Urban Footprint as a Tool to Measure the Sustainability of Cities Concept, Elements and Calculation

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***Abstract*: The ecological footprint is a signal or indicator to measure the effects of man's activities on the environment, and therefore it is considered a bell to the extent of human impact on the environment and depletion of its resources. As cities are the container that contains these activities and are the direct drain of environmental resources, that valuable tool should be adopted (ecological footprint) to measure environmental resources consumption in cities. Therefore, the research focuses on simulating the method of ecological footprint to measure the sustainability of cities by finding equations to calculate the ecological footprint of the city components to give the overall value of the urban footprint; this means that the impact of urban areas on the environment is calculated. Therefore, the research aims at accessing the tools of new equations to calculate the urban footprint of each sector of the city to identify its impact on the environmental resource's consumption and identify the imbalance or shortage of resources consumption accurately as well as to identify the city possibilities. Thus, that gives the opportunity to take the necessary measurements to deal with them.**

***Keywords:* Footprint; Urban; Ecological; Sustainability; Environmental; Sustainable and Cities.**

I. INTRODUCTION

Sustainability, in general, is a balance between its various social, environmental and economic dimensions. Each dimension has a role in activating the development in societies that seek to achieve sustainability through the interplay of the development objectives through the three dimensions.

In fact, the origin of sustainability is to provide an integrated healthy environmental life in the present and in the future as well and that requires the transfer of life with all its aspects to the future in a sustainable way. The sustainable development is a system that links human beings to the environment in a way that organizes this relationship and puts in consideration the right to access resources by generations in the same age and by generations in the future. Therefore, it develops strategies for applying intergenerational justice through dealing with sustainable development. It has served as a model for thinking more comprehensively to create a balanced civilization according to development considerations. The development has focused on the formulation of all human and natural determinants to achieve one goal of conserving natural resources for future generations.[1]

Environmental assets are at the center of each nation's long-haul riches. However, population growth and its' consumption are putting more pressure on these basic resources. Today, many countries in the world suffer from ecological deficit because of using more resources that exceeds the possibility of ecosystems to regenerate. This makes those cities to depend heavily on resources from other places around the world and leads to an increasing pressure on other places on the planet. The effects of ecological deficits can be devastating, and their increase will lead to resources loss, ecosystem collapse, poverty, famines, and wars.[1]

The sustainable city is an environmentally friendly green city where the resources capacity and local ecosystems are balanced by raising the efficiency of resources use and minimizing the polluting outputs that enables the ecosystem to renew itself and prevents pollution by reducing the waste that nature can receive and in the context of global climate change. The sustainable city is distinguished by being a low or a zero-carbon emission city and thus it contributes to reducing carbon dioxide and other organic compounds which lead to increase those climate changes.and to ensure sustainability, cities need tools to measure their sustainability, one of these tools is the ecological footprint.

The concept of ecological footprint was created in 1990 by Mathis Wackernagel and William Rees at the University of British Columbia, Vancouver, Canada. It has become an important instrument for measuring the quantity of nature's resources that humans exploit globally through production, consumption and waste management. [2]

Accounting of Ecological Footprint was proposed to represent human consumption of biological resources and flow of wastes in terms of specified ecosystem area, which could then be compared to the biosphere's productive capacity annually.[2]

The rest of this paper will be discussed: In Sec.2, Urban footprint (concept and its factors affecting in it) is discussed. In Sec.3, concept of methodology of calculating is presented. In Sec.4, The proposed model for urban footprint calculating is discussed. access to the model of urban footprint calculating is made in Sec.5. finally, Application of proposed equations for urbanfootprint In Sec.6, for London city. as shown in **Fig 1.**

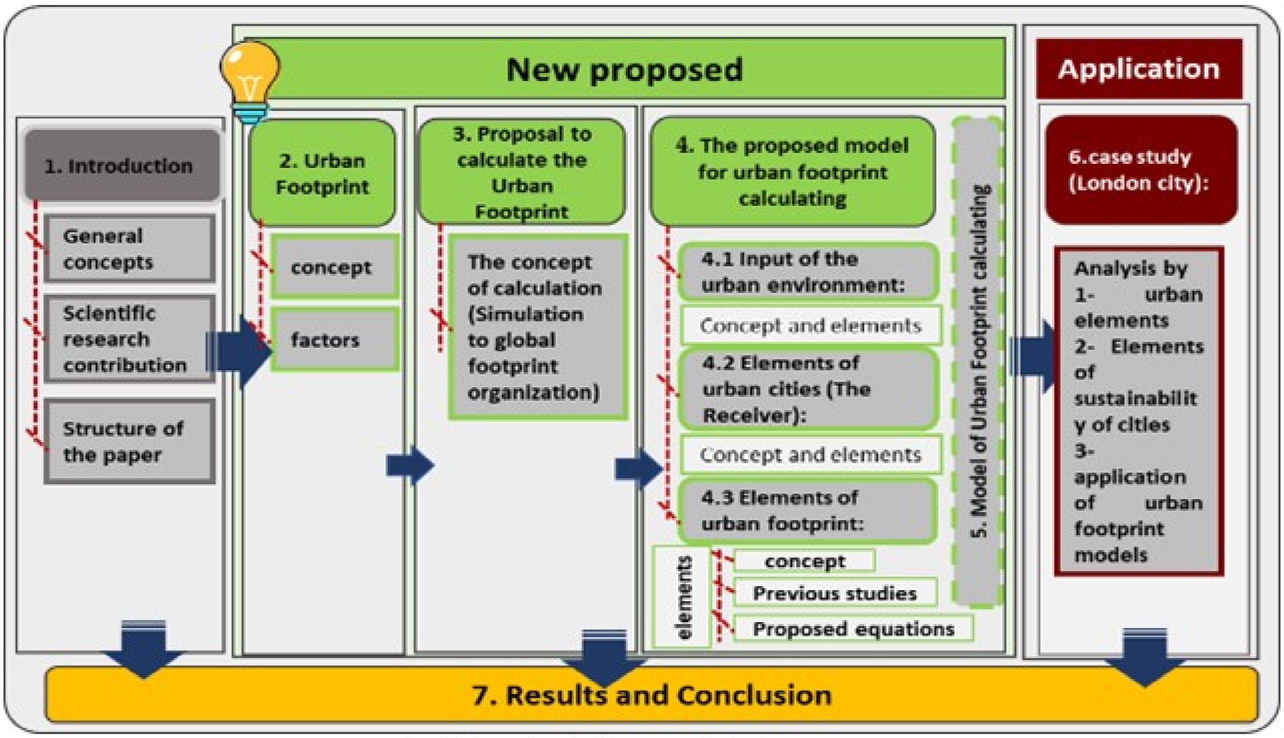

Fig 1. Structure of the research study.

The contributions of this manuscript can be summarized as follows:

- To find a new tool (footprints of urbanization) to calculate the sustainability of cities by simulating the idea of calculating the global ecological footprint.
- Develop a model to measure the urban footprint.
- To provide a precise calculation tool that enables comparison between the sustainability of cities and some of them.
- Dealing with the proposed model to measure the urban footprint of the cities allows to identify the shortcomings and strength in the various sectors of the city and the possibility of dealing with them yet.
- the possibility of knowing the sustainability of each sector of the city accurately.

II. URBAN FOOTPRINT

The urban footprint is one of the expressions of the amount of environmental impact by calculating the effect of man dealing with natural capital from the consumption of resources and the absorption of waste within a certain area represented by the city area.

Cities are the container that embraces all human activities in different fields practiced by man, but they may be considered as one of the greatest human achievements on this planet. There is no doubt that they are the largest consumer of environmental resources on this planet.

Figure 2.Logo of Urban Footprint.

As mentioned by Ress, Ecological Footprint analysis not only measures the sustainability gap, but it also provides insight into strategies for sustainable urban development. However, it is believed that the urban footprint is more accurate to focus on shortcomings in the implementation of cities sustainability strategies. [3]

Ecological Footprint for different cities Values is largely driven by many factors as economic and social, such as available income, infrastructure, and cultural habits, Therefore, the factors affecting the urban footprint can be limited to the following points:

- ***Form of urban pattern:*** that the planning of cities and urban pattern has a significant impact on the size of the urban footprint in the city where the compact pattern reduces the value of the urban footprint on the extended pattern, which reduces the infrastructure services and reduce the areas of paths and roads.[4]
- ***Living style & type of housing:*** Walker (1995) has demonstrated that the increased density related with high-rise apartments, contrasted with single-family houses, reduces those components of the per capita ecological footprint related with housing type and urban transportation by 40%. in any case, People frequently move to cities owing to greater economic opportunities. To the extent that the higher incomes related with urban employment result in increased average personal consumption (net of any savings resulting from urban agglomeration economies), the urban ecological footprint may well expand beyond the base case.[3]
- ***Culture & environmental awareness:*** Sometimes, there are many human impacts on the environment related to consumption do not affect the characteristics of cities of the formation or style, but the effects are the result of a reflection of values and behavior and community and individual activities and customs and traditions.
- ***Land use and distribution of services in the city:*** Style of distribution for services in the city affects the distribution of infrastructure networks, traffic distances and roads and thus affects the ecological footprint of the city. Therefore, the use of mixed land reduces the value of the ecological footprint.
- ***Population density:*** The higher the population, the greater the pressure on facilities (infrastructure) as the rate of consumption in the city while at the same time the decline in the rate of population in the city than the normal rate is a waste of resources in the city, so must find a ratio between the size of the city and the population in them and in both cases affect the Increased ecological footprint.
- ***Environmental management & Recycling policy:*** environmental management strategies control the ability to reduce the value of the ecological footprint through the development of many obligations and safeguards and to guide existing technology in the service of the environment through transport technologies, policies, recycling of used materials and recycling of waste.

III. THE METHODOLOGY OF CALCULATING URBAN FOOTPRINT

The proposed methodology is designed to compute the Urban Footprint by simulating the idea of calculating the same ecological footprint as described in the following diagram in **Fig 3.**:

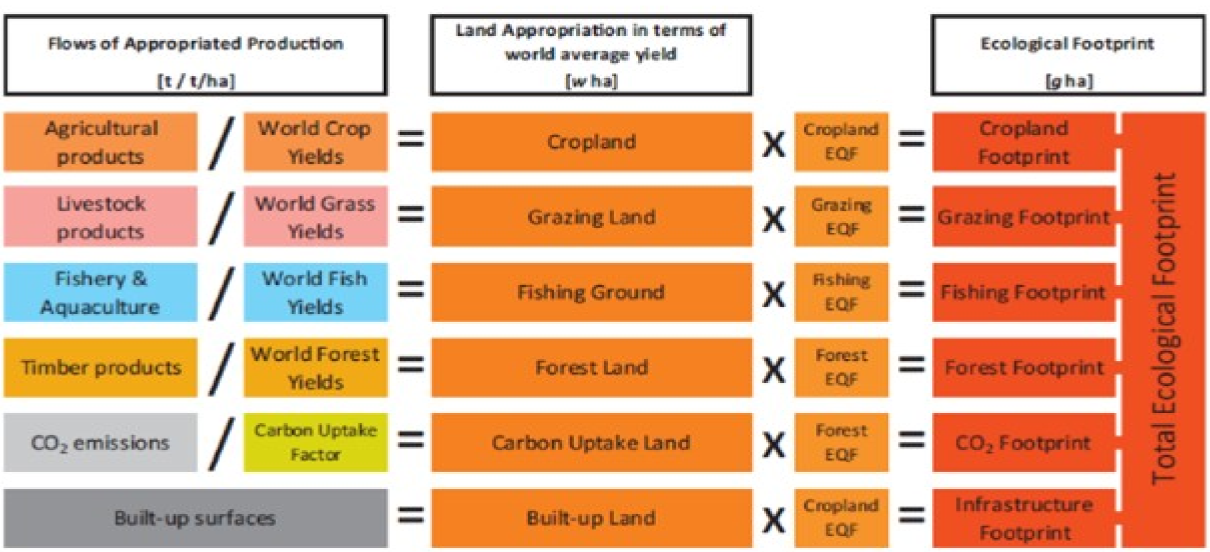

Fig 3. The framework of the National Footprint Accounts.[18]

The methodology of calculating the ecological footprint depends on the conversion of the consumption amount of each type of land to the global hectare by multiplying the quantity of consumption and the equivalence coefficient and dividing them on the yield coefficient. Thus, it is easy to compare any kind of land anywhere in the world in the same way by converting the consumption to an area per hectare.

In the same way, the footprint will be calculated by calculating the amount of consumption in any sector of the urban areas of the unit. It was then multiplied by the conversion factor. This coefficient is specific to the emissions for each sector and varies from one country to another and from one sector to another to convert them in hectares. It facilitates the calculation of the urban footprint. So, the idea of calculating the footprint of the urban areas is based on multiplied by the conversion factor and amount of consumption, As shown in **Fig 4.**

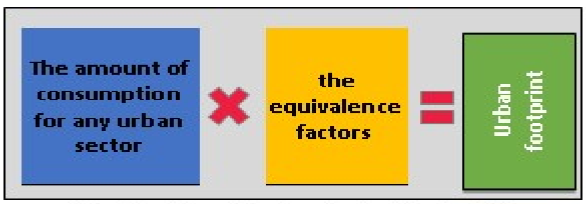

Fig 4 The idea of urban footprint calculating

The following is a detailed presentation of the proposal for calculating the urban footprint for each element of the city elements.

IV. THE PROPOSED MODEL FOR URBAN FOOTPRINT CALCULATING

Urban footprint is more accurate as more data are available on the consumption patterns. Due to the difficulty of data availability with extreme precision, the methodology of the analysis of the urban footprint has been reached by dividing it into three axes or stages by dealing with the city as a user who receives the inputs of the environmental and produces environmental impacts that is its urban footprint, as shown in **Fig 5.**:

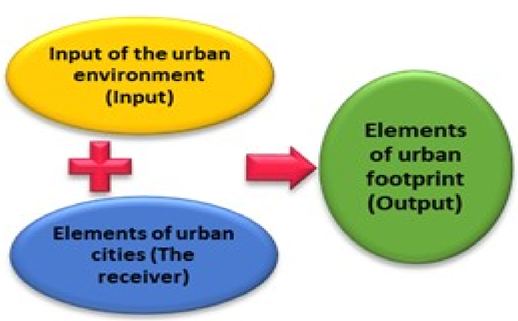

Fig 5. Components of urban footprintcalculating

The first axis: the inputs of the urban environment, which is the data of the environment for urbanization.

The second axis: the components of the city which are the elements of the city and represent the future of those inputs.

The third axis: the outputs of the urban environment, the urban footprint, which are the product of receiving the city's urban components for environmental inputs.

Based on what has been shown from the previous studies, the components of each axis of the methodology in **Fig 6.**

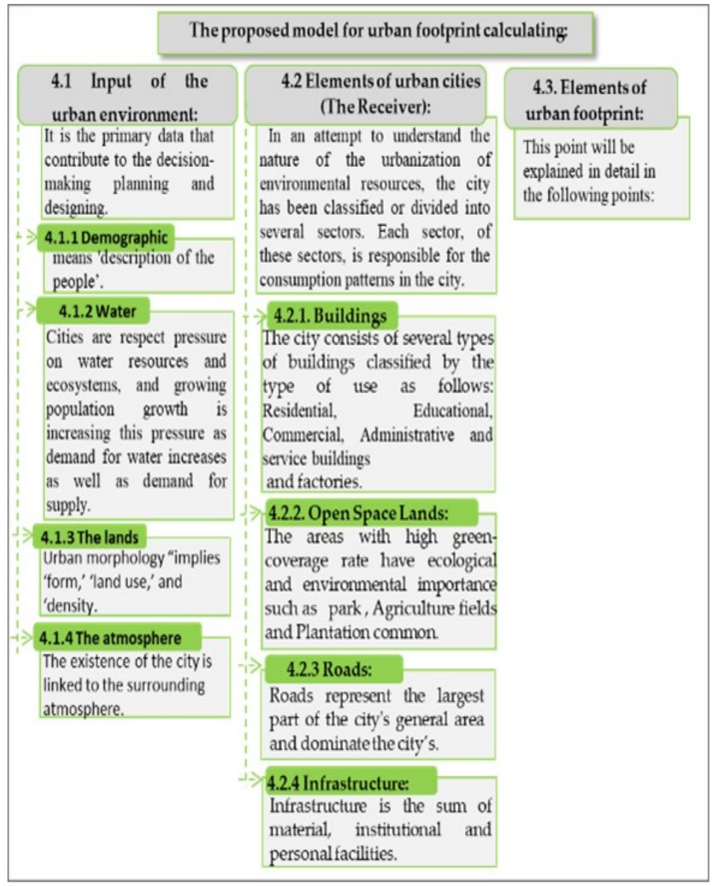

Fig 6. The proposed model for urban footprint calculating

Elements of urban footprint

To achieve sustainability, it is necessary to identify measuring tools. Thus, to evaluate the sustainability of cities, there must be tools that measure sustainability and measure the impact of human activities on the environment.

These elements have been reached based on what was studied in the previous literature reviews through the analysis of indicators of measuring sustainability and linking them to the idea of ecological footprint, as shown in Fig 7. These indicators have been transformed into computable data and thus provide a more accurate product of the sustainability of cities, based on what has been studied, each component will be identified and studied the factors affecting each element and method of calculating each.

Fig 7. Elements of Urban Footprint.

1. Transportation Footprint:

Transportation is one of the major activities that generate the ecological footprint. ecological footprint analysis is one of the means to measure the environmental impacts caused by humans on the planet. A sustainable city should be with a sustainable transport system and if it does not have a sustainable transport, this leads to ecological imbalance and unsustainable growth and affects the life quality. Transport footprint refers to the land area required to sequester the carbon dioxide (CO_2) emitted from the burning of fuels by vehicles driving along highways[5].

There are several factors that increase the effects of transport on the environment, thus increasing its ecological footprint, at the same time, it is considered the key to reducing the ecological footprint of transport in **Fig 8.**:

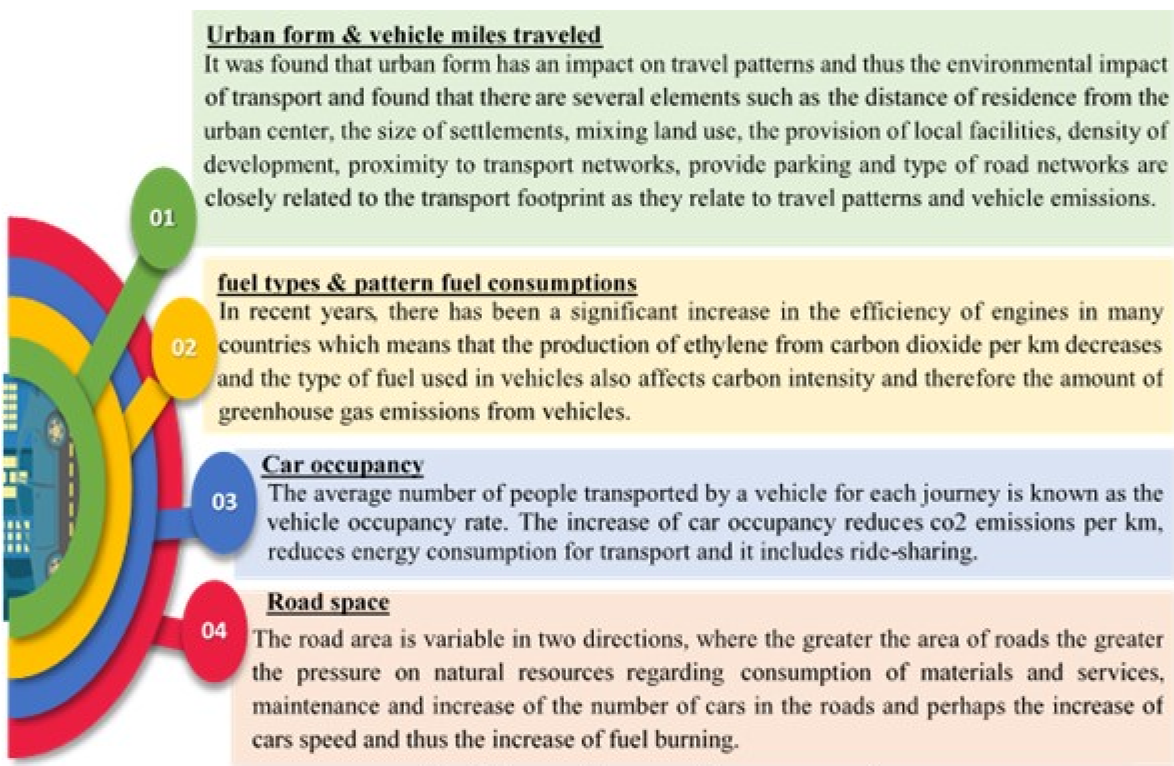

Fig 8. Factors affecting in Transportation footprint

One of the previous applied studies, [6] showed the importance of estimation of ecological footprint. In this study, the ecological footprint of transportation activities in the city of Isphahan in central Iran was estimated at 0.4 global hectares. It means that for each Isphahan resident, 0.4 global hectares area is needed to sequester the CO_2 released to atmosphere from different transportation activities.

The study has a methodology for calculating the transportation networks footprinton three steps[7]:

1. Assessing the physical footprint of the roadway (step 1)
2. Assessing the energy footprint of the roadway (step 2)
3. Combining the land territories of the physical and vitality impressions to determine a gauge of the complete transportation impression. (Step 3)

The transport footprint account is expressed in global hectares, it is measured by calculating the use of fuel and materials used in the manufacture and maintenance of vehicles, the transport footprint account includes the following:

Built-up for transport (e.g. road space, car parks).

Emissions of carbon dioxide from the manufacture and the maintenance of vehicles

Built-up for transport (e.g. road space, car parks).

Step one: Calculate built-up for transport (Built – up footprint):

Through the following equation **No. (1):**

$$EF_{Built} = A * EQF (1)$$

Where, EF_{Built} is Built – up footprint (for transportation), A is roadway area (ha) and $EQF$is Equivalence factor for Built-Up land are thus used in the Footprint calculation, that equal 2.52 (gha/ha).

Step two: Calculate emissions of carbon dioxide from the burning of petroleum (Energy Footprint):

The emissions can be calculated depending on three types of data: (diesel or petrol) liters of fuel consumed; or amount (in dollar) associated with fuel consumption or km covered.[8], Through the following equation**No. (2):**

$$EF_{T\ energy} = C_{co2} * f * EQF \quad (2)$$

Where, $EF_{T\ energy}$ **is** Energy footprint for fuel consumption of vehicles.

C_{co2} **is** Co_2 consumption for fuel (ton Co_2 /year), Where, co_2 consumption for fuel= Average vehicle journey (km per yr.) * Number of vehicles * fuel consumed per km per yr.* emissions factor for all fuel types, f **is** conversion factor is average Co_2 sequestration factor in the world and it equal 3.818 (ton co2/wha/yr.) and EQF Is Equivalence factor for forest land are thus used in the Footprint calculation, that equal 1.29 (gha/ha).

Step three: Calculate emissions of carbon dioxide from the manufacture and the maintenance of vehicles (GHG footprint):

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". So, the road construction and maintenance can be calculated through the following equation in **No. (3):**[6]

$$EF_{mv} = 45\% \, C_{co2} * f * EQF \quad (3)$$

Where, EF_{mv} **is** GHG footprint for the manufacture and the maintenance of vehicles, $45\% \, C_{co2}$ **is** 45% from Co_2 consumption for fuel Co_2 ton/year, f **is** conversion factor is average Co_2 sequestration factor in the world and it equal 3.818 (ton co2/wha/yr.) and EQF Is Equivalence factor for forest land are thus used in the Footprint calculation, that equal 1.29 (gha/ha).

Finally, the final equation in **No. (4).** is compensated:

$$T_{footprint} = EF_{Built} + EF_{T\ energy} + EF_{mv} (4)$$

Considering that the consumption of fuel varies depending on the type of vehicle and the type of fuel used in addition to the rate of speed on the road. Therefore, for calculating the transport footprint, a table is required to discharge the fuel consumption according to the classification of vehicles and fuels.

2. Water Footprint:

The water footprint is an indicator of freshwater use that looks not only at direct water use by a consumer or by producer, but also at the indirect water use. It is a measure of humanity's appropriation of fresh water in volumes of water consumed and/or polluted. and it measures the amount of water used to produce each of the goods and services that are used. It can be measured for a single process. The water footprint can also tell us how much water is being consumed by a particular country – or globally – in a specific river basin or from an aquifer. [9]The value of a water footprint depends on several factors in **Fig 9.**:

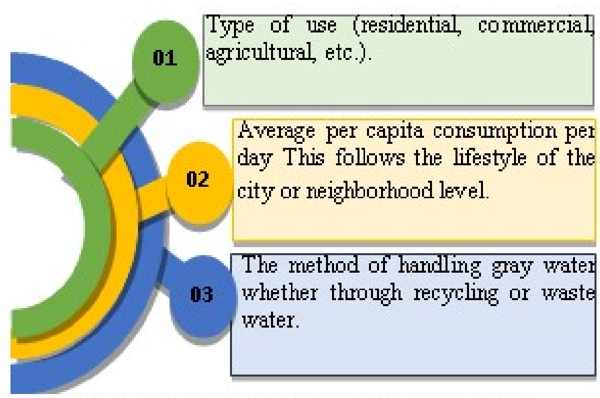

Fig 9. Factors affecting in Water footprint

A previous study on the city of Liverpool [10]presented method to calculate water footprint by multiplying the amount of water consumption ML in the Energy Requirement per ML then calculate the carbon dioxide emissions of supplying this energy.

The ecological footprint of water is calculated by considering the energy required to supply the water. Domestic, commercial and industrial uses are all taken into consideration. The water footprint can be calculated through the following equation **No. (5).**[11]

$$W_{footprint} = C_{water} * f \quad (5)$$

Where, $W_{footprint}$ **is** Water footprint (gha), C_{water} **is** total consumption of water (Megaliters) and f **is** ecological footprint conversion (gha/Megaliters).

As ecological footprint conversion (gha/Megaliters) is MultiplyingEquivalence factor and carbon per and carbon responsibilityand divide them on world carbon absorption as follows **equation No. (6)**:

$$f = \left(EQF * carbon * C_R \right) / C_W \quad (6)$$

Where, f **is** ecological footprint conversion (gha/Megaliters),EQF **is** equivalence factor is 1.29 [12], $carbon$ **is** carbon per megaliter is 0.1 [13], C_R **is** carbon responsibility is 69% [14]**and**C_W is world carbon absorption (ton/c/ha/yr) is 0.97[12].

3 Energy Footprint

Energy consumption is considering the largest contributor to carbon dioxide (CO2) emissions, the main source of environmental change. It is essential to comprehend which areas consume the most energy to take appropriate remedial actions for emissions reduction. So, an energy footprint is a measure of land required to absorb the Co2 emissions.

There are several factors or classifications that affect the control of the value of energy footprint in **Fig 10.**:

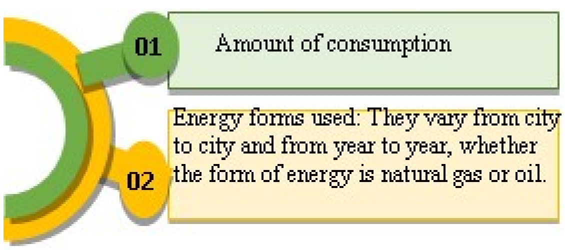

Fig 10. Factors affecting in Energy footprint

All the energy component footprints are based on a relatively simple calculation; the measure of carbon dioxide delivered by the forms of energy, multiplied by the carbon sequestration rate for forests. For the component approach the same sequestration as Wackernagel (1997) is applied (100GJ/ Ha. / yr.). For example, the consuming of coal emanates more carbon than oil consuming, and oil consuming transmits more carbon than the consuming of gas.[11], Thus, the equation will be as follows **equation No. (7)** :

$$E_{footprint} = C_{Energy} * e * EQF / f \quad (7)$$

Where, $E_{footprint}$ **is** energy footprint (gha), C_{energy} **is** total consumption of energy (GHW), $e$is emissions factor for all fuel types (ton co2/GHW/year), EQF is emissions conversion factor for forest land are thus used in footprint calculation, that equal 1.29 (gha/ha) and $f$conversion factor is average co2 sequestration factor in the world and it equal 3.818 (ton co2/wha/yr.).

4 Waste Footprint:

Human activity is the main contributor to waste generation which produces greenhouse gas emissions and therefore solid waste plays an important role in the carbon footprint of the community. The waste is classified as solid waste consisting of biodegradable and non-degradable substances as well as organic wastes whose unsustainable discharge leads to atmospheric methane emissions.

The waste footprint is the loss of embodied energy to be disposed by:

- Transfer of waste from homes to the landfill and is linked to several determinants such as Waste collection method.

1. Number of persons and thus the amount of waste such as Waste transport distance and container area.

The energy used in the recycling of waste and the values vary according to the materials to be recycled.

There are several factors or classifications that affect the control of the value of a waste footprint in **Fig 11.:**

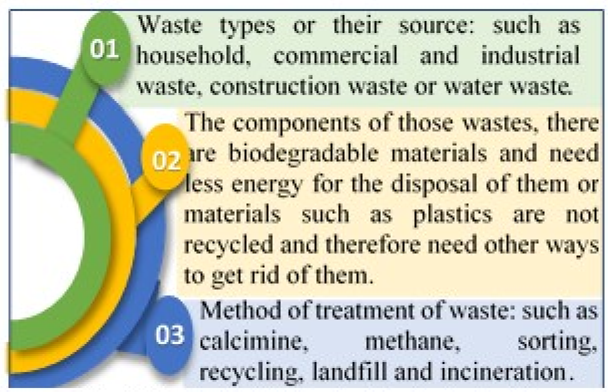

Fig 11. Factors affecting in Waste footprint

One study presented one way to calculate the ecological footprint of waste by applying to an area in the city of Bangladesh [15]through calculateWaste generation energy.

The calculation of the waste footprint depends on the waste components and their sources, where all the waste is sorted separately, and the waste footprint account is divided into three axes:

1- The energy used for waste treatment or disposal.
2- The amount of emissions resulting from them.
3- The area of land occupied by it.

Accordingly, the footprint of waste can be calculated through the following equation **No. (8)** :

$$WS_{footprint} = E_{CO2} * e * EQF / f \quad (8)$$

Where, $WS_{footprint}$ **is** waste footprint (gha), E_{CO2} **is** co2 emissions from MSW combustion (t), e is emissions conversion factor calculating emissions from energy use (Kg of c_{o2} / GHW), EQFisemissions conversion factor for forest land are thus used in footprint calculation, that equal 1.29 (gha/ha) and $f$conversion factor is average co2 sequestration factor in the world and it equal 3.818 (ton co2/wha/yr.).

and Co_2 emissions (Co_2 ton/year) can be calculated from the following equation in **No. (9)** :[16]

$$\mathbf{ECO2} = \mathbf{MSW} * \sum(\mathbf{WFj} * \mathbf{DMj} * \mathbf{CFj} * \mathbf{FCFj} * \mathbf{OFj}) * \mathbf{44/12(t)} \quad (9)$$

where: **ECO2** is CO2 emissions from MSW combustion (t).

MSW is Amount of municipal solid waste (as wet weight) (t).

WF_j is Fraction of waste component j in the MSW (as wet weight).

DM_j is Fraction of dry matter content in the component j of the MSW.

CF_j is Fraction of carbon in the dry matter of component j.

FCF_j is Fraction of fossil carbon in the total carbon of component j.

OF_j is Oxidation factor (assumed equal to 1).

44/12 is Conversion from C to CO2.

J is component of the MSW incinerated/open-burned such as paper/cardboard, textiles, food waste, wood, garden (yard) and park waste, disposable nappies, rubber and either, plastics, metal, glass, other inert waste

Fig 12. Model of the measurement Urban Footprint.

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5 Built-up Land Footprint:

Land is one of the Earth's most precious resources, it provides many of the resources required to enable human activities and to absorb the waste from these activities.[17]

It respects the amount of land occupied by buildings and roads as well as the materials stored within the buildings. It can be calculated through the following Equation in **No. (10)** :[18]

$$Built_{footprint} = A * EQF \qquad (10)$$

Where, $Built_{footprint}$ is Built – up land footprint, A is built – up area (ha) total surface area of built – up land and $EQF$is Equivalence factor for Built- Up land are thus used in the Footprint calculation, that equal 2.52 (gha/ha).

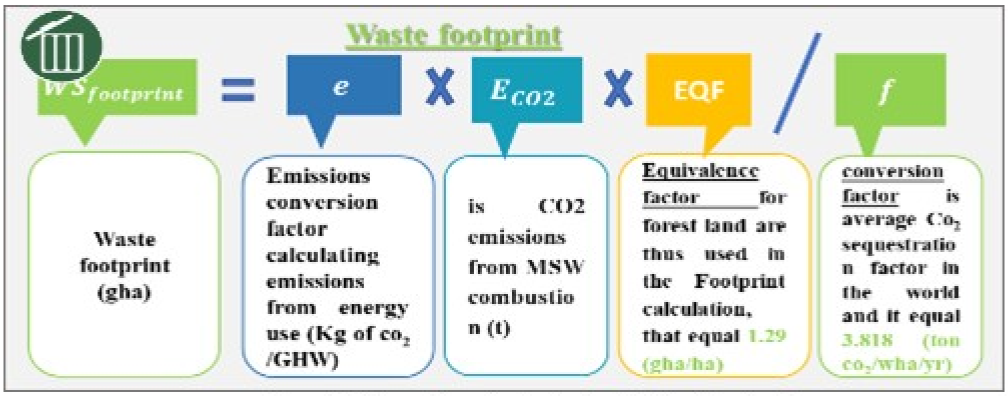

Figure 28. Equation of calculating Waste Footprint

As the Built-up area represents the total surfacearea of built - up land such as buildings, roads and railsBased on the fact that human settlements historically developed and congregated on the most agriculturally fertile land, infrastructure areas are assumed to occupy former cropland and yield and equivalence factors for cropland are thus used in the Footprint calculation.

V. MODEL OF URBAN FOOTPRINT CALCULATING

As a result, each of the elements of city planning has a strong impact and its own footprint on the environment, which is calculated by means of the equations studied.

Based on the above, a model has been designed. This model enables us to calculate the footprint of each element of the city, so that the shortcomings and strengths of the city's ecological footprint and the speed of finding suitable solutions can be known.

VI. CASE STUDY (LONDON CITY)

The study sample was analyzed through several stages:

- Analysis of city from urban perspective.
- Analysis of city through elements of Urban Footprint.
- Evaluation results by Urban Footprint.

London is the UK's biggest city and its capital. It has likewise come to be perceived as a worldwide place for money related and professional services, as well as a major tourist destination. The city has a populace of 10.5 million and is the central station for more than one-portion of the UK's biggest companies.

6.1 Analysis of city from urban perspective:

The urban analysis of the city is carried out through the following points:

• *Urban development history*: London has a long and complex history that extends back for more than 2,000 years. As far as its populace and spread, however, it has been the last two hundred years that have seen the best change. In 1801 when London had one million individuals it was as yet an exceptionally conservative city for the most part contained inside a sweep of some 3km. By the 1851 enumeration the populace had multiplied yet that sweep was still under 5km1. Notwithstanding, all that changed with the happening to the worker railroads, which empowered Londoners to escape from the clogged focal regions to live in the quickly developing and considerably more roomy rural areas. Subsequently, throughout the following one hundred years, London spread itself out to reach extensively its present degree.[19]

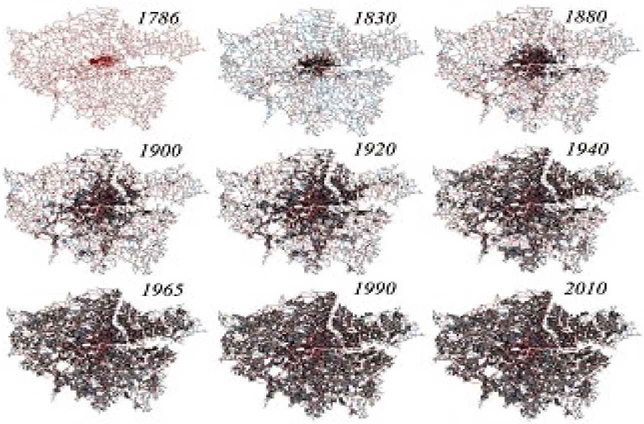

Fig 13. London urban area growth.[30]

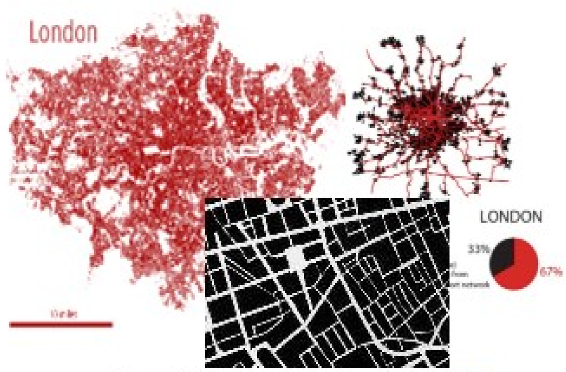

Fig 14. Urban fabric for London city.[29]

- *Pattern of urban fabric:*_London has overlapping organic fabric as a result of the accumulation of civilizations and ages in the city.

- *Land Use:* Whilst there are many land use types within the City, this map focusses on the four principal land uses which make up the majority of existing and permitted floorspace in the City. Data is derived from the City of London Local Land and Property Gazetteer and associated data derived from planning records and historic land use data records.

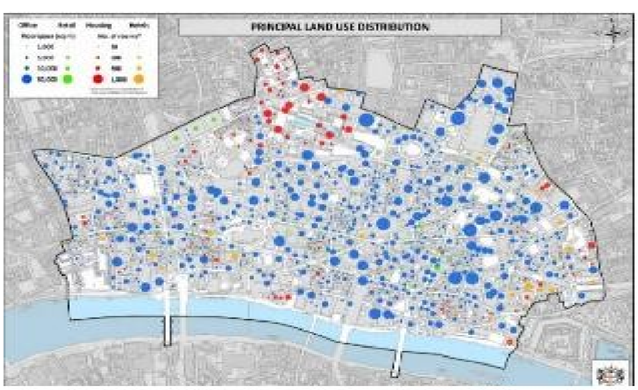

Fig 15. Land use for London city.[20]

6.2 Analysis of city through elements of urban footprint

The urban footprint of London City was analyzed by calculating each element of the urban footprint as detailed in the following points:

- *Transportation*: Transport networks in London are a huge network with an area of 2.2542 hectares and are characterized by vast network of railways, Tube lines, highways, local roads, bus routes, pedestrian and cycle links, trams and light railways cater for these needs.*[20]*

Transport has proved a difficult challenge as it is totally dependent on oil, and less energy is currently used in London than in other cities of comparable income and size. [21]

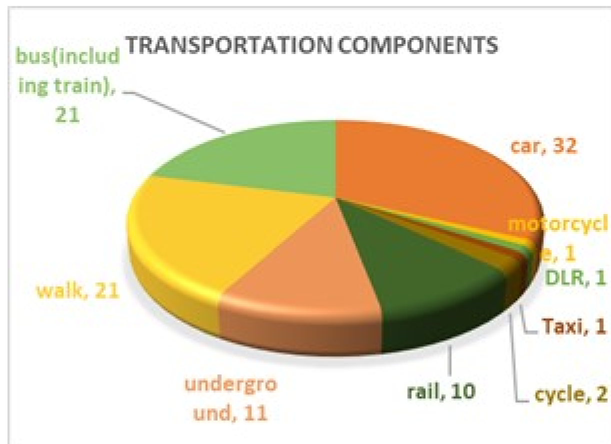

Fig 16. Transportation components

Water: London's drinking water is of high quality, given that one-portion of its water mains are more than 100 years of age, and its broken Victorian-period channels are being supplanted. Yearly water utilization per head is just 57.6 cubic meters. it intends to have diminished spillage rates to 690 megaliters for each day.[22]

- *Energy:* London has several energy sources through which it gets power*:[23]*
  - Electricity from the grid: Electricity is generated in power stations across the UK.
  - Local generation: London had the least domestic solar PV capacity installed between 2010 and April 2015 of any region in England
  - -Heat such as heat networks that capture heat from nearby buildings or infrastructure.

- *Waste:* London's municipal waste stream is comprised of an assortment of materials. The principle components of municipal waste in London are food and green garden waste (22 per cent) and common dry recyclables paper, card, plastics, glass and metals (60 per cent).

comprised of littler amounts of materials including materials, squander electricals wood, furniture and household cleaning chemicals. [22]

- *Built-up;* The percentage of residential buildings in the city of London is 20%, while the gardens allocated to it 54%. The non-residential Mabini represents 11% of the total area of the city.

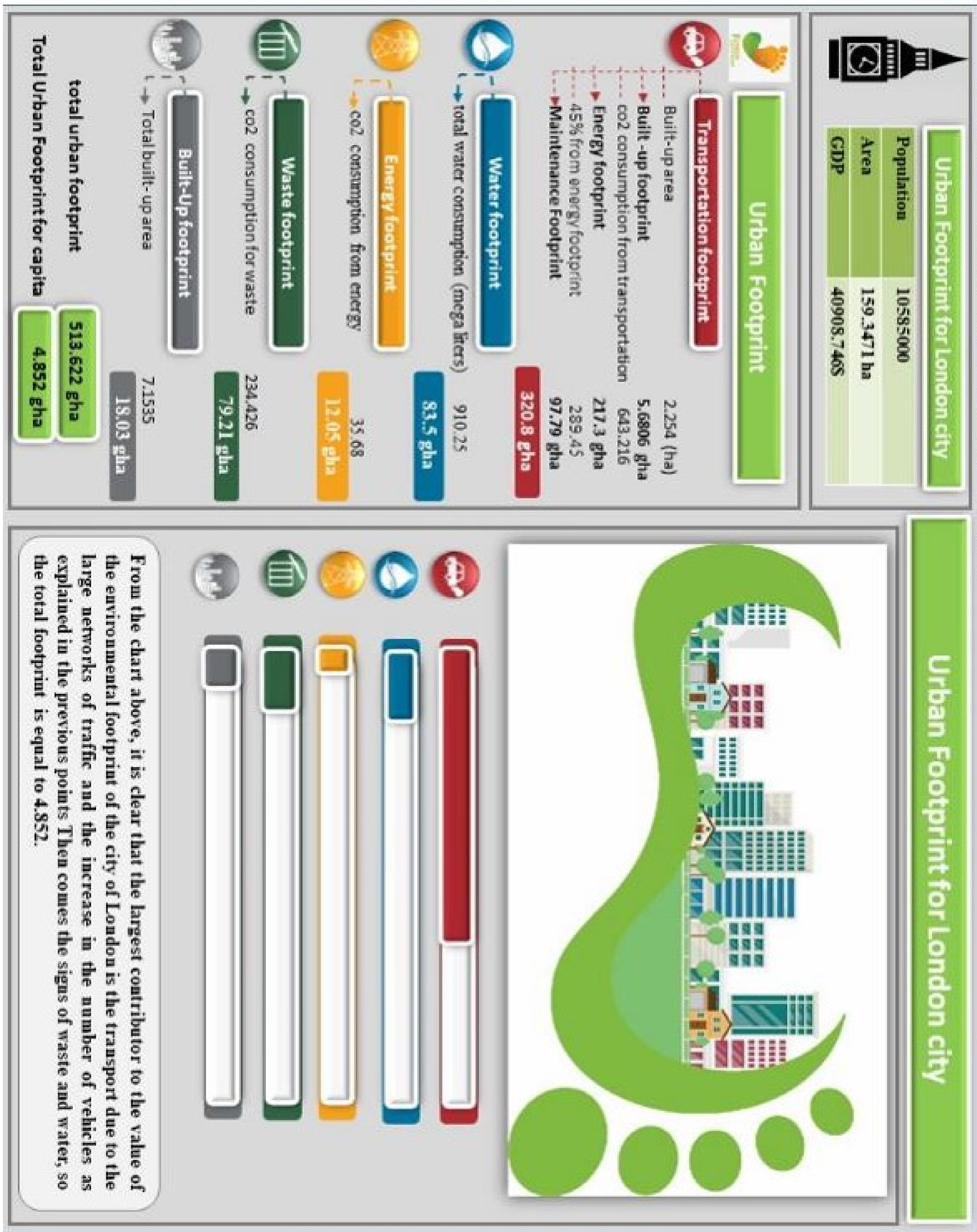

Fig 18. Model of Urban Footprint of London city

6.3 Evaluation results by Urban footprint model[24]

The results of the equations are based on the data shown in the table .1:

Table 1.
General indictors of London

Transportation built - up area	2.2542
co_2 consumption from transportation	643.22
maintenance value for transportation	289.45
total water consumption (mega liters)	910.25
co_2 consumption from energy	35.68
co_2 consumption for waste	234.42
built - up area	7.154

Based on the above, the value of Urban Footprint is the sum of its five components: total urban footprint for London = 513.622 gha, 4.852 gha/citizen as shown in **Fig 17.**

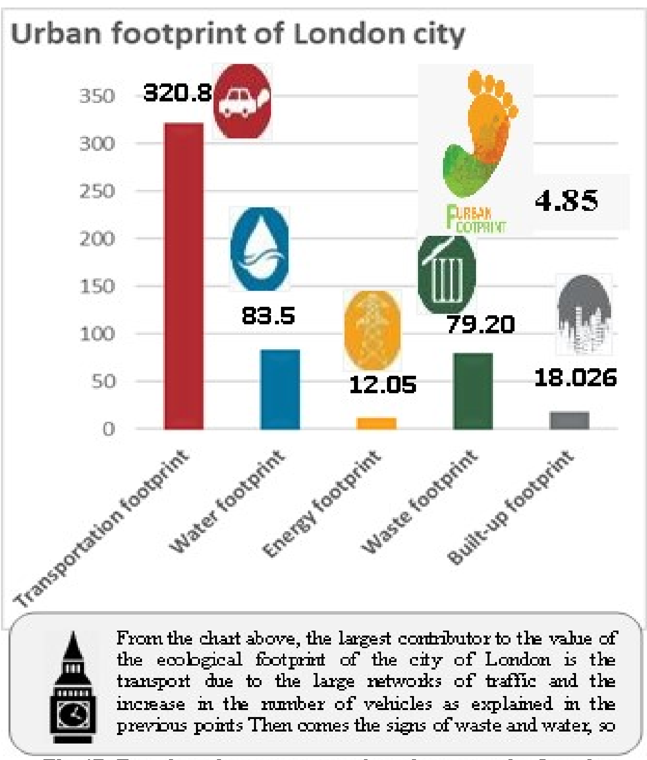

Fig 17. Results of measuring urban footprint for London

VII. RESULTS AND CONCLUSION

Cities are an integrated system for life. Cities already represent 75% of global resource consumption and greenhouse gas emissions. The city represents an organism that feeds, co-exists and is influenced by its surroundings and influences the planet.

The city's food represents the inputs that keep it alive or the inputs that make up the city's being in this place. These inputs are based on the previous study (Human, land, water and air).

The outputs of the city are the effects of the coexistence of the city on this planet. The following elements (transport, energy, water, waste, built-up and emissions), which have been linked to the ecological footprint to be the elements of the urban footprint so that they can be measured digitally to show more accurate values and accurate indicators of the city's footprint on this planet.

To conclude, the urban footprint is a digital environmental indicator that is distinguished by accuracy to evaluate the environmental impact of cities. It measures the urban sustainability extent of cities accurately through using their resources, outputs and the impact of activities practiced in cities on both of resources and outputs. The urban footprint is distinguished by the following;

1. It is an accurate tool used to measure the urban sustainability extent of cities.
2. It reflects the advantages and disadvantages in the different city sectors, and this gives a possibility of suggesting suitable solutions and finding out the shortcomings in any sector of the city. It also gives an opportunity to know the potentials of the city sectors to be exploited later.
3. It is possible to compare between a city sustainability and another one or of the city itself over different years to measure the environmental improvement level and this is related to it is a digital too. This makes the comparison processes and sustainability judgment easier.
4. The urban footprint equations help to evaluate the urban alternatives for cities that are more sustainable, so it is considered a good tool for planners when designing cities and evaluating the planning alternatives.
5. It is possible to compare the sustainability extent of the different sectors of the city itself as it has only one unit which is the global hectare (gha).

To analyze the urban footprint of cities accurately, the environmental footprint of each sector in the city were measured separately. Then, the results of each sector were collected to calculate the total value of the urban footprint as shown in the following **Figure 19**.:

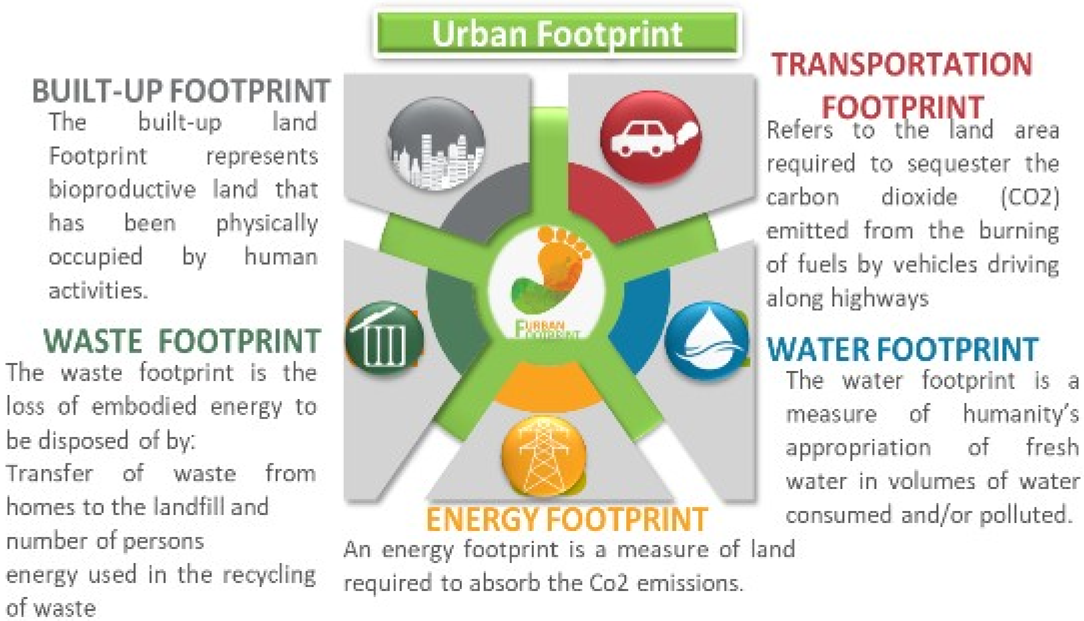

Fig 19. Elements of Urban Footprint

Based on the analysis of the ecological footprint and its simulation with urbanization, the city's inputs represent its biocapacity and urban elements are as the receiver of those inputs.

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