World Academy of Science, Engineering and Technology
International Journal of Energy and Environmental Engineering
Vol:13, No:4, 2019

The Carbon Footprint Model as a Plea for Cities towards Energy Transition: The Case of Algiers Algeria

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***Abstract*—**Environmental sustainability rather than a trans-disciplinary and a scientific issue, is the main problem that characterizes all modern cities nowadays. In developing countries, this concern is expressed in a plethora of critical urban ills: traffic congestion, air pollution, noise, urban decay, increase in energy consumption and CO_2 emissions which blemish cities' landscape and might threaten citizens' health and welfare. As in the same manner as developing world cities, the rapid growth of Algiers' human population and increasing in city scale phenomena lead eventually to increase in daily trips, energy consumption and CO_2 emissions. In addition, the lack of proper and sustainable planning of the city's infrastructure is one of the most relevant issues from which Algiers suffers. The aim of this contribution is to estimate the carbon deficit of the City of Algiers, Algeria, using the Ecological Footprint Model (carbon footprint). In order to achieve this goal, the amount of CO_2 from fuel combustion has been calculated and aggregated into five sectors (agriculture, industry, residential, tertiary and transportation); as well, Algiers' biocapacity (CO_2 uptake land) has been calculated to determine the ecological overshoot. This study shows that Algiers' transport system is not sustainable and is generating more than 50% of Algiers total carbon footprint which cannot be sequestered by the local forest land. The aim of this research is to show that the Carbon Footprint Assessment might be a relevant indicator to design sustainable strategies/policies striving to reduce CO_2 by setting in motion the energy consumption in the transportation sector and reducing the use of fossil fuels as the main energy input.

***Keywords*—**Biocapacity, carbon footprint, ecological footprint assessment, energy consumption.

I. Introduction

ANTHROPOCEN is identified as a new geological epoch in which mankind holds the ultimate responsibility for altering Earth's biogeochimical cycles. Across the world, urban areas are considered as a hot spot of production, consumption and waste generation [1]-[3]; in fact, cities are responsible of releasing 80% of GHG, of which 70% is carbon dioxide (CO_2) [4]-[9] which directly affects the global climate system and causes the climate change phenomenon. For instance, CO_2 emissions are associated to the combustion of fossil fuels such as coal, oil and natural gas for producing electricity, heating houses, land use changes, public and private transportation, commercial activities and industrial processes. As a consequence, worldwide urban areas are characterized by the same environmental issues, especially MENA region countries which are experiencing several urban problems such as: traffic congestion, air pollution, noise, reduced quality of urban environment, increase in emission of greenhouse gases (GHG) which might dramatically threaten the health and welfare of citizens.

According to the International Energy Agency (IEA), the transport sector accounts for 23% of global energy related emissions in 2010 [10], [11]. In 2014, transport was responsible for 25% of GHG emissions [12]. Road transport, in particular, was responsible for 20% of those emissions. Thereby, the transportation sector is a highly relevant field to endeavor mitigation actions given the fact that it is responsible for nearly a quarter of global primary energy use and greenhouse gas emissions [13], because mainly 95% of overall transport's typology are dependent on fossil fuels (oil) [4], [14]. However, a myriad of cooperative initiatives and actions have been trigged across the world to minimize GHG emissions from the transportation sector such as the C40, the Cities Clean Bus Declaration, the Urban Electric Mobility Vehicles Initiative (UEMI), the International Union of Railways (UIC) Low-Carbon Sustainable Rail Transport Challenge (LCSRTL), and the International Association of Public Transport (UITP) Declaration on Climate Leadership (DCL) pledging to decarbonize the transport sector.

World cities, especially in the Mediterranean region, where environmental problems take on a new dimension characterized by an ecological deficit on a multiple scale from local, meso to macro [15]. In addition, MENA countries are experiencing severe environmental sustainability issues. However, the current "*environmental problems*" could be apprehended by two types of factors (Fig. 1); on the one hand, a set of factors that determine the upgrade trend such as: energy consumption, CO_2 emissions, urbanization level, and on the other hand, a set of factors that determine the degrade trend such as: GDP per capita, biodiversity and ecological assets loss. As a consequence, countries with the same trends also face similar socioeconomic inequalities. As such, the MENA region must adopt several stringent environmental policies/strategies in order to minimize their ecological overshoot.

The transportation system in Algiers is primarily qualified as "*anarchic*" [17], as it is mostly dominated by private cars [18]. In addition, private vehicles are experiencing a notable increase in use over the last decade of an average one car per four people, and this trend is expected to grow in the coming years. In fact, one of the most encouraging factors is the

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lowest fuel price, given that Algeria is the third oil producer in Africa. Despite that, public transport could be a relevant solution to minimize anthropogenic emissions. Nevertheless, to accommodate the negative externalities generated by private transport in Algiers, the government and territorial stakeholders provide multiple platforms of sustainable transport typologies such as metro and tramway, alongside the train in the city and enforcing the existing bus network. Despite all this effort, public transport could not keep up with the rapid urbanization which highlights several urban planning instrument failures (Plan Directeur d'Aménagement et d'Urbanisme and Plan d'Occupation des Sols) which have led to urban sprawl. Regardless of this issue, the Algiers public transport network is unable to meet the plurality, nor the diversity of the modes of its users.

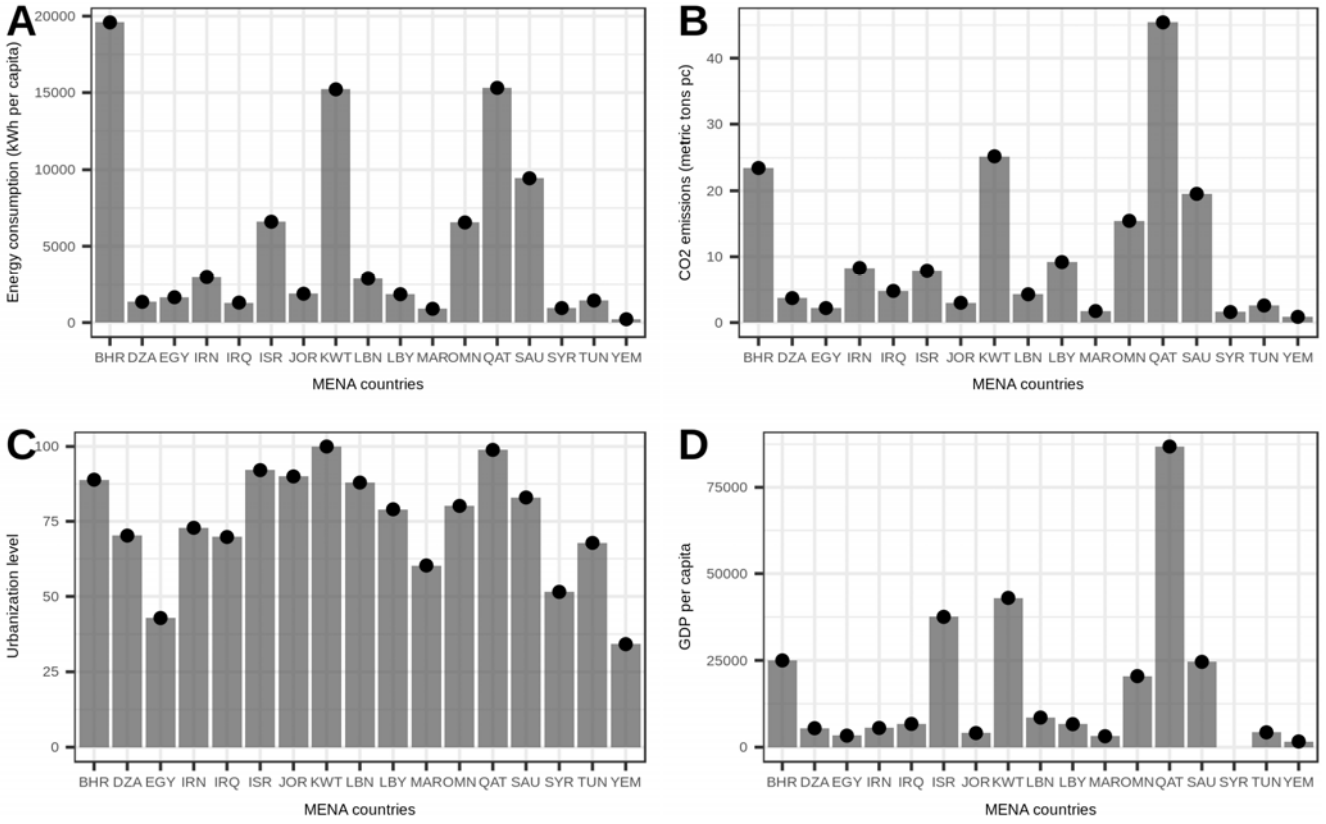

Fig. 1 (A) represents energy consumption, (B) represents CO_2 emissions per capita, (C) represents urbanization level and (D) represents GDP per capita for MENA countries; source of data [16]

II. Ecological Footprint Assessment

The ecological footprint is an assessment based on biomass resources accounting, aiming to keep track of the human demand on natural supply of biosphere (raw materials and sequestration of carbon dioxide emissions) [19]-[25]. This concept was introduced by William Rees and Mathis Wackernagel in 1996 at the University of British Columbia, Canada [20]. This assessment is associated to six types of ecosystems: cropland, grazing land, fishing grounds, forest land, built-up, and uptake land for carbon assimilation. As such, it can be used to provide quantitative assessment of the two principles of sustainability determined by Daly in 1990 [26], [27] which are: *(i) consumption of natural resources by human kind should not exceed the earth's regenerative capacity and (ii) waste emission should not exceed the natural assimilative capacity* [23], [28]. The EFA is one of the tools that can determine the ecological deficit, also referred as *'biocapacity deficit'* or *'Overshoot'* [19], [29], by comparing two indicators, the ecological footprint and the biocapacity of a region. Furthermore, this accounting tool offers a benchmark in order to compare the human demand, and it is as applicable on a single product as to the world as a whole [30], alongside, providing quantitative information on biosphere and ecosystems accounting; as such, it could help decision makers to redesign and reshape the environmental aspect [24], [31]-[34]. The EFA is mostly used in order to recognize that most developed world cities are operating beyond the Earth's ability to regenerate resources. Usually, the ecological footprint methodology fit consists of two main approaches. The first is Top-Down (compound). This approach operates on large scales and evaluates major trends, without specifying or detailing its segments, and uses general data which are driven from global data bases (i.e., energy consumption data on a global scale from the IEA [35]; World Bank [36]; or categories of consumption via Multi-Regional Input-Output (MARIO) tables, which are themselves based on the current data of materials and energy flows. This approach could make a comparison between different countries, regions, cities and offering general guidelines for reducing the ecological footprint). The second approach is Bottom-Up (component). This approach in an information processing based specified data relative to the studied subsystem. This approach is operated at finer scale levels such as: city, neighborhood. It projects the local situation in a pragmatic and scientific way by providing concrete actions and steps to be easily understood and accepted by local authorities. Nevertheless, it requires large resources, intensive data and it require more time for analyzing and processing data compared to the Top-Down approach [37], [38].

Within the Ecological Footprint methodology, the Carbon Footprint is defined as the amount of the *'area equivalent'* required to sequester the carbon dioxide emissions (CO_2); it is calculated as the area of world-average forest land that would be required to take up emissions at the same rate at which they are produced, after subtracting out a percentage due to sequestration by the ocean [22]. In fact, the carbon footprint model deals with the waste part of the Ecological Footprint assessment and is used as a quantitative and a comprehensive method for determining the quality of the system to which it is applied. However, as has been mentioned by Mancini in 2016 [39], the carbon footprint does not aim to answer how many trees should be planted to offset carbon under various scenarios (e.g., reforestation) but rather aims to calculate the amount of forest area needed in each year to sequester the actual anthropogenic emission for that year given the actual forest situation (i.e. forest surface, biomass growth) of that year. This method is important for decision making in order to operate mitigation and adaptation actions to help cities develop resilience against climate change and build a new path towards environmental sustainability.

A. Review of Existing Transport Carbon Footprint Assessment

Many studies have been done to determine the carbon footprint of vehicles around the world such as those mentioned in Table I.

TABLE I
EXISTING TRANSPORT CARBON FOOTPRINT ASSESSMENT

Country	City	Year	Emissions sources	Methodology	Inventory framework	Authors
Caribbean	Puerto Rico	2007	(i), (iii)*	Top-Down	Calculating CO_2 emissions released to the atmosphere from consuming per KWH of each fuel considering a wide range of transportation typologies: road transport (private cars, trucks, buses and motorcycles), rail, air and marine transport.	[40]
Great Britain	National level	2003	(i) (ii)	Bottom-Up	Air and rail transport, metro, buses, cars, motorbikes and scooters, and infrastructures.	[41]
Australia	Adelaide	2006	(i), (ii)	Bottom-Up	The use of private vehicles like cars and trucks, motorcycles, buses, rail and air transport and passenger boats.	[42]
Iran	Tehran	2016	(i)	Bottom-Up	Considering the amount of diesel fuel, gasoline, CNC and electricity in the transport sector in Tehran city.	[43]
Finland	City of Jyväskylä	2016	(i)	Bottom-up	The study shows that library deliveries can be crow-sourced through *PiggyBaggy* delivery service. Results shows that each crow-sourced delivery reduce an average of 1.6 km driven by a car which leads eventually to a significant reduction in the total carbon footprint.	[44]
Spain	A set of municipalities located in the south of the province of Madrid	2015	(i)	Bottom-Up	Considering the ecological footprint of heavy and light vehicles, in order to allow implementation of preventive measures based on urban planner decisions and not on individual behaviors.	[45]
Switzerland	National level	2010	(I),(iii)	Bottom-Up	Transport's carbon footprint of tourism, considering: cars, train, bus, boat, ship, motorbike, bicycle and air travel. The aim of his work is to identify the types of travel situations in which tourists make environmentally friendly choices considering travel mode.	[46]
Spain	163 Municipalities of the Barcelona Metropolitan Region (BMR)	2005	(i)	Bottom-Up	Ecological footprint of transport considering cars, motorbikes, trains, buses, etc.), construction and maintenance of transport infrastructures (roads, railways. . .), in addition to the land occupied by the Transport infrastructures	[47]

*According to Lazarus [48], NFA considers three sources of CO_2 emissions from anthropogenic activities which are derived from International Energy Agency [35]: (i) emissions from fossil fuel combustion by country and economic sector; (ii) emissions from non-fossil fuel sources; (iii) emissions from international marine and aviation transport, named "bunker fuel".

III. METHOD AND MATERIALS

A. Study Area and Data Resource

Algeria, as one of the Mediterranean countries, is considered as a debtor country that experience many environmental issues. According to the Global Footprint Network, in 2013 Algeria was operating with a biocapacity deficit of -1.8 gh, in which the country required 1.4 Earths or 4 times the country's surface—given the fact that Algeria is the biggest country in Africa—in order to satisfy its demand. The present research focuses on Algiers, the capital of Algeria, as it constitutes the biggest city of the country with a population of 3,154,792 covering an area of 1,190 km², and a density of 3,900 habitants/km².

In order to calculate the carbon_EF, data were collected from APRUE, while to determine Algiers' biocapacity, data were taken from DFCV of Algiers.

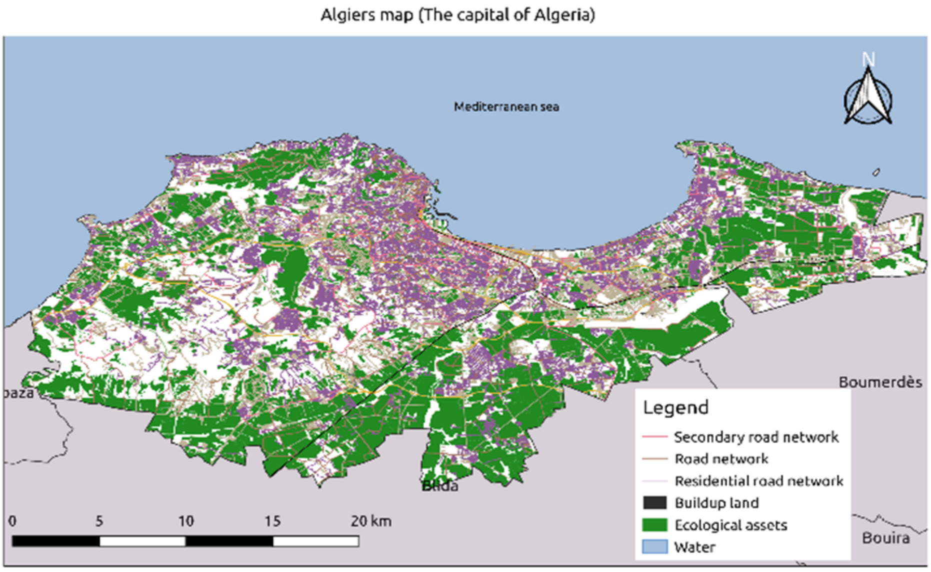

Fig. 2 Map of Algiers (the capital of Algeria), source of data [49] and local data from DSA and DFCV of Algiers

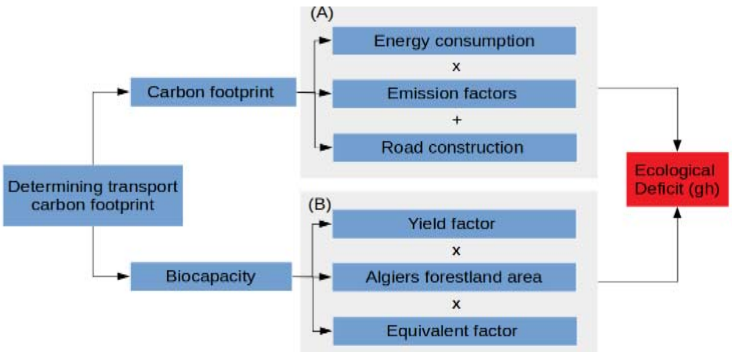

Fig. 3 The methodology adopted to calculate Algiers' transport overshot

B. Method

The carbon footprint tracks the demand for biological productive land (forest land or CO_2 uptake land) areas in order to sequestrate the anthropogenic carbon dioxide (CO_2). Both the emissions and the land area required are expressed in global hectare -gha- (or hectare-equivalent units), which represent hectares with world average biological productivity [23]. However, notice that the present method is following the recent carbon_EF method which has been refined by Mancini [39].

We calculated the carbon_EF as mentioned in (1).

$$EF = \left(\frac{Ti}{Ywi}\right) * EQFi \quad (1)$$

where: P_C: is the world's annual anthropogenic emissions of carbon dioxide measured in Mt CO_2; S_{OCEAN}: is the fraction of anthropogenic CO_2 emissions sequestered by oceans in a given year. The oceanic uptake fraction for the year of 2010 is 28% according to [38], according to research by [50]. EQF: Is the equivalence factor used to weight forest land. The current GAEZ-based method assigns forest land a value of 1.26 (indicating that a hectare of world-average forest is 1.26 times as productive as world average hectare of land); Y_w: is the annual rate of carbon dioxide sequestration per hectare of world average forestland; AFCS: is the average forest carbon sequestration, expressed in t C $ha^{-1}yr^{-1}$. For instance, the AFCS is calculated as in (2):

$$AFCS = \frac{NFP}{AF} \quad (2)$$

The biocapacity [48], [51], in the context of the carbon footprint is calculated as in (3):

$$BC = \Sigma Ai * YEFi * EQFi \quad (3)$$

where: Ai: represents the estimated bio-productive area that is available for the product i at the national level; YFi: is the nation-specific yield factor for the production of product i; and, EQFi: is the equivalence factor of the land producing each flow i.

In order to determine the ecological overshoot of Algiers transportation system, we used the methodology mentioned in Fig. 3.

IV. Results

Algiers' carbon footprint:

TABLE II
CO_2 Emissions and Carbon Footprint of Algiers

Sector	Energy consumption (Tep)	Carbon emissions (t CO_2)	Energy's carbon footprint
Transport	813591.89	1998644.3	193713.50
Residential	398819.55	979727.6	94957.61
Industry	191433.38	470269.3	45579.66
Tertiary	143575.03	352701.9	34184.74
Agriculture	47858.34	117567.3	11394.91
Road construction and maintenance	45%	899389.9	87171.07

The results (Figs. 4 and 5) show that transport's energy footprint represents 51% of Algiers' total carbon footprint, after the residential sector (25%) and industry sectors (12%). These results emphasize that Algiers' transport system is not sustainable. These results (Fig. 5) show that Algiers' forest land is not playing a leading role in sequestering the anthropogenic carbon emissions. In fact, Algiers' forest land areas are compromised each year for the benefit of urbanization. This result highlights that Algiers is experiencing a deficit of forest land, which explains that the city is facing a loss of biodiversity, both fauna and flora.

TABLE III
Biocapacity of Algiers

	Forest area (ha)	Yield factor (YFi)	Equivalence factor (EQFi)	Biocapacity (gh)
Values	492 7.71	0.44	1.29	2796.96

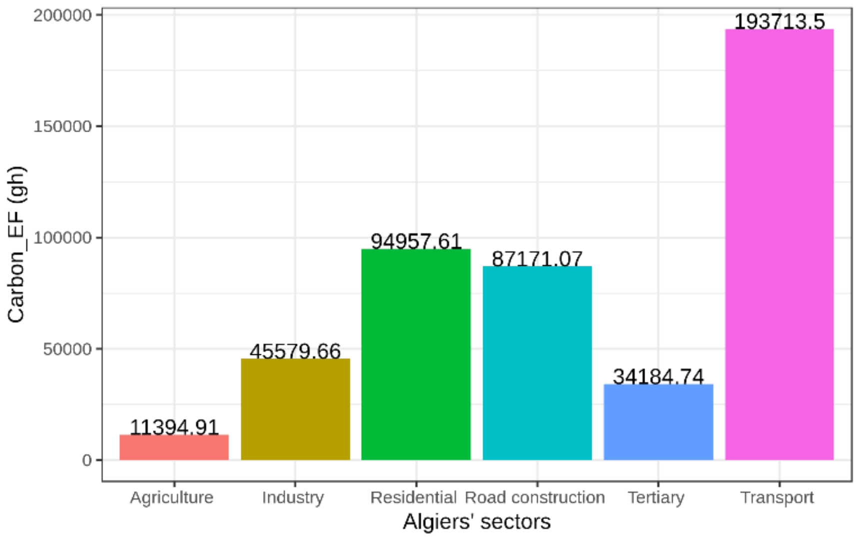

Fig. 4 Algiers' ecological carbon footprint per sector

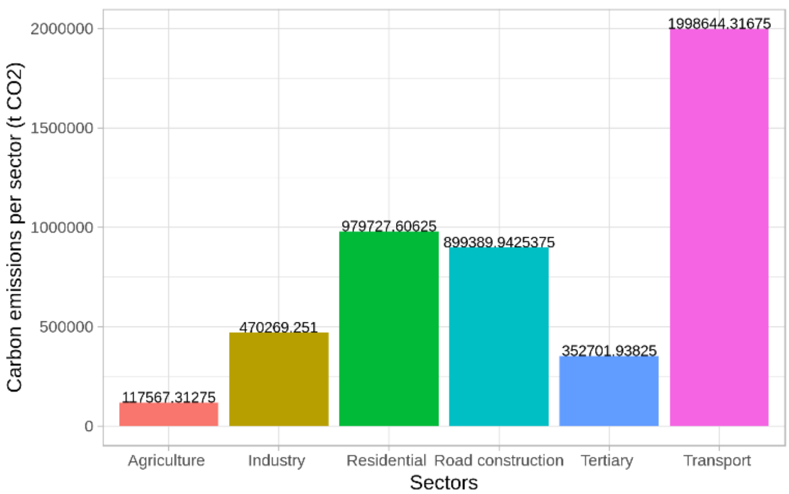

Fig. 5 Algiers' carbon emissions (CO_2) per sector

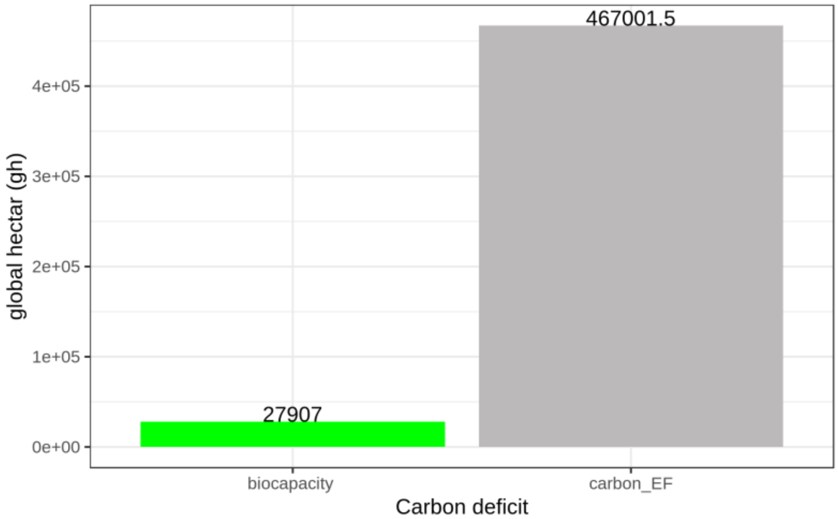

Fig. 6 Algiers' carbon footprint versus biocapacity

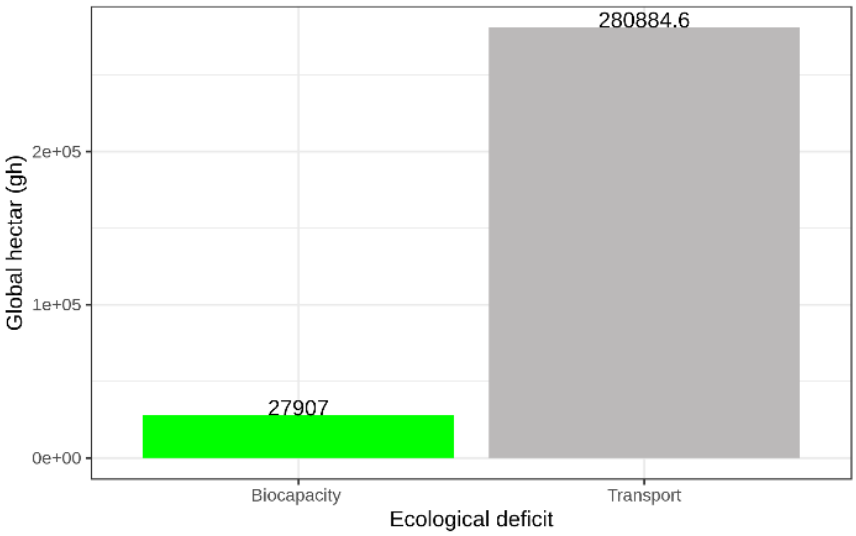

Fig. 7 Algiers's total carbon footprint inventory versus total biocapacity

V. Discussions

It is clear that, according to the ecological footprint philosophy, cities should increase and upgrade their ecological assets in order to achieve sustainable development policies. The results of this study show that Algiers carbon footprint exceeds the CO_2 uptake land capacity by 16.73 times. This critical situation shows that Algiers is operating beyond it carbon budget (27,907 gh). However, transport systems represent 51% of the total city carbon footprint. In fact, this sector is operating with – 439,094.5 global hectares of biocapacity deficit. Nevertheless, in order to sequester all transport CO_2 by forest land, it will require forest land area equivalent to 822,765.2 ha; this supplementary area represents 10 times its actual area.

VI. Conclusions

As long as the environmental problems are ubiquitous in the world, humanity must minimize its anthropogenic signatures on nature. The current study is based on comparing two indicators (i) *carbon_EF* of Algiers urban transport and (ii) Algiers' *biocapacity*. The aim of this research is to determine the ecological deficit (carbon component) of Algiers, which local authorities could use to design new urban planning instruments based on transportation networks, because setting strategies for urban development should be based on some key parameters that belong to the urban decision and urban land use and not on the individual behaviors or lifestyle patterns.

On a local scale, Algeria was among developing countries in the world that pledged to reduce its anthropogenic signature during the COP 21 in Paris; nevertheless it is efficient if the local mitigation actions focus on the transportation sector given the fact that it represents 51% of emissions of CO_2. However, this study also reveals that forest land in Algiers is playing a minor role in sequestering the city's carbon dioxide emissions. Nevertheless, to live within the Algiers' carbon budget, the transport system must adopt a plethora of strategies. Several suggestions might be taken into consideration:

- Reduce the presence of private vehicles by increasing fuel prices and introducing a schema of urban replacement;
- Increase the efficiency of public transport, especially tramway, metro and trains by expanding the actual transportation lines;
- Introduce and encourage using bicycles as a green transportation;
- Exclude old cars;
- Increase Algiers' ecological assets (forest ecosystems);
- Encourage redesign and reshape of buildings to include garden roofs and plant more trees in streets;
- Extend public transport network to serve the new urban centralities;
- Design new urban planning tools based on Transit Oriented Development and local carrying capacity.

ACKNOWLEDGMENT

The authors would like to think the APRUE agency for data availability about Algiers' energy consumption.

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