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Comparing the Ecological Footprint of Urban Subway and Road Transport System (Case Study: Tehran)

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ABSTRACT

One of the pressures of human population on the planet is the rapid and unbridled growth of cities. In the cities, the concepts of sustainability and sustainable urban development are on the basis of ecological, economic and socio-political, cultural, and spatial dimensions and contrast of these dimensions. In recent decades, many indicators have been developed to investigate the stability of the cities and one of the best indicators in this field, is the ecological footprint. The purpose of this study is to evaluate sustainable transportation of Tehran applying ecological footprint model and Compare the ecological footprint of urban subway and road transport system. The results of the study showed that the ecological footprint of Tehran transportation is equal to 3348734.16 global hectares while Tehran's biological capacity to absorb the carbon released in the transport sector is equal to 9664.2(gha). Also, the carbon footprint of metro transit system is equal to 12,428 global hectares and the carbon footprint of road system transportation is equal to 3,323,152 global hectares and the produced carbon in road transport system, per kilometer, is 85 times larger than the produced carbon in the Metro system. The ecological footprint of Tehran transportation points to the deterioration of the current situation and it is clear that the policies of transport development are unsustainable and the current transport patterns will make Tehran uninhabitable in the near future. In such conditions, for the development of sustainable transport system based on environmental criteria, a low-carbon transport, transit-oriented development (TOD), and the creation of Green corridor could be some tools for sustainable development in the transportation sector of Tehran.

Introduction

The thermodynamics teaches us that the earth is a planet with finite resources in which endless growth is impossible (Tiezzi, 1984). But the trends and styles of life and the increasing growth of human population on the planet are beyond the tolerance of this planet and Earth cannot endure this trend in the long-term (Kitzes et al, 2008; Odum, 1998). There is an increase in factors of global population growth, demand for resources, waste production and resource consumption, in the way that all the principles of sustainable development proposed by Daly (1990) have been violated. Typically, population growth is accompanied by environmental degradation processes such as soil erosion, desertification and deforestation (Gharakhluo et al, 2013). Fortunately, many countries have taken some steps toward treating the problem and are in the process of designing and implementing sustainable development models; the beginning of this process was in United Nations Conference on Environment and Development (UNCED), Rio de Janeiro in1992 (Brady et al, 1994). One of the pressures of human population on the planet is the rapid and unbridled growth of cities. In the cities, the concepts of sustainability and sustainable urban development are on the basis of ecological, economic and socio-political, cultural, and spatial dimensions and contrast of these dimensions (Azad and Eftekhari, 2000). In recent decades, various concepts and indicators for measuring and assessing the sustainability of urban areas are provided. One of the factors that have attracted more attention in the academic and political levels is Ecological footprint assessment (EFA). Ecological footprint is an index which estimates the pressure made by population and industrial processes into their ecosystem by evaluating the energy and materials used in a town, region or country (Ress, 1992; Wackernagel and Ress, 1996). This indicator shows that the energy consumption and utilization of resources can be directly linked to the land allocated to each member in the city, region or country and assess them (Gottlib et al, 2012). More specifically, the ecological footprint of a population calculates the level of land and water needed to produce consumer goods and absorb all the waste produced by the population (Rees, 2000). The ecological footprint shows how the consequences of consumption patterns of a human population push the Earth Resources (Ewing et al., 2010). In other words, the ecological footprint is used as a tool to calculate the environmental impacts caused by human activities (Peters and Schouten, 2010).

The ecological footprint concept and practical framework

Production on arable land, pastures, forests, and productive seas and constructed regions shows the demand of human from nature and they are all equal to ecological footprint. Since the average productivity is different in a variety of terrains, the ecological footprint is measured in global hectares and is expressed in common units (Ewing et al, 2010). Global hectare is evaluated with the help of two factors: the Yield Factor which compares the average of national yield per hectare with the global efficiency average of the same terrain (Kitzes et al., 2007)

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and the Equivalence Factor which shows the relative productivity of different types of land and water areas (Ewing et al., 2010).

The ecological transportation footprint

One of the human activities is the use of fossil fuels for transportation. One of the results of the use of fossil fuels is releasing CO2 into the atmosphere. To capture and sequester carbon dioxide accumulated in the atmosphere, resulting from the use of fossil fuels by various human activities, a sink is required (GFN, 2006). Therefore, the amount of CO2 released into the atmosphere can be considered as a subset of energy footprint. The ecological footprint of transport consists of footprints of fuel and traces of constructed areas for transportation infrastructure (Agrawal et al, 2006).

Sustainable transportation

Sustainable transport system must have the following qualifications (Labib et al, 2013 :(

• Provide individuals, businesses and communities with access to their needs in a manner compatible with human health and ecosystems and upgrade equity within and between successive generations.

• It should be affordable; it has fair and efficient performance; it offers selection of different modes of transport; it supports the competitive economy and it also takes into account balanced regional development .

• Waste and greenhouse gases should not be beyond the Earth's ability to absorb them; it should use renewable energy sources, equal to or lower than their production rate; it should use non-renewable energy sources, equal to or lower than their growth rate; it should minimize the human impact on the earth and audio production.

The aim of this attempt is to estimate the ecological footprint of urban subway and road transport system of Tehran transportation and compare them.

Methodology and instrumentation

Study area

Tehran is the capital of Iran with an area of 730 square kilometers. According to the latest census, the population of Tehran was 8250000 in 2012.

The status of transportation in Tehran

Transportation vehicles in Tehran include buses, minibuses, taxis, motorcycles, trucks, private vehicles and the metro whose energy is supplied by fossil fuels such as diesel, gasoline and electricity. The private car ownership rate in Tehran was 0.37 per person in 2012. There were 17.4 trips daily in 2012 in Tehran, in which 56% was for public transport and 44% of trips were by private vehicles. Metro's share of total daily trips in Tehran, is equal to 13%. (Fig.1)

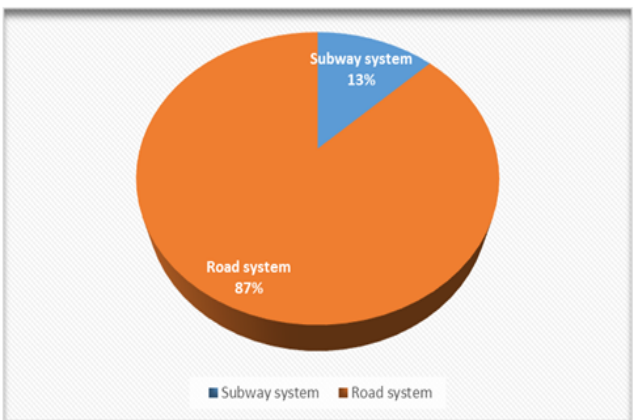

Fig 1. Metro's share of total daily trips in Tehran in 2012

Most trips conducted in Tehran are business trip and travelers are forced to use vehicles to get to work as due to the lack of proper and sustainable planning, user status in Tehran is designed in a way that people are forced to work away from residential areas and there is no possibility to walk from home to work .

On the other hand, a wrong policy has been adopted in the housing sector so that the houses around the metro and public transport networks are very expensive and most employed people are not able to rent or buy such houses and are settled in suburbs. Also, the sidewalks of the city of Tehran do not have good status. Narrow width and insecurity, lack of green spaces and attractiveness, the lack of mixed use (commercial, official and entertainment) and poor sidewalks, not suitable for various ages, have reduced the tendency of people to walk. Cycling is the non-motorized vehicle in Tehran and based on the latest statistics of the municipality, there is a bike path length of 192 km dedicated to cycling and 4330 bikes. But due to the lack of bicycle equipment, the absence of a culture of cycling, shortage of cycling and bike path in Tehran, the use of non-motorized vehicle is not sensible.

Methodology

In this study, In order to calculate the ecological footprint of Tehran transportation, the model proposed by Chi and Stone (2005) has evolved. The methodology developed to calculate the ecological footprint of transportation networks is presented as a chart in Fig. 1. As indicated, our approach consists of three principal steps: Step (1): estimating the physical footprint of the transport network on the basis of the surface area of paved roadways, parking lots, passenger terminals, train and subway stations, car manufacturers, car service stations, asphalt factories and Metro service centers .

The total area of land involved in the physical footprint is multiplied by equivalence factor to estimate the global hectare (Wiedmann and Lenzen , 2007). The equivalence factor for physical footprint is 2.51 (Ewing et al, 2010). Step (2): estimating the energy footprint of the transport network on the basis of the area of forest land required to sequester carbon emissions produced by network travel during one year; 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. In addition to the fuel consumed by vehicle traveling 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. To estimate the energy footprint, the amount of carbon emissions in the construction and maintenance of networks should also be added to the carbon produced by all types of vehicles (Zamba and Hadjibiros, 2007). This estimate is multiplied by a carbon Equivalence Factor to estimate the area of forestland required to absorb the CO2 emitted from fuel consumption in the study area (Wiedmann and Lenzen, 2007). The equivalence factor for Energy footprint is 1.26 (Ewing et al, 2010). And finally in the third step, Transportation Footprint is the summation of physical and Energy footprints.

In order to apply the methodology in Tehran, information relating to the consumption of fossil fuels and electricity in the transport sector, the road network area, the infrastructure area of subway lines and stations, parking areas, passenger terminals,

automotive industries, car service stations, asphalt factories and Metro service centers were collected by the government.

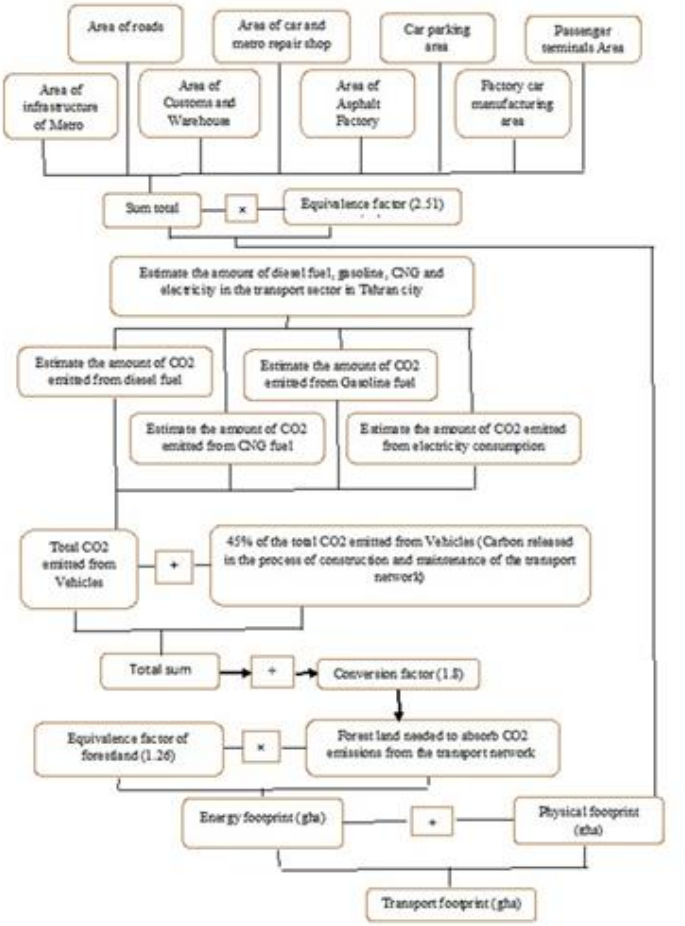

Figure 1. Developed methodology for calculating the ecological footprint of transport

(Source: authors)

Results

Energy consumption in the transport sector in Tehran

Major fossil fuels consumed by vehicles in Tehran include gasoline and diesel. Also, the subway systemprovides its energy from the power grid. The use of fossil fuels and electricity consumption in the transport sector in Tehran in 2012, based on data from the transport and traffic studies company of Tehran, is presented in Table 1.

The physical infrastructures of transportation network

The physical infrastructures of Tehran transportation network include Asphalted roads, bus terminals, customs warehouses, parking lots, Car factories, car and subway repair shops, asphalt factories and subway and train stations,. The area of such infrastructures was prepared by the organization of Tehran Municipality and is presented in Table 2.

Calculating physical footprint

The physical transport footprint is calculated using the following formula:

$$physical\ footprint = physical\ area \times Equivalence\ factor\ (2.51)$$

The total land devoted to infrastructure of road system of transportation in Tehran is 5036.1 hectares and the total land devoted to infrastructure of subway system of transportation in Tehran is 204.6 hectares . Considering this, the physical footprint of road transport in Tehran is 12640.611 (gha) and the physical footprint of subway transport is 513.546(gha). The total physical transport footprint is equal to 13154.16 global hectares.

Estimating energy footprint

The road transportation sector of Tehran uses fossil fuels of diesel and petrol as well as electric power for supplying the energy of subway transport system. The total consumption of such fuels and the electricity in the transport sector in 2012 in Tehran is used to calculate the total production of CO_2 (Table 1). Different fuels have different levels of CO_2 production. Diesel fuel will produce approximately 138700 BTU per gallon which finally releases 19.95 tons of carbon per billion BTU (Pezzeta and Drossman, 2002). Unleaded gasoline would also produce approximately 125000 BTU per gallon which finally releases 19.35 tons of carbon per billion BTU (Pezzeta and Drossman, 2002).

To calculate CO_2 emissions from electricity consumption, we must first determine the KJ amount in a certain amount of KWh. Then, the amount of coal used to produce kJ electricity consumption should be calculated. Finally, admitting the fact that there is 85% carbon in coal, it is possible to estimate the released CO_2 (Gharakhluo et al, 2013).

In addition to fuel consumed through vehicle travel along a network, annual 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). Studies conducted by Wackernagel and Rees in 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. Considering the above mentioned factors, the amount of CO_2 released by each fossil fuels and electricity is provided in Table 3.

Now considering the fact that each hectare of forest land would absorb 1.8 tons of carbon, the amount of forest land required to absorb the CO_2 released in the road transport sector is equal to 2,637,422.5 hectares. This amount should be calculated in global hectares and expressed in common units (Ewing et al, 2010). The equivalence factor for Energy footprint is 1.26 (Ewing et al, 2010). Thus the forest land required to absorb the CO_2 released in the road transport sector is equal to 3,323,152 global hectares.

Amount of forest land required to absorb the CO_2 released in the subway transport sector is equal to 9,864 hectares. This amount should be calculated in global hectares and expressed in common units. Thus the forest land required to absorb the CO_2 released in the subway transport sector is equal to 12,428 global hectares.

Open space in Tehran

Tehran has an area of 730 square kilometers and according to the latest census, the population of Tehran was 8250000 in 2012. It is estimated that 35.6% of the total area of Tehran is dedicated to open spaces which is equivalent to 26,000 hectares. From this area, 43.8% is related to the street network and access roads, 29.9% is devoted to the green space (forest and grass), 13.46% goes for agriculture and horticulture and 15.77% is related to arid areas (Tehran Comprehensive Plan, 2006). In addition, forested area of green space in Tehran (natural and artificial forests and gardens) is about 7670 hectares (Figure 2).

Comparative analysis

Sustainable development in the development of transport systems requires green space to absorb carbon dioxide in this sector. Based on the ecological footprint of transport, it is clear that Tehran should have 3335580 global hectares of forest area for absorption of CO_2 produced from the transport sector of Tehran.

Table 1. Consumption of fossil fuels and electricity of transport network in Tehran in 2012 (Source: transport and traffic studies company of Tehran)

Consumption type	Total consumption of 2012
Gasoline	951047473 (gallon)
Diesel	351887565 (gallon)
Electricity	370 (Gwh)

Table 2. The area of physical infrastructure of transport network in Tehran

transport network	infrastructure	Area (ha)
Road system	Asphalt pavements	4300.9
	Passenger terminals	32.8
	Parking lots	180.5
	Automotive industries	466.1
	Auto Repair Shops	50.2
	Asphalt industries	5.6
	total	5036.1
Subway system	Metro lines	108
	Subway Stations	49
	Metro Workshops	47.6
	total	204.6

Table 2. The total CO2 produced by fossil fuels

Transport system	fuel	Annual use (gallon or Gwh)	tons CO2
Road system	Gasoline	951047473 (gallon)	2300346
	Diesel	351887565 (gallon)	973695.765
	construction and maintenance	45% of the total CO2 emitted from Vehicles	1473318.8
	Total tons of CO2		4747360.5
Subway system	Electricity	370 (Gwh)	17755.5
	Total tons of CO2		17755.5
Total			4765116

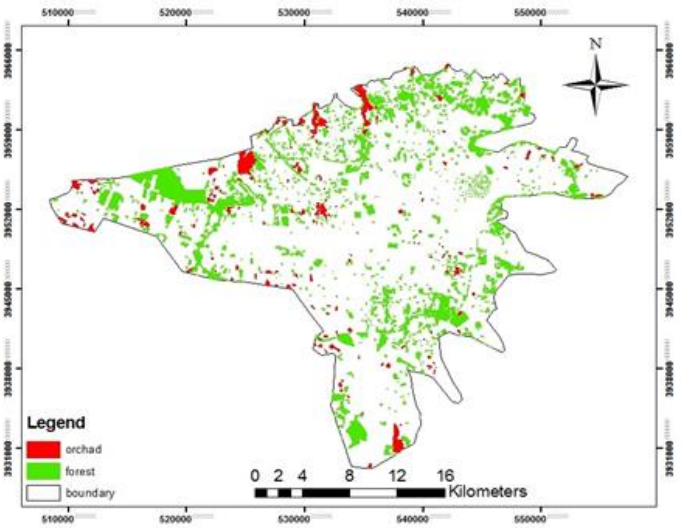

Figure 4- the map of forest green space in Tehran
(Source: GIS network of Tehran municipality)

Among these, the forest land needed to absorb the CO_2 produced from the metro transit system equal to 12428(gha) and that is nearly 0.37% of the total forest land required for the absorption the CO_2 produced from the transport systems. Whereas 13% of daily trips are done by Metro. In 2012, 814,320,000 trips were done by Metro and 17,755.5 tonnes of carbon, were produced in this transport system. Thus, 21.8 g of carbon was produced in each trip.

In 2012, the number of trips by road transport system, were equal to 5,449,680,000 trips and 5449680000 tons of carbon, were produced in this transport system. Thus, 871 g of carbon was produced in each trip. Therefore, the produced carbon, In each road trip, is forty times greater than any subway trip.

On the other hand, the average length of movement of each trip on the subway, Equal to 10 km and the average length of movement of each trip, in the road transport system Equal to 4.7 km. Therefore, the produced carbon in road transport system, per kilometer, is 85 times larger than the produced carbon in the Metro system.

The population of Tehran is 8250000. Thus, the energy footprint of Tehran transport per capita is equal to 0.4043 global hectares. If the forest land in Tehran is converted into global hectare area (gha) using Equivalence Factor, Tehran's total forest land would be 9664.2 (gha) and the per capita forest land in Tehran, considering the population of 8250000 people, is equal to 0.0011 global hectare and this amount points to the significant difference between energy footprint of transport sector per capita and forest land per capita of Tehran. Thus, Tehran has a deficit of forest land per capita required to absorb the CO_2 emissions from the transport sector by the value of 0.4032 (gha) and it is not able to absorb and isolate CO_2 produced in the transport sector and such pollution would spread in Tehran and surrounding areas and cause environmental problems. On the other hand, in the transport sector, major road infrastructures are being created which makes heavy use of personal vehicles and this leads to large amounts of fuel consumption and increase in CO_2 emissions. So if this trend continues, the gap between the per capita ecological footprint and biological capacity would increase and an intolerable effect would be created in Tehran and its surrounding environment. Based on the above, the development of Tehran's transport system is not compatible with the principles of sustainable development. In addition, the infrastructure of the city is not compatible with the principles of sustainable development. User distribution is designed in a way that there is a long distance between people's houses and office and commercial buildings

and people are forced to use motorized transportation system. The lack of affordable housing near the metro network and public transport networks has forced the low-income residents to live in the suburbs and the high-income residents who live near public transportation network would also use their private cars and would increase the fossil fuels consumption. Also, the design of sidewalks of Tehran is in the way that people are reluctant to walk and this makes them to use motor vehicles even for short distances.

Conclusion

The concept of the ecological footprint has attracted a lot of attention to itself as a useful indicator of sustainable development. Estimation of this can be regarded as an analytically useful method to estimate the total impact of various activities, including transportation and air pollution. This study investigated the sustainable development of transportation applying this index in Tehran transportation and found that the energy ecological footprint of Tehran is 3335580 global hectares and 12428 is devoted to metro footprint and 3,323,152 goes for road transportation. While, Tehran's biological capacity to absorb the carbon released in the transport sector is equal to 9664.2 and energy footprint of Tehran transportation is 345 times larger than the biological capacity and 46 times larger than Tehran's area and this points to crisis in Tehran's transport system .

Ecological Footprint can act as a powerful tool in studies regarding identifying potential sources of instability. In the field of transport, environmental impact of various fuels is an important factor in transportation planning and as can be seen in the results of these studies, the use of fossil fuels can have disastrous results on the environment. Therefore, the use of alternative fuels such as biofuels and electricity are among the main solutions to reduce carbon dioxide emissions in the transport system. Overall, in such conditions, for the development of sustainable transport system based on environmental criteria, a low-carbon transport, transit-oriented development (TOD), and the creation of Green corridor could be some tools for sustainable development in the transportation sector of Tehran.

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