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\textsubscript{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\textsubscript{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\textsubscript{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(ga/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
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).

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

<table>
<thead>
<tr>
<th>Bus/Minibus</th>
<th>Taxi</th>
<th>Truck</th>
<th>Motorcycle</th>
<th>Pick-up</th>
<th>Public Transport</th>
<th>Private car</th>
</tr>
</thead>
<tbody>
<tr>
<td>2800</td>
<td>25,000</td>
<td>3400</td>
<td>514,000</td>
<td>77,000</td>
<td>10,000</td>
<td>700,000</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Product</th>
<th>Liquid Gas</th>
<th>Natural Gas</th>
<th>Regular Gasoline</th>
<th>Premium Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit quantity</td>
<td>ton</td>
<td>Million m³</td>
<td>Million liter</td>
<td>Million liter</td>
</tr>
<tr>
<td></td>
<td>1756</td>
<td>121</td>
<td>589</td>
<td>27</td>
</tr>
</tbody>
</table>
ranging from private cars and trucks, motorcycles and buses, rail and air transport and passenger boats, and regarding this point that how much CO₂ 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 CO₂ 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**

Ispahan 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 Ispahan, 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 CO₂, NOₓ and Methane emissions from burning of fossil fuels in vehicle engines.
- The CO₂ 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 Ispahan transportation footprint (2011)

<table>
<thead>
<tr>
<th>Components</th>
<th>Consumption Quantity</th>
<th>Released CO₂</th>
<th>Conversion Factor</th>
<th>Ecological Footprint (ha/year)</th>
<th>Equivalence Factor</th>
<th>Ecological Footprint (gha/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular Gasoline</td>
<td>589 Million Liter</td>
<td>1432200</td>
<td>3.996Ton CO₂/ha/year</td>
<td>358408.4</td>
<td>1.26 gha/ha</td>
<td>451594.58</td>
</tr>
<tr>
<td>Premium Gasoline</td>
<td>27 Million Liter</td>
<td>283697.568</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CNG</td>
<td>121 Million m3</td>
<td>283697.568</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LPG</td>
<td>1756 ton</td>
<td>5268</td>
<td>45%Energy Footprint</td>
<td>1318</td>
<td>1.661</td>
<td>244219.32</td>
</tr>
<tr>
<td>Maintenance actions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Built-up land</td>
<td>3506 ha</td>
<td></td>
<td></td>
<td>3506</td>
<td>2.51 gha/ha</td>
<td>8800</td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td></td>
<td></td>
<td>628053</td>
<td></td>
<td>795728.9</td>
</tr>
</tbody>
</table>
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 roadway 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 CO2 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 CO2 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 CO2 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 Figure 2. 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)

CO2 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.
There are different kinds of vehicles used in Isphahan as the study area of this survey, and the forest land required to absorb the CO2 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.

REFERENCES