JOURNAL OF PURE AND APPLIED MICROBIOLOGY, Nov 2015. Vol. **9**(Spl. Edn. 2), p. 495-504

Evaluating Sustainable Transportation of Tehran Applying Ecological Footprint Model

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(Received: 18 February 2015; accepted: 10 April 2015)

Sustainable city with sustainable transportation is becoming one of the main demands of citizens, especially in cities such as Tehran. While imbalanced development and unsustainable growth in all sections with the city's environmental capacity has led to intolerable conditions resulting in the degradation of the quality of life. Transportation in Tehran has become a major cause of environmental degradation with its massive CO_2 emissions in the atmosphere. The purpose of this study, in the first instance to improve the ecological footprint model of the transport sector, and then attempts to estimate the ecological footprint of Urban transport in Tehran. The results of the study showed that the ecological footprint of Tehran transportation is equal to 4398241.968 global hectares while Tehran's biological capacity to absorb the carbon released in the transport sector is equal to 9664.2 and ecological footprint of Tehran transportation is 455 times larger than the its biological capacity. 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.

Key words: Sustainable transportation, Ecological footprint, Transportation of Tehran city, Low carbon transport, Green corridor.

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. 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). While the thermodynamics teaches us that the earth is a planet with finite resources in which endless growth is impossible (Tiezzi, 1984). 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

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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 *et al*, 2000).

What is certain today is that urban sustainability is a form of modern development which guarantees sustainable development of cities and urban communities for future generations (Hall, 1993). In fact, the city will be stable when it benefits the habitable living environment, clean air, clean water, land and groundwater and surface water with no pollution and with lasting economic. Urban population in the mid-twentieth century was 30% of the total population; in other words, about 737 million of the world's 2.5 billion people lived in cities. This percentage rose to 47 percent in 2000 and in 2008, for the first time in human history, more than half of the world's population became urban dwellers. Projections indicate that the world's urban population will increase to about 5 billion in 2030, i.e. about 60 percent of the total world population and in 2050, the world's urban population will increase to about 6.4 billion people (UN, 2008). Comparing urbanization in developed countries with developing countries shows that in all the years, urbanization in developed countries has been more, but the acceleration of urbanization in developing countries was about 60 percent and it was equivalent to 8% in developed countries, in the period 2000-1970. In 2003, about 74 percent of the population in developed regions and 42% of the population in developing regions were urban dwellers. Interestingly, in this year, 40 percent of the urban population in developed countries lived in Small towns, whereas in developing countries this figure was 20 percent. It is anticipated that the proportion of urbanization in developed countries increases to 82% in 2030 from 74 percent in the mentioned year and the share of urban population in less developed countries over the same period increased to 57 percent from an amount of 42 percent. The population growth over the period 2003-2030, especially in urban areas of less developed countries, would be faster and would have an increase of about 3.2 percent (United Nations 2004: 1). In fact, one of the most important new demographic trends that is expected to make more change even in the future development is the rapid growth of urbanization in developing countries (Todaro, 2005).

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 *et al*, 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 *et al*, 2010).

The ecological footprint concept and practical framework

Ewing *et al*, 2010 said: 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 (as cited in Shayesteh *et al*, 2014).

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 CO_2 into the atmosphere (Shayesteh *et al*, 2014). Based on 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 (as cited in Shayesteh *et al*, 2014). Therefore, the amount of CO_2 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 purpose of this study, in the first instance to improve the ecological footprint model of the transport sector, and then attempts to estimate the ecological footprint of Urban transport in Tehran.

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.

METHODOLOGY

In this study, In order to calculate the ecological footprint of Tehran transportation, the model proposed by (Shayesteh *et al*, 2014) 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 (In the model presented by Shayesteh *et al*, only paved roads are considered).

The total area of land involved in the physical footprint is multiplied by equivalence factor to estimate the global hectare (Wiedmann *et al*, 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 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 (Shayesteh *et al*, 2014).

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 (as cited in Shayesteh *et al*, 2014). 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 *et al*, 2007). This estimate is multiplied by a carbon Equivalence Factor to estimate the area of forestland required to absorb the CO_2 emitted from fuel consumption in the study area (Wiedmann *et al*, 2007). The equivalence factor for Energy footprint is 1.26 (Ewing *et al*, 2010). (At this stage of the model provided by Shayesteh *et al*, only road transport is considered and metro system and electric power consumption in this system is not considered).

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.

RESULTS

Energy consumption in the transport sector of Tehran

Major fossil fuels consumed by vehicles in Tehran include compressed natural gas (CNG), gasoline and diesel. Also, the subway and trolley buses provide their 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 Statistical Center of Iran, is presented in Table 1.

The physical infrastructures of transportation network

The physical infrastructures of Tehran transportation network include Asphalted roads, subway and train stations, bus terminals, customs warehouses, parking lots, Car factories, car and subway repair shops, and asphalt factories. The area of such infrastructures was prepared by the organization of Tehran Municipality. The total area of land used for such purposes is 5364 hectares. The GIS maps of these applied lands are shown in Figures 2 and 3.

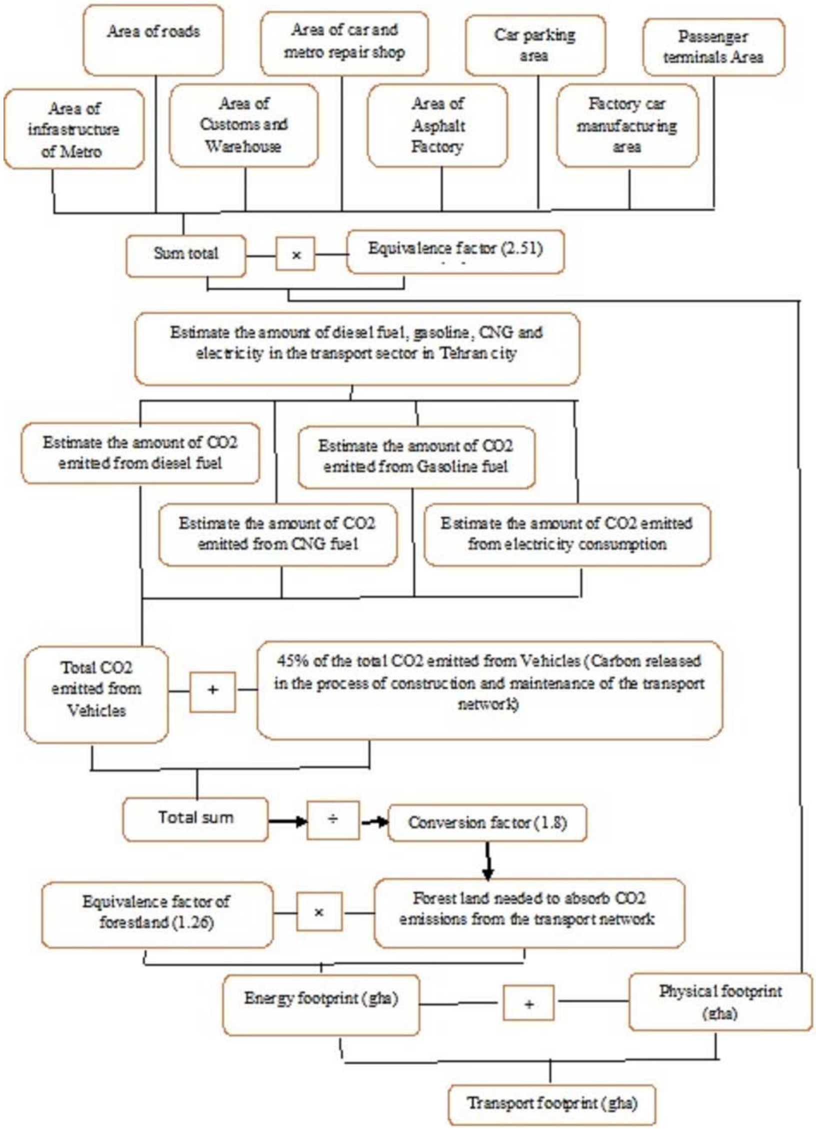

Fig. 1. Developed methodology for calculating the ecological footprint of transport

Calculating physical footprint

The physical transport footprint per capita is calculated using the formula (1)Formula 1:

$$Physical\ EF = \frac{\text{Total area devoted to } transportation \times \text{Equivalence factor (2.51)}}{\text{Number } of\ population}$$

The land devoted to infrastructure of transportation in Tehran is 5364 hectares and the population is 8250000 in 2012. Considering this, the physical transport footprint per capita in Tehran is 0.0016 and the total physical transport footprint is equal to 13463.64 global hectares.

Estimating energy footprint

The transportation sector of Tehran uses fossil fuels of CNG, diesel, petrol as well as electric power for supplying the energy of 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 *et al*, 2002). Unleaded gasoline would also produce approximately 125000 BTU per gallon which finally releases 19.35 tons of carbon per billion BTU (Pezzeta *et al*, 2002).

In addition, in per cubic foot of CNG, there is an amount of 0.0532 kg CO_2 (Climate Leader – EPA, USA, 2012). 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 *et al*, 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 2.

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 transport sector is equal to 3479982.8 hectares. This amount should be calculated in global hectares and expressed in

Table 1. Consumption of fossil fuels and electricity of transport network in Tehran in 2012; (Source: Statistical Center of Iran)

Total consumption of 2012	Consumption type
3641000000 (Lit)	Gasoline
1337000000 (Lit)	Diesel
16756493000 (cft)	CNG
370.9 (Gwh)	Electricity

Fig. 2. The map of Tehran roadway network (Source: GIS network of Tehran municipality)

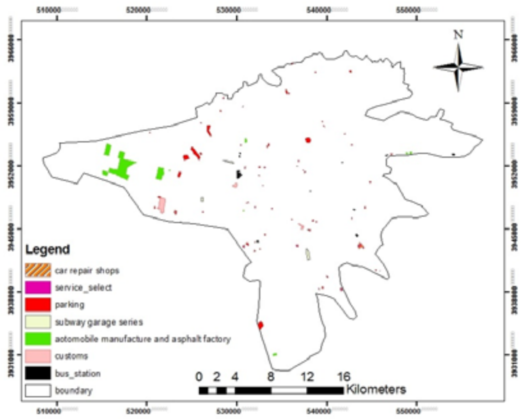

Fig. 3. The map of physical infrastructures of Tehran transportation network. (Source: GIS network of Tehran municipality)

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 transport sector is equal to 4384778.328 global hectares.

Footprint of the total transport network

The footprint of the total transport network is the sum of the physical footprint and energy footprint. Considering the fact that the physical footprint of Tehran transportation system is 13463.64 global hectare and its energy footprint is equal to 4384778.328 global hectares, the footprint of the total transport network is equal to 4398241.968 global hectares and considering the population of Tehran which is 8250000, the ecological footprint of Tehran transport per capita is equal to 0.5331 global hectare (gha).

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

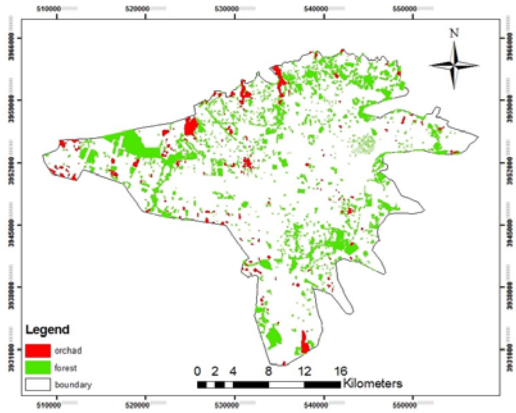

Fig. 4. The map of forest green space in Tehran. (Source: GIS network of Tehran municipality)

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 4).

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 CNG 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. 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, and have reduced the tendency of people to walk. Cycling is the non-motorized vehicle in Tehran and based on the latest

Table 2. The total CO2 produced by fossil fuels

Fuel	Annual use (cft or liter)	Tons CO2
CNG	16756493000 (cft)	891445.4
Diesel	353208464 (gal)	977350.78
Petrol	961878847 (gal)	2326544.46
Electricity	370.9 (Gwh)	180725.15
construction and maintenance	45% of the total CO2 emitted from Vehicles	1887903.288
Total tons of CO2	6263969.078	

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.

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 4398241.968 global hectares of forest area for absorption of CO_2 produced from the transport sector of Tehran. The population of Tehran is 8250000. Thus, the energy footprint of Tehran transport per capita is equal to 0.5314 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 0.5303 (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.

Recommendations for reducing the impact of transport systems in Tehran for Sustainable Development

• Pedestrian-oriented

Because of major difficulties in walking including lack of properly designed sidewalks, lack of adequate protection of pedestrians against climatic factors and threats that are done by motor vehicles, the air pollution and noise pollution in the streets, lack of appropriate plan to combine the roadway and pedestrian movement in the street, there is a daily decrease in the number of people who are willing to walk in the city and people prefer to travel the very short distances by car. This leads to increased traffic and increased CO_2 emissions. Widening sidewalks, mixing applications, making the passages suitable for different age groups, creating pedestrians access to the destination, creating luxury commercial centers adjacent sidewalks, guaranteeing pedestrian security, providing ample green space adjacent to sidewalks and making 24-hour shopping malls adjacent to sidewalks can encourage people to walk.

• Promoting non-motorized transport

Non-motorized vehicles (e.g. bicycles) do not use any fuel and thus do not have any carbon dioxide emissions. Using such equipment would increase health and safety of traveling and reduce traffic. They would produce little noise and greatly reduce human impact on ecosystems. Promoting the use of these devices can meet many of the principles of sustainable urban development.

• Innovation and exploitation of low-carbon transport systems

In addition to the use of non-motorized vehicles, efficient public transport and the use of non-fossil energy sources for vehicles and the combined use of fossil fuels and other non-fossil sources are two important aspects of low-carbon transport system. In Tehran, the majority believe in the excellence of using public transport but in practice, most people use private vehicles and this is due to the inefficiency of public transport system in meeting the demands of the people. Thus, there is a need for a management plan with improved accessibility and providing public services and reducing the cost of public transport to encourage all groups of people to use public transport. This planning would decrease the use of private transport, especially gasoline cars, which emit large amounts of CO_2 in the atmosphere. Therefore, fuel efficiency can be improved by the use of public transport.

• Non-fossil energy sources for vehicles and the combined use of fossil fuels and non-fossil sources

Electric vehicles (EV) can be used greatly in Tehran. Among such vehicle, one can refer to subway network, which provides its energy from electricity and this energy do not leave carbon dioxide in the movement of passengers; on the other hand, this energy has the capacity to carry a large number of passengers.

Another innovation can be the use of biofuels in Tehran's transport system. Biofuels are liquid fuels derived from biological sources, such as sugar, wheat, corn, rapeseed, soybean and palm oil. This material can be converted into liquid fuels that can be combined with gasoline or diesel or be used alone, or converted into gaseous fuels such as biogas (Labib *et al*, 2013). This type of fuel would reduce carbon emissions and reduce the resulting ecological footprint in the transport sector.

Hydrogen and fuel cells could be another solution to reduce carbon emissions from vehicles. In a fuel cell of a vehicle, hydrogen is split and combined with oxygen, it is used to produce car's electricity. The use of these new technologies to reduce carbon emissions and reduce dependence on fossil fuels can be a good solution for improving environmental conditions of Tehran.

Moreover, the imposition of a tax proportional to fuel consumption and raising prices of stops in the parking lots for private cars can be a good solution to reduce carbon dioxide emissions.

• Transit-oriented development (TOD)

Transit-oriented development (TOD) would reduce the CO_2 release by reducing reliance on private motor vehicles and increasing dependency on public transport facilities. High density and mixed uses near public transportation stations make people more dependent on public transport.

• Mixed uses

Mixed land use is necessary for economic efficiency. This will also lead to lower dependence to the transport system because little distance from home to the office or shopping centers in mixed use will increase the willingness of people to walk and reduce dependence on the transport system. So this leads to low CO_2 emissions. Urban planning policies should reduce the extent of land uses and encourage mixed land uses.

• Creating a Green corridor

Development of green Green corridor is a very new concept in transport system used in new developments of the reconstruction process. In Tehran, many new developments are in progress in the transport system. Now merging the Green Corridor with them is possible. Green Green corridor can create a buffer for new routes and it will be able to reduce the environmental impact of transport. So this has helped create a Green corridor to control carbon emissions and reduce our carbon footprint on the environment surrounding.

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 ecological footprint of Tehran is 4536099.26 global hectares and 13463.64 is devoted to physical footprint and 4522635.62 goes for carbon . 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 468 times larger than the biological capacity and 62 times larger than aTehran'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.

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