Estimating the Ecological Footprint of Transportation in the City of Isphahan (Iran)

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ABSTRACT

Different methods aimed to quantify the effects of human activities on the natural environment have been developed. One of them is ecological footprint that is the total area of land, to produce all the resources a population consumes and to absorb all of the wastes it generates. An important impact of human activities on the environment is climate change that relates to the concentration of greenhouse gases in the atmosphere. The most important gas is CO_2 which is released to atmosphere as a result of burning fossil fuels in daily life of human activities. A main part of increasing CO_2 in urban atmosphere is road transportation; so estimation of ecological footprint of it can describe the situation of consuming fossil fuels in a city. To do so, the amount of different fuels consumed in a period of time, the area under transportation constructions and also the energy consumed in the process of network construction and annual road maintenance should be regarded. In this study the ecological footprint of transportation activities in the city of Isphahan in central Iran was estimated at 0.4 global hectares. It means that for each Isphahan resident, 0.4 global hectares area is needed to sequester the CO_2 released to atmosphere from different transportation activities.

Key words: Ecological Footprint, Transportation, Global Hectare, Isphahan.

INTRODUCTION

One of the most important demographic phenomena of economic and industrial development of every country is the rapid growth of cities and urban population (Isazadeh and Mehranfar, 2012). Population growth typically accompanies by environmental degradation such as soil erosion, desertification and deforestation (Gharakhluo *et al.*, 2013). Cities consume three quarters of the energy produced in the world, and are the reason of about three quarters of world's pollution (Jomepour *et al.*, 2013). Modern cities, by consumption of land, energy, water and food, material flow, and also emissions of greenhouse gases, solid wastes, air and water pollution press a considerable pressure on the planet's natural environment (Zamba and Hadjibiros, 2007). Economic efficiency and social welfare depends on the ability of natural resources to provide services, while human activities that cause the destruction of resources, will lead to a decline in long-term human welfare (Borucke *et al.*, 2013).

Great efforts have been done to identify and reduce the impact of human life on the environment. The goal of all these efforts is the creation of an ecologically sustainable city, which the use of its resources is effective, reducing ecological impacts and maintaining its ecological role provides higher living standards, and it will provide a healthier urban environment for its citizens (Barret and Simmons, 2003).

Different methods, with the aim of quantifying the effects of human activities on the natural environment have been developed (Zamba and Hadjibiros, 2007). One of the tools in order to assess the environmental impacts of resource use

is the concept of Ecological Footprint. Ecological footprint estimation of a city is based on its population. The underlying philosophy of the global ecological footprint is that human activities place a demand on planets available land, thereby leaving a footprint on land (Agrawal *et al.*, 2006).

Ecological footprint show people how the consequences of their consumption patterns press on the planet resources (Ewing *et al.*, 2010). In other words, Ecological Footprint is used as a tool to calculate the environmental impact of human activities (Peters and Schouten, 2010).

Ecological Footprint, which assesses the relationship between people and resources, and is an indicator of carrying capacity of regions, nations and the planet, is defined as the total area of land in different ecological zones, to produce all the resources a population consumes and to absorb all of the wastes it generates, using prevailing technology and resource management practices (Wiedmann and Barrett, 2010).

The Ecological Footprint is an indicator that aims at measuring human demand on biological resources and setting it in relation to the regenerative capacity on Earth. (Wiedmann and Barrett, 2010)

The Ecological Footprint shows how much land area is required to sustain the socioeconomic use of resources for a certain period of time (in the majority of cases one year) with available technologies and given resource management conditions and to provide infrastructure and absorb waste and pollutants (Giljum *et al.*, 2007). Both land and water surfaces are taken into account. Indeed, the object of ecological footprint 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 (Zamba and Hadjibiros, 2007).

The Concept of Ecological Footprint

The production in arable lands, pastures, forests, or productive seas and also the built-up areas express the human demand on nature, and the total of them is equal to ecological footprint. Because the averages of productivity in different land types are not the same, they need to be converted, using its corresponding equivalence factor in order to be expressed in global hectares. (Schaefer *et al.*, 2006)

Footprint=Area(ha)*Equivalence Factor(gha/ha)

Normalizing bio-productive areas, hectares to global hectares

Estimates of the ecological footprint are expressed in a common unit of measurement: global hectare (Ewing *et al*, 2010). Ecological Footprint is scaled with yield factors and equivalence factors to convert physical land demanded to world average biologically productive land, usually expressed in global hectares (gha) (Wiedmann & Lenzen, 2007)

Yield Factors account for the difference in production of a given land type across different nations (Kitzes *et al.*, 2007).

Productivity is defined for a certain period of time (usually one year), certain products (like Crops, pasture-fed animal products,…) and a certain land-use (Arable land, pasture,…) (Kitzes *et al.*, 2007; Ewing *et al.*, 2010; Schaefer *et al.*, 2006)

A hectare of pasture in New Zealand, for example, produces more meat on average than a hectare of pasture in Jordan (Kitzes *et al.*, 2007). Thus, in terms of productivity, one hectare of grassland in New Zealand is equivalent to more than one world average grazing land hectare; it is potentially capable of supporting more meat production (Ewing *et al.*, 2010). These differences may be due to natural factors, such as precipitation or soil quality, or management practices (Kitzes *et al.*, 2007; Ewing *et al.*, 2010).

To account for these differences, the yield factor compares the production of a specific land type in a nation to a world average hectare of the same land type. Each country and each year has its own set of yield factors. (Kitzes *et al.*, 2007).

Equivalence factors convert the areas of different land use types, at their respective world average productivities, into their equivalent areas at global average bio-productivity across all land

use types (Ewing *et al.*, 2010). Equivalence factors translate a specific land type (i.e. cropland, pasture, forest, fishing ground) into a universal unit of biologically productive area, a global hectare (Kitzes *et al.*, 2007). Equivalence factors vary by land use type as well as by year. (Ewing *et al.*, 2010; Kitzes *et al.*, 2007).In 2003, for example, primary cropland had an equivalence factor of 2.21 , indicating that primary cropland was more than twice as productive as a hectare of land with world average productivity. This same year, pasture had an equivalence factor of 0.49, showing that pasture was approximately half as productive as the average bio-productive hectare. (Kitzes *et al.*, 2007).

The rationale behind Equivalence factors' calculation is to weight different land areas in terms of their capacity to produce resources useful for humans. The weighting criterion is therefore not just the quantity of biomass produced, but also the quality of such biomass, meaning how valuable this biomass is for humans. (Ewing *et al.*, 2010).

Transportation Footprint

A city is a complex and organized set that is constantly changing and evolving. This complexity and dynamism makes it necessary to have strategic planning based on accurate and updated data and information.

To calculate the ecological footprint of a city, different components can be considered: Cropland, Grazing Land, Marine and Inland water, Energy and Built-up area (Ewing *et al.*, 2010).

This classification can be useful for better understanding the human demand on different land-use types.

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 (CO2), which is the predominant greenhouse gas. An important component of this contribution is the emissions from urban transportation activities and specifically the road transport (Zamba and Hadjibiros, 2007).

One of the activities in a city that uses fossil fuels is the issue of transportation, as a result of using different types of fuels for vehicles CO_2 is released into the atmosphere. For accumulated carbon dioxide in space, resulting from the use of fossil fuels by various human activities, a sink to absorb and sequester it is required (GFN, 2006). Accordingly, the amount of released CO_2 is considered as a subset of energy footprint.

Footprint of transportation-related activities includes the footprint of transportation fuel consumption and the footprint of built-up areas for transportation infrastructures. Thus all forms of public transportation such as Buses, taxis, motor-cycles, private cars and freight vehicles which consume fossil fuels like CNG, LPG and petrol (Agrawal *et al.*, 2006).

Footprint of transportation in the United States of America, Considering all kinds of vehicles

Table 1: Totals vehicles in each category, traveling in Isphahan (2011)

Bus/Minibus	Taxi	Truck	Motorcycle	Pick-up	Public Transport	Private car
2800	25,000	3400	514,000	77,000	10,000	700,000

Table 2: The quantity of fuel consumed in Isphahan (2011)

Product	Liquid Gas	Natural Gas	Regular Gasoline	Premium Gasoline
Unit	ton	Million m^3	Million liter	Million liter
quantity	1756	121	589	27

ranging from private cars and trucks, motorcycles and buses, rail and air transport and passenger boats, and regarding this point that how much CO_2 is released to atmosphere for consuming per KWH of each fuel, was estimated at 1.94 global hectares (Christensen *et al.*, 2007).

In Great Britain in 2003, with regard to the water, air and rail transport , metro, buses, cars, motorbikes and scooters, and regarding infrastructures, ecological footprint of transportation of 0.67 Global hectares was calculated (Barret and Simmons, 2003).

In York, the amount of CO_2 produced per KWH from various types of fuels used for vehicles such as private cars, buses, motorcycles and aircrafts were calculated and Transportation Footprints of 1.49 hectares for the city was estimated. (Barrett *et al.*, 2002)

Footprint of transportation in the city of Adelaide in Australia with regard to the use of private vehicles like cars and trucks, motorcycles, buses, rail and air transport and passenger boats was calculated as 0.66 Global hectares per capita (Agrawal *et al.*,2006).

In the city of Kermanshah in western Iran, considering the amount of diesel and gasoline consumption by public and private vehicles such as buses, minibuses and cars and motorcycles, the ecological footprint of transportation was estimated at 0.32 hectares (Gharakhluo *et al.*, 2013).

MATERIAL AND METHODS

Isphahan has long been an important urban center on the plateau of Iran, its area is approximately 17,585 hectares and about 1,978,168 people are living there in 14 districts (Zarrabi *et al.*, 2009). A variety of vehicles, including buses, trucks, personal cars and motorcycles are used in Isphahan, each of which has its own fuel.

An estimation of the ecological footprint related to the impact of road transport combines activities such as (Barret and Scott, 2010):
- The CO_2, NO_x and Methane emissions from burning of fossil fuels in vehicle engines.
- The CO_2 emissions from manufacture and maintenance of vehicles and road infrastructures.
- The road space and the other land that is occupied by different vehicle facilities.

The methodology developed to calculate the ecological footprint of transportation networks is presented as a chart in Fig. 1. As indicated by the figure, our approach consists of three principal steps (Chi and Stone, 2005):

1   Estimating the physical footprint of the roadway network on the basis of the surface area

Table 3: Detailed data of Isphahan transportation footprint (2011)

Components	Consumption Quantity	Released Co_2	Conversion Factor	Ecological Footprint (ha/year)	Equivalence Factor	Ecological Footprint (gha/year)
Regular Gasoline Premium Gasoline	589 Million Liter 27 Million Liter	1432200	3.996Ton Co_2/ha/year	358408.4	1.26 gha/ha	451594.58
CNG	121 Million m3	283697.568		70995.38		89454
LPG Maintenance actions	1756 ton	5268 45%Energy Footprint		1318 193825		1661 244219.32
Built-up land Sum	3506 ha			3506 628053	2.51gha/ha	8800 795728.9

Step 1

- Roadways width
- Roadways Length
- × → Total roadways area. (ha)
- Equivalence Factor=2.51 gha/ha
- × → Physical Footprint

Step 2

- The proportion of total vehicles in each class in the city → Calculation the amount of used CNG, LPG and Petrol
- Estimation the amount of CO_2 emitted from burning LPG
- Estimation the amount of CO_2 emitted from burning Gasoline
- Estimation the amount of CO_2 emitted from burning CNG
- Total amount of CO_2 emitted from vehicles → ÷ → Conversion factor → Required area (ha/ year)
- Required area (ha/ year) × Equivalence factor of forestland (1.26 gha/ha) → Area required to sequester the emitted CO_2(gha)
- Area required to sequester the emitted CO_2(gha) × 1.45 Transportation Footprint for Maintenance actions → Energy Footprint (gha)

Step 3

- Energy Footprint (gha)
- Physical Footprint (gha)
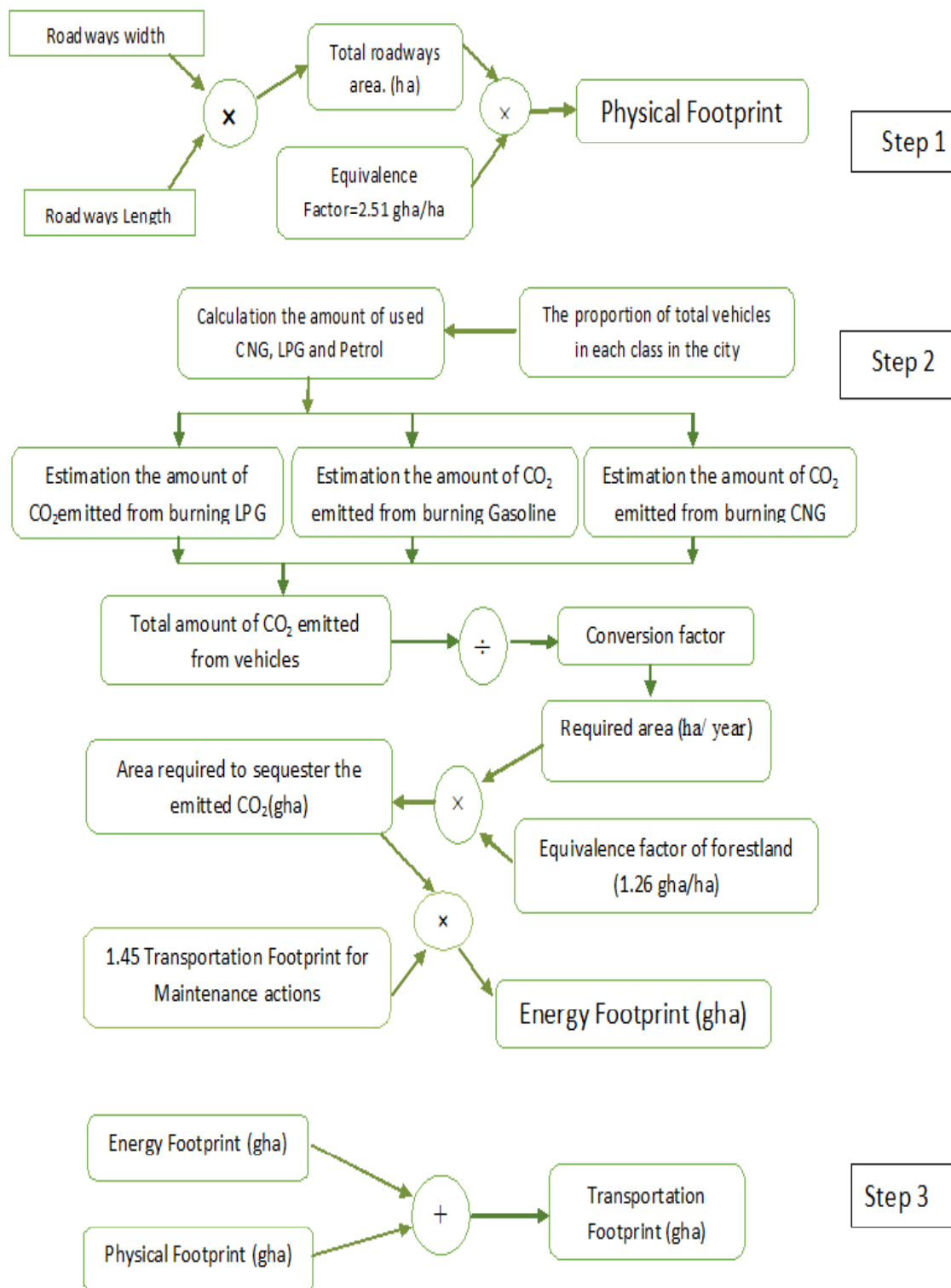- + → Transportation Footprint (gha)

Fig. 1: The methodology developed to calculate the ecological footprint of transportation

of roadway paving; (step 1)

2   Estimating the energy footprint of the roadway network on the basis of the area of forest land required to sequester carbon emissions produced by network travel during one year;

3   Combining the land areas of the physical and energy footprints to derive an estimate of the total transportation footprint. (Step 3)

The Physical Footprint (Step 1) is the sum of the areas of all roadways segments in the study area (Zamba and Hadjibiros, 2007). The equivalence factor for physical footprint is 2.51 (Ewing *et al.*, 2010).

For Energy Footprint (step 2), the total quantity of fuel consumed in one year of travelling along the study area is estimated. To calculate the land area required to absorb or sequester the CO_2 emitted from burning fossil fuels used in urban transport, the footprint of each fuel is regarded separately because of the differences in the rate of CO_2 emissions per volume unit of each fuel. (Based on data cited in tables 1, 2 and 3)

In addition to fuel consumed through vehicle travel along a network, energy consumed in the process of network construction and annual road maintenance must also be reflected in the total transportation network footprint (Chi and Stone, 2005). Wackernagel and Rees (1996) estimated that the indirect carbon emissions for road construction

and maintenance are equivalent to 45% of the total annual fuel consumed for vehicle travel. This estimate is multiplied by a carbon sequestration factor to estimate the area of forestland required to absorb the CO_2 emitted from fuel consumption in the study area. (Zamba and Hadjibiros, 2007). The equivalence factor for Energy footprint is 1.26 (Ewing *et al.*, 2010). And finally, Transportation Footprint (Step 3) is the summation of physical and Energy footprints.

RESULTS

The portion of each part in the Transportation Footprint of Isphahan is shown in Figure2. According to the above calculations, required forest land for transportation in Isphahan equals 795728.9 global hectares, or 0.4 gha per capita. If the total area of the city, using the equivalence factor, is converted to global hectares, per capita availability of available land for every Isphahan citizen is about 0.022 global hectares, while the per capita footprint of transportation is 0.4 Global hectares. This means that the land needed to meet the transportation requirements of each person is 18 times the per capita availability of land for every person in the city of Isphahan. Transportation is one component of total Ecological Footprint and this illustrates the fact that cities placing further environmental burdens on city hinterlands. They have drawn in energy and matter from all over the ecosphere. (Wackernagel and Rees, 1996)

CO_2 release to atmosphere depends directly on the amount of fuel consumed. Releases of other gases depend on other factors like speed , acceleration and vehicle type. Thus, the type of vehicle, its technology and the type of fuel affect the emission control.

CONCLUSION

The concept of Ecological Footprint has received considerable attention as a useful indicator in the context of sustainable development. This concept can be a useful analytical method for estimating the total impacts of different activities such as transportation and the air pollution that is resulted from vehicles traffic.
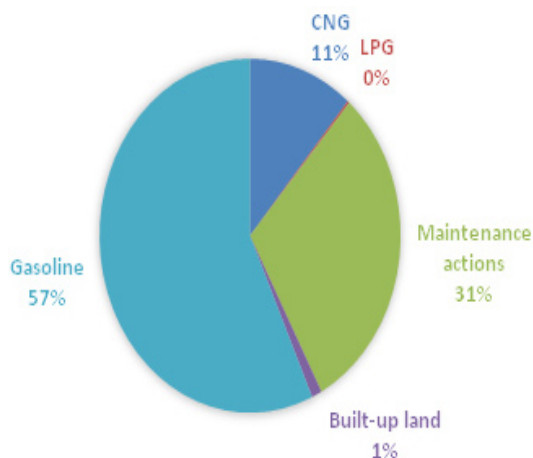
Fig. 2: Share of the participating components in transportation Footprint of Isphahan

There are different kinds of vehicles used in Isphahan as the study area of this survey, and the forest land required to absorb the CO_2 emissions released to atmosphere from these vehicles was estimated at 799688.9 global hectares, that is 18 times the size of Isphahan. This estimation is comparable to other findings like the corresponding estimation for Oslo which is about 22.5 (Aall and Norland, 2002).

Ecological Footprint can act as a strong statement in studies to identify potential sources of unsustainability; in the field of transportation, Environmental Impacts of using different fuels is an important factor in transportation planning. As can be seen in the chart, gasoline has a major role in the transportation footprint of Isphahan, so a decrease in the proportion of gasoline, would lead to a decrease in ecological footprint and the total impacts of transportation on the natural environment.

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