A Textbook Explanation of Global Hectare†

Katsura Nakano[a] and Yoshihiko Wada[b]

[a]Shiga University and [b]Doshisha University

Abstract: A key notion on Ecological Footprint is ‘global hectare.’　A global hectare is defined as a hectare that is normalized to have the world average productivity of all biologically productive land and water in a given year. There are many discussions regarding the use of global hectare. The purpose of this paper is, first, to clarify the notion of global hectare by constructing a simple textbook model. Secondly, we present an interpretation of global hectare based on the model. The model clearly shows that local-based or physical hectare is associated to efficiency while global hectare is to equity. Some discussions will follow.

Keywords: Ecological Footprint (EF), local-based footprint, global-based footprint, equivalence factor

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1. Introduction

The Ecological Footprint (EF) was co-developed by William E. Rees and Mathis Wackernagel at the University of British Columbia, Canada, in the early 1990s (Wackernagel and Rees [1996]). The Ecological Footprint converts our economic activities to the land area required for the activities. In the EF analysis, we also estimate the total land productivity of our planet or a region, which is called ‘biocapacity.’ Comparing the EF with the biocapacity, we can analyze if the resource consumption of our economy is ecologically sustainable or not.

A key notion on Ecological Footprint is ‘global hectare.’ A global hectare is defined as a hectare that is normalized to have the world average productivity of all biologically productive land and water in a given year (Global Footprint Network, 2006).

As the concept of EF becomes popular, many new approaches to estimate EF have been proposed (See for example Bicknell et al. [1998], Ferng [2001], Lenzen and Murray [2001] and Hubacek and Giljum [2003]). If you, however, take a close look at those new approaches, you will often find slight differences in the definition of ‘EF’ in the literature.[1] For example, the input-output approach has provided us a strong tool in order to analyze the EF on subnational levels. It is usually based on local land productivity rather than global average land productivity, as is pointed out by Wiedmann and Lenzen [2006].

The purpose of this paper is, first, to clarify the original definition of global hectare suggested by Wackernagel et al. [1999]. For that purpose we present a simple textbook model. Secondly, we present an interpretation of global hectare based on the simple model. Some discussions will follow.

2. Local Hectare[2]

Consider a world which consists of two countries, A and B. Both countries produce only two products, wheat and timber. The amounts of each product are shown in rows A1 and B1 of Table 1. The areas of land used for the production are given respectively by A2 and B2. We assume, for simplicity, that there is neither export nor import so that the domestic production level defines the level of consumption of each country. The sum of area used for production of wheat and timber is called physical Ecological Footprint, or **local-based footprint**. Let us call this as local-based footprint from now on. Therefore, the local-based footprint in A country and B country is 200 ha and 250 ha, respectively.

From the rows A1 (or B1) and A2 (or B2), we can calculate local land productivity for each country, simply by dividing production by the production land area. For instance, the local land productivity of the wheat in Country A is 1 t/ha. The productivity is about 0.67 t/ha in Country B. Hence, the local land productivity of the wheat is higher in Country A. In the production of timber, the land productivity is 0.2 in Country A, whereas 0.05 in Country B. In this example, Country A is efficient in production of both products. Country A is more efficient in production of timber than Country B. From these two outcomes, it is said that Country A has absolute advantage in production of both wheat and timber.

As a consequence, Country A enjoys, with less land used, 100 tones of wheat and 20 tones of timber, while Country B 100 tones of wheat and 5 tones of timber.

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1 For literature survey, please refer to, for example, ECIP[2002] in English and国土交通省国土計画局 [2004] in Japanese.

2 The numerical example used in this section first appeared in Nakano and Wada [2007] in Japanese.

As we will later discuss more in detail, to gain efficiency is one of major objectives in Economics. Efficiency is defined as to get the most out of the least resources used. In other words, high efficiency can be achieved by reducing wastes.

Table 1 Local-based Footprint, Global-based Footprint and Ecological Footprint: A Numerical Example:

	Country A	Agriculture	Forest	Physical or Local-based footprint	Global-based footprint	Ecological Footprint
		Wheat	Timber		Without equivalence factor	With equivalence factor
(A1)	Output(t)	100	20			
(A2)	Physical production area(ha)	100	100	200		
(A3)	Local productivity(t/ha)	1.0	0.2			
(A4)	Production area measured by world average productivity(ha)	125	160		285	
(A5)	Production area measured by world average productivity and equivalence factor(gha)	200	40			240

	Country B	Agriculture	Forest	Physical or Local-based footprint	Global-based footprint	Ecological Footprint
		Wheat	Timber		Without equivalence factor	With equivalence factor
(B1)	Output(t)	100	5			
(B2)	Physical production area(ha)	150	100	250		
(B3)	Local productivity(t/ha)	0.67	0.05			
(B4)	Production area measured by world average productivity(ha)	125	40		165	
(B5)	Production area measured by world average productivity and equivalence factor(gha)	200	10			210

	World (Countries A and B)	Agriculture	Forest	Physical or Local-based footprint	Global-based footprint	Ecological Footprint
		Wheat	Timber		Without equivalence factor	With equivalence factor
(W1)	Output (t)	200	25			
(W2)	Physical production area (ha)	250	200	450		
(W3)	World average productivity(t/ha)	0.8	0.125			
(W4)	Production area measured by world average productivity (ha)	250	200		450	
(W5)	Equivalence factor	1.6	0.25			
(W6)	Production area measured by world average productivity and equivalence factor(gha)	400	50			450

3. Global Hectare

3.1 Global Average Productivity (yield factor)

Now let us derive Ecological Footprint originated by Wackernagel and Rees [1996]. It requires us to take two steps; evaluating the local production with the world average productivity, and adjusting for productivity difference between land types.

Let us first consider the world average productivities. The aggregate production of wheat and timber is, respectively, 200 tones and 25 tones, while the land used for the production is 250 ha and 200 ha. Therefore, the world average land productivity for each industry is, respectively, 0.8 t/ha and 0.125 t/ha (W3).

Based on this world average productivity, we can calculate a hypothetical land area used for the production in the following way. Suppose that our current production, that is the same as our current consumption, was made on the world average land. For example, if 100 tones of wheat which is produced and consumed in Country A was produced on the world average land, 125 hectare of land will be required since the world average productivity of the crop land is 0.8 tones per hectare. This hypothetical area is larger than the actual area used in Country A for production of wheat, which is 100 hectare. Similarly, for Country B the hypothetical area for wheat is 125 hectare, while the actual area is 150 hectare. Let us call this as **global-based footprint**. Note that the global-based footprint is not the same as Ecological Footprint, yet.

The benefit of this hypothetical area is that it reflects the level of consumption equitably. Both Country A and Country B produces and consumes the same amount of wheat. However, the physical areas used are different since the productivities are different in both countries. In contrast, if you evaluated them with the world average productivity, their hypothetical areas, i.e. the global-based footprints, are the same.

The total hypothetical areas for Country A and B are, respectively, 285 ha and 165 ha. As opposed to the local-based footprint, Country A uses larger (hypothetical) area (A4 and B4 in Table 1). This reflects the fact that Country A consumes more than Country B.

The use of the world average productivity is strongly related with the second objective of Economics; equity. In order to understand this, now we have to introduce the notion of 'per capita.' Our model has not explicitly considered the size of population in each country so far. Suppose, however, that the populations are the same, say one hundred, in both countries. The per capita global-based footprint, i.e. the hypothetical land area per person, becomes 2.85 for Country A and 1.65 for Country B. This implies an average person in Country A consumes more than an average person in Country B. If we use local-based or physical area to calculate this, the per capita area is 2.00 for Country A and 2.50 for Country B.

Based on the notion of local-based footprint, as we have already seen, its policy implication is to increase the efficiency of production in Country B. With the increased efficiency, we can reduce our footprint. On the other hand, if we look at this per capita footprint which is evaluated at the world average productivity, it suggests us to reduce the personal consumption level in Country A because a person in Country A is consuming more than a person in Country B.

3.2 Equivalence Factor

Here we add a final touch in order to derive Ecological Footprint in this simple two sector model. That is to introduce an equivalent factor (or equivalent coefficient).

The bio-productivity of crop land and forest land must be different. It must be more so between crop land and residential land. In order to reflect the difference, WWF and GFN are calculating ‘equivalence factors’ (WWF et al., [2006]). See table 2. Currently, the equivalence factors are calculated from the suitability index (SI) of Global Agro-Ecological Zones (GAEZ) 2000 instead of actual biomass production (Wackernagel et al. [2005]). The SI model breaks down earth's landmass into cells and integrates detailed data to calculate the potential biological productivity of the land type in each cell. “The equivalence factor is the ratio of the specific land use SI to the average SI” (ibid: 11). Thus, different land types are compared not by their actual productivity in a given year (which fluctuates), but by their potential productivity “with an assumed level of inputs such as water and fertilizer, regardless of current management practices” (ibid: 12). The equivalence factor for marine are is found by valuing their capacity to supply the same amount of calories that a single global hectare of pasture will produce (Kitzes et al., 2008, p.85). Further detail on equivalence factors can be found in Kitzes et al. (2007), section 2.11.

Table 2 Equivalence Factors, 2003

Primary cropland	2.21
Marginal cropland	1.79
Forest	1.34
Permanent pasture	0.49
Marine	0.36
Inland water	0.36
Built-up land	2.21

WWF et al. [2006].

Table 2 tells us that bioproductivity of, for example, primary cropland is 2.21 times higher than the world average bioproductivity, while that of forest land is only 1.34 times higher.

In our model, the equivalence factor was computed in two steps. First, the total sum of wheat and timber production was divided by the total area for production of both products, i.e. the sum of agriculture land and forest land. This gives us the world average productivity of all land types. In the next step, the world sectorial average productivity was indexed with this world average productivity. In other words, the world average productivity in each sector or land type was divided by the world average productivity of all land types. The obtained values are the equivalence factors. The equivalence factor for the agricultural land is 1.6, while that of forest land is 0.25 in our numerical example (W5 in Table 1).

As you may have already noticed, here we employ a somewhat strong assumption; the bioproductivity of land is simply measured by the actual amount of product yielded from that land. This is NOT the way that WWF and GFN measure bioproductivity of land in their report. However, we hired this assumption for a simple textbook explanation. The consequence of this simplification is that, as is discussed later, it reduces the possibility of ‘over-shooting,’ but does not entirely eliminate it.

3.3 Ecological Footprint

Ecological Footprint (A5 and B5) can be obtained, multiplying the production area measured with world average productivity (global-based footprint, A4 and B4) by the relevant equivalence factor for relevant land types (W5). While the global-based footprint for agriculture land is 125 hectare for both Country A and B, the Ecological Footprint becomes 200 (=125 times 1.6). On the other hand, the Ecological Footprint of forest industry is 40 (=160 times 0.25) and 10 (=40 times 0.25) for Country A and B, respectively.

In sum, the Ecological Footprint for Country A is 240 while that for Country B is 210.

4. Overshooting

4.1 Local Level

When a footprint is larger than the size of bioproductive area of a region or country, it is said that overshooting is happening. As you see in Table 1, an Ecological Footprint of Country A is 200, 285, or 240 ha, depending on the definition of 'footprint.'

How much is the bioproductive area in our model? The answer depends upon the definition of 'bioproductive area.' Here we assume, again for simplicity, that the all the bioproductive areas are utilized in our model. This means that the physical bioproductive area is 200 for Country A. Because we do not have any export or import in our model, the physical footprint is always the same as the physical bioproductive area. Hence, when it is measured in local-based footprint, overshooting at local level will never occur. When, however, a footprint is measured with the world average productivity (yield factor), overshooting at local level can happen even in our model. For Country A, its global-based footprint (285 ha) exceeds its bioproductive area (200 ha). Its Ecological Footprint (240 ha) also shows that their consumption level is larger than its bioproductive area.

Obviously, introduction of export and import should also create imbalance between biocapacity in a region and physical or local consumption footprint.

4.2 Global Level

You have to note that in our numerical example, when a country overshoots, the other country must be experiencing 'undershooting.' A footprint of Country B is 250, 165, or 210 ha, depending on the definition of 'footprint.'

The sum of footprints for both countries under the same definition is always 450. This is because the weighting methods used to derive global-based footprint or Ecological Footprint is literally just to change the weights to the physical areas. Therefore, at global level, we will never observe overshooting in this setting.

The readers may wonder then when we observe overshooting at global level. The major source of global overshooting in general Ecological Footprint analysis is two-holds. One is that the existence of build-up land. Suppose that each country in our model has 100 ha of build-up land. The way that build-up land is in Ecological Footprint calculation is to multiply the physical build-up area by its equivalence factor. Currently the equivalence factor is estimated to 2.21, which is the same as that of primary cropland. Hence it will become 221 gha in Ecological Footprint account. The difference, i.e. 121 gha (= 221 minus 100), is attributed to the overshooting.

Secondly, the land associated with CO_2 is another source for overshooting. Although CO_2 land is not included in our two sector model, there are many ways to includes CO_2 land in the calculation of footprint. One common method is to calculate the land required to absorb CO_2 emitted by human activities. Alternatively, one can estimate the area of land required to get enough biomass energy to supply the same amount of energy that we get from fossil fuels. With either method, CO_2 land is usually the largest source in Ecological Footprint account.

Beside of theses two major sources for overshooting, land requirement for nuclear energy is another issue that currently some people are focusing. The use of nuclear power certainly is a burden to our planet, and should be in the Ecological Footprint account in some form.

5. Discussion and Concluding Remarks

Our numerical model clearly shows that local-based footprint is associated to efficiency while global hectare is to equity.

Given the consumption level, the higher the efficiency, the smaller the footprint. We, however, have to note that this happens only when the consumption level is fixed. Suppose that you have obtained a hybrid car which is twice as much efficient in fuel consumption as a conventional car. Now you can travel double mileage with the same bill on the fuel. If your travel distance is doubled, your fuel consumption, and therefore your EF, has not been changed. Assume then that you travel only the same distance as before. Your expense on the gas will be half. What would you do with the saved money? If you buy something with the money, you might increase your EF as much.

Gaining efficiency itself is not a bad thing. However, we have to keep monitoring what will follow. The saved money and/or resources have to be spent wisely in order to reduce environmental burden.

Attaining equity is also important when we consider environmental issues. The use of global hectare sheds light on the difference in consumption level between regions.

Although we identify the major sources of overshooting, build-up land and CO_2 land, this does not mean that we can ignore the other sectors such as agricultural land and forest land. The reason why our numerical model, shown in Table 1, does not generate overshooting at global is because we assumed, for simplicity, biocapacity of land is equal to the actual amount of product. But the actual amount of product yielded from the land might be exceeding the biocapacity of land. Imagine a piece of forest land. One can cut trees at higher rate than the annual growth rate of the forest. In this case, actual yield is higher than its biocapacity.

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