IJBPAS, December, 2015, 4(12), Special Issue: 1722-1735

ISSN: 2277–4998

International Journal of Biology, Pharmacy and Allied Sciences (IJBPAS)

'A Bridge Between Laboratory and Reader'

www.ijbpas.com

ECOLOGICAL FOOTPRINT METHOD IN SUSTAINABLE DEVELOPMENT MEASUREMENT OF KARAJ CITY

SHAHRAM FARAHMAND[1], KERAMATOLLAH ZIARI[*2]

1-Master of urban planning, Department of **Urban Planning and Design**, Qazvin Branch,Islamic Azad University, Qazvin, Iran. shm.farahmand@yahoo.com

2 - Full professor of Qazvin Islamic Azad University.

Zayyari@ut.ac.ir

ABSTRACT

Footprint method is one of the approaches which is used in sustainable development measurement of countries, regions and cities and analyzed rate of human usage from biomass resources. Ecologic footprint method is an evaluation of utilization and recycle of human biological natural resources from the fertile earth. And carries a message beyond a simple reform. Fundamental change in structure of industrial society depends on function change toward ecological considerations. Thus, ecological footprint accounted as sustainability index observed from two views. First, ecological footprint calculates ecological supply and services cost of human in society and manifested that not only people need earth for agriculture productions and road and building construction directly, but also required service and goods of people is supplied via earth, second, ecological footprint interpretation as sustainability index has led to introduction of bearing capacity.

City of Karaj is populated 1386030 and 1614626 in 2006 and 2011, respectively and currently is posed in four place after Tehran, Mashhad and Esfahan considering most populated cities of Iran. After Tehran, it is hosted most immigrants and featured younger population in comparison with other cities of Iran. Karaj is accounted as one of the megacities of Iran in regard to its development and population and political changes in last decades.

This research aims to analysis of growth in accelerated population, urban, consumption and natural reserves around Karaj and is examined by ecological footprint approach. Necessary recommendations and warnings derived from results will be announced to authorities and civilians. The results of this study indicate that resources and infrastructures as well as environment will be exposed to danger due to development and growth of Karaj city and the area of services for Karaj and its civilians is larger than its legal restrictions.

Keywords: sustainability development, the environment. Ecological footprint, Karaj megacity

INTRODUCTION

Nowadays ecological footprint index is applied in many countries from local to national level. This index is integrated method of natural resources consumption and absorption of human wastes by nature. Definitely, this index indicates that in which area there is pressure more than power on natural resources (Sarayi et al, 16:2009). This approach is a tool that helps to provide long time plans and life stability and not only states future goals and strategies to prevent destruction and material inequalities but also guides natural decision makings toward right way (Arjmandnia, 96:2009). The main message is ecological footprint of sustainable development which is beyond a simple reform. Fundamental changes in industrial society depends on function change toward ecological considerations (Hussainzade, Dalir and Sasanpoor, 13:2008). Therefore, ecological footprint can be accounted as sustainability index considering two viewpoints. First, ecological footprint calculates ecological supply and services cost of human in society and manifested that not only people need earth for agriculture productions and road and building construction directly, but also required service and goods of people is supplied via earth, second, ecological footprint interpretation as sustainability index has led to introduction of bearing capacity. Concept of ecological footprint is based on following hypothesis:

1-Food consumption, housing, transportation, infrastructure, commodities and service is measurable by population.

2-Rate of population consumption is changeable to required equivalent field (such as possessed fields, cut forest field and area of land occupied for construction) useful for produce, growth, industry, trash disposal, transportation, infrastructure, commodities and service.

3-The land area used for resources which are consumed by population and related trash disposal are equal to ecological footprint of that population (Seattle, 2, 2004).

Karaj is located on 51 degrees and 0 minutes and 30 seconds of longitude on east and 35 degrees and 48 minutes and 45 seconds of latitude on north(Karaj historical bridge, Karaj-Chaloos road entrance), 1297 AMSL(railway station) and on 48 kilometers of Tehran northern west. This city has area of 175/400 square kilometers and bordered about 178/900 square kilometers and located on the skirt of central Alborz Mountain and is capital of Karaj city.

City of Karaj is populated 1386030 and 1614626 in 2006 and 2011, respectively and currently is posed in fourth place after Tehran, Mashhad and Esfahan considering most populated cities of Iran. During 2006-2011, the rate of Karaj population was 3.10 percent which was considered as one of the highest growth rate among other megacities at the time. Provided that, after Tehran, it was hosted most immigrants and featured as young population.

Theoretical Fundamentals and Concepts

Ebenezer Howard developed a strategy to solve industrial city issues via publication of a book titled as *future garden city* (1989) which applied a special method including huge amount of details. The strategy tried to balance urban and rural regions by a method called sustainability (Willer and Beateli, 7: 2005). Later urban planners such Reymond Alvin, John Nolen, Louis Mamford, Patrick Abercrombie, Yahn mac Harg and Peter Caltrope, were looking for different methods to create primary theory.

Attitude developments in last decades in world societies after 1972 described in table 1-2 and is categorized in three levels:

Table 1: Global Attitude Changes on Environment (ref: Macknon, 2004, 13)

Year	City	Subject
1972	**Stockholm**	**Human and environment**
1992	**Rio de Janeiro**	**Environment and development**
2002	**Johannesburg**	**Sustainable development**

Beside the conferences and statements issued in global level which indicate sensitivity of sustainable development and urban sustainability specifically, the attempts of Matis, Wackernagel and William Reyes should be highlighted.The joint throughput of Wackernagel and Reyes was published as a book titled *our ecological footprint* which was an introduction of a qualitative and modern approach to assess environmental power of various spaces called ecological footprint. The book includes five chapters and authors describe their outlook via experts anxiety bring up. They focus on knowledge power, technology consequences, growth,

barriers, limitations and planning for sustainable future along with description of ecological footprint. Authors also analyze necessary conditions of sustainability with human and environmental considerations and state its analysis approaches (Sasanpoor, 12, 2006).

Wackernagel (1990) believes that this book introduces the tool for specific planning in which can help to interpret and understand sustainability issues in general activities. This matter (ecological footprint) identifies important energy and economic materials and its relationships with earth and exploitation of nature.

This approach is applied in most places around the world for two decades to analyze environment effect of development, therefore too many international and global foundations and institutes as well as private companies are active in this field to assess its measurement indices and analysis of its result and the results are assessed and presented to scientific and global societies. These results include: index analysis and presenting rate of ecologic footprint of regions and neighborhoods (specifically at lake level and etc.) of large cities, mega cities, countries as well as continents and comparing them with biological capacity and presentation of global average. In this regard it can be mentioned be global reports of "Ecological Footprint Atlas" and "Living Planet Report" and etc. Also, urban, regional and national reports such as "an Ecological Footprint Analysis of Hamburg" and "Ecological Footprints of Canadian" exist.

During recent years (last 20 years), an index named as footprint emerged in the domain of environmental sustainability analysis. Ecological footprint was introduced and developed by Reyes and Wackernagel and water footprint by Hoekstra and Hung in 1995 and 2002, respectively. Carbon footprint and its results derived from Global Warming Potential (GWP) concept, was introduced to scientific literature and concepts by Hugold in 2003. Other footprints have not identified well and its results have not analyzed so far. The review of Gali et al in 2011 indicates that major concepts developed in footprint field are ecological footprint, carbon footprint and water footprint which are introduced as group of footprints. There are also other footprints such as Nitrogen footprint, social footprint and economic footprint. By comparison of biological capacity capitation with Iran footprint capitation, we conclude that Iran ecological footprint is much larger than biological one which manifested overconsumption of resources and

dependence to the other regions of world resources to supply ecological needs of residents. Also, according to ecological footprint approach and its results it should be mentioned that ecological status of Iran is unstable. Besides, it should be noted that ecological instability and lack of biological capacity in national and regional level can be compensated by applying resources of supportive regions (Sara Shahanavaz).

Mahmood Jomepoor et al (1392), conclude that Rasht has ecological instability by using ecological footprint approach in analysis of sustainable development status.

Mostafa Yalve (1391) in his Ph.D. thesis about assessment of urban sustainable development via ecological footprint approach (Kermanshah city) concludes that ecological footprint of Kermanshah is 1.82 Hectares in consumption group of food, transportation, natural gas warming, water, electricity and the ground needed for waste disposal, while, when comparing to supportive spaces such as city and province, it indicates that Kermanshah needs a region beyond Kermanshah province to fulfill biological necessities and sustainability.

Karim Hassanzade Dalir and Farzaneh Sasanpoor in their article about ecological footprint approach in Tehran capital (1390) stated that Tehran footprint is 3.79 Hectares per person, in fact it is 1.91 more than one person share which forces to its supportive region namely, Iran and is 2.39 Hectares larger than its global average, therefore this means that each person in Tehran is misusing biological capacity and ecological power 2.5 times more than its share. Thus, because Tehran is not a producer, therefore the most pressure which is forced to its supportive region namely Iran is done by Tehran residents in service and good consumption. If Iranian production and consumption approach would exist in this manner, therefore, we would have needed a space three times larger than current Iran.

Case Study

Karaj province contains of three towns Karaj, Mehrshahr and Rajayishahr and recently Fardis and Mianjaddeh was added, too. After Tehran, Karaj specifies fastest growth rate in the province and lead to generation of population centers in its domain such as Kamalshahr, Mahdasht, Mohammadshahr and Meshkindasht, however, it became a megacity populated about one million and six hundred thousand in area of more than 179 square kilometers.

Risk factors that underlie accelerated growth of Karaj city can be divided as follows:

-Close distance (less than 40 minutes) to political and economic points of the country, Tehran.

-Appropriate quality and number of connection roads (freeway and two major roads: special road and old road of Karaj, railway and metro of Tehran-Karaj).

-Location that is between major connection roads of the country toward north and south.

-Formation of most important industrial pole (and therefore job opportunities) on Tehran-Karaj- Qazvin road

-Appropriate climate and topography situation.

-Less prices of housing in comparison with Tehran.

Karaj city is located on the skirt of central Alborz and is sloped north-south. The slope of north east in east side of Chaloos is east-west. The most significant local ripples is Tappeh Moradab which is located on north east of city.

The most important green area of city is on the bank of Karaj River, government gardens, Mehrshar apple garden and southgardens of Mehrshahr and Fardis. Also, there are too many branches separated from Karaj River and flow through different part of city. Generally, north domain of city (Azimieh, Gohardasht and Baghestan) which located on mountains skirt have more slopes and this natural topography underlies appropriate sightseeing.

This quality is also clear on Moradab Tappeh which is the best point of city due to its fine location, but reseed tissue neutralize this natural quality. Karaj River and its banks is one of the special opportunities of city to develop free spaces and green area and recreation centers, but is turned to place of trash disposal and in the lower areas, exploitation of sand mines destruct environment.

Natural geography of this region generated special situation for north- south streets which reflected in large outlook and connection of city and countryside and green space areas.

All of the items above have been planned due to following considerations such as location of Karaj in domain of Tehran and as part of capital and in urban study framework of Karaj- Shahriar, 20 years outlook of country. Documents of 5 year program of development or land use and regional logistics. Although the output of these documents and plans proposed as criteria of action and upstream projects, but during the formation of Alborz province, its modern position against other cities of province as well as other provinces and analysis of success or non-success of regional and

national plans indicate this truth that Karaj is situated in sensitive and special role in country and province. It is clear that in this manner, accelerated sustainability development measurement and its important environment play an important role.

METHODOLOGY

Calculation pattern of ecological footprint presented by Reyes and Wackernagel (1993-1996) uses consumption matrix and land use is as following:

A) Consumption categories described as: food, housing, transportation, commodities, service and wastes and produced wastes.

B) Land use categorization includes of six separate components and every good and service that is used by human during his lifetime should be involve in these six components as follow:

1) Agricultural land: sufficient land area to produce for consumers of society.
2) Energy absorption land (absorption of CO2): forest area needed by members of society to absorb CO2 created from direct and indirect fuel consumption.
3) Pasture land: pasture area required for breeding and their productions of society.
4) Woodland: woodland area required for production of wood and paper.
5) Water area: sea area required for production of fish and seafood used by society.
6) Constructed area: land area required for construction of building and infrastructures(Sarayi et al, 18,2009).

Liquid gas (M^3)	Petrol (M^3)	Super petrol (M^3)	Kerosene (M^3)	Gasoil, gasoline (M^3)	Fuel oil (M^3)	Natural gas (MM^3)
42740	476297	33200	20769	158565	638	3122

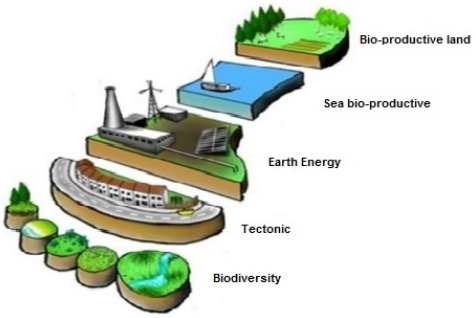

Figure 1: Categorization of different types of fields in estimation of ecological footprint (ref: Global footprint Network)

By comparison of footprint and biological capacity on earth areas, it can be concluded that the only area that Iran biological capacity is higher than ecological footprint is forest area. This means that people do not use from forest area completely and in this part there is ecological footprint. In constructed land, biological capacity and ecological footprint is equal which indicate that consumption has not gone beyond biological capacity. In other areas, ecological footprint is higher than biological capacity manifested instability in these areas.

Table 2: Reyes and Wackernagel (2003) classification in consumption domain

CONSUMPTION DOMAIN	SUB-DOMAIN
DIRECT CONSUMPTION OF ENERGY (EXCEPT TRANSPORTATION)	- Electricity - Gas - Liquid fuel, oil, gasoline(except transportation) - Solid fuels(coal) - Other fuels
TRANSPORTATION	- Travel by car, motorcycle and ship - Air travel(citizens and business trips) - Railway and underground travel - Autobus travel(diesel) - Other transportation vehicles
GOODS , COMMODITIES AND MANAGEMENT OF WASTES	- Goods and service movement(different goods and materials) - Energy recycling validity - Resources and energy recycling validity via recycling
FOOD	- Animal based foods - Plant based food
HOUSING	- Construction(except direct energy consumption for operation) - Construction credit for recycling - Urban grounds(grounds used for construction)

FINDINGS

Estimation of ecological footprint of Karaj city in field of energy consumption: transportation (Carbon production)

According to statistic information of Alborz province, consumption rate of petroleum productions in Karaj city is as follows:

Table 3: Consuption Rate of Energies of Karaj city (ref: statistical yearbook of Alborz province government, 2011, general administration of Gas)

*Consumption for Karaj: petrol 597284, super petrol 41634, kerosene 26045, gasoline 198843, fuel oil 800 M^3 and natural Gas 3916 million M^3 and liquid gas was 63860 M^3 which is balanced based on population proportion.

To estimate major fuels of transportation (petrol and gasoline), two approaches could be applied. First, using number of automobile trips and transported passengers and etc. in different transportation systems which there is lack of information about fuel consumption. And second approach is direct use of statistical websites of national Iranian oil producing and distributing company. In this calculation it has been used from second approach for formal and authentic

documents. Unleaded petrol produce 125000 BTU per Gallon which lead to release 19.35 Tone of Carbon in each billion of BTU. However, Gasoline produce 138700 BTU per gallon which lead to release 19.95 Tone of Carbon in each billion BTU.

(476297+33200)*1000/1614626=315/55

Liter petrol consumption per person in one year

315/55 Liters (petrol per capita consumption) ÷3/7853=83.36 Gallons petrol per capita consumption

Karaj× 125000BTU/Gallon=10420244÷10^9=0.010420 Billion BTU × 19.35 Tone of Carbon/Billion BTU=0.2016 Ton of carbon released from petrol consumption.

In regard to annual regulation there is one hectare of ground to absorb 1.8 Ton of carbon, therefore:

0.2016×1 Hectare÷1.8 Ton of carbon=0.1120 Footprint per capita×1614626 city population=180866.57 Hectares, city petrol footprint

(158565) ×1000/1614626=98.20 Liters gasoline consumption per person in one year

98.20 Liters (Gasoline consumption per capita) ÷3.7853 = 25.94 Gallons per capita consumption

Karaj Gasoline× 138700 Btu/Gallon = 3598417 BTU ÷ 10^9 = 0/003598 Billion Btu × 19/95 tons of carbon/billion BTU=0.071788 Tons carbon released from Gasoline consumption.

In regard to annual regulation there is one hectare of ground to absorb 1.8 Ton of carbon, therefore:

0/071788 ×1Hectare÷ 1/8Tons of carbon=0.03988

Footprint per capita ×1614626 city population=64395.25 Hectares Gasoline footprint

CNG of vehicles fuel rates are not presented separately and would not calculated, but in most cases it is used by vehicles.

In field of food:

-Fruits (garden)

Fruit consumption per capita in Karaj is 85 Kg, besides there are 5758 Hectares of gardens in Karaj that produce about 92700 tons of fruit in one year (In Alborz province this number is 26964 Hectares with annual production of 512097 tons).(Agricultural organization of province , levels and production during 91-92) In regard to amount of cultivating gardens and their production focusing on Karaj in calculations, the average harvester of fruit is 16.27 tons per Hectare.(and there is no other fruit garden in urban borders except apple garden of Mehrshahr) therefore:

85 Kg×1614626 persons= 137243210Kg/1000=13724 tons total consumption of city

13724 Tons/16.27products per Hectare/1614626=0.0052 Hectare per person= 8435 Hectares

Thus, fruit products footprint of each Karajian is estimated 0.0052 Hectare in regard to high rate efficiency of gardens in province borders.

-Cereals, beans, meat and etc.(Agricultural field and pastures and grasslands):

The total number of agricultural fields of province is 49512 Hectares (and Karaj city is 2840 Hectares). (Province statistics board, 2013, and agriculture census 2001). The amount of harvest of these fields is 1117186 tons and it could be said that average harvest is 22.56 per Hectare. (Agriculture products statistics, 2010-2011).

Table 4: Food consumption rate of citizens in Karaj

Consumption type	Consumption per capita(Kg) author statistics	Proportion of bestial to agricultural	Consumption amount (Kg)
Wheat	80	1	80
Sugar	10	1	10
Beans	14	1	14
Rice	45	1	45
Oil	15	2.33	34.95
Red meat	18	16	288
Chicken meat	30	6	180
Egg	13	6	78
Milk	103	5	515
Vegetables(no fruits)	20	1	20
Total			1264.95

Ref: agriculture organization statistics and questionnaires provided by author. (Wheat is absolutely calculated from bread and sugar is calculated from direct consumption of sugar and cubed sugar. It is not included candies and sugars used in administrative environment)

Based on estimation, each Karajian food consumption is 1.26 tons which have to be added to wastes amount that is 10% of pre consumption based on agriculture organization declaration, to calculate total food consumption.

Thus, according to the table 5 and 10% addition of pre consumption wastes, consumption rate of Karaj civilian measured as: 2042421×1/1=2246663 Tons per year. This means:

2246663 tons/products of each Hectare, 22.56=Hectares

99586 required fields

99586/1614626=0.062 Hectare per person (food footprint)

In field of goods consumption

-Wood consumption

Wood per capita consumption of country and Karaj is 0.33 M^3 and average harvest of wood per hectare is 1.43 M^3 annually and average rate of annual wood is more than 640

Kg. (Natural resources administration). Therefore,

1.43×640=915Kg per Hectare

640×0.33= 211.20 Kg/Person/Year

211/20/915=0.23 Hectare, per person (wood footprint from forests)

0.23×1614626=371364 Hectares forest required for civilian

-Wastes productions (trash)

According to municipality of Karaj statistics, (Deputy of urban service, ISNA, collection of 1500 tons of trash in 12 regions), generated trash in 2015 is 0.339 tons annual per capita for each civilian that is 547358 tons for total of city. Since 80% of trashes are high quality material, therefore while burying the volume reduced to 25% of its initial volume and because each cube meter of trash weighs 450 Kg so:

547358000Kg/450=1216351 M^3 ×0.25=304088M^3

During burying process if we suppose that depth of trash bury is 2 meters, then:

304088M^3/2=152044M^2/10000=15/20 Hectares required to bury the trash

15/20/1614626 person=0.0000094 trash footprint per civilian

In the field of residence consumption energy

-Natural gas warming (Gas needed for in-house consumption)

Gas consumption rate of Karaj city was 3916 million M^3 in 2012(according to statistics of Alborz government) and the annual average consumption has estimated about 3122 million M^3 in appropriate with population by describing to the city domain.

In regard to lack of gas in many villages and gas consumption in automobiles, these were adjusted in Karaj and total estimates of gas consumption have been evaluated.

N= (Number of Moles in cube feet) / (V volume cube feet × P as atmosphere pressure)(T as Kelvin temperature × R as constant ratio of each psi (natural gas pressure in-house)) which equals to 14.5 atmosphere.

P=0.25÷14.5=0.017 atm

V=1 ft^3=28.3 L (Number of Moles in one cube feet)

R= 0.08206 L constant ratio atm/Mole K

T= S Fahrenheit= 15.55 Centigrade= 288.50 Kelvin

N= (0/017 × 28/3) ÷ (0/08206 × 288/50) = 0/02

So, there is 0.02 Moles of Methane in one cube feet and by considering the molecular mass of methane as 16.043 grams per Mole, then:

16.043gr/Mole × 0.02 Mole= 0.32 grams of CH4 in Ft^3

Considering that 75% of Methane is Carbon so:

0.32 Grams of Carbon in cube feet × 0.75= 0.24 Grams of Carbon in cube feet and each cube meters equals to 35.314 cube feet and each cube feet equals to 0.02832 cube meters:

3122000000M^3 annual consumption of Gas/1614626=1933.57 M^3 Gas consumption per capita for each civilian

1933.57 Gas consumption per capita× 35.314= 68282.25 ft^3 natural Gas consumption

68282.25×0.24=16387.74grams of Carbon ÷ 10^6= 0.016 tons of Carbon

Annual regulation to absorb 1.8 tons of carbon is one Hectare, therefore:

0.016tons of Carbon÷1.8=0.00910 Hectare that is Carbon footprint of Gas consumption per person

0.00910× 1614626 = 14700 Hectares, Carbon footprint due to natural Gas consumption belong to total of city

-Electricity power

Total annual consumption of electricity in Karaj is 5194066 Megawatts in 2014 according to automated collection system of western electricity distribution Company of Tehran province (Karaj, 2015).

519406 MwH

5194066000 KwH

As we know 85% of coal is Carbon, so we calculate the amount of Carbon as below:

2977490063694 × 0.85=2530866554140 grams of carbon ÷10000000=2530866.55 Tons of Carbon

Considering regulation of 1.8 tons of Carbon absorption by one Hectare:

2530866/55 ÷ 1/8 = 1406036/97 Hectares, total city footprint ÷1614626=0.8707 Hectares, Carbon footprint due to electricity consumption of each civilian

In field of water

Required per 0.08 Hectares is one million M^3 according to investigation (Samadpoor, 13, 2006) and water consumption (Karaj water consumption in 2011 was 138766000M^3) of Karaj equals to 110657000 M^3 (Alborz government statistical yearbook 2011).

110657000000 Liters × 0.08 Hectares ÷1000000=8852.6 Hectares water footprint ÷ 1614626 population=0.00548 water footprint for each civilian.

RESULTS

Ecological footprints of Karaj residents, although ecological footprint of Karaj in calculated fields is less than other cities which have been studied by other researchers that is due to high level of water and specific climate and its fertile fields , but, pollutant gases and malabsorption of those gases even

in province has reached to the warning level. This Carbon is generated by fossil fuels and especially electricity generation- current methods of production- however, a space 4 times larger than Karaj province is not sufficient to be named as supportive spaces of Karaj- especially in case of required forests to absorb CO2.

Components	Ecological footprint (EF) (Hectares per person)	Required field (Hectares)
Total	1.27	2089859

Although Karaj footprint has lower rate in comparison with other estimated cities of Iran, but, this rate is more than total biological capacity of Iran and it has instable status based on its development and approach applied.

Karaj ecological footprint is 1.27 Hectares that is less than country average but is higher than Iran biological capacity. In regard to global footprint average of 2.7 and global biological capacity average of 1.8 in optimal level. Its Carbon production posed in serious level (also water resources present red statistics and lines during this year). In Karaj, maximum footprint belongs to energy earth to absorb Carbon released from electricity energy rated 0.87 Hectares and minimum belongs to about wastes and trash rated 0.0000094 Hectares.

Currently, it is clear that megacities and cities are not able to provide their population necessities and their supportive region has been provided beyond their province borders, despite, the resource management should be changed to provide desirable future for civilians of Karaj. These changes should be applied in some fields such as reduce of waste and trash production, intelligent management of water resources, using healthy energies, reformation of consumption pattern, economic valuating of natural resources and legal and political efficient solution to achieve resources.

And megacities sustainability depends on setting and manipulating of input (material and energy) and output (wastes and environment pollutants) flows at the level of capacity associated with their supportive area and therefore the sustainable development would be epidemic.

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