ESTIMATING THE ECOLOGICAL FOOTPRINT OF VEHICLES IN THE CITY OF ATHENS

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EXTENDED ABSTRACT

Modern cities exert a considerable pressure on the natural environment of the planet, by consuming land, energy, water, food and raw materials, as well as by producing greenhouse gases, solid waste, toxic air and water pollutants etc. Many different methods aiming at a quantification of impact from human activities on the natural environment have been developed. One of them is the ecological footprint, which is the biologically productive land or sea area that can reproduce the resources consumed or assimilate the pollutants produced by a human community. The object is to estimate whether a region, a city or a state consume or pollute at a rate higher than the one at which Biosphere is able to produce goods or to assimilate pollutants. The ecological footprint is measured in hectares per capita or per region or per economic activity. The total land area which is necessary to support the way of life of a human population is usually estimated on the basis of some particular categories of consumption, e.g. food, transportation, housing, consumer goods and services.

A crucial impact of human activities on the environment is the risk of climate change which is related to the concentrations of greenhouse gases in the atmosphere; the most important gas being carbon dioxide produced mainly by fossil fuel burning. One important component of the contribution of a big city to the increase of the atmospheric carbon dioxide is the emissions from urban transportation activities. To estimate the carbon dioxide component of the ecological footprint of car circulation in a city, one should take into account the emissions from gasoline consumption, construction and maintenance of cars, the area covered by roads and different vehicle facilities etc. The main part would be the estimation of the footprint of fuel burning, which depends on an estimation of the mean number of kilometers per vehicle, the mean fuel consumption, the carbon dioxide emissions from every fuel unit burned etc. The study area of the present work has been the “greater ring” of Athens, which covers an area of 15400 hectares, corresponding to 25 municipalities. Traffic data have been considered for a period of 6 years (2000 to 2005). Data on fuel consumption have been selected from an international vehicle emission factor database. Assumptions have been adopted regarding relative percentages of different vehicles (private cars, buses, tracks and motorcycles), their fuel consumption and mean vehicle velocities. The calculation of the ecological footprint is based on a universal factor corresponding to the number of hectares of forest area that could assimilate the carbon dioxide produced.

Keywords: ecological footprint, carbon dioxide, road transport, traffic data, fuel consumption, Athens.

1. INTRODUCTION

Modern cities exert a considerable pressure on the natural environment; they consume land, energy, water, food and raw materials much faster than nature can replenish them; they also produce greenhouse gases, solid waste, toxic air and water pollutants etc. The ecological footprint has been proposed as a standard methodology for evaluating quantitatively these pressures. "Ecological footprint analyses is an accounting tool that enables us to estimate the resource consumption and waste assimilation requirements of a defined human population or economy in terms of a corresponding productive land area" (Wackernagel and Rees 1996). More specifically, the ecological footprint is the total biologically productive land and water area required to produce all of the resources, which a population consumes and to assimilate all the wastes it generates, using prevailing technology and resource management (Wackernagel et al 2005). As a result, the footprint measure provides a means of assessing the amount of a resource that is being used relative to the amount that is available (Chambers et al 2000). In short, the ecological footprint can be compared with nature's ability to renew the resources (Chi and Stone 2005, Chatzimpiros 2007).

The ecological footprint is measured in hectares per person. Though, in order to achieve a meaningful comparison of the ecological footprint of different countries, which have different qualities of bioproductive lands, the footprint is expressed in global hectares per person (gha/person). A global hectare is a hectare whose biological productivity equals the global average. The ecological footprint of Earth in 2002 has been estimated at 2.2 gha/person, while the productive area of the Biosphere was 1.8 gha/person (Fig.1). In other words the humanity's ecological footprint exceeded global biocapacity by 21% (WWF 2004). To determine the total land area, which is necessary to support a particular pattern of way of living, the land-use implications of five major consumption categories must be estimated: food, housing, transportation, consumer goods and services (Wackernagel & Rees 1996).

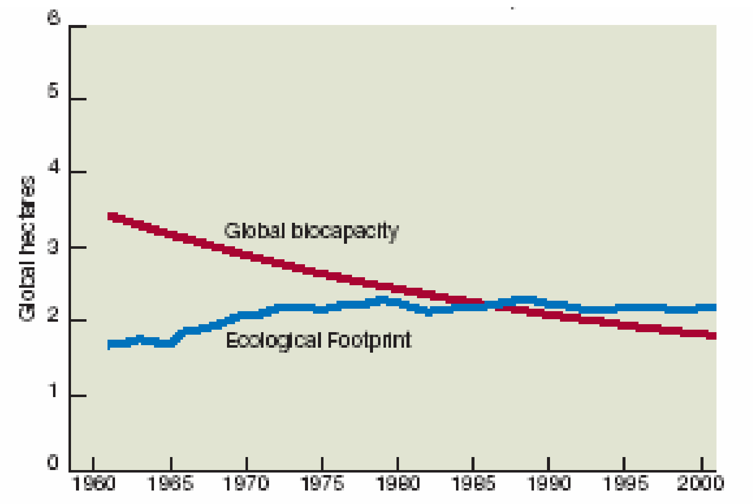

Fig. 1: Humanity's Ecological Footprint and Biocapacity per person (1960 – 2001)

2. THE ECOLOGICAL FOOTPRINT OF ROAD TRANSPORT

A crucial impact of human activities on the environment is the risk of climate change; a big city is a major contributor to the increase of atmospheric carbon dioxide (CO_2), which is the predominant greenhouse gas. An important component of this contribution is the emissions from urban transportation activities and specifically the road transport. An estimation of the ecological footprint related to the impact of road transport combines activities such as (Barrett and Scott 2003):

- The CO_2 emissions from the burning of fossil fuels in vehicle engines.
- The CO_2 emissions from the manufacture of vehicles.
- The CO_2 emissions from the maintenance of vehicles.
- The CO_2 emissions from the construction and maintenance of road infrastructure.
- The road space and the other land that is occupied by different vehicle facilities.

Occupation of space is a direct land type impact, while CO_2 emissions can be indirectly converted into corresponding land required for the absorption of the CO_2. At present, it is estimated that one hectare of forest can sequester annually the CO_2 generated by the consumption of 100 GJ of fossil fuel. This translates to a sequestration rate of 1.42 tonnes of CO_2 per hectare of forest in one year (Wada 1994). The estimation of the CO_2 emissions from the vehicle engines mainly depends on the estimation of vehicle kilometers traveled on annual basis, on vehicle fleet characteristics (i.e. percentage of each vehicle category and fuel consumption of each) and on the CO_2 production from every fuel unit burned.

3. OVERVIEW OF METHODOLOGY

The methodology suggested (Zamba 2006) consists of:

a. Estimation of the total land area that roadway network of a region covers (physical footprint).
b. Estimation of the forest land required to sequester CO_2 emissions, produced by the travel of vehicles during one year, within that region (energy footprint).
c. Estimation of the total ecological footprint of road transport which will be the sum of the physical and the energy ones.

<u>Estimation of the physical footprint:</u> it is the sum of the areas of all roadway segments in the study region. The necessary data can be collected from digital or conventional maps which are available from public services:

$$PF_i = 1/10 * W_i * Li \qquad (1)$$

Where: PFi – the physical footprint of a roadway segment i (ha)
Wi – mean width of the roadway segment i (m)
Li - length of the roadway segment i (km).

<u>Estimation of the energy footprint:</u> on the basis of annual vehicle travel and vehicle fleet characteristics, the total quantity of fuel consumed in one year of travel along the network is estimated. In addition, the quantity of fuel consumed in constructing (allocated over the life time of the network) and maintaining the roadway network is combined with that consumed in annual use to estimate the total quantity of fuel consumed per year of network operation. This estimate is multiplied by a carbon sequestration factor to estimate the area of forestland required to absorb the CO_2 emitted from fuel consumed in the operation of the roadway network:

- *Estimation of annual vehicle kilometers of travel*

Data on annual vehicle travel flows can be obtained from public services. In order to calculate the vehicle kilometers of travel in a roadway segment during one year, the annual average daily traffic in the segment is multiplied by its length. The estimation is based on the following equation:

$$TVK = \sum 365 * AADT_i * L_i \quad (2)$$

Where: TVK – Total vehicle kilometers of travel in the study region, during the study year n (km).

AADTi – Annual Average Daily Traffic in the roadway segment i (vehicles/day).
Li - Length of the segment i (km).

- *Estimation of fuel consumption per kilometer*

The quantity of fuel consumed annually from the vehicles is obtained by multiplying the total annual vehicle kilometers of travel by the fuel consumption per kilometer per vehicle category. Because different categories of vehicles consume fuel at different rates, it is necessary to determine the relative fleet proportion of different vehicle types. We have considered four different vehicle categories:

1. Passenger cars (including taxis)
2. Trucks
3. Buses
4. Motorcycles.

In addition, fuel consumption is also depending on the speed of vehicles. To estimate the weighted average of fuel consumption per kilometer by the vehicles we apply the following equation:

$$WFC = \sum FC_{is} * P_i \quad (3)$$

Where: WFC- Weighted Fuel Consumption (lt/km)
FC_{is} – Fuel consumption index per vehicle type i, corresponding to speed s (lt/km)
Pi – Fleet composition percentage for the vehicle type i.

- *Estimation of the energy footprint from the consumption of 1lt of fuel*

Given the total liters of fuel consumed in a year of travel, we have to calculate the quantity of CO_2 emitted and the area of forestland required to sequester these greenhouse gas emissions. As previously noted, 1 ha of forest can absorb annually the CO_2 generated by the consumption of 100GJ of fossil fuel (Wackernagel and Rees, 1996). Each liter of benzene produces about 0.033GJ of energy and each liter of diesel produces about 0.036GJ. The average value of 0.035GJ per liter for both benzene and diesel (Chi and Stone, 2005) gives the following result:

$$\{1(lt) * 0.035\ GJ/lt\}/\ \{100GJ/ha/year\} = 0.00035\ ha/year \text{ or } 3.5\ m^2/year$$

Consequently, over the period of one year, an average of 0.00035ha of forested land is required to sequester the CO_2 emitted from the burning of 1lt of fuel.

- *Road construction and maintenance adjustment*

According to Wackernagel and Rees (1996), the indirect carbon emissions for road construction and annual road maintenance are estimated to be equivalent to 45% of the total annual fuel consumed for vehicle travel. Therefore, the total annual consumption of fuel for network operation is estimated by multiplying the annual consumption of fuel for vehicle travel by the factor 1.45:

$$EF_n = 1{,}45 * 0.00035\ (ha/year) * WFC_n * TVK_n \quad (4)$$

Where: EF_n – energy footprint from the vehicle travel for the study year n (ha)
WFC_n – weighted fuel consumption per km for all vehicle types, for the study year n (lt/km)
TVK_n – total vehicle travel within the study region for the study year n (km).

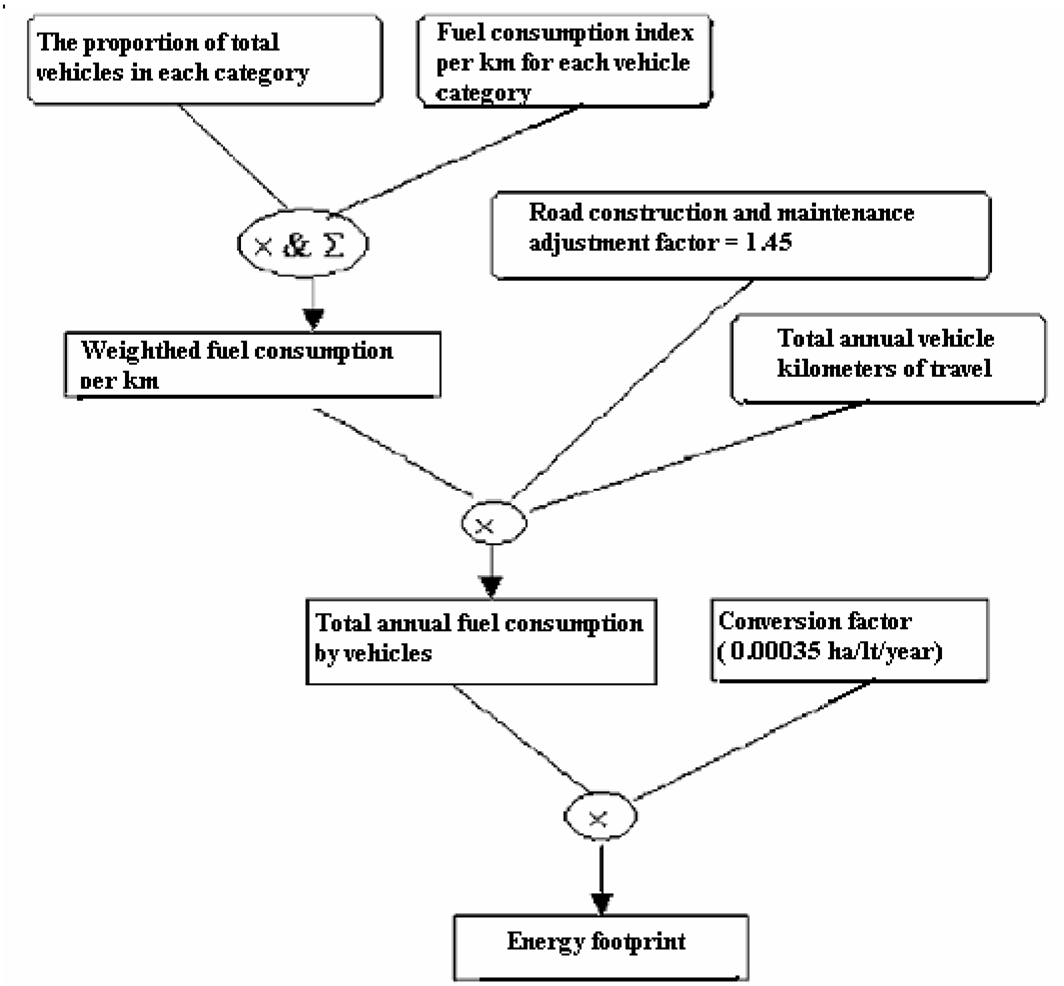

Fig. 2: Flow diagram for estimating the energy footprint

Estimation of the total ecological footprint of road transport: the total land area required to physically support the roadway network and to sequester the CO_2 emissions associated with the annual operation of the network in the study region will be the sum of the physical and the energy footprint:

$$TEF_n = PF_n + EF_n \quad (5)$$

4. CASE STUDY: THE ROAD TRANSPORT ECOLOGICAL FOOTPRINT OF THE GREATER RING OF ATHENS

The above methodology has been applied (Zamba 2006), for a study time period of 6 years (2000 to 2005), within the boarders of the “greater ring” of Athens that covers an area of 15400 hectares, corresponding to 25 municipalities, and has a population of 1215451 people. Data for the fleet composition percentages and the annual vehicle traffic counts were obtained from relevant authorities for 16 of the main roads of the center of Athens (Mesogeion, Alexandras, Kiffisias, Vas. Sofias, Vas. Konstantinou, Vas. Amalias, Syggrou, Panepistimiou, Stadiou, Akadimias, Patision, Michalakopoulou, Kallirois, Filellinon, Solonos, Ippokratous). We have selected some main roads, as there were no adequate data for all the roads included in the study region. Traffic estimations have been extended to the whole roadway network of the study area, based on assumptions. Data for the fuel consumption indicators for each vehicle type were obtained from the British National Atmospheric Emissions Inventory (2002). The indicators are relative to the travel speed of the vehicle. Moreover, the indicators are classified according to the vehicle category and the model of it (Euro I, Euro II etc).

- *Simplifying assumptions*

According to the obtained data, estimations were made about the relative percentages of each vehicle type and were extended to the whole daytime. On average, these are:

- 75% passenger cars and taxis
- 20% motorcycles
- 3% buses
- 2% trucks.

The travel speed of vehicles is different during the day and through various roads. An average speed value for each vehicle type has been assumed:

- Passenger cars: 25km/hr
- Motorcycles: 30km/hr
- Buses: 20km/hr
- Trucks: 25km/hr.

As for the fuel consumption indicators, assumptions were made about the categorization of the vehicles, as there were not available data for more detailed classification relatively to model or power. The fuel consumption indicators for the above travel speed for each vehicle class, are presented in the Table 1. The annual average daily traffic data for each of the studied roads has been estimated on the basis of the traffic counts of all the survey stations along the road, for the years 2000 to 2005. Table 2 shows indicative data for Alexandras Av.

Table 1: Fuel Consumption Indicators for each vehicle category

Vehicle Category		**Fuel Consumption Indicator (lt/km)**	**Average Fuel Consumption Indicator (lt/km)**
Passenger cars (Euro II)	Benzene cars (1400cc – 2000cc)	0.08827	*0.0875*
	Diesel cars (>2000cc)	0.08667	
Motorcycles (250cc – 700cc)	Pre-2000	0.0537	*0.050*
	97/24/EC	0.0462	
Trucks (Euro II)	Benzene Trucks LGV	0.1249	*0.1944*
	Diesel Trucks LGV	0.1124	
	Benzene Trucks HGV	0.3460	
Buses (Euro II)		0.3599	*0.360*

Table 2: Annual Average Daily Traffic for Alexandras Av. (vehicles/day)

Survey station	*Alexandras Avenue*					
	2000	**2001**	**2002**	**2003**	**2004**	**2005**
005053	43110	44205	45769	42846	45285	44015
005258	40174	38922	43227	41894	39422	37404
005243	41717	38444	42662	39809	40184	38288
Average	*41667*	*40524*	*43886*	*41517*	*41630*	*39902*

Full data on traffic counts for each survey station were not available from the Ministry for all the years. For some stations where data were available only for one or two years, estimates have been made for the rest of the time. Moreover, for the rest of the roads within the study region, an average annual daily traffic has been assumed, which was 1000 vehicles/day for all the small roads and 40000 vehicles/day for the rest of the big roads. Finally, an assumption was made about the estimation of the physical footprint of the road network. The area covered by the small roads (collector streets, local streets) of the region has been estimated at the 1/10 of the total land area of the study region (154 km^2), while the area covered by the rest main big roads of the region, for which no data were gained (for example Piraios, Iera Odos etc), has been estimated at 3 times the area covered by the 16 roads, for which data were obtained.

5. RESULTS

Applying the above mentioned methodology, we end up to the following results:

- The weighted average fleet consumption fuel per kilometer, as derives from the equation (3), is *0.0903 lt/km*
- The physical footprint of the 16 studied roads is *50.75 ha,* and the total physical footprint of the roadway network of the study area is *1692 ha*.
- The total vehicle kilometers traveled each year within the region, according to the equation (2), the obtained traffic data and the relative assumptions are shown in the Table 3. The energy footprint is calculated, according to the equation (4).

Table 3: Energy footprint of road transport

	Total annual vehicle travel (Km)	Weighted average fuel consumption (lt/km)	Conversion factor (ha of forest/lt)	Energy footprint (ha)
2000	1 963 555 095	0.0903	1.45 * 0.00035	89 984
2001	1 962 906 125	0.0903	1.45 * 0.00035	89 954
2002	1 963 689 050	0.0903	1.45 * 0.00035	89 990
2003	1 930 859 490	0.0903	1.45 * 0.00035	88 486
2004	1 955 001 320	0.0903	1.45 * 0.00035	89 592
2005	1 926 107 190	0.0903	1.45 * 0.00035	88 268

The average energy footprint for the period 2000-2005 is: 89379 ha, therefore the total ecological footprint of road transport in Athens for this period is:

EF_{Ath} = 91071 ha, according to equation (5).

6. CONCLUSIONS

Each individual has the potential, through the ecological footprint, to understand his contribution to global environmental degradation. This method can be a useful analytical tool for indicating the impact from air pollution caused by the vehicle circulation. Because of lack of detailed and accurate data, many simplifying assumptions were made in the particular case-study. These assumptions were based on real facts and personal crisis, and of course affect the accuracy of the result.

The study region covers an area of 15400 ha. According to the above calculations, the forested land required to absorb the CO_2 emissions generated from the vehicles within the study region measures 91071 ha that is about 6 times the size of the study area. This result seems to be an underestimation, if we compare it to other findings (Birch et al 2004), for example, the corresponding estimation for Oslo, which is about 22.5 (Aall and Norland 2002). Moreover, taking into account the population of the region, we estimate the ecological footprint per capita at 0.1 ha/cap. This figure also seems to be too low, if we compare it, for example, to the corresponding estimation for Toronto, which is about 1.9 ha/cap (Onisto et al 1998). Therefore, it would be useful to restart the whole calculation after obtaining more detailed and accurate data and reducing the simplifying assumptions.

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