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Procedia Engineering 181 (2017) 123 – 130

Procedia Engineering

www.elsevier.com/locate/procedia

10th International Conference Interdisciplinarity in Engineering, INTER-ENG 2016

Environmental Impact of Road Transport Traffic. A Case Study for County of Iaşi Road Network

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Abstract

The continuous increase of vehicle fleet along with the development of road transport networks has associated a wide range of externalities. Main types of externalities refer to environmental impact, expressed as Greenhouse Gas Emissions, raw materials depletion, energy and fuel consumption or disruption of ecosystem equilibrium, social impact, expressed as quality of people life, human health and economic impact, expressed as economic growth. The current development of road transport promotes a growing interest for sustainable and eco-friendly transportation worldwide. In the context of a wide range of externalities, the present paper aims to emphasize the ecological impact associated with road transportation traffic, customized for specific road networks from North-East Region of Romania and expressed in atmospheric polluting emissions. In correlation with traffic pollution, the current research highlights the exponential increase of the greenhouse gas effect and fuel consumption, providing specific strategies, necessary for the improvement of road network sustainability, based on the results of the undertaken study. The analysis of the environmental impact implies a quantitative assessment of energy consumption and CO2e emissions produced by road traffic. In this respect has been carried out the evaluation of atmospheric pollution produced by the traffic recorded in 2010, using the annual daily average traffic for the year in question. Based on the coefficients of traffic evolution it has been forecasted the pollution level for 2015, 2020 and 2030. The calculations have been performed based on the current configuration of the vehicle fleet from NE Region of Romania, investigated for two types of roads, namely a road with an optimum pavement condition in comparison with a road pavement with distresses. For the first case study, was considered a road pavement suitable rehabilitated, by intervention works of maintenance and rehabilitation, applied to an optimum moment. This case study presents the ideal situation, from traffic sustainability point of view, since the vehicles speed isn't influenced by the pavement condition, the road level of service is free flow. The evaluation performed for this particular case study showed that, for the current vehicle fleet and average vehicles speed, the environmental impact expressed in pollutant emissions registers the lowest values. For the second case study, the evaluation focused on the ecological impact associated with the road traffic, based on the current road network pavement condition. Considering the traffic congestion and pollution increase due to road distresses,

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Peer-review under responsibility of the organizing committee of INTER-ENG 2016
doi:10.1016/j.proeng.2017.02.379

the studies in the present paper were focused on the pollution level, specific to County of Iaşi road network. For a proper analysis of pollutant emissions, associated with road transport traffic, has been used European Environment Agency (EEA) computer software COPERT 4. The software was developed to perform evaluations of air pollutant and greenhouse gas emissions specific to road transport, the deliverables being consistent with the latest regulations in the field. The research objective was to deliver intervention strategies and scenarios, related with the high increase in vehicles fleet, usage of alternative fuels and CO2e emissions level, towards sustainable road transportation.

Peer-review under responsibility of the organizing committee of INTER-ENG 2016

Keywords: environmental impact; road transport; traffic; externalities.

1. Introduction

Transportation, in all its forms, is a key component of the current development process. The overall purpose, at national and international level, is to make it “faster, safer, cheaper (FSC)”. Unfortunately, this desiderate of transport development is associated with a wide diversity of, mostly, negative impacts.

If transportation is considered as a system, this implies associating five subsystems, independent and though interdependent from each other, consisting of air transport, railway transport, road transport, water transport and underground transport. The current desiderate is to provide a sustainable development for these transport subsystems.

Based on the diversity of transportation subsystems, the exponential increase of vehicle fleet and proportional development of the road network, the present paper focuses on road transport. The development process in this area comes associated with a wide range of externalities. These refer to environmental impact, expressed as Greenhouse Gas Emissions, raw materials depletion, energy and fuel consumption (FC) or disruption of ecosystem equilibrium, social impact, expressed as quality of people life, human health and economic impact, expressed as economic growth. In order to handle the externalities associated with the continuous development of road transport, the national and international agencies promote sustainable and eco-friendly transportation policies worldwide.

Statistics on the consequences of transport development highlight the connection with climate change, high levels of pollution and depletion of lithographic resources. In this context, it is necessary to make changes, take adequate measures and focus on low carbon mobility and reduced energy consumption as fundamental features for a sustainable future and competitive urban areas.

Given the high levels of pollution nowadays and the fact that, according to European Commission, transport activities are responsible for 32% of Europe’s energy consumption and 28% of total CO_2 emissions [1], the development of sustainable road construction technologies and processes is more and more important. Furthermore, besides the initial construction, maintenance and rehabilitation of a road pavement, the vehicle traffic represents a major factor in the exacerbation of greenhouse effect. According to PIARC Report [2] the energy consumption associated with road transport results mostly from vehicle traffic and less from pavement construction. Hence, making an analysis on the environmental impact associated with road transport using Life Cycle Assessment (LCA) Methodology implies considering for the “in use” phase but also the environmental indicators resulted from vehicle traffic.

2. Road Traffic Externalities

The pollution effects resulted from road traffic are extensive, due to a significant number of factors like atmospheric conditions, topographical and climatic conditions, traffic congestion, type of used fuel, age and poor maintenance of vehicles.

The consequences are reflected in exhaust emissions discharged in atmosphere, fuel leakage to the road surface, dust and noise pollution, resulted from vehicles and accidental spillage of toxic chemicals in the event of road accidents. These externalities, expressed in CO_2e emissions, ecosystem fragmentation and release into the atmosphere of particulate matter (PM10) [3], resulted from road traffic, are currently considered the most pressing problems facing humanity. These are accompanied by soil sealing, due to permanent cover with an artificial impermeable material of the ground surface, noise pollution, NO_x and ozone levels [3].

Exhaust emissions discharged into the atmosphere, in addition to affecting air quality, population health and ecosystems equilibrium, contribute also to intensification of global warming.

The process of fossil fuels combustion in engines provides the necessary mechanical energy to start and move the vehicles but in the same time, it creates a mixture of harmful gases and particles which are released into the atmosphere. The air pollution caused by traffic has negative effects also on the built environment. Metal corrosion and deterioration of coatings, lime, mortar and construction elements through the action of acidic deposits of NOx, SO_2 and particulate matter represent some of the current challenges. Complementary, soil contamination with chemical compounds from transport activities contributes to soil erosion, as the pollutants lead to the destruction of existing vegetation and soil organisms.

As a response to these issues, specific prevention, mitigation and compensation measures must be developed and implemented shortly. The new emerging technologies, in order to reduce the carbon dioxide emissions, refer mostly to carbon efficient cars, which use alternative sources of fuels, plug-in hybrid cars, electric cars, fuel cell cars and flex-fuel vehicles.

The new low carbon mobility configuration of the vehicles fleet implies fuel efficiency by usage of improved vehicle structures and engines, but mostly alternative fuels. The features related to improvement of fuel efficiency refer to reduction of CO_2, NO_x and particulate matter emissions. Nowadays, these objectives might be successfully accomplished due to progress in vehicle design. This way, enhancing fuel efficiency can be achieved by improvements brought to aerodynamic characteristics, reduction of vehicles total weight and usage of high performance engines. Improving the vehicles characteristics aims a significant decrease in atmospheric pollutants, mainly of CO_2 emissions. The development of new polymers, composite materials and so-called "memory metals" which are more resilient and lighter as compared with conventional materials should also lead to significant reductions in quantities of burned fuel [4; 5]. Mitigation of negative impacts derived from motor vehicles also can be achieved boosting chemical energy conversion efficiency of the fuel into mechanical energy required to start up and move the vehicle by increasing the thermodynamic efficiency, reducing friction forces inside the engine, improving the transmission of the vehicle and installing smaller tanks and photovoltaic panels to power cooling system [6; 7]. The use of alternative fuels like liquid hydrogen (H_2), biofuels, synthetic fuels and liquefied natural gas (LNG), as alternative energy sources (fuel cells) leads to a significant reduced quantity of pollutant emissions released into the atmosphere [8].

In the context of significant changes in transportation policies and technology, the way for improving the sustainability of a city or region consists in the construction and integration, in the existing road network, of cycling infrastructure, as the first step in promoting modal shift from car to bicycle with significant benefits on environment and social sectors. Also, the decarbonisation of urban public transport can be achieved through a smart use of resources, emphasize on public transport (electric buses), rail transport and use of eco-efficient vehicles. The context of providing better operating condition for buses, for example an increase of 5 km/h of commercial speed on a bus, leads to a reduction with 20% of the consumption and thus of GHS emissions [9].

Prevention and mitigation of traffic pollution can be achieved by taking measures as traffic diversion in urban areas or placing junctions and crossings at a significant distance from residential areas. Other sustainable measures for CO_2 emissions reduction refer to: decrease in traffic congestion by increasing road capacities, planting trees on the side of the road, creating appropriate road geometry, pedestrian areas in dense and compact areas with a wide diversity of services and encouragement of the use of public transport, walking and cycling [10]. In order to customize the analysis accordingly to sustainability principles, the specific measures mentioned above have been considered for the development of several case studies on traffic scenarios regarding a new fleet composition.

3. Case Study - Assessment of atmospheric pollution caused by road traffic on DN 28–Săbăoani–Iaşi–Albiţa

In order to support the theoretical aspects presented above, the present paper presents in a case study performed on the national road DN 28 Săbăoani-Iaşi–Albiţa, a comparative analysis between the current vehicle fleet and an improved rolling stock. The envisaged vehicle fleet includes modal shift to public transport, walking, cycling and combined mobility, meaning car sharing, car-pooling, taxis etc., which represent the best carbon decreasing strategy.

Table 1. Pollutant emissions produced by the traffic of national road DN 28 for 2015 for current road pavement condition.

Road	Sector	Kilometric position	Sector limits		Sector length [km]	CO [t]	CO2 [t]	FC [t]	NOx [t]	PM [t]
DN 28	Sec. 1	7.100	0.000	17.820	17.820	0.35	51.65	16.49	0.33	0.01
	Sec. 2	19.030	17.820	26.350	8.530	0.19	26.43	8.45	0.17	0.01
	Sec. 3	29.500	26.350	48.800	22.450	0.94	116.78	37.38	0.69	0.03
	Sec. 4	57.720	48.800	65.150	16.350	0.81	101.44	32.48	0.59	0.02
	Sec. 5	65.360	65.150	75.797	10.647	0.81	88.27	28.31	0.46	0.02
	Sec. 6	81.250	80.600	101.835	21.235	0.66	82.53	26.42	0.50	0.02
	Sec. 7	115.350	101.835	117.900	16.065	0.11	12.11	3.88	0.06	0.00
	Sec. 8	118.300	117.900	141.410	23.510	0.10	11.33	3.63	0.06	0.06

As presented in Table 1, DN 28 road has been divided for the analysis into 8 sectors of different lengths, according with the traffic characteristics, road pavement type and hydro climatic conditions. For these sectors different types of emissions have been evaluated. As can be seen in Table 1, sector 3 registers the highest values of pollutant emissions. The traffic emissions can be separated in:

- **Hot emissions:** emissions produced by a "hot" engine. Hot emissions depend mainly on how the vehicle is driven (traffic situation), the road gradient, vehicle category and the type of used fuel.
- **Cold start excess emissions:** this type of emissions differ from those corresponding to hot emissions, since these additional cold start excess emissions depend on the engine temperature, ambient temperature, parking time before engine start, traveled distance and driving behavior. Cold start emissions also depend on the engine type and fuel.
- **Lube oil emissions:** this type of emission connected with lube oil consumption depends on the vehicle technology and are due to lubricant oil which is used in engines in order to reduce friction and cooling down of specific components. The result is an unintentionally contribution to the CO_2 emissions without taking part to the energy consumption of road transport [11].
- **Air conditioning emissions.**
- **Selective Catalytic Reduction (SCR) emissions:** result from the installation in vehicle engines of systems that reduce the amount of NO_x emitted [11].

In order to facilitate the evaluation of different pollutant types, were developed several computer software that integrate the methodology necessary for the analysis. For the paper particular case has been used COPERT 4 software coordinated by European Environment Agency (EEA), in the framework of European Topic Centre for Air Pollution and Climate Change Mitigation activities [12]. This software was developed to perform evaluations on pollutant emissions associated with road transportation, but also for the analysis of fuel consumption [11]. The specific data required for running the software relates to monthly average minimum and maximum temperatures and relative humidity per month, characteristics and annual fuel consumption, fleet configuration with their actual numbers recorded on the investigated road sector, fleet mileage and movement speed. The input data is performed in stages, the first step consisting in introduction of regional particularities in “Country” Section of the Menu, which also contains the submenu “Country Info” for climate and hydrological characteristics and “Fuel Info”, for fuel quality description. Complementary, it is necessary to introduce information on maximum/minimum temperatures recorded for the area of interest, monthly relative humidity (RH%) used to calculate the emissions generated by air conditioning (A/C). A high value of RH% indicates an intensive air conditioning so that the pollutant emissions emitted into the atmosphere will be enhanced. The next step refers to configuration of vehicles fleet according to the dates recorded in the census traffic conducted in 2010 (Input Fleet Data). The vehicle fleet is divided first by vehicle category in passenger cars, heavy vehicles, light commercial vehicles, buses and motorcycles. Secondly, each group of vehicles is segmented by size class and technology, emission concept and type of fuel used.

The case study was performed based on two situations. For the first case was taken into consideration the current pavement condition of the national road DN 28, determined previously based on the current standards. In this situation, the road presents multiple distresses which interfere with vehicle circulation speed, especially with the traffic service level (free flow, heavy, saturated and stop and go). Given these assumption, for the assessment of pollutant emission associated with road transport it was applied a reduction of 10 km/h to the average vehicle speed for each vehicle segment. After entering the information concerning the vehicles circulation speed, corresponding mileage, hot/cold start, evaporation, lube-oil, etc. can be calculated the emission factors and emissions pollutants.

The emission factor measures the average value of a specific pollutant or material discharged into the atmosphere through a certain process, equipment or fuel source. It is expressed as number of kg/t of material or fuel and is used to calculate the total emissions from a source. Table 1 summarizes the results of the analysis performed with COPERT 4 program for different sectors of the national road DN 28, investigating on different pollutant emissions. As seen in Table 1, the highest amount of emissions was recorded in Sector 3, which is characterized by a total length of 22.450 km and an annual average daily traffic AADT = 20542 standard vehicles. The analysis results, obtained by the use of COPERT 4 software for DN 28 road have been structured in the following figures in order to underline the main differences between pollution sources by vehicle categories. Fig. 1 presents the distribution of the total quantity of carbon monoxide (CO) depending on emissions source and vehicle category.

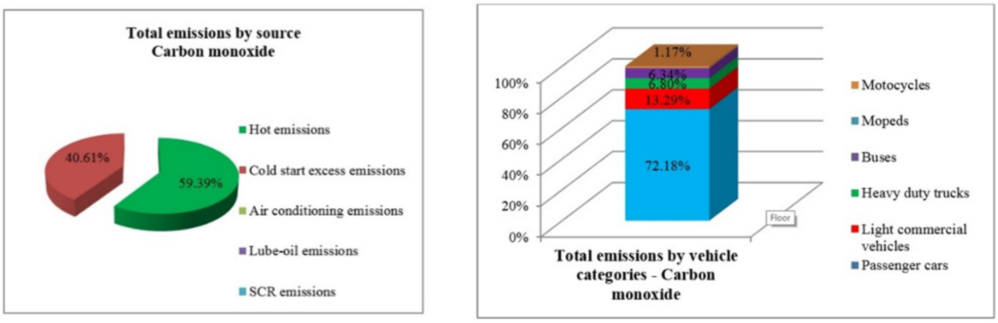

Fig. 1. Distribution of total CO quantity due to traffic a) by emissions source and b) by vehicle categories.

The conclusion drawn from the results presented in Table 1 and the distribution diagrams for different types of pollutants is that the maximum pollution with carbon monoxide (CO), that contributes to the increase of Ozone concentration and amplification of global warming, is being caused mainly by passenger cars (72.18% from total emissions). This emission is the result of low combustion efficiency, which is why for the reduction of its concentration, is recommended the use of modern vehicles.

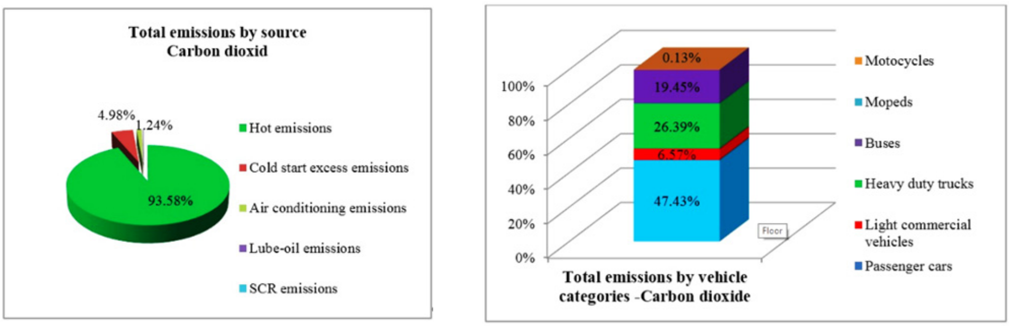

Fig. 2. Distribution of total CO_2 quantity due to traffic a) by emissions source and b) by vehicle categories.

Similarly, the emissions distribution according to their type and vehicles category for CO_2 pollutants is presented in Fig. 2. The vehicles engines produce the highest quantity of carbon dioxide CO_2 (47.43%).

Considering the source, 93.58% of pollutant emissions are produced when the engine is hot and they depend, largely, by the way in which a vehicle is being driven and by the type of used fuel. In order to reduce the carbon dioxide, it is recommended the usage of alternative fuel types and avoidance of the use of old vehicles.

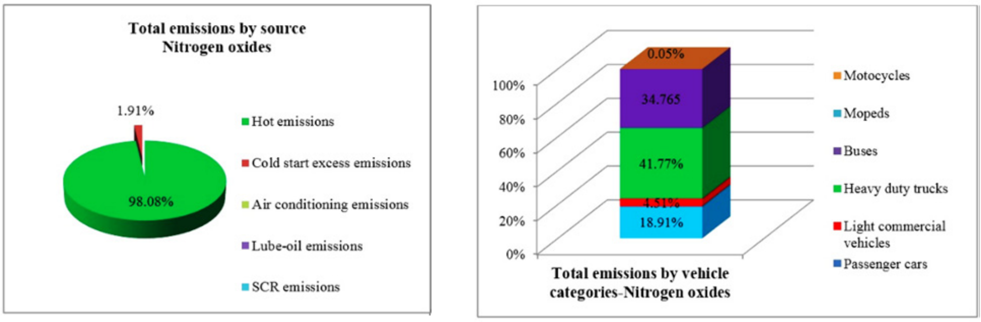

Fig. 3. Distribution of total NOx quantity due to traffic a) by emissions source and b) by vehicle categories.

Similar to the first images, Fig. 3 presents the distribution of total NO_x emissions. As can be observed from the figures, the hot engines produce also the highest quantity of nitrogen oxides (98.09%), but this time the heavy vehicles are the main producers in a percentage of 41.77%, as compared with the passenger cars that produce in the atmosphere only 18.91% from the total concentration of NO_x.

For the second part of the analysis, for the same road, DN 28, has been evaluated the atmospheric pollution produced by traffic in the hypothesis of a corresponding technical state (Pavement Condition Index, PCI>55). The PCI, according to ASTM 6433 Standard Practice for Roads and Parking Lots Surveys [10], represents a used term for indicating the pavement condition of the surface. It is calculated considering the distresses measured in the pavement, providing a tool for the assessment of structural integrity and surface operational condition of a road. A PCI value higher than 55 implies that pavement condition is at least fair and the safety and comfort condition of the traffic are being fulfilled.

Following the application of different intervention strategies, the road will reach a corresponding pavement condition, so that the atmospheric pollution will be influenced, in this particular case, only by traffic. For this hypothesis have been evaluated the quantities of pollutant emissions on DN 28 National Road in Iași for the years 2010 and 2015. Based on the traffic evolution coefficients, has been estimated their development for the years 2020 and 2030. Similar with the evaluation of real pavement condition hypothesis, the analysis for evaluation of corresponding technical state hypothesis was performed using COPERT 4 software. The main difference in the analysis is that the traffic is at normal average speeds. The results envisaged for 2010, 2015, 2020 and 2030 are presented in Table 2.

Table 2 presents the summary results of traffic modelling performed in order to quantify the pollutant emissions due to vehicle circulation on DN 28. One may notice that in the condition of vehicle fleet configuration remaining mostly the same, while the traffic evolves according to the evolution coefficients developed based on the traffic census, the level of pollution will significantly increase until 2030. Thus, is compulsory a drastic upgrade of rolling stock and an intensive promotion of alternative modes of non-motorized transportation and the use of public transport in order to comply with the EU reduction target for pollutant emission, as part of the Kyoto Protocol. However, from a comparative point of view, another important aspect for reducing the carbon footprint correlated with road traffic is represented by the pavement condition, driving behavior and speed circulation.

As it can be seen in Table 2, in the hypothesis of a good pavement condition, the total emissions are reduced by 10.21% as compared with the previous case. If we were to take into account the significant reduction and radical change of the vehicle fleet configuration, the transition steps towards low carbon mobility will be achieved, resulting a more sustainable future and a clean society. This hypothesis is meant to underline the importance of applying the proper intervention strategies for periodical road maintenance and rehabilitation in order to move towards a zero carbon society. For reaching this extremely important milestone, a large set of action should be undertaken for each component of the transport system, namely the rolling stock, road infrastructure and management system.

Table 2. Quantitative evaluation of pollutant emissions on national road network from Iasi County by COPERT computer software

National Road	Sector	Sector Length [km]	Year reference	CO [t]	CO2 [t]	FC[t]	NOx [t]	PM [t]
DN 28	Sec. 1	17.820	2010	0.27	38.21	12.20	0.25	0.01
			2015	0.33	46.40	14.82	0.29	0.01
			2020	0.40	54.69	17.47	0.34	0.01
			2030	0.58	76.58	24.48	0.46	0.02
	Sec. 2	8.530	2010	0.14	19.50	6.23	0.13	0.00
			2015	0.18	23.69	7.58	0.15	0.01
			2020	0.21	27.97	8.94	0.18	0.01
			2030	0.31	39.25	12.56	0.24	0.01
	Sec. 3	22.450	2010	0.69	87	27.84	0.52	0.02
			2015	0.87	104.85	33.57	0.62	0.02
			2020	1.05	126.94	40.65	0.73	0.03
			2030	1.53	179.35	57.45	1.01	0.04
	Sec. 4	16.350	2010	0.59	72.68	23.27	0.42	0.02
			2015	0.74	90.37	28.94	0.53	0.02
			2020	0.90	107.56	34.46	0.62	0.02
			2030	1.32	152.73	48.95	0.85	0.03
	Sec. 5	10.647	2010	0.6	63.02	20.21	0.33	0.01
			2015	0.76	80.45	25.80	0.42	0.02
			2020	0.92	94.95	30.47	0.49	0.02
			2030	1.36	138.00	44.29	0.69	0.03
	Sec. 6	21.235	2010	0.47	50.99	16.35	0.28	0.01
			2015	0.6	73.17	23.43	0.44	0.02
			2020	0.70	75.16	24.11	0.40	0.02
			2030	1.02	107.78	34.59	0.55	0.02
	Sec. 7	16.065	2010	0.09	9.10	2.92	0.05	0.00
			2015	0.11	10.84	3.48	0.05	0.00
			2020	0.13	12.70	4.07	0.06	0.00
			2030	0.18	18.51	5.94	0.09	0.00
	Sec. 8	23.510	2010	0.08	8.91	2.85	0.05	0.00
			2015	0.10	10.36	3.32	0.05	0.00
			2020	0.12	12.28	3.94	0.06	0.00
			2030	0.17	17.77	5.70	0.09	0.00

4. Conclusions

The pavement condition influences the quantities of pollutant emissions. The present paper underlines this aspect along two comparative case studies performed on several road sectors (DN 28 Săbăoani – Tg. Frumos – Iași –

Răducăneni – Albița, Iași County road network) with different pavement condition. The analysis performed with COPERT 4 software on a deteriorated road pavement concluded that:

- ✓ road pavements with distresses force the vehicles to reduce their speed and produce higher quantities of pollutants,
- ✓ maximum pollution with carbon monoxide (CO) is caused mainly by passenger cars (72.18%),
- ✓ vehicles engines produce the highest quantity of carbon dioxide CO_2 (47.43%), 93.58% of pollutant emissions being produced when the engine is hot and they depend, largely, by the way in which a vehicle is being driven and by the type of used fuel. In order to reduce the CO_2, it is recommended the usage of alternative fuel types and avoidance of the use of old vehicles,
- ✓ hot engines produce also the highest quantity of nitrogen oxides (98.09%), the heavy vehicles being the main producers with 41.77%, as compared with the passenger cars that produce in the atmosphere only 18.91% from the total concentration of NO_x.

For the particular case of road pavement with Pavement Condition Index, PCI>55, the pollution associated to traffic is reduced by 10.21%, implying that pavement condition is fair and the safety and comfort condition of the traffic are being fulfilled.

The study conclusion is drawn towards the importance of application of different intervention strategies in order for a road to reach a good pavement condition and consequently to create the frame for low pollution due to traffic. Based on the traffic evolution coefficients, has been estimated their development for the years 2020 and 2030 that mentions that in the context of vehicle fleet remaining mostly the same and traffic evolution, the level of pollution will significantly increase until 2030. In this context is compulsory a drastic upgrade of rolling stock and an intensive promotion of alternative modes of non-motorized transportation and use of public transport in order to comply with the EU reduction target for pollutant emission, as part of the Kyoto Protocol. For reaching this extremely important milestone, a large set of actions should be undertaken for each component of the transport system, namely the rolling stock, road infrastructure and management system.

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