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Ecological footprint of Shandong, China

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Abstract: Ecological footprint has been given much attention and widely praised as an effective heuristic and pedagogic device for presenting current total human resource use in a way that communicates easily to almost everyone since 1996 when Wackernagel and Rees proposed it as a sustainable development indicator. Ecological footprint has been improving on its calculation and still can be a benchmark to measure sustainable development although there are still ongoing debates about specific methods for calculating the ecological footprint. This paper calculates the ecological footprint of Shandong Province, China with the methodology developed by Wackernagel and analyzes the current situation of sustainable development in Shandong.

Keywords: ecological footprint; carrying capacity; sustainable development; Shandong

Introduction

Sustainable development was the challenge set forward by the UN Brundtland Commission (WCED, 1987) and confirmed by over 100 heads of State at the Earth Summit in Rio in 1992. If development is getting sustainable there must be an effective method of monitoring trends in sustainability so that the performance of development policies can be assessed. Therefore, "indicators of sustainable development need to be developed to provide solid bases for decision making at all levels and to contribute to self regulating sustainability of integrated environmental and development systems" (UNCED, 1992). However, a major difficulty associated with sustainable development objectives, is the absence of reliable indicators to measure progress towards the goal of sustainability. The ecological footprint provides a conservative estimate of humanity's pressure on global ecosystems. They represent the biologically productive area required to produce the food and wood people consume, to supply space for infrastructure, and to absorb the greenhouse gas CO_2 emitted from burning fossil fuels (Wackernagel, 2002a). The ecological footprint of a designated population is the area of productive land and water ecosystems required to produce the resources that the population consumes and assimilate the wastes that the population produces, wherever on the earth the land and water is located (Rees, 1996; Wackernagel, 1996). On an aggregate basis, the ecological footprint may be compared with the amount of ecologically productive land available to give an indication of whether consumption patterns are likely to be sustainable. The aim of this paper is to provide a brief overview of carrying capacity and ecological footprint; and to calculate the ecological footprint of Shandong with the methodology developed by Wackernagel. The current situation of sustainable development in Shandong is also discussed.

1 A brief explanation of carrying capacity and the ecological footprint

1.1 Carrying capacity

In ecological terms, the carrying capacity of an ecosystem is the maximum size of the population that can be supported indefinitely upon the available resources and services of that ecosystem (Simon, 1999; Atkinson, 1997). Living within the limits of an ecosystem depends on three factors: (1) the amount of resources available in the ecosystem; (2) the size of the population, and (3) the amount of resources each individual is consuming.

A simple example of carrying capacity is the number of people who could survive in a lifeboat after a shipwreck. Their survival depends on how much food and water they have, how much each person eats and drinks each day, and how many days they are afloat. If the lifeboat made it to an island, how long the people survived would depend upon the food and water supply on the island and how wisely they used it. A small desert island will support far fewer people than a large continent with abundant water and good soil for growing crops. In this example, food and water are the natural capital of the island. Living within the carrying capacity means using those supplies no faster than they are replenished by the island's environment: using the "interest" income of the natural capital. A community that is living off the interest of its community capital is living within the carrying capacity. A community that is degrading or destroying the ecosystem on which it depends is using up its community capital and is living unsustainably.

Equally important to community sustainability is living within the carrying capacity of the community's human, social and built capital. Carrying capacity is much harder to measure for these types of capital, but the basic concept is the same—are the different types of capital being used up faster than they are being replenished? For example:

- A community that allows its children to be poorly educated, undernourished, and poorly housed is eroding its human capital.
- A community that allows the quality of its social interactions to decline through lack of trust, respect, and tolerance is eroding its social capital.
- A community that allows its buildings, roads, parks, power facilities, water facilities, and waste processing capability to decay is eroding its built capital. Additionally, a community that is creating built capital without considering the future maintenance of that capital is setting itself up for eventual decay.

So, in the context of sustainability, carrying capacity is the size of

Foundation item: Cooperation Program for Human Ecology in VUB and WHO; * Corresponding author the population that can be supported indefinitely upon the available resources and services of supporting natural, social, human, and built capital.

1.2 Ecological footprint

The ecological footprint(EF) is a measure of the "load" imposed by a given population on nature. It provides a conservative estimate of humanity's pressure on global ecosystems and represents the fraction of the biosphere necessary to maintain the current material throughput of human economy under current management and production practice (Wackernagel, 2002a). The concept of an ecological footprint is based on the understanding that every individual human appropriates a share of the productive and assimilative capacity of biosphere. Thus, the ecological impact of humanity is measured as the area of biologically productive land and water required to produce the resources consumed and to assimilate the wastes generated by humanity, under the predominant management and production practices in any given year (Wackernagel, 2002b). Humanity's footprint or its aggregate ecological demand can only temporarily exceed the productive and assimilative capacity of the biosphere without liquidating and weakening the natural capital on which humanity depends fundamentally. Therefore, accounting tools for quantifying humanity's use of nature are essential for overall assessments of human impact as well as for planning specific steps towards a sustainable future.

Ecological footprint may estimate the amount of space on the earth that an individual uses in order to survive with existing technology. This space includes the biologically productive land and water area that produces the resources consumed by that individual such as food, water, energy, clothing, and building materials. It also includes the amount of land and water required to assimilate the wastes generated by that person. In other words, the ecological footprint measures a person's demand on the bio-capacity of the Earth. Since the area of land owned or controlled by the population is usually a finite and identifiable quantity, it can be compared to the EF. This juxtaposition of the actual land available and the EF and the difference between the two, termed the "ecological deficit", serves to show the dependence of the population of the ecosystem services outside of the political area. The rationale for representing impacts upon the environment in units of area is that biologically productive land area produces or absorbs flows of many of the materials utilized by our society(ECOTEC-U.K, 2001).

2 Methodology of ecological footprint

Ecological footprint (EF) was developed in the early 1990s by scientist Mathis Wackernagel and William Rees in Canada. A number of textbooks have been written on EF methodology (Wackernagel, 1996; Chambers, 2000) and there has been lively debate in the academic literature(for instance Ecological Economics March 2000 special issue on Ecological Footprinting). Ecological footprints have been produced for different scales of organization; from the world/nation(WWF, 2000), cities(Folke, 1997), companies (Chambers, 2001) and individuals (Best Foot Forward's Eco-Cal Software).

Among a variety of compatible methods to calculate people's footprints, there are two basic approaches—the compound approach developed by the originators of the EF concept, Wackernagel and Rees and the component-based approach developed by the UK based consultancy best foot forward(Chambers, 2000). Depending on the size of the population, we can choose between the two or use a hybrid of both to get the most accurate and useful results.

2.1 Compound approach

Compound approach is the most robust and comprehensive approach. Applied at the national level, it traces all the resources a nation consumes and the waste it emits. The nation's consumption is calculated by adding imports to, and minus exports from, the domestic production. To put it in mathematical terms: consumption = production − exports + imports. This balance is calculated in approximately 50 categories, such as cereals, timber, and tubers. Each category includes both primary resources(such as raw timber or milk) and manufactured products that are derived from them(such as paper or cheese). Resource use is expressed in units of space by dividing the total amount consumed by the respective ecological resource productivity and the total amount of waste by the corresponding capacity to absorb waste.

The total quantity of production is converted in area by dividing by the corresponding(world average yields) biotic productivity that gives the arable, pasture, or forestland and productive sea areas necessary to sustain this consumption. This would be repeated for each of different crops. Net imports of commodities are converted into their land equivalent using information on CO_2 absorption in their embodied energy and any direct land inputs. All these adjusted components can be added for a total footprint. If the ecological footprint exceeds the ecological capacity(Haney, 2000), this means that the region has an ecological deficit. If the per person footprint is higher than global average, the magnitude of the person's contribution to the global ecological deficit is clarified.

The advantage of compound approach is that it automatically captures many indirect effects of consumption, which are hard to measure, because this approach does not require knowing what each consumed resource is used for. For example, it is irrelevant for the accounting whether the consumed energy powers vehicles, heats homes, produces cars sold in the country, or is merely wasted. Since there are robust statistics on overall energy consumption but much less accurate data on exact use of the energy, the overall assessment of compound approach makes the accounts more reliable(Wackenagel, 2003).

2.2 Component-based approach

In the component-based model the ecological footprint value for certain activities are pre-calculated using data appropriate to the region under consideration. It is necessarily more data intensive than the compound approach since national statistics are rarely collected in a manner that will easily identify material and energy flows for a sub-national population. Therefore, component-based can apply to the effect of local issues such as transport, energy, water and waste using data appropriate to the region under consideration(Barrett, 2001a; 2001b). Still, sometimes sufficient data from life cycle analyses is available to develop reasonably good estimates at the product level.

3 Ecological footprint calculation for Shandong

For Shandong EF calculations compound approach are applied and based five assumptions: (1) It is possible to keep track of most of the resources humanity consumes and the wastes humanity generates. (2) Most of these resource and waste flows can be measured in terms of the biologically productive area necessary to maintain these flows (those resource and waste flows that cannot are excluded from the assessment). (3) By weighting each area in proportion to its usable biomass productivity (that is, its potential production of biomass that is of economic interest to people), the different areas can be expressed in standardized hectares. These standardized hectares, which we call "global hectares," represent hectares with biomass productivity equal to the world average productivity that year. (4) Because these areas stand for mutually exclusive uses, and each global hectare represents the same amount of usable biomass production for a given year, they can be added up to a total representing the aggregate human demand. (5) Nature's supply of ecological services can also be expressed in global hectares of biologically productive space (Wackernagel, 2002). Because there are not complete data sets to work with, the data used is based on several sources including Shandong Statistical Yearbook (1999); Chinese Statistical Yearbook (1999; 2000); Shandong Statistical Bulletin (1997—2000).

Total calculations may be divided into three main sections:

The first section assesses Shandong's consumption of 19 basic biotic resources, including its sub-products (Table 1). The data in rows represent resource types, while the data in columns show the yield, the production, import and export. It also presents the apparent consumption, footprint component and land category. Apparent consumption is calculated by adding imports to production and subtracting exports. We call consumption as "apparent consumption" since it varies from true household consumption because it includes the resources that are processed for export goods while excluding the resources that are embodied in imported finished products. This error can be mitigated through more detailed trade flow analyses. Consumption also includes the waste between production and final consumption. In the case of forestry and dairy products, all the processed trade items of their secondary products such as wood panels, pulp, cheese or butter is converted into their roundwood or raw milk equivalent. This is done to get a more accurate estimate of real household consumption. We use "biological productive area with world average productivity" as a common measurement unit for footprints and ecological capacity. It allows Shandong's footprint to be directly contrasted with the globally available biological capacity. Using estimates from the Food and Agriculture Organization of the United Nations (FAO, 1995a) of world average yield, consumption and waste absorption are translated into appropriate biologically productive areas. Thus, the consumption quantities are divided by their corresponding (world average) biological productivity which shows the land and sea areas necessary to sustain the consumption. These areas form a part of the total footprint. In the case of wheat, for example, the footprint component per capita would be:

$$\frac{\text{Production}_{\text{cereals}} + \text{Import}_{\text{cereals}} - \text{Export}_{\text{cereals}}}{\text{Yield}_{\text{cereals}} \times \text{Population}} = \frac{\text{App. consumption}_{\text{cereals}}}{\text{Yield}_{\text{cereals}} \times \text{Pop.}}$$

$$= \text{Footprint component}_{\text{cereals}}\ (\text{hm}^2/\text{capita}),\ \text{i.e.,}$$

$$\frac{37774000\ \text{t} + 0 - 20952360\ \text{t}}{2752\ \text{kg/hm}^2 \times 88.72 \times 10^6\ \text{people}} = 0.0689\ \text{hm}^2/\text{capita}$$

Table 1 Annual consumption of biotic resources in Shandong

Resource unit	Global yield, kg/hm²	Production, t	Import, t	Export, t	Apparent consump, t	Ecological footprint, hm²/cap.	Land category
Meat							
Fresh meat							
Beef, buffalo	32	601000		415773.6	185226.4	0.0652	Pasture
Sheep, goat	72	209000		133440	75560	0.0118	Pasture
Other meat	761	4174400		3171114	1003286	0.0149	Arable
Dairy product							
Milk	458	275000		76500	198500	0.0049	Pasture
Cheese, butter	34	145690	436	76580	69546	0.0170	Pasture
Eggs	534	3220000		2058905	1161095	0.0245	Arable
Fish (sea)	29	5665200	65	5203296	461969	0.0002	Sea
Cereals	2752	37774000		20952360	16821640	0.0689	Arable
Wheat		20245000					
Rice		1189055					
Maize		16104331					
Millet		275535					
Kaoliang		129663					
Fruit & veg.	8136	63416179		49287972	24729567	0.0343	Arable
Vegetable		55019193					
Mellon		9628152					
Apple		5995588					
Pear		714667					
Grape		268986					
Peach		589610					
Apricot		47673					
Date		320042					
Persimmon		125143					
Tea	566	1561	35600	1092.6	36068.4	0.0007	Forest
Tobacco	1548	115006	156	86720	28442	0.0002	Arable
Cotton	1000	412506	154	34710	377946	0.0042	Arable
Jute	1500	9505		5840	3665	0.0000	
Pulse	802	1142491	652	239112	903981	0.0127	Arable
Animal feed	2752	9506825	32		9506793	0.0389	Arable
Root & tuber	12814	5537357		2698310	2839047	0.0025	Arable
Wool	15	23433	103	2381	21155	0.0159	Pasture
Timber	*1.99*	2332335			2332335	0.0132	Forest

Sources: Yearbook, 1999; SDSB, 2000; China Statistics Yearbook, 1999—2000

The energy component for wheat production (tractors, fertilizers, pesticides, etc.) and processing (domestic transportation, packaging, distribution and cooking) would already be included in the energy balance of the province (Table 2) and does not need to be calculated separately.

Table 2 Annual consumption of primary energy in Shandong

Primary energy use unit	Global average energy to land ratio, GJ/($hm^2 \cdot a$) a	Energy use, GJ/cap. b	Ecological footprint component, hm^2/cap. $c = b/a$	Land category
Coal consumption	55	26.02	0.473	Energy land
Liquid fossil fuel consumption	71	6.89	0.097	Energy land
Fossil gas consumption	93	0.00	0.000	
Total fossil fuel consumption		32.91		
Nuclear energy consumption	71	0.00	0.000	
Energy embodied in net imported goods	71	0.00	0.000	
Hydro-electricity consumption	1000	3.00	0.003	Build-up land

Source: Chambers, 2000; Yearbook, 1999

The second section calculates the footprint of Shandong's energy consumption (Table 2). Energy is analyzed separately from other resources for a number of reasons. First, it occupies a significant share of a region's footprint. Second, there is more detailed data available for this particular resource consumption category. Third, the accuracy of these energy statistics is superior to the estimates one could calculate from the trade statistics. And last but not least, these consumption statistics are easily available. Therefore, detailed provincial energy consumption statistics are used directly to assess the ecological footprint of commercial energy consumption. Various energy types are distinguished. Firewood is included in the biotic resources. The land use of hydro-electricity is estimated by dividing total production by the typical space use of hydro dams and corresponding corridor spaces for transmission rows. For the present calculations, an average of GJ per hm^2 and year is assumed. For fossil gas, liquid fossil fuel and solid fossil fuel, we estimate 1 hm^2 of footprint for the annual consumption of 93, 71 and 55 GJ, respectively. This is calculated by assessing the land requirements for the corresponding CO_2 absorption, using data from the International Panel on Climate Change (IPCC, 1997). Slightly larger footprints would result if the fossil fuel footprint were calculated with the land areas necessary for growing biological substitutes (Wackernagel, 1996).

In the last section, Shandong's footprint and its ecological capacity are summarized into two boxes (Table 3): The left box shows how much the footprints per capita are in Shandong. To aggregate the used arable land, pasture, forest and sea areas in a more accurate and realistic way, they are multiplied with "equivalence factors". Without this adjustment, the totals would be distorted, as the various ecological categories represent large differences in biological productivity. For example, arable land is far more bio-productive than average pasture. Therefore, equivalence factors are introduced which scale the area of each ecological category in proportion to their yield. For example, the arable land factor of 2.8 showed that arable land can produce 2.8 times more biomass than the biologically productive would average space. Through this scaling, the total bio-capacity of the world is not distorted, the global, scaled with the equivalence factors, adds up to the same amount as the global total expressed in true physical spaces. As a result, the average Shandong's footprint adds up to 1.20 hm^2, including sea space. Multiplying the per capita data by 88.72 million people, Shandong's population in 1998, gives the total footprint of Shandong.

The right box shows how much biologically productive capacity exists within the Shandong and, for comparison, in the world. Obviously, these areas are multiplied by the equivalence factors as well. In addition, as the yield of Shandong's land areas is higher than world average, its physical bioproductive areas are multiplied by the factors by which the local yield exceeds the worlds average (second column in the supply part of the table). As shown, Shandong's yield adjusted ecological capacity measures 0.79 hm^2 per capita. Because of no data available, we take 1 as the yield factor of the sea (Wackernagel, 1999b). For build-up land, the yield factor is equal to the one of arable land, as settlements are typically located on such land (Wackernagel, 1999b).

Table 3 Summary of Shandong's footprint

Demand: Footprint, per capita				Supply: Existing bio-capacity within Shandong, per capita			
Category	Total, hm^2/cap.	Equivalent factor	Equivalent total, hm^2/cap.	Category	Yield factor	Land area, hm^2/cap.	Yield adjusted equivalent area, hm^2/cap.
Fossil energy	0.57	1.1	0.63	CO_2 absorption		0.00	0.00
area	0.003	2.8	0.01	Land	1.98	0.040	0.22
Arable land	0.17	2.8	0.48	Build-up land	1.98	0.075	0.42
Pasture	0.14	0.5	0.07	Arable and	59	0.003	0.09
Forest	0.01	1.1	0.01	Pasture	1.5	0.030	0.05
Sea	0.00	0.2	0.00	Forest	1	0.040	0.001
				Sea			
Total used			1.20	Total existing	(minus 12%)		0.79
				Total available			0.7

4 Discussion

As the footprint and ecological capacity available within Shandong are measured in the same units they can be compared directly with other regions or populations. As shown in Table 3, the average Shandong citizen occupies 1.2 hm^2 of biologically productive space (based on the world average productivity). This means that to support the average citizen of Shandong at least 1.2 hm^2 of biologically productive space is needed. Nevertheless only 0.7 hm^2 is available in Shandong at present situation, which is less than either the 2 hm^2 per capita available on average in the world or the 0.8 hm^2 available on average in China (Wachernagel, 1999b). As we know, the ecological footprint shows the global impact of local consumption; it may also be interesting to determine to what extent local ecological productivity can provide the local consumption. If the ecological footprint of a region is larger than the available ecological capacity, the region runs a regional ecological deficit. In the case of Shandong the ecological deficit is 0.5 hm^2 per capita, which means the region alone cannot provide sufficient ecological services sustainably to satisfy its population's current pattern of consumption although its footprint is smaller than that of the developed countries.

The ecological footprint is compared with the locally available ecological capacity. Shandong located in the warm temperate zone with a semi-monsoon climate. The annual average temperature ranges from 11 to 14 degrees centigrade. The annual precipitation ranges from 550 mm to 950 mm. The frost-free period is more than 180 days to more than 220 days. Plains and basins account for 63% of the total area. The favorably natural condition is benefit crop growth so that yield factor is high as 1.98 in arable land, 59 in pasture land. Even so, the locally ecological capacity in Shandong is still very low as the calculation result shows: the available ecological capacity is only 0.7 hm^2 per capita. The carrying capacity of the world is calculated so as to ascertain if an inhabitant of Shandong occupies more or less biologically productive space compared to what should fall to him/her in a fair distribution at world level (Table 4). It should be pointed out that the data in the Table 4 is dynamic as further ecological degradation and/or population growth are taking place. Thus the per capita fair earth-share, to which each world citizen is entitled after equal distribution, is decreasing over year.

Table 4 Biological production available on the world

World population	5.5 billion
Total land of earth	9.8 billion hm^2
Arable land	1.35 billion hm^2 in total; 0.25 hm^2 per capita
Pasture land	3.35 billion hm^2 in total; 0.6 hm^2 per capita
Forest land	5.1 billion hm^2 in total; 0.9 hm^2 per capita
Build-up land	0.06 hm^2 per capita
Sea	36.6 billion hm^2 in total; 6 hm^2 per capita. Of these 6 hm^2 only 0.5 hm^2 contain over 95% of the sea's ecological production with 12 kg fish reaching the table per year. Therefore, only 2 hm^2 per capita of land and sea space are available for human use. These 2 hm^2 become the ecological benchmark figure for comparing people's ecological footprint

Notes: Source: Wackernagel *et al*. (1999b)

It is notable that the footprint of Shandong per capita is within the world average biologically productive capacity but it is the same as in China (in deficit). The question is how to develop their economy, how to improve their quality of the life and how to secure their future generation survival with equal or even better quality of life?

The development path being taken by China—the so-called China factor—remains a common thread running through many discussions of the world resources scarcity. If China were to increase its per capita consumption to that of the US, for example, whilst other countries continued along their own growth paths, could the global environment cope with the resource depletion? While from an ethical perspective the affluent countries have no business condemning China for extending its footprints, ecologically speaking, there are not enough planets for this business as usual approach. These are the basic conflicts we are facing as we move towards sustainability as the Worldwatch Institute points out (Chambers, 2000):

China is teaching us that the Western industrial model is not viable, simply because there are not enough resources. Global land and water resources are not sufficient to satisfy the growing grain needs in China if it continues along the current development path. If carbon emissions per person in China ever reach the current US level, this alone would roughly double global emissions.

Simple ecological footprint calculations can shed some useful light on this debate. The footprint of the average American, just for food, fibers, timber, and absorbing the CO_2 released by fossil fuel consumption, adds up to about 9.6 hm^2 of bioproductive space (Table 5). If we generously assume that the area of bioproductive space (including land and sea) remains at 12.5 billion hm^2 and an average 12% of this area is set aside for other species, then the approximate number of people that the planet could sustain at US level of consumption can be determined as follows:

12.5 billion hm^2/9.2 hm^2 per person × 88% = 1.2 billion people.

Interestingly, this is close to the lower estimates of carrying capacity written about by notable sustainability researchers such as Anne and Paul Ehrlich and D. Pimental (Pimental, 1999). A more optimistic scenario which saw the population maintain a good quality of life with a footprint 1.2—the current level of average Shandong footprint-would permit a sustainable global population of more than nine billion:

12.5 billion hm^2/ 1.2 hm^2 per person × 88% = 9.2 billion people.

To make this happen would require a significant rethink of our institutional structures, such as changes in the way taxes are applied, encouragement of eco-efficient technologies, and a massive redesign of our urban infrastructures. Therefore, ecological footprint does not tell us how bad the situations with which we are facing but tell us how far the sustainable development to which we are trying to go.

Table 5 Comparison of footprint by land type for Shandong, China and USA

Land type	Shandong	China*	USA*
Fossil energy	0.63	0.6	5.8
Built-up land	0.01	0.0	0.7
Arable land	0.48	0.6	1.0
Pasture	0.07	0.1	0.9
Forest	0.01	0.1	1.1
Sea	0.00	0.0	0.1
Total	1.2	1.4	9.6

Notes: adjusted to world average bioproductive area; * 1995 data (Chambers, 2000)

5 Conclusions

As an indicator of sustainable development, the concept of ecological footprint has been developed for almost 10 years. Although it is not perfect enough and there are still debates for some calculations such as energy, some modified calculation models are still based on the two basic methods (Bicknell, 1998; Ferng, 2002; Haberl, 2001; van

Vuuren, 2000). An attractive aspect of ecological footprint is that it highlights several inter-related topics directly relevant to sustainable development(van Vuuren, 2000). These include: (1) the consequences of increasing consumption patterns; (2) several key resources for sustainable development; (3) the issue of distribution of access to natural resources; (4) the consequences of trade and issue of geographical reallocation of environmental pressures, and (5) the powerful communication of results. The most important strength of the ecological footprint metaphor is conceptual simplicity and intuitive appeal. Better than other methods, ecological footprint seems to successfully communicate critical dimensions of human ecology to other disciplines and to non-scientists alike(Rees, 2000).

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