ECOLOGICAL FOOTPRINT

RAMPRASAD SENGUPTA

DISSEMINATION PAPER - 17

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Ecological Footprint

1.0 Concept

How can we describe or measure the pressure of human activities on the biosphere and monitor the sustainability of human society and its development process. Human activities create the pressure in the form of demand for natural resources which would imply a requirement of the regenerative capacity or bio-capacity of the concerned ecosystems of the biosphere. The process of regeneration of resources, in an ecosystem as endowed with the resources of land, soil, water and climate system is driven by solar energy flow through the food chain and the biogeochemical cycles. Given a pattern of land use, there would exist a potential regenerative capacity. A concept of bio capacity has been defined to represent the total biologically productive area in terms of crop land, pasture, forest, fisheries, etc. that is available to meet the human needs with their respective primary productivities per hectare on sustained basis. Human requirement for such biologically productive land area which would produce enough food, fibre, timber, absorb carbon dioxide wastes, etc. for certain given assumed average primary productivities of land for such uses may be within limits or exceed the bio capacity. In case the demand for bio capacity exceeds the availability, it would lead either to over harvesting of the biomass leading to the depletion of the stock of standing biomass in the areas of land including water bodies or to over use of the concerned land by raising temporarily these primary productivity per unit of land area per unit of time which is not sustainable. The consequences of such demand for bio capacity exceeding its availability has been two fold: (a) depletion of the biotic resource stocks ending up with loss of biodiversity and (b) erosion of the ability of the biosphere to support human population. Two indicators have been developed to measure the impact of human society on the biosphere to capture these two respective aspects of pressure on biosphere. (1) Living Planet Index to monitor the biodiversity which is the central factor in determining the robustness and the health of the planet's ecosystem, and (2) Ecological Footprint which gives the estimate of human demand for natural resources in terms of biologically productive land-areas including water bodies for various uses and that of withdrawal of water resources. Humans also consume directly and indirectly the substantive amount of the abiotic resource of fresh water as both life support as well as inputs in economic process which would trace the water foot print. We elaborate here the concept of Ecological foot print along with some data to describe the current state of Ecological deficit or surplus of the planet.

2.0 Measurement of Ecological Foot Print

Ecological footprint measures the demand of the humans for the natural resources in the biosphere for direct use and waste absorption in terms of biological productive area in land and sea. This would capture the area of cropland, grazing land, forest, fishing ground in water bodies – in land or in coastal sea required directly or indirectly to produce the food, fibre and timber for human consumption and for absorbing wastes in the form of emissions generated by energy production and consumption and for providing space for the construction of infrastructure. This does not however capture the pressure created by human use of water and therefore water withdrawals in volume unit is to be additionally considered to describe the total pressure on the ecosystem. It may be noted here that although water withdrawal is not included in the ecological foot print measure, the energy required to pump it is accounted for in it. As land is required for housing, buildings and infrastructure causing diversion of biologically productive area, the built up land is included in the footprint calculation. This built up land area also includes land area used for the construction of dam or water storage. While biomass energy requirement by the humans would be normally accounted for in the calculation of ecological footprint, the major part of energy consumed today in human society is based on fossil fuels like coal, oil and natural gas which are nonrenewable resources not producible by the ecosystems in human time scale. The combustion of such fossil fuels would on the one hand cause depletion of these nonrenewable resource stock, and the emission of gases such as carbon dioxide (CO_2) on the other which has a long life of residence of about 100 years in the atmosphere contribute to the global warming and eroding the sustainability of the human society and economy. While all carbon based fuel would cause CO_2 emission, the same is recycled into plant body through carbon cycle and captured in the growth of biomass fuel. Unlike bio fuels, the CO_2 emission by fossil fuel is not as such naturally sequestered and requires special human initiatives for sequestration. The United Nations Framework Convention on Climate Change (UNFCCC) has set the goal of avoiding further accumulation of CO_2. This goal can be achieved by human sequestration of CO_2 emission from fossil fuel either by way of artificial carbon capture and its injection into the underground deep well or by aforestation which will enhance the rate of natural sequestration by the total forest area. The requirement of biologically productive land for such purpose of natural sequestration to achieve UNFCCC goal would therefore be the bio capacity in units of forest land area required to sequester the total CO_2 emitted from fossil fuel less the sum of the amount of CO_2 absorbed by oceans and human sequestration. Till now the amount of human sequestration has been negligible. The ecological footprint of fossil fuel would be currently mainly determined by the amount of CO_2 emission from its combustion and the capacity of a unit of forest area to absorb CO_2 which in turn depend on the level of maturity of the concerned forest area. The absorptive capacity of CO_2 by a forest tends to be zero with growing maturity. In the context of nuclear energy the ecological foot print has been taken to be the footprint of fossil fuel energy which it would replace, although its logic is not all that clear.

How is the Ecological foot print calculated? The calculation of requirement of biologically productive areas of land and water for human use assumes certain norms of foot print intensity of human consumption of food, fibre, fuels, timber, built in area for housing or construction for other buildings and infrastructure. These norms of foot print intensity would depend on the technology and resource management prevailing in the country or region of the concerned economy and the biological primary productivity of land varies across different uses – like crop land, forest, pastures, ocean, fisheries etc. Again the productivity per hectare for a given type of land use varies across both countries or regions and over the years for the respective varying ecological conditions and changing conditions of resource management and time.

The ecological foot print for any particular type of end use of land in any actual biomass output of any region has been based on the world average yield of the concerned primary biomass output item per unit of land (or water) area and thus expressed in units of global hectare for that end use. The assumption of this yield should be a sustainable one over time for repeated use. The aggregate footprint of all human consumption requiring all kinds of use of land would be obtained by aggregation with the application of an equivalent factor for normalizing different kinds of land use into a common unit of equivalent land of average global productivity across all end uses. The calculation of both the ecological foot print and bio capacity are explained below along with derivation of ecological deficit or surplus and discussion on monitoring sustainability of use of global resource system in any region.

While the ecological foot print represents appropriated bio-capacity, the bio-capacity represents the availability of productive area on land and sea.

Ecological Footprint (Demand)	=	Population * Consumption per person * foot print intensity
Bio-capacity (Supply)	=	Area * Bio-productivity
Overshoot of the Footprint (Ecological Deficit)	=	Demand – Supply.

The consumption of people of a country or a region can be tracked down to the direct or indirect use of some primary product of the ecosystem – i.e., land area or water area. The alternative land uses required for all kinds of use of such primary product needed can be categorized broadly into 6 types: - crop land, grassing land, forest land, fishing ground, carbon uptake land and built up land. For certain land use type (*K*) like crop land or forest or fishing ground there would be a range of primary products (*i*) which can be produced by such use with an yield rate. We can derive the yield factor for a land type use as given below which can be used to convert the country level land use of a particular type into equivalent global acreage of that type of land use.

Let the actual production and actual yield of the i^{th} primary product from k^{th} type of land use be denoted by $P_i(K)$ and yield from such land type to be $y_{Ni}(K)$ at national level. The same would be denoted by $P_{wi}(K)$ and $y_{wi}(K)$ to represent the primary output and yield at the global level for the same land use type for the same period or year.

Thus the requirement of land use for product *i* at the national level for the actual national level of bio-productivity and the global average level of bio-productivity would be $A_{Ni}(K)$ *and* $A_{wi}(K)$ where

$$A_{Ni}(K) = \frac{P_{Ni}(K)}{y_{Ni}(K)},\ A_{wi}(K) = \frac{P_{Ni}(K)}{y_{wi}(K)}$$

Thus the yield factor for k^{th} type of land use to obtain the global acreage equivalent of the concerned type of land use at the national level would be

$$y_N(K) = \frac{\sum_i A_{wi}(K)}{\sum_i A_{Ni}(K)}.$$

This factor thus would depend on product mix and the basic product yield pattern of land of the k^{th} type at the national and global level. Thus the total land use of the k^{th} type for the country in equivalent global acreage can then be denoted by A_{WN} (K), where A_{WN} (K) = $y_N(K) * \sum_i A_{Ni}(K) = y_N(K) * \sum_i \frac{P_{Ni}(K)}{y_{Ni}(K)}$. The estimate of $y_N(K)$ would thus vary from year to year. The following is a table of illustrative yield factors for a different land uses yield for a set of countries in 2005.

Table 1: Sample Yield Factors for Selected Countries, 2005.

	Cropland	Forest	Grazing Land	Fishing Ground
World average yield	1.0	1.0	1.0	1.0
Algeria	0.6	0.9	0.7	0.9
Guatemala	0.9	0.8	2.9	1.1
Hungary	1.5	2.1	1.9	0.0
Japan	1.7	1.1	2.2	0.8
Jordan	1.1	0.2	0.4	0.7
New Zealand	2.0	0.8	2.5	1.0
Zambia	0.5	0.2	1.5	0.0

In order to combine the impact of all types of land use into a common footprint acreage unit, a second scaling factor has been invented and called equivalent factor used by the global footprint network which calculates the country wise footprint. The equivalent factors would translate all types of land use into the units of global acreage based on world average biological productivity of land or sea area. These factors have been based on the relative primary biological productivity of alternative uses of land. The Global Footprint network which regularly computes the foot print index, calculates the equivalent factors using the suitability indexes from the Global Agro-ecological Zones model (GAEZ model) and the data of actual areas under cropland, forest land, grassing areas, etc. from FAOSTAT (FAO and IIASA Global Agro-Ecological Zones 2000, FAO Resources STAT Statistical Data-base 2007). GAEZ classifies all land into five categories depending on their suitability for primary production; i.e., potential productivity. The assigned values of indices which converts any land use type acreage into equivalent global acreage are as follows:

a) Very suitable (VS) - 0.9
b) Suitable (S) - 0.7
c) Moderates suitable (MS) - 0.5
d) Marginally suitable (MS) - 0.3
e) Not suitable (NS) - 0.1

While the cropland should have the highest suitability, forest and grazing land falls under the second and the next third best category, the marine area of the continental shelf and inland water area would follow as the fourth and the fifth in the sequence of suitability. As built up areas are located in or near the settlements of people, they are often on land with high primary productivity or crop land, they would be assigned suitability index as the same as that of cropland. The equivalent factor is now taken as the ratio of suitability index of the concerned land use category to the global average suitability index of all types of land being taken together. As the global land use pattern in terms of acreage distribution may change from time to time the average suitability index and therefore equivalent factor would also change over time. Table 2 thus gives the equivalent factors as assumed for 2005.

Table 2: The Equivalent Factors for Different Types of Land Use, 2005

Area type	**Equivalent factor**
Primary Crop land	2.64
Forest and Grazing land	1.33
Marine area	0.50
Inland water	0.40
Build up land area	2.64

Ecological Footprint of a particular land use type in question for a country would thus be.

$$EF_N(K) = A_N\ (K) * y_N\ (K) * eq(K) \qquad (1)$$

where A_N *(K)* is the actual land use of a given type in country *N* for a given type *K*, $y_N(K)$ is its yield factor for the concerned country and *eq(K)* is the equivalent factor for land use type K globally valid for all countries as explained above. Total ecological footprint of land use of all types of a country would then be

$$EF_N = \sum_K EF_N(K) = \sum_K A_N(K) * y_N(K) * eq(K).$$

$$= \sum_{K} \left(\sum_{i} \frac{P_{iN}(K)}{y_{iN}(K)} \right) * y_N(K) * eq(K) \quad (1a)$$

where $P_{iN}(K)$ is the consumption of product i produced by land use type K in country N; $y_{iN}(K)$ is the physical yield of product i of land use type K in country N; $y_N(K)$ is the yield factor of land use type K in country N to obtain equivalent global acreage of land use type K; $eq(K)$ is the global equivalent factor of land use type K.

3.0 Trade and Estimation of Ecological Footprint

The manufacture of goods and production of various utilities involve directly or indirectly the appropriation of some bio-capacity for obtaining the inputs or for removing the wastes from the ecosystem as required at the different stages of production. In order to arrive at the ecological footprint as embedded in the final goods and services delivered it is important to correctly assign the footprint as calculated and tallied at the point of primary harvest or waste up take by land uses of various types, to the different final end use goods and services. While in a closed economy the supply and consumption of goods and services balance in equilibrium, there is no divergence between the demand for land use requirement in terms of ecological foot print and bio capacity actually used in such equilibrium situation. However, in an open economy bio-capacity appropriated and embodied in commodities and services of the trade flows and their foot print are to be assigned to the consumers or users of the country of destination of the flows. In other words the calculation of demand for bio-capacity or ecological foot print of domestic consumption is to take account of such flows and in that case the ecological foot print of consumption will differ from the ecological foot print of production even if there is macro-economic balance of trade or payments. If we ignore the changes in stocks, and consider the ecological footprint of apparent consumption (EF_c) which is production + import – export, then

$$EF_c = EF_p + EF_{im} - EF_x$$

where EF denotes the ecological footprint, the subscript *p, m* and *x* standing for production, import and exports, respectively.

If $EF_c > EF_p$, then the nation is an ecological debtor and if $EF_c < EF_p$ then it is a net ecological creditor. If a country is a net ecological debtor, it would either appropriate bio-capacity from abroad, or demand bio-capacity of the global commons or deplete the stock of resources or ecological capital whose natural growth or regeneration as driven by geo-chemical cycles falls short of the appropriation. If the country is an ecological creditor it implies that its consumption could have been met by its own ecological capital without involving any net decumulation and possibly contributing to either conservation of the global common resources or accumulation to its own stock of ecological capital stock. The difference $EF_c - EF_p$ is called the ecological deficit or surplus of a nation depending on its sign. A situation of ecological deficit is called one of overshoot in the literature.

As already mentioned the bio-capacity of a country in a year is the availability of land of various types of use as translated into units of global acreage based on average global primary biological productivity.

Bio-capacity $A_{NW}^{e} = \sum_{K} A_{NW}^{C}(K) = \sum_{K} A_{N}^{C}(K) * y_N(K) * eq(K).$

where $A_N^C(K)$ is the actual supply and use of area of land or water of use type K and $A_{NW}^C(K)$ is the bio-capacity in units of land or water area with global average bio-productivity for land use type *K*. Can $A_N^C(K)$ exceed EF_N (K) for any or all K?

At the individual country level the footprint of human use of any given type of land or water area may exceed the bio-capacity if a country consumes more of the primary product of such land or water area than what the actual bio-capacity can produce i.e., the growth of the biomass of the concerned biomass type, the deficit of the product being imported and reflected in the ecological footprint of imports. However, if such a product is not tradable then the deficit may be met by drawing down from the stock of past accumulated biomass product as standing in the concerned land or water body, like forest biomass or stock of fishery biomass. In such a situation forest or fishery of country may get depleted to meet the gap. However, there are the important land use type like cropland or grazing land where the annual primary production above ground is entirely harvested, so that no standing biomass is available to meet any such deficit. In such a situation even if there be any deficit at national level, there can be no deficit or surplus at the global level. For the purpose of waste removal of carbon dioxide the demand for carbon uptake land in global forest foot print unit may exceed the actual forest area available for the purpose both at the national as well as global level and this would lead to the accumulation of CO_2 in the atmosphere.

4.0 Land Use Types and Ecological Footprint Accounts[1]

The world had globally a total of 1.6 billion hectares of designated cropland which has been used for the production of 195 different crop categories and the foot print has been calculated for these crops in terms of global hectare area as defined above, required to produce the harvested quantity of a year. The entire crop output is harvested and no significant residue of the crop is left on the ground which can have the same use as the main crop. For such crop land use there may arise ecological deficit at national level, but not at global level. However, even with no deficit for crop land use at the global level, there may be some over all global shortage of food crop or crop for livestock feed etc, because of the demand supply gap in those product markets. As we do not address such product shortage problem, one should not confuse the zero deficit calculations for the cropland at global level with no shortage of crop outputs. It may in fact be accompanied by a situation of acute global food shortage with adverse socio-economic consequences.

The demand for pasture use of land is the total feed requirement for livestock less the cropland producing crop for animal feed or other

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[1] National Foot Print Accounts, (2008), Living Planet Report (2006), Global Footprint Network, www.footprintnetwork.org.

marketed crops and crop residue. For the grazing or pasture land comprising grassland, sparsely wooded land used to feed livestock, ecological footprint measures the area of such grass and wood land in global hectare necessary to meet such feed requirement. The world had 4.8 billion hectares of land classified as grazing land. Again grazing land cannot experience accumulation of biomass stock as the entire growth of biomass along ground is to be regularly harvested in its entirety. Global Footprint account 2008 provides methods of improved calculation for grazing land foot print. However, it should be noted here that such zero ecological deficit for grazing land does not mean there is no shortage in livestock feed stock market and no unsatisfied demand in the product market of grazing land.

The calculations of foot print of fishing ground aims at working out the requirement of area of sea water or inland water bodies which would have such growth of primary products – phytoplankton, algae, etc. – that the energy flow from the biomass through food chain could lead to the growth of the wet fish stock required to meet the human consumption of a given year. However, the growth of such biomass can be accumulated as stocks which can be drawn down when the ecological footprint arising from the demand for fishing ground in global hectare exceeds the current growth of such fish stock measured in units of water area actually available at the national or even at the global level. Such deficit at global level would be met by the depletion of the global stock of fishes.

The main source of demand for forest land is forest product of fuel wood, timber and other miscellaneous forest product and also for the removal of the waste of carbon dioxide through natural sequestration. Forest is also the habitat for biodiversity which itself is a valuable asset. However, while we can have some data on output of forest product it is difficult to distinguish between the demand and supply of area of forests for forest products and those required for the eco-services of carbon uptake or for biodiversity conservation per year due to data limitation. Such limitation partly arises from the basic fact that the latter eco-services and marketable forest products are often joint products of forest. In 2005 there had been 3.95

billion hectare of forest land supplying the wholly or partly the requirements of forest products and carbon uptake, etc. The carbon uptake land can however be calculated as the forest and requirement which would yield a growth of carbon stock through their fixation in plant body driven by carbon cycle in the concerned period to remove the balance of total CO_2 emission from fossil fuel after netting out the share of absorption of such gas by the oceans. The total requirement of forest product land and the carbon uptake land together for a year if exceeding the bio-capacity of the forest area the forest product requirements may be met for some time by harvesting more timber or fuel wood than what forest biomass growth due to bio-capacity would permit, while the excess of requirement of forest land for carbon uptake over the bio-capacity would lead to global warming and its consequences of climate change. The global foot print net work till now considers however, the removal of CO_2 only for foot print calculation. Thus the forest land footprint can overshoot the bio-capacity leading to unsustainability.

It is worth mentioning here that the carbon footprint concept is often used in the context of demand for carbon uptake. It includes the forest land expressed in global hectare of average biological productivity required to remove the total direct carbon dioxide emission from the use of fossil fuel and the indirect emissions abroad for manufacturing of products imported. It also includes the CO_2 emissions occurring at the stage of extraction of the fossil fuels, like gas flaring, and also in cement production and tropical forest fires. While part of the CO_2 footprint may be removed by the ocean and the balance of the CO_2 emission would require forest land for their removal which is taken into account in forest land footprint. Such requirement often over shoots bio-capacity. If we do not consider the oceanic absorption separately, the entire excess of CO_2 emission over the CO_2 uptake by forest land would be the amount absorbed by the ocean as well as accumulated in the atmosphere.

Finally, the footprint of built up land is estimated to be all land used for human infrastructure – housing, transportation, industrial structures and water reservoirs for hydroelectricity. The world had 165 million hectares of built up land in 2005. The national footprint accounts of the global network has assumed such land use to be the diversion of cropland unless some specific evidence is obtained for the diversion of other types of land use. For the lack of data for hydroelectric projects its land use has been assumed to be the case of diversion of land of global average primary productivity and the area of coverage to be proportional to the generation capacity. As built up area is a case of diversion of other types of land, the bio-capacity requirement as well as supply would be measured in terms of loss of bio-capacity of such diverted land. As a result such footprint calculus would not show up any national or global level ecological deficit, although such land diversion may have adverse impact on the product market of the primary or the derived products of the land so diverted.

5.0 Ecological Deficit, Global Distribution of Foot Print and Sustainable Development

The estimates of ecological footprint of a nation's human consumption of all goods and services, bio-capacity of its ecosystem and the ecological deficit would thus vary from year to year not only because of changes in human demand and land use pattern, but also due to variation of primary productivity of land and water area for various uses and changes in technology and trade flows. As we have seen for certain land uses like cropland, grazing and or built up land there cannot be any ecological deficit at least at the global level. In the case of built up area, the same is true at the national level. However, the overshoot is possible at both local or global level for the land use for forestry, fishing ground and carbon uptake land.

Table – 3 Humanity's Ecological Footprint and Biocapacity Through Time (global Hectares Per Capita)

	1961	1965	1970	1975	1980	1985	1990	1995	2000	2005
Global Population (billion)	3.1	3.3	3.7	4.1	4.5	4.9	5.3	5.7	6.1	6.5
Total Ecological Footprint	7.0	8.1	10.0	11.2	12.5	12.9	14.5	14.9	16.0	17.4
Cropland Footprint	3.4	3.5	3.6	3.6	3.7	3.8	3.8	4.1	4.1	4.1
Grazing Land Footprint	1.2	1.3	1.3	1.4	1.4	1.4	1.5	1.7	1.6	1.7

	1961	1965	1970	1975	1980	1985	1990	1995	2000	2005
Forest Footprint	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.4	1.5	1.5
Fishing Ground Footprint	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.6
Carbon Footprint	0.8	1.7	3.2	4.2	5.3	5.6	6.8	6.9	7.9	9.1
Built-up Land	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4
Total Biocapacity	13.0	13.0	13.1	13.1	13.1	13.2	13.4	13.4	13.4	13.4
Ecological Footprint to Biocapacity ratio	0.54	0.63	0.76	0.85	0.95	0.98	1.09	1.11	1.19	1.31

Table 3 shows the land use wise ecological foot print, bio-capacity, ecological deficit or surplus for several years over the past five decades. These are all expressed in units of global hectare per person. The detailed break up of footprint and bio-capacity for India, China and USA are given in Table 4. This shows to what extent a country is overshooting the bio-capacity and how equitably the bio-capacity of the world is being shared among nations and people. We also show in Figure 1 how the global ecological footprint is increasing over time and has exceeded the bio-capacity since late nineteen eighties.

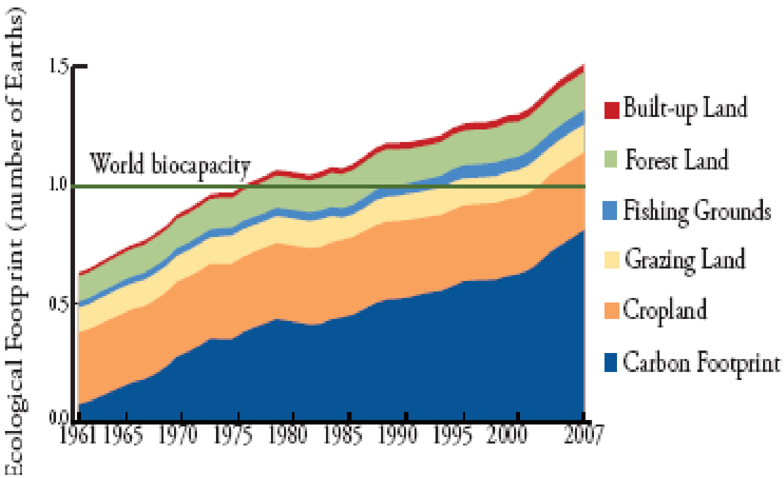

Figure 1. Trend in Global Ecological Footprint

Table 4. Ecological Footprint and Biocapacity, 2007

		ECOLOGICAL FOOTPRINT (global hectares per capita)							BIOCAPACITY (global hectares per capita)						
	Population (million)	Total Ecological Footprint	Cropland Footprint	Grazing Footprint	Forest Footprint	Fishing Ground Footprint	Carbon Footprint	Built-up Land	Total Biocapacity	Cropland	Grazing Land	Forest	Fishing Ground	Built Land	Ecological (Deficit) or Reserve
World	6.476	2.7	0.64	0.26	0.23	0.09	1.41	0.07	2.1	0.64	0.37	0.81	0.17	0.07	(0.9)
High Income Countries	972	6.4	1.15	0.28	0.61	0.17	4.04	0.13	3.7	1.42	0.33	1.20	0.58	0.13	(2.7)
Middle Income Countries	3.098	2.2	0.62	0.22	0.16	0.09	1.00	0.08	2.2	0.62	0.40	0.83	0.23	0.08	0.0
Low Income Countries	2.371	1.0	0.44	0.09	0.15	0.02	0.26	0.05	0.9	0.35	0.28	0.13	0.07	0.05	(0.1)
China	1323.3	2.1	0.56	0.15	0.12	0.07	0.13	0.07	0.9	0.39	0.15	0.16	0.06	0.07	(1.2)
India	1103.4	0.9	0.40	0.01	0.10	0.01	0.33	0.04	0.4	0.31	0.01	0.02	0.04	0.04	(0.5)
Japan	126.1	4.9	0.58	0.04	0.24	0.28	3.58	0.08	0.6	0.16	0	0.27	0.06	0.06	4.3
North America	330.5	9.2	1.42	0.32	1.02	0.11	6.21	0.10	6.5	2.55	0.43	2.51	0.88	0.10	2.7
Canada	32.3	7.1	1.83	0.50	1.00	0.21	3.44	0.09	20.0	4.89	1.80	9.30	3.96	0.09	13.0
United States of America	298.2	9.4	1.38	0.30	1.02	0.10	6.51	0.10	5.0	2.30	0.29	1.78	0.55	0.10	(4.4)
Europe(EU)	487.3	4.7	1.17	0.19	0.48	0.11	2.58	0.17	2.3	1.00	0.21	0.64	0.29	0.17	(2.4)

In 2005 world's ecological footprint exceeded the bio-capacity by 31% of the total footprint of 17.4 billion global hectare, the carbon footprint amounting to be 9.1 billion gha, constituting 52.2% share of the total. Next comes in importance the role of cropland footprint which accounts for 23.6% of total ecological footprint. Across countries, the per capita ecological footprint of high income countries, middle income countries and low income countries have been 6.4, 2.2 and 1.0 respectively. The per capita ecological deficit for these groups of countries have been 2.7 gha for high income countries, 0.1 gha for low income countries and negligible for middle income countries, the global deficit being 0.6 gha per capita. It may again be noted from Table 4 that the carbon foot print itself accounts for 63% and cropland footprint 17% of the total foot print of the high income countries. For the low income countries, the corresponding shares have been 26% for carbon footprint and 44% for cropland footprint. It is thus important to note that greenhouse gas emissions and land use for food for human and feed for animals account for the major share ecological pressure of the different groups of countries. These estimates of footprint point to the gravity associated with the carbon footprint for the sustainability of the economic development process.

India has an ecological deficit of 0.5 which is far lower than those of China and USA which are 1.2 and 4.4 global hectares respectively. It is important to note that India's consumption pattern has caused ecological deficit for cropland, forest land and has left a carbon footprint. Out of the ecological deficit of 0.5 gha per capita, the carbon footprint alone accounts for 0.33 gha, i.e., a share of 66%. The cropland deficit accounts for another 18% of the total ecological deficit of India.

So far as the distributional issues are concerned, although the total ecological footprint at global level is exceeding the global bio-capacity, per capita ecological footprint of India 0.9 gha is well below the per capita bio-capacity of the world which has been 2.1 gha in 2005. While the per capita ecological footprint of China is around the same level of the per capita bio-capacity of the world, the same for the USA has been 9.4 which is 4.45 times the per capita bio-capacity of the world. While the low income countries have their per capita footprint as 1.0 which is less than half of the world's average bio capacity, the high income countries have their per capita footprint to be more than 3 times of it. As the bio capacity of the world is being very inequitably distributed resulting in appropriation of bio-capacity across national boarder through trade flows and CO_2 accumulation in the atmosphere, the world faces a challenge in raising the level of living of the poor countries of the world whose per capita footprint is low but remaining within the world's bio-capacity and restraining the high income countries from exceeding the world's per capita bio-capacity by abating their carbon emission which is a major factor behind the global ecological deficit.

Growth of population, per capita human consumption, changes in product mix and technology have caused the total ecological footprint of humanity to grow at the rate of 2.09% per annum while world's bio-capacity has grown only at a rate of 0.08 rate per annum and population has grown at the rate of 1.697 per cent per annum. Thus earth's regenerative capacity cannot any more keep pace with the growth of demand for the biotic resource supply and ecoservice of degradation wastes to convert it into resources. The humanity is living no longer using the return from its natural or ecological capital, but living off the capital itself by drawing down its stock. It is however, interesting to note that the bio-capacity of all kinds of land and water areas for various uses have been more than the humanity's total demand as expressed in footprint unit for the various types of their uses, excepting for the carbon footprint. The carbon footprint of the humanity's total consumption has been 1.41global hectare per capita while the ecological deficit has been 0.6 global hectare per capita. Thus the abatement of CO_2 emission alone will be able to restore the balance of supply and demand for ecological resources of the world and hence the rationale of importance of low carbon economic growth of the world which would also be able to control climate change which is the threatened to be the fall out of the accumulation of ecological deficit mainly in the form of accumulation of CO_2 gases in the atmosphere.

One should however remember that the calculation of ecological footprint of human consumption does not take any account of the requirement of animal species and wild life. This would mean that growth of footprint particularly for crop land or grazing land may cause such diversion of land from other uses like forest and wilderness, that may seriously affect the biodiversity at the national and the global level. As the loss of biodiversity is likely to erode the resilience of the ecosystems of the earth, the closing of the gap between the ecological footprint and the bio-capacity becomes an important issue requiring policy initiatives. This may be achieved by both reducing human demand and better sharing the limited bio-capacity of the world among the different nations and peoples on the one hand, and enhancing the bio-capacity of the ecosystems by the application of science, technology and better resource management on the other. A combination of policies for the control of population, reduction of per capita consumption through better redistribution of income and consumption, reduction of footprint intensity of goods and services consumed, introduction of new carbon free or low carbon energy technologies and higher energy efficiency, expansion of both the bio-productive land and water area and enhancement of their bio-productivity per global hectare would be crucial for a rapid transition to a sustainable world of the future.

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Centre of Excellence in Environmental Economics

The Ministry of Environment and Forests, Government of India has designated Madras School of Economics as a Centre of Excellence in the area of Environmental Economics for a period of ten years from April 1, 2002. The centre carries out research work on: Development of Economic Instruments, Trade and Environment, and Cost-Benefit Analysis. The Centre is primarily engaged in research projects, training programmes, and providing policy assistance to the Ministry on various topics. The Centre is also responsible for the development and maintenance of a website (http://coe.mse.ac.in), and for the dissemination of concept papers on Environmental Economics.

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