual"), was selected (Transportation Research Board, 2010).
- According to Barrett (2010), the VOT was estimated approximately as 1/3 of the country's average hourly wage.
- The external costs of both 2013 and 2004 are given in euros in 2013 euros.

Discussion of results

The implementation of the initial steps of the methodology leads to the results presented in Table 4. More specifically, the average hourly traffic volumes for the hours: 15.00 - 16.00 (peak) and 04.00 - 05.00 (free flow) were inserted in the speed-flow functions of Table 3 for the estimation of the corresponding values of average hourly speed, with the exception of the "free flow" speed for the Streets: Egnatia, Botsari and Plastira, which was estimated as described in the previous section.

Table 4. Average hourly traffic speed along the examined segments

Street	Average hourly speed (km/h)			
	2004		2013	
	peak	free flow	peak	free flow
Egnatia	24.5	40.0	25.4	40.0
Tsimiski	28.4	48.9	27.0	59.0
Aggelaki	32.2	41.8	30.6	45.6
Botsari	24.2	40.0	25.2	40.0
Plastira	23.7	40.0	24.5	40.0

Source: own elaboration

The average hourly speed was used for the calculation of travel time, according to Goodwin's function. Furthermore, the required traffic volumes were estimated using the speed-flow functions. Thus, the "Congestion cost" was calculated for the years 2004 and 2013 respectively and the results, which refer to the "peak" traffic conditions, are presented in Table 5. According to the Table, the cost for 2004 is higher than the cost for 2013, due to the reduction by 1.9 € in the VOT of 2013 compared to 2004 due to the drop in the average hourly wage. It should be noticed here that the average value of "Congestion cost", as well as of "Air pollution cost" and "Climate change cost", weighted by the length of each segment was calculated, in order to formulate a comprehensive indicator that integrates the results from each one of the examined segments.

Table 5. External cost due to congestion along each roadway segment

Street	Congestion cost (€2013)	
	2004	2013
Egnatia	197.0	109.0
Tsimiski	72.7	109.3
Aggelaki	16.4	22.5
Botsari	36.7	14.2
Plastira	55.7	22.4
Weighted average	**94.2**	**60.7**

Source: own elaboration

The data used for the assessment of "Congestion cost", i.e. travel speed and volume, combined with the distribution of the traffic volume per transport mode and per engine technology were also used for the application of the COPERT 4 model in order to estimate the air pollutant emissions. The distribution of the vehicles per engine technology derives from the COPERT 4 database for Greece's vehicle fleet after the necessary adjustments for the specific study area, such as the exclusion of non-diesel engine busses etc. The estimations of pollutant emissions are presented in Table 6. Due to the overall decrease in traffic flows and the improvement in engine technologies, the emissions during the crisis period are lower than the corresponding estimations before the crisis.

In order to calculate the external cost for each pollutant emission, the IMPACT Handbook was used, which provides a list of indicative values of cost per unit for each category of air pollutant. The results are presented in Table 7. In accordance to the pollutant emissions, the "Air pollution" cost decreases from the period "before" to the period "after" the emergence of the economic crisis.

Table 6. Estimations of air pollutant emissions in free-flow and peak-hour traffic conditions along each roadway segment

Year	Street	Condition	$PM_{2,5}$	NO_x	NMVOC
			Air pollutant emissions (g per hour)		
2004	Egnatia	free flow	0.0110	0.1980	671.4640
		peak hour	0.0860	1.5430	4441.6030
	Tsimiski	free flow	0.0050	0.0980	921.9720
		peak hour	0.0280	0.4940	4290.9700
	Aggelaki	free flow	0.0040	0.0610	509.5200
		peak hour	0.0160	0.2480	1785.7970
	Botsari	free flow	0.0030	0.0480	385.2100
		peak hour	0.0130	0.2180	1618.9540
	Plastira	free flow	0.0040	0.0700	433.3010
		peak hour	0.0180	0.3120	1817.2120
2013	Egnatia	free flow	0.0070	0.0950	543.3630
		peak hour	0.0600	1.1330	3294.9570
	Tsimiski	free flow	0.0030	0.0390	650.6620
		peak hour	0.0480	0.5650	5938.3410
	Aggelaki	free flow	0.0020	0.0180	307.9370
		peak hour	0.0140	0.2320	2068.4920
	Botsari	free flow	0.0005	0.0070	103.3380
		peak hour	0.0050	0.0620	883.5550
	Plastira	free flow	0.0008	0.0090	120.1590
		peak hour	0.0060	0.0920	1000.0400

Source: own elaboration

Table 7. External cost due to air pollution in free-flow and peak-hour traffic conditions along each roadway segment

Year	Street	Condition	Cost $PM_{2,5}$	Cost NO_x	Cost NMVOC	Total
			Air pollution cost (€2013 per hour)			
2004	Egnatia	free flow	0.0023	0.0008	0.5956	0.5986
		peak hour	0.0177	0.0062	3.9397	3.9636
	Tsimiski	free flow	0.0010	0.0004	0.8178	0.8192
		peak hour	0.0058	0.0020	3.8061	3.8138
	Aggelaki	free flow	0.0008	0.0002	0.4519	0.4530
		peak hour	0.0033	0.0010	1.5840	1.5883
	Botsari	free flow	0.0006	0.0002	0.3417	0.3425
		peak hour	0.0027	0.0009	1.4360	1.4396
	Plastira	free flow	0.0008	0.0003	0.3843	0.3854
		peak hour	0.0037	0.0012	1.6119	1.6168
	Weigthed average	**free flow**	**0.5161**			
		peak hour	**2.6365**			
2013	Egnatia	free flow	0.0014	0.0004	0.4820	0.4838
		peak hour	0.0123	0.0045	2.9226	2.9395
	Tsimiski	free flow	0.0006	0.0002	0.5771	0.5779
		peak hour	0.0099	0.0023	5.2673	5.2794
	Aggelaki	free flow	0.0004	0.0001	0.2731	0.2736
		peak hour	0.0029	0.0009	1.8348	1.8386
	Botsari	free flow	0.0001	0.0000	0.0917	0.0918
		peak hour	0.0010	0.0002	0.7837	0.7850
	Plastira	free flow	0.0002	0.0000	0.1066	0.1068
		peak hour	0.0012	0.0004	0.8870	0.8886
	Weigthed average	**free flow**	**0.3146**			
		peak hour	**2.2734**			

Source: own elaboration

Similar conclusions can be extracted from the results of GHG emissions and the related "Climate change" cost. More specifically, the results from the assessment of the aforementioned features are presented in Table 8.

According to the accident data presented in Table 2, while the number of slightly injured is the same for the years 2004 and 2013, heavy casualties and fatalities were reduced. Consequently, the total cost of accidents in 2013 is lower by 75% compared to the cost in 2004. In specific, according to the unit values provided by the IMPACT Handbook, the "Accident cost" is equal to 11,001,760€ in 2004 and 2,765,780€ in 2013. The decrease in the "Accident cost" derives only partially from the relative decrease in the observed traffic volumes, since it depends mainly on the presence of a significant number of accidents with severe injuries which occurred along Egnatia St. in 2004.

The above observation is the reason for excluding the component of "Accident cost" in the synthetic presentation

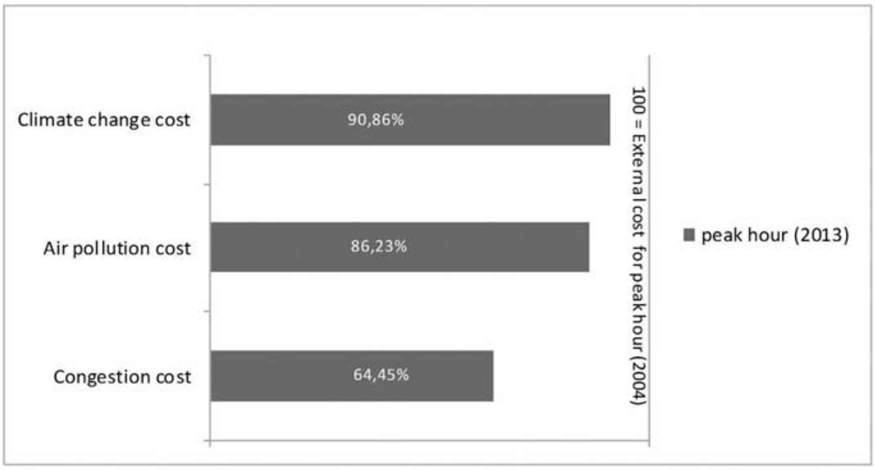

Figure 3. External cost in the year 2013 as percentile of the external cost in the year 2004 [own elaboration]

Table 8. Estimations of CO_2 emissions and related external cost in free-flow and peak-hour traffic conditions along each roadway segment

Year	CO2 emissions (g/hour)			
	Street	Condition	CO_2	Cost CO_2 (€2013/hour)
2004	Egnatia	free flow	50.5080	0.0047
		peak hour	452.1720	0.0423
	Tsimiski	free flow	24.6700	0.0023
		peak hour	144.5980	0.0135
	Aggelaki	free flow	15.6420	0.0015
		peak hour	66.9620	0.0063
	Botsari	free flow	13.5580	0.0013
		peak hour	72.7660	0.0068
	Plastira	free flow	19.5840	0.0018
		peak hour	105.5810	0.0099
	Weighted average	**free flow**		**0.0027**
		peak hour		**0.0197**
2013	Egnatia	free flow	45.7900	0.0043
		peak hour	392.1910	0.0365
	Tsimiski	free flow	19.9240	0.0019
		peak hour	231.9920	0.0216
	Aggelaki	free flow	10.3740	0.0010
		peak hour	90.2760	0.0084
	Botsari	free flow	4.2050	0.0004
		peak hour	43.5960	0.0041
	Plastira	free flow	6.2500	0.0006
		peak hour	65.1700	0.0061
	Weighted average	**free flow**		**0.0020**
		peak hour		**0.0179**

Source: own elaboration

of the case study's main results (Figure 3). More specifically, the weighted average values of the estimated external costs from each component, i.e. congestion, air pollution and climate change, during a peak hour of a typical workday of the year 2013 are represented in the Figure as percentiles of the corresponding weighted average values of the external costs from each component during the same peak hour of the year 2004. The overall conclusion is that the decrease in the traffic volume leads to a higher diminishment of the external cost due to less congestion than the external cost due to fewer emissions. This fact may be explained by the effect of the crisis on the level of hourly wages and, consequently, on the VOT, as well as to the fact that during the crisis the vehicles are not renewed or maintained at the same rate as before the crisis, with negative impacts on the transmitted emissions.

CONCLUSIVE REMARKS AND FUTURE PROSPECTS

The case study is indicative of the fact that the proposed methodology can be adjusted to the local features of all cities and, especially, in the case of a city with limited availability in time-series of traffic data, such as Thessaloniki, due to the use of speed-flow functions for the estimation of the required traffic speed and volume. Furthermore, the methodology provides useful information about the variation of external costs due to the impact of the economic crisis on the mobility conditions along the road network, based on the combined implementation of valid methodologies and models.

Regarding the case study, the main conclusion is that the economic crisis leads to an unexpected economic surplus for the society due to the decrease of external costs from the operation of the road transport system. This surplus could be invested towards the enhancement of sustainable mobility for the city of Thessaloniki. Towards this purpose, the stakeholders should produce a comprehensive framework of short-term policies, such as the formulation of an inclusive fare policy for public transport and the provision of incentives for car-sharing in commuting trips, as well as of long-term interventions regarding transport and urban infrastructure, such as the use of the "spare" (due to the decrease of travel demand) roadway's width along selected roads for the strategic development or expansion of public and active transport infrastructure. In this way, the attractiveness of public and active transport is expected to be increased and, thus, further reductions in the external costs are anticipated, which would lead to a higher economic surplus for the society.

However, despite the use of the weighted average as a common indicator, the methodology lacks the ability to integrate the costs from the different components of external impact, i.e. congestion, air pollution, climate change and road safety, into a total or average expression of external cost. This conclusion is the main motivation for future research in the specific topic. Moreover, further research should be conducted towards the implementation of the appropriate techniques and technologies, such as Floating Car Data (FCD), in order to collect primary data and generate estimations of external cost along the whole of the road network as well as to formulate a mechanism which, based on the proposed methodology, will be able to monitor on a regular basis the economic impact of traffic changes along the road network.

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