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Evaluating City Carbon Carrying Capacity: How many people can Algiers sustain?

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ABSTRACT/RESUME

Abstract: *The current study sets to determine theoretical paths in order to balance Algiers CO_2 emissions with city's carbon sink capacity by i) calculating carbon sink potential (forest land, wetlands, soil and technology) and ii) calculating Algiers' carbon emissions considering territorial emissions (Scope 1 and 2) within Algiers' administrative boundaries. The analysis shows that Algiers carbon emissions (estimated to 392 9243 t CO_2) exceed the city carbon sink capacity (estimated to 157 4044 t CO2) by 1.5 times. Thus, per capita carbon emissions in Algiers for the year 2016 were estimated to 1.24 tones CO_2/y composed by 0.84 tones CO_2/y (67.7%) from the combustion of fossil-fuels and 0.39 tones CO_2 (31.4%) from the consumption of electricity. This study exhibits that to live within Algiers' carbon budget, urban policy-makers should endeavour three major paths to accommodate Algiers'carbon deficit: either i) to limit Algiers's population to 1 268 963 inhabitants –that means 1/3 of Algiers' current population size-. ii) increase Algiers's ecological assets area to 36 709 ha. Or iii) introduce and generalize decarbonized energy for residential and transportation sectors which represent the main driving sectors for CO_2 emissions as they emit respectively 25% and 51% of Algiers total CO_2 emissions. City-level carbon emissions inventory can help to introduce cities with developing economies, such as Algiers, into the global climate issues and suggest solid recommendations for shifting current urban models towards a more sustainable urban planning intricately linked to sustainable forest management.*

I. Introduction

Within the Anthropocene, humankind represents the main driving force for shifting Earth's geological epoch from Holocene to Anthropocene at frequencies and scales unprecedented for any other species nor natural catastrophes [1]–[7]. Indeed, our modern world is defined by two trends, nature-trend in which global biodiversity, environment security and ecological assets are sharply decreasing [8]–[11], and an anthropogenic-trend in which economic activity, urbanization level and population size are intensely increasing [12]. These polar-trends reflect -without any scientific schism- the degree in which recent society's lifestyle patterns and consumption behaviours are causing multi-scalar environmental distortions [13], [14]. Since the beginning of 1970s, Homo sapiens started to operate beyond the Earth's biophysical limits leading to a massive multi-scalar supply-demand chain shortage, according to the Global Footprint Network [15], it would take 1.7 Earths to sustain the current world's socioeconomic metabolism. Unfortunately, there is only one Earth on which humanity is invited to thrive within its safe operating space [16]–[19]. Because -as it has been mentioned before by Hardin in 1968 - "Space" is no escape [20].

Nowadays, cities occupy only 3% of the Earth's land surface [21] and they contain more than half (55%) of the world's population [22]. Correspondingly, urban areas are the main source of production, consumption and waste generation [23], [24]. They are responsible for 66% energy consumption produced in the world [25] and releasing 80% of overall GHG [26]–[28], of which 70% is CO2 [29], [30]. Modern cities are also inspected as ecological debtors, where the human final demand is exceeding the environment's regenerative and supply capacity for providing natural resources and absorb wastes. Furthermore, in an era of resource scarcity, the "ecological deficit" or "overshoot" can apply a significant effect both on society's well-being on the demand side and nature on the supply side by leading critical ecosystems into collapse [31]. In fact, future cities will be defined as wealthiest or poorest in terms of their ecological assets as cities that relay substantially upon abroad ecosystem services will become exceptionally vulnerable compared to cities that just balance or export their ecological services. Moreover, easy access to ecological services will be a core element for contemporary societies to narrow poverty, hunger, and diseases [31]. Despite the disruptive aspect of cities, they also offer an opportunity for renewal, regeneration, remodelling, and reconstruction by acting simultaneously on several sectors known as the sustainability multipliers. Because indeed at city scale-level we can manage densities, optimize energy and raw material flows, where population size can be monitored and controlled and transportation modes can be substituted particularly in emerging and developing cities of Africa, Latin America, and South-East Asia which are experiencing the highest population growth rates in the world (Fig. 1). As a result, cities can be positive artefacts.

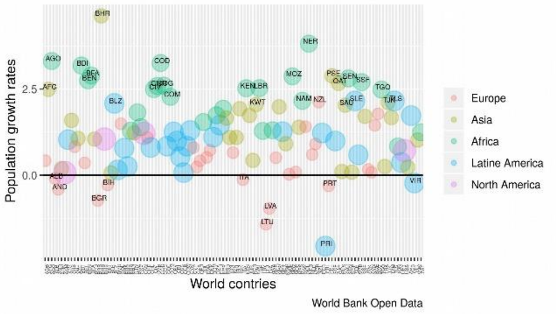

Figure 1. World population growth rates. The figure is based on World Bank Open Data and was created in R using ggplot2 package.

Luckily, as the overshoot is not inevitable, the current study aims to explore whether Algiers lives in a state of "carbon equilibrium", in other words, the ecological performance Algiers' will be evaluated to have the first glimpse on the main key-drivers for carbon deficit by estimating i) Algiers carbon dioxide emissions within the city's administrative boundaries and ii) carbon sink capacity using the City Carbon Carrying Capacity framework for a one-year time frame (2016), as specific data were not available for establishing a time series results, analyzing and forecasting Algiers' carbon carrying capacity trends. In 2016, Algeria had a total per capita ecological footprint of consumption estimated to 2.4 gha, with a per capita carbon footprint of 1.4 gha (58% of Algeria's total ecological footprint). Meanwhile, total per capita biocapacity was estimated to 0.5 gha, as such Algeria was operating with a total per capita ecological deficit of 1.9 gha, and we assume that this overshoot has been expanded over the past four years. Likewise, to balance the full final demand for Algeria from different ecological services, it required near to 4.5 countries [32].

Not surprisingly, many developing countries with a developing economical structure may get trapped in the misconception of, economically speaking, those who act first for climate might be in a competitive disadvantage (especially for large economies: China, India, and Brazil) and also, they may question the full access to the "right for development". However, we highly believe that the opposite is systematically true, as developing economies should guide their economic growth with the current climate circumstances as an opportunity to better shape their climate-friendly future with less resources cost economies and design greater coping capacity against demand-supply perturbations.

The novelty of this study is that it provides the first insights on the main key-drivers for Algiers urban carbon emissions using City Carbon Carrying Capacity (C4) framework which allows consistently to trigger promising carbon emissions reduction strategies especially for transport and housing and also highlights that Algiers' ecological assets are in constant decline. Results for carbon inventory, carbon sink, and carbon overshoot are reported in t CO2/yr. Finally, a plethora of operational actions and leverage points to stimulate local-climate-friendly policies are discussed by double-focusing on carbon sources and carbon sinks.

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I.1. Literature review on environmental carrying capacity: The struggle for a stable biosphere against the great imbalances of our modern world

The concept of carrying capacity has known many revolutions since the end of the 1680s. The concept supposes existing thresholds in the biosphere, it reflects the ability of natural ecosystems to sustain a determined number of human/animal population that can be supported by a given region without causing any environmental degradation [33]. The carrying capacity framework aims to quantify the two sustainability principles defined by Daly [34], [35] which are (i) *"the consumption of natural resources by humankind should not exceed the earth's regenerative capacity"* and (ii) *"the waste emissions should not exceed the natural assimilative capacity"*. Nowadays the carrying capacity assessment became one of the centrepieces in defining socio-economic and socio-spatial development.

The history of *"carrying capacity"* is very rich. Starting in the field of ecology to study plants and animals population, in which the term is defined as *"The number of individuals in a population that the resources of a habitat can support; the asymptote, or plateau, of the logistic and other sigmoid equations for population growth"* [36], after the worldwide recognition of the concept, was, therefore, transposed to human population, in which scientists test a plethora of factors to determine human population size (food, water, pollution...etc). Nevertheless, after transposing the term from ecology to human societies, it became more volatile and primarily constituted by demographic factors (births, deaths, age structure, migration, marriage). The term has known huge notoriety and it has been used many times to evaluate the world's population limit. The first use of the concept goes back to 1679, on April 25, in Holland, the inventor of the Microscope Antoni Van Leeuwenhoek, wrote down what could be the first estimation of how much people can Earth support, the author proclaimed that the biosphere could contain 13.4 billion people with a density of 120 people per 1 Km². Later, in 1695, Gregory king stated that the Earth could sustain only 12.5 billion people. After a decade, in 1765, Johann Peter Sü Ssnilch compared his own finding (13.9 billion) with the finding of Van Leeuwenhoek, and Sébastien le Prestre de Vauban (5.5 billion) and Thomas Templewan (11.5 billion) to examine the elastic hospital capacity of the Biosphere.

However, according to the recent literature review, many authors declaim that the first use of the concept in humankind population was introduced by Malthus in 1798 [37, p. 196] in his *"An Essay on The Principle of Population"* in which Malthus argues that world human population is growing geometrically, on the other hand, natural resources are generated linearly, as such, resources will not be sufficient in the future for human survival. After nearly 200 years, the term has known a sharp rise in the scientific literature. In 1966, Buildings argued that the current humankind cannot continue to grow beyond the planetary boundaries and on a finite closed-system, this idea was carried till the end of the 1980s by Garrett Hardin which the end of the 1960s- [20] the author emphasizes on the same idea in his *"tragedy of the commons"*. Later, the publication of Odum's textbook *"Fundamentals of Ecology"* [38] in which the author defined the term as *"the upper bound beyond which no major increase can accrue"*. At the beginning of the 1970s, particularly in 1971, the neo-Malthus equation was introduced to scientific literature known as IPAT (I: human Impact, P: Population, A: Affluence per capita and T: Technology), IPAT reveals the human impact on Earth's ecological support-system [3], [39], [40]. After one year, the famous MIT report of *"Limits to Growth"*, in which a hypothetical model was developed bringing together complex and interdependent forces that affect human population size on Earth by introducing five variables which have been considered as a reference in human carrying capacity. After 18 years, Aldo Leopold reintroduced the term *"human carrying capacity"* in 1987, in his textbook *"Game Management"* [41], in which Leopold argues that there is some difference between saturation level and carrying capacity. After one year, Dhondt [42] argues that the human carrying capacity can be attributed back to Hadnen and Plame (1992). Despite the semantic confusion and term chronology-use, it's widely recognized that the term was introduced into the scientific literature by Aldo Leopold in 1933.

The evolution of the term *"human carrying capacity"* can be amalgamated into three major scientific approaches' evolution that contributes to the recognition of the term: (i) Ecological services-based inventories (i.e., Ecological Footprint, Ecological Rucksack…etc.), (ii) Thermodynamics laws [43]–[45] and (iii) Planetary boundaries (Pbs) framework [18], [19]. It is important to highlight that three factors that affect the carrying capacity that all the previous literature agreed upon which are: (i) Extrinsic environmental conditions (ii)

Specific time frame and (iii) Human innovation and technology.

Given the full-complexity of carrying capacity assessment, many scientists provide a plethora of different methodologies that can be operated on a small-scale to a large-scale area (Fig. 2). Nevertheless, it is important to stress that in the previous researches, setting population limits was primarily based on the capacity of the environment to regenerate resources (supply capacity), and during all these years the assimilative capacity of the environment has been ignored (and still considered as a common) until various interdependent modern environmental crises became ubiquitous such as climate change, plastic pollution, freshwater scarcity, by which several national and international, multilateral and bilateral actions are pledged to minimize humanity footprints.

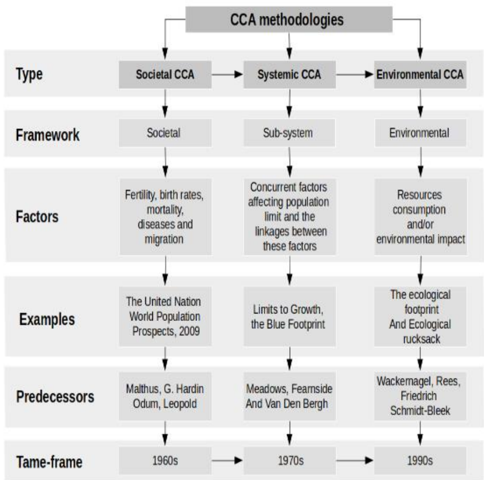

Figure2. *Evolution of carrying capacity assessment methodologies.*

I.2. City Carbon Carrying Capacity (C^4) Assessment

The biogeochemical carbon cycle is a multi-process phenomenon that makes Earth capable of sustaining life being [46], it's closely related to Nitrogen (N), Phosphorus (P), Sulfur (S), Oxygen (O_2) cycles and to other bio-essential elements, in which the carbon atom is exchanged along the i) biomass, ii) pedosphere, iii) hydrosphere and vi) atmosphere [47]. The carbon exchange chain occurs as a result of various chemical, physical, geological and biological processes. However, each carbon pool detains a limited capacity of carbon sink (for instance, Atmosphere: ~720 gigatons; Ocean: ~38 400 gigatons; Biosphere: ~2000 gigatons). As such, modern societies should live within the environmental carbon budget to maintain biosphere integrity [48]. Likewise, carbon sink capacity could be a relevant limitation factor for *"urban growth"*, particularly in the developing countries with a developing economy where almost 66% of the global population's growth occurs (especially in Africa) [49] as it contains the highest population growth rates (average population growth rates: Africa: 2.28, Asia: 1.42, Latin America: 0.86, Europe: 0.54) [50]. City carbon budget could represent a consistent approach for designing new effective urban planning tools and reinforce existing strategies for enhancing the urban ecosystem's resiliency against climate change and biodiversity loss. The C^4 is an environmental-based carrying capacity assessment that focuses primarily on comparing two key processes of sustainability second law [34], [51] by determining how many people could be sustained by a city (i.e., city and its urban region/hinterland). Therefore, City Carbon Carrying Capacity is a composite indicator that compares the ability of natural and technological carbon sink potential and cities' direct carbon emissions (Scope 1 and 2) using t CO_2/y metric. The idea behind the City Carbon Carrying Capacity is to i) Create a local benchmark tool, which can in return increase city competition to cut urban carbon emissions. ii) Implement new targets for restoring cities' ecological assets and iii) Monitor urban growth phenomena by double-focus on anthropogenic and environment components given the fact that the boundaries advocated by the C^4 are not targets that should be reached, but rather they act as an upper threshold that should not be transgressed.

II. Materials and methods

II.1. Study area

The research presented in this paper sets out to assess City Carbon Carrying Capacity (C^4) of Algiers (capital city of Algeria) (Fig. 3) which contains approximately 9% of Algeria's population [52] on 0.049% of overall country's land area and with a total energy consumption of 15%. As such, it is relevant to know whether the environmental component of Algiers could sustain the current population size and its current socioeconomic metabolism profile.

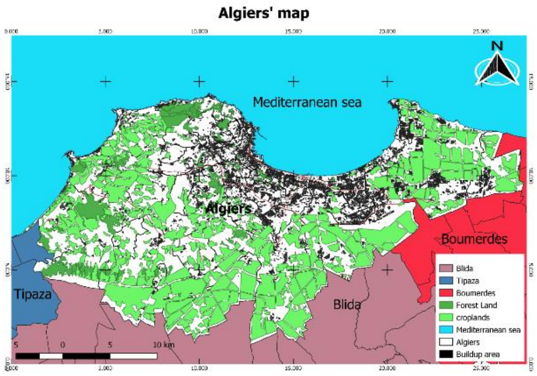

Figure 3. *Studied area: Algiers (capital of Algeria). The map is based on the Natural Earth public domain data set and was created in Qgis 3.0.1 using local data collected from the Direction of agricultural service and the Direction of forests and the greenbelt of Algiers.*

II.2. Data Sources for Determining Carbon Sink Capacity

According to the carbon cycle in the biosphere. The carbon atom flows between four reservoirs (biosphere, lithosphere, hydrosphere, and atmosphere). Knowing that every carbon pool detains a determine capacity of carbon dioxide sink relative to i) biological and climate zones, ii) soil types and iii) temperature [53]. To calculate the carbon stock in soil (forestland, cropland, and grassland) and forestland carbon sequestration through photosynthesis, data for the year of 2016, were retrieved from Algiers' agricultural services branch (DSA) and direction of forests and greenbelt of Algiers (DFCV), this capacity is calculated as discussed by the IPCC guidelines for national greenhouse gas inventories [53]. Notice, the current study uses Tiers 1 approach for which the IPCC provides default values. Knowing that Tiers 2-3 approaches require country or region-specific data for more than a one-year period, which is not available for the case of Algiers. However, using Tiers 2-3 approaches, on the one hand, refines the inventory's accuracy and minimizes uncertainty, on the other hand; the inventory will be more complex because of processing a wide panel data of different years and scales.

II.3. Data Sources for Determining Carbon Sink Capacity

A territorial-based approach has been used to calculate Algiers' anthropogenic carbon emissions, which estimates carbon emissions emitted within Algiers' administrative boundaries. This approach accounts for direct emissions from all socioeconomic actors (farms, households, institutions, urban facilities), this type of emissions are dressed by the IPCC guidelines within the UNFCCC framework on climate change, Kyoto Protocol and Paris agreement [54]–[56]. This approach account emissions from Scope 1 (combustion of fossil fuel) and Scope 2 (consumption of electricity). Notice that this approach does not reflect city-scale emissions from national and international trade (Scope 3). To calculate Algiers direct carbon emissions data were retrieved from the National Agency for the Promotion and Rationalization of the Use of Energy (APRUE) and National Agency for Climate Change (ANCC).

II.3. Method

To determine Algiers C^4, first, we calculated the carbon sink potential using Tiers 1 approach proposed by the IPCC guidelines as it is mentioned in section (2.4.1), and then we calculated the carbon emissions per capita using a territorial-based approach as it is mentioned in section (2.4.2).

Method for calculating Algiers' carbon carrying capacity

In this study, the carbon sink capacity is calculated as:

$$C^4 = \sum (C_{Photosynthsis} + C_{Soil} + C_{Ocean} + C_{technology})$$

Where:

$C_{Photosynthsis}$: Carbon quantity sequestered in biomass (forestland) through photosynthesis, this capacity is calculated as mentioned in IPCC guidelines [53].

C_{Soil}: Carbon quantity stocked in sol (grassland and cropland) through soil-respiration, this capacity is calculated as mentioned in IPCC guidelines [53].

C_{Ocean}: Carbon quantity absorbed by the ocean, according to Khatiwala et al [57] it represents 28% of total carbon emissions.

$C_{technology}$: Carbon quantity stocked by technology (i.e., CSC), this capacity is calculated as mentioned in IPCC guidelines [53].

Method for Calculating Algiers' Population Limit

After calculating Algiers per capita direct carbon emissions (from Scope 1 and 2) using the Emissions Factor Method (EFM) and carbon sink capacity within its administrative boundaries. Algiers' population limit was determined by dividing the overall carbon sink capacity by per capita carbon emissions as mentioned in (Fig. 4).

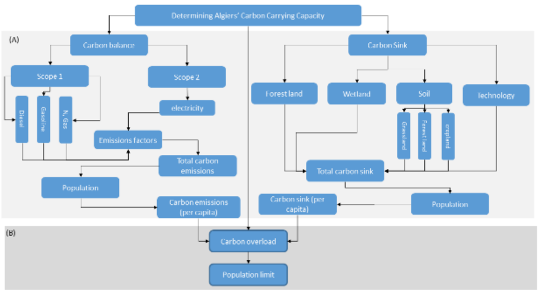

Figure 4. *Adopted methodology for estimating City Carbon Carrying Capacity.*

III. Results and Discussion

In section (3.1) we represent the results of Algiers carbon sink capacity, and then in section (3.2) we represent Algiers carbon emissions inventory. Adversely to the Carbon Footprint component within the Ecological Footprint Accounting (EFA) which assumes that only the forest constitutes the biocapacity required for uptake of carbon dioxide emissions, the City carbon Carrying Capacity (C^4) takes into account the whole bio-geochemical cycle of carbon in the biosphere.

III.1. Algiers carbon sink capacity

The carbon sink is evaluated in different carbon pools and estimated as mentioned in tables 1-5.

Forestland carbon sink capacity

Table 1. *Carbon sink through photosynthesis.*

Forest land area (ha*)	ΔC_G (tones C/y)	ΔC_L (tones C/y)	ΔC_B (tones C/y)	t CO_2/y
2 927.71	8 671.192	**0**	8 671.192	318 23.27

**Algiers forestland area data were retrieved from The direction of the forest and the greenbelt of Algiers (DFCV).*

Soil carbon sink capacity

Table 2. *Carbon sink through cropland soil.*

Cropland area (ha)*	$\Delta C_{Mineral}$ (t C)	$\Delta C_{organic}$ (t C)	$\Delta C_{inorganic}$ (t C)	ΔC_{Soils} (t C)	t CO_2 /y
32 526	98 748.9 36	0	0	98 748.9 36	362 408. 6

**Algiers cropland land area data are retrieved from the direction agricultural services of Algiers (DSA).*

Cropland soil carbon sink

Forestland soil carbon sink

Table 3. *Carbon sink through forestland soil.*

Forestland area (ha)	$\Delta C_{Mineral}$ (t C)	$\Delta C_{organic}$ (t C)	$\Delta C_{inorganic}$ (t C)	ΔC_{Soils} (t C)	t CO_2/y
2 927.71	21 681. 924	0	0	21 681. 924	7957 2.7

Grazing land soil carbon sink capacity

Table 4. *Carbon sink through grazing land soil.*

Grazing land area (ha)	$\Delta C_{Mineral}$ (t C)	$\Delta C_{organic}$ (t C)	$\Delta C_{inorganic}$ (t C)	ΔC_{Soils} (t c)	t CO_2/y
0	0	0	0	0	0

Wetland carbon sink capacity (ocean carbon uptake fraction)

Table 5. *Carbon sink through the wetland.*

Wetlands carbon sink fraction	Algiers total carbon emissions (tonnes CO_2/y)	Wetland carbon sink (tones CO_2/y)
28%	3 929 243.44	1 100 188.16

Technology carbon sink capacity

Technological improvements play a leading role in alleviating environmental problems. To mitigate the global warming phenomenon. The IPCC estimates that the potential of CCS could be between 10% ~ 55% of the mitigation effort until 2100 [58]. However, there is no CCS in Algeria (except In Salah); therefore, there is no carbon sink potential through technology in Algiers.

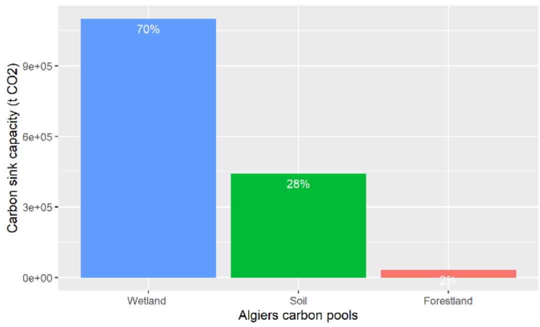

Figure 5. *One of the two key factors in determining Algiers' carbon carrying capacity. The figure displays carbon sink capacity per each carbon pool. The figure was created in R using ggplot2 package.*

Results from Fig. 5 and Tables 1-5 exhibit that forest land (trees carbon sequestration through photosynthesis) plays a minor role in sequestering Algiers' carbon emissions, Algiers forest ecosystems represents a share of 2% of overall carbon sink capacity, compared to Wetlands which represents a share of 70% and followed by Soil with a share of 28%. Notice that Algiers' forest areas are mostly fragmented, deteriorated and endangered, and they comprise each year at the expense of urbanization. Likewise, local authorities must protect and restore Algiers' ecological assets. As such, urban decision-makers have to recognize that forest ecosystems play a primordial role on a global scale since they have a very close

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relationship with the climate system, atmospheric gases, habitat for fauna and flora, control erosion and hydrologic cycle [59]. But also at local-scale, given the fact that researchers are constantly studying the beneficial effects of forests on human beings [60]–[62], namely improving well-being with some socioeconomic, physical and psychological benefits. Likewise, Algiers local authorities must integrate sustainable forest management within their local planning tools such as PDAU (master plan and urban planning) and SDAAM (master plan for metropolitan areas). Knowing the inherent state of forestland, which represents the main cause that Algiers is experiencing biodiversity loss, both fauna, and flora. According to the Algerian Ministry of Planning and Environment, on 19 June 2011, Algeria has experienced a severe biodiversity crisis given the fact that anthropogenic activities endangered 51-66% of animals and plants, this environmental crisis is primarily linked to the booming in human population and unsustainable development programs).

III.2. Algiers carbon emissions inventory

Scope 1: Algiers carbon emissions from fossil-fuel consumption

Table 6. *Algiers carbon emissions from Scope 1.*

Feul type	fuel consumption (Tep)	Emissions factors*	Carbon emissions (t CO_2)
Natural gas	968 420	2.3	2 227 366
Diesel (superior)	762. 072	2.9	2 210
Disiel (unleaded)	395 9.2	2.9	11 481.68
Gasoline	141 259. 35	3.1	437 903. 985

**Emissions factors are retrieved from (APRUE)*

Scope 2: Algiers carbon emissions from electricity consumption

Table 7. *Algiers carbon emissions from Scope 2.*

/	Energy consumption (Tep)	Emissions factors*	Carbon emissions (t CO_2)
Electricity	480 877. 6	2.6	125 028 1.76

**Emissions factors are retrieved from (APRUE)*

Carbon emissions per capita

/	Algiers' carbon emissions (t CO_2)	Algiers' population	Carbon emissions per capita (t CO_2/cap*y)
Value	3 929 243.44	3 154 792	1.24

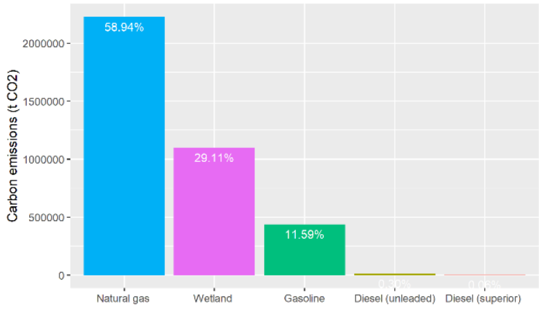

Figure 6. *One of the two key factors in determining Algiers' carbon carrying capacity: The graph represents Algiers' carbon emissions based on territorial accounting system (t CO_2). The figure was created in R using ggplot2 package.*

Figure. 7 depicts that the transport system represents the bulk of Algiers' total carbon emissions with a share of 51%, followed by residential with 25% and industry with 12%. As many Middle-Income Countries cities, Algiers displays the same carbon emissions pattern from the urban environment. Algiers contains roughly 2.8 million inhabitants generating daily over 6.5 million trips [63]. The lack of an adequate and efficient public transport infrastructure in the city pushed citizens to use private cars [64]. Knowing that Algiers' car fleet passed from 628 093 cars in 2000 to 1 150 077 cars in 2011, a total increase of 55% [65]. Transport system within cities of developing countries is operating with two massive problems, on the one hand, the vast majority of citizens use private cars because of the inadequacy of public transport and public infrastructure and its inefficiency in terms of serving new urban centres, as such transportation system within Middle-Income Countries is primarily qualified as "anarchic" [66] as it is mostly dominated by private car. On the other hand, the fuel price is very low [67]. With a very low fuel price citizens get attracted more into private cars, and therefore, carbon emissions from the transport system will eventually arise. Notice that to shift transport modes from passive to active, this will require to design a new holistic skeleton for Algiers based on the urban model component and not on individual behaviours and lifestyle patterns.

It is widely recognized that all major cities are considered as ecological debtors [68], [69], as they engender more wastes (carbon emissions) than the immediate environment can absorb. The research presented in this paper emphasizes on the fact that Algiers is knowing a severe carbon overshoot because Algiers environment carbon carrying capacity (estimated to 157 4044 t CO_2) could not sustain the current type and magnitude of its socioeconomic metabolism profile. Likewise, Algiers citizens fail to live in harmony with their environment as the magnitude of CO_2 output (estimated to 392 9243 tCO_2) exceeds the assimilative environment capacity (Fig. 6 and Fig. 7). That been said, this critical situation highlights that Algiers is too far from being a sustainable city that lives in tune with its environmental thresholds. However, this study provides three theoretical trajectories consisting an urgent road map to amortize Algiers' carbon overshoot and better preparing the city into the global climate issues as it was stressed at COP21 in Paris that all countries and cities should establish their GHG inventories (at both scales: national and city-level) and then design real efficient actions to reduce their greenhouse gas emissions. First, it is optional whether to limit Algiers population to 1 268 963 inhabitants in case the current path in terms of energy consumption, energy supply mode and lifestyle patterns are maintained. Nevertheless, notice that according to C^4 framework Algiers currently contains almost three times (2.5) population size more than that it can sustain, in other words, 235 528.43 t CO_2/y is released to the atmosphere which represented almost 60% of Algiers' overall carbon inventory, therefore only 40% is sequestered by natural processes.

Unfortunately, population status, precisely age structure, can potentially influence Algiers' population size extension in the next decades. Algiers' age structure reveals that the urban population is primarily dominated by a large portion of individuals in young age-classes which are equal or under the age of 15 and this age-class represents 61.8% of the total population and while being accompanied with a national population growth rate of 2.17% [52], these two factors exhibit that there are more young people that soon will be reproducing. In this context, age structure factor might lead eventually to a tremendous demographic momentum in the upcoming years which might likely conduct to an urban collapse, leading to a massive construction dynamic at the expense of green spaces (agricultural land and forest ecosystems) and conducting eventually to biodiversity losses and the reduction of Algiers' ecological assets. However, it is important to highlight that household size, as discussed by Ala-Mantilla et al [70], is a core element in cutting carbon emissions within cities with a higher population growth rates, as such monitoring demographic growth of cities with developing economies is a solid recommendation to prepare and introduce cities into the global climate challenges. Second, Algiers local authorities might extend the city's ecological assets (forestland area) to sequester the totality of anthropogenic carbon dioxide, unfortunately, that will require a forest-based area of 36 709 ha. However, at present in Algiers, there is only 4 927 ha of forestland, this supplementary required area represents 30 times Algiers's area. In a similar research framework, several studies have suggested extending the forestland ecosystems area to capture all the carbon emissions from the built environment. For instance, the evaluation of Tehran's (Iran) biocapacity required for its transportation system [71] of the forest-land area was equivalent to 4 384 777.5 ha to sequester the carbon emissions emitted from transport sector only (with average carbon sequestration of 1.8 t carbon per each hectare). In other words, in 2012, Tehran's transportation system required an area of forestland equal to 58 Tehran's size which exhibits a sever unsustainable development in Tehran's transportation system. Barret and Simmons in 2003, have estimated the energy footprint of transportation systems in Great Britain considering all types of transport and urban infrastructure, the energy footprint was evaluated to 0.67 gha, the study shows that for each one global hectare it will require a 5.2 hectares of newly planted forest with the same forest yield factor [72] which was assumed to be at 1.35 times higher than the global forest average productivity, in other words, 5.2 tonnes of CO_2 is absorbed by 1 hectare of forest. In another study elaborated by elioth® group for Paris, local authorities were aiming to achieve carbon neutrality of Paris (France) by 2050, the study shows that Paris will require to plant more than 5% of France total surface [73] to absorb, via trees photosynthesis, all the carbon emissions emitted from the city of Paris. A study for Oslo (Norway), established by Norland et al [74], displayed that the city required 22.5 Oslo's size of forest land-based area. Isphahan (Iran), in 2014, required almost 18 times the size of the city [75] to balance carbon emissions from urban activities with Isphahan's carbon carrying capacity (also called biocapacity or regenerative capacity).

Nevertheless, it is important to highlight that Algiers' local authorities may manage to increase the Average Forest Carbon Sequestration (AFCS) of Algiers by planting tree categories that stock big amount of carbon and that can survive with local climatic conditions of Algiers (for instance, eucalyptus), for more information about the (AFCS) see Mancini et al [76].

The third point, which is the most empirical, is to make an ecological transition that can only be an energy transition. Stakeholders and local authorities should endeavour gradual action towards the use and generalization of renewable energies and the development of close-range smart grids, especially for households final-energy consumption (cooking, heating space, and water and air conditioning) and transportation system which represent respectively 25% and 51% of Algiers overall CO_2 emissions,

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and invest more in renewable resources (wind, air, solar, nuclear, geothermal) knowing that Algeria's geographical zone is propitious to develop this kind of energy known as green, decarbonized, low carbon or renewable energy [77].

Addressing the full responsibilities to urban final consumption sectors is thus highly relevant to prepare developing countries into the global climate issues and also to tetanize the resiliency and sustainability of urban ecosystems and shrink their window of vulnerability while being accompanied with a preservation process of biodiversity at multiple geographical scales and presenting an easy-to-follow steps to forward sustainability policymaking at the local level and triggering leverage points for cutting urban carbon emissions. Shaping a new path for Algiers' socio-economic metabolism towards a more sustainable, resilient and low-carbon behaviours and consumption patterns represents the first stepping-stone towards designing efficient massive stimulus efforts for creating climate-safe future especially with the widespread of the One Planet City Challenge and One Planet Alliance to faster worldwide cities to achieve the 1.5°C climate path.

Based on the results of this study, Algiers' transportation sector should be viewed as a priority to endeavour new urban policy targets to cut GHG emissions whether by changing the current patterns of urban planning or increasing in sustainability factors of Algiers transport network. Knowing that promoting cycling and walking in hot cities (Algiers' summer heat temperature reaches 45°C) is not an option to decarbonize Algiers transportation system, as such, local authorities and urban policymakers should endeavour new solid targets taking new measures that affect: i) Fuel price. ii) Increase public transport efficiency –availability and its accessibility to all social classes-. iii) Increase in Algiers' ecological assets –forestland- and encourage citizens/architects to adopt more green design habits –green roofs, walls, and planting more trees in streets-. iv) Shift the current planning strategies towards a "green-urbanism" and "smart-growth" focused-approaches. v) Upgrade Algiers' current urban tools SDAAM, PDAU and POS using Transit Oriented Development (TODs) and Transport Network Management (TNM) to collapse the share-use of private cares.

Our study exhibits that Algiers citizen's lifestyle patterns and consumption behaviours are unsustainable and they are eventually responsible for several environmental distortions ranging from local to a global scale. Therefore, developing cities with developing economies, especially those in the MENA region, must design new urban tools to control and monitor their environmental damages, and redesign their urban strategies using environment thresholds to cope with the modern environmental challenges such as climate change. By which a drastic systemic change in patterns of land-use, lifestyle patterns, and consumption behaviours are required. Yet, it is important to stress that the C^4 is a weak approach to urban environmental sustainability, as it does not take into account the state of local biodiversity, decline, and resilience of ecological assets.

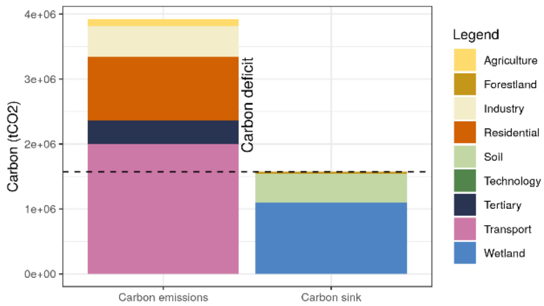

Figure 7. *Algiers' carbon overshoot, the figure shows a comparison of Algiers carbon sink capacity in (t CO_2) and Algiers' CO_2 emissions per sector in (t CO_2). The figure was created in R using ggplot2 package.*

IV. Conclusion

Climate change is spotted as one of the greatest challenges that modern societies have to face and that all the countries should establish future climate-friendly roadmaps to achieve the 1170 Gt CO_2 target and stabilize Earth's surface temperature to 2°C by 2100. However, many developing countries with a developing economy are currently hesitating whether to join the international race on climate agreements or not, afraid to act for climate and lose the competition for economic development. Nevertheless, it's highly important to stress that those cities should establish climate mitigation actions to enhance their resiliency to supply-demand perturbations and shape a solid long-term sustainable economy.

The evaluation Algiers City Carbon Carrying Capacity (C^4) presented in this paper allowed consistently comparing the carbon sink requirement of Algiers's socioeconomic metabolism wastes. Overall, we triggered that Algiers –as one of the Mediterranean cities and one of the Upper Middle-Income Countries- is experiencing environmental sustainability issues because territorial direct anthropogenic carbon emissions are exceeding the environmental assimilation threshold. Our research is based on comparing tow indicators i) *carbon sink* considering the entire bio-geo-chemical carbon cycle, and ii) *carbon emissions* considering territorial emissions emitted within the Algiers administrative boundaries (assessing Scope 1 and 2). Luckily, the state of carbon deficit is avoidable by double-focusing on cities' ecological assets and the sectoral composition of carbon footprint.

Global warming phenomenon dissipates of its dice aspect it offers an opportunity to reshape and redesign world cities to implement new efficient actions in favour of global sustainability. In this context, as carbon emission, energy overconsumption, population growth and decline of ecological assets are the most frequently stated problems in scientific literature and a fundamental concern to urban policymakers, the C^4 highlights the urgent need to submit measures to limit and control overpopulation and energy overconsumption especially in developing countries with developing economies –alongside with other critical limitation factors such as food, water- where population size is growing too fast outstripping the environment capacity to provide resources and absorb built environment wastes. Likewise, the C^4 could constitute a comprehensive tool to rebalance cities function with their carbon budget by i) Maintaining and restoring cities' ecological assets. ii) Monitoring cities' carbon overshoot. iii) Reducing carbon emissions and one key process in helping to guide developing cities into an ecological transition and better prepare local actions for global climate issues following the adage *"think globally, act locally".* The City Carbon Carrying Capacity does not intend to stop nor to shrink the demographic growth but rather to introduce a new tangible path for cutting urban carbon emissions by double-focusing on the issues related to sustainable urban development and sustainable forest management.

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