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Ecological footprint (EF): An expanded role in calculating resource productivity (RP) using China and the G20 member countries as examples

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ABSTRACT

As resources become scarcer measuring resource productivity (RP) is more important. Quantifying the value of natural resources is challenging but the ecological footprint (EF) concept provides one method of uniformly describing a variety of natural resources. Current assessments of RP mainly revolve around output efficiency of resources, namely the ratio of GDP to natural resource usage.This paper develops a new method of calculating the RP by using the EF as an indicator of the natural resource input and gross domestic product (GDP) as the output in the equation of RP = GDP/EF. A regression analysis is carried out using GDP per capita and RP of China from 1997 to 2011, and a comparative analysis with the members of the G20 countries according to their RP and per capita GDP in 2008. The results indicate that RP correlates with the per capita GDP, showing that RP is a valid indicator which can be used to measure a country's level of economic development.

1. Introduction

Since the early 1970s, scholars have warned of the natural resources damage done by unsustainable production systems used to satisfy the growth of market demand. Georgescu-Roegen (1976) claims that economic process cannot go on without a continuous exchange which alters the environment in a cumulative way. "Silent Spring" (Carson, 1962) first put forward the other road to preserve our earth, which enlightens environmental protection consciousness. The environmental protection movement has prompted the formation of the sustainable development (Table 1). One main themes of the sustainable development is the harmonious development between man and nature. Now environmentally sustainable development is a core national and global issue (Pillarisetti and van den Bergh, 2010). Daly (1996) claims that sustainable development is only possible in a steady-state economy whose scale is sufficiently small so as to allow the proper function of Earth's ecosystems. The relationship between the resources and economic growth (Sachs and Warner, 1995, 2000) has always been the focus study of economists.

Natural resources, considered as human social wealth, have and continue to be depleted or degenerated, by human impact, faster than the resource regeneration rate and growth of alternatives. Thus, the sustainable utilization of resources has become the primary issue of sustainable development. Being able to adequately measure the extent of human impact on resources is vital so that action can be agreed and implemented to provide an acceptable quality of life without using the earth's biological productive capacity beyond its ability to regenerate (Niccolucci et al., 2012). This paper focuses a new method of calculating the resource productivity and its contribution to the economic development.

2. Method

2.1. The plight of resource productivity (RP)

From classical economics to neoclassical economics, through the Harold–Domar theory of economic growth, to Solow's economic growth theory, and onto the new institutional economics, economic growth is measured using only capital, technology, labor, savings rate, employment or system functions. Resources can be replaced with other production factors, mostly to avoid the

Abbreviations: RP, resource productivity; EF, ecological footprint; G20, group of twenty finance ministers and central bank governors.

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Table 1
The environmental protection prompted the sustainable development progress.

Contribution to sustainable development	Main publications
Enlightenment	Silent spring (Carson, 1962)
Promotion	The economics of the coming spaceship earth (Boulding, 1966).
	The entropy law and the economic process (Georgescu-Roegen, 1971).
	The Limits to Growth (Meadows et al., 1972)
Formally put forward sustainable development	Our Common Future (WCED, 1987)

constraints of the natural resources on economic growth. Because the utilization of environment and resource factors is not included in the production function, these resources have been abused by overuse without regeneration in sustainable systems. As economies continue to grow, resource constraints become more and more obvious. RP has become a national strategic policy issue (Bleischwitz, 2010).

In an attempt to overcome the challenges associated with creating a uniform classification for measuring natural resource productivity scholars, rather than using energy, land and other resources as evaluative categories, have proposed the use of direct material consumption (Bleischwitz, 2010), shadow price (Bulckaen and Stampini, 2009) and green GDP (Talberth and Bohara, 2006). But the challenges still exist.

2.2. A comprehensive index: ecological footprint (EF)

The most comprehensive measure of humanity's overall impact may well be the 'Ecological Footprint' (hereafter EF) concept (Wackernagel and Yount, 2000). The term EF was created in 1992 (Rees, 1992) with an improved concept published by Wackernagel and Rees (1996). EF is a comprehensive index and it measures our use of nature, analyzing six main categories of ecologically productive area including arable land, grazing land, forest land, fishing area, built-up land and energy land. In the progress of EF calculation, resource use and the export trade has been considered in tons.

Wackernagel and Rees (1997) put forward EF as natural capital, which would include all the biophysical resources and waste sinks needed to support the human economy. The space mutually exclusive assumption includes all types of biologically productive area (Wackernagel and Yount, 2000), so as to create a unified description of various natural resources. By introducing the concept of biologically productive area, EF directly reflects the use of natural resources and it is a measure of the impact of human society on the extent and intensity of use of those natural resources. The EF concept should therefore be seen as an indicator, or biophysical measure, of natural capital utilization (Kratena, 2008). It is a good indicator (and unified description) of the various natural resources utilized to create the output in the production function.

The EF has attracted world wide attention since it was proposed. The research scope of EF is very wide, pervading various countries and regions all over the world. 'Footprint' has become an accepted term within ecological and environmental sciences (Jarvis, 2007). "Ecological Economics" focused on discussing it with special issues in 2000 volume 32 (e.g., Rees, 2000; Wackernagel and Silverstein, 2000; Simmons et al., 2000). At the same time, the World Wildlife Fund for Nature (WWF) reported ecological footprints for many countries and some countries attach great importance to it (Wackernagel, 2009). Although some scholars question EF (Moffatt, 2000; Fiala, 2008), it does reflect ecological well-being and gives an indication regarding whether current consumption and production patterns are likely to be sustainable (Bicknell et al., 1998).

2.3. Using EF in the RP calculation

The basic idea of calculating RP revolves around output efficiency of resources, namely the ratio of the welfare index (mainly GDP) and natural resource usage, which measures the efficiency of productive activities and the conversion of input to output. The crux of the problem is the inability to find one or more

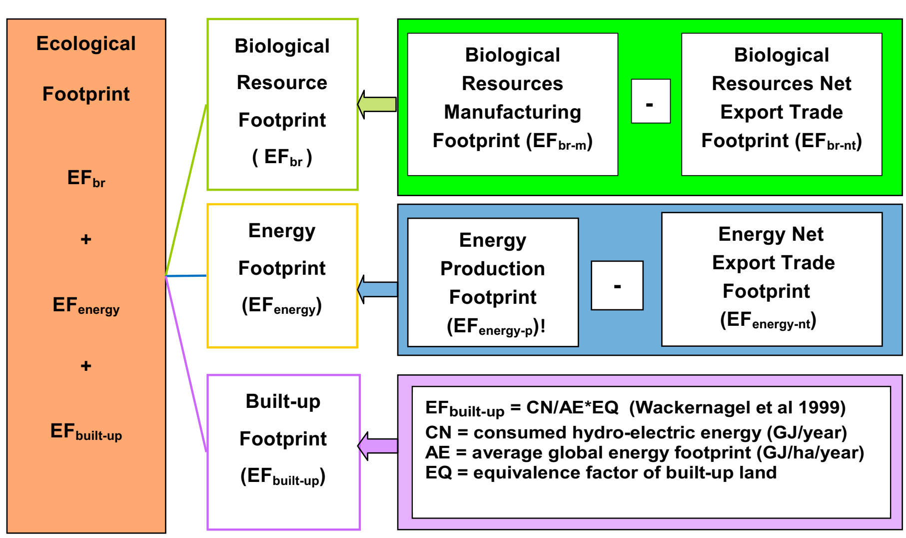

Fig. 1. The ecological footprint (EF) calculation, method and steps.

simple and reasonable indicators to describe the input of natural resources.

The RP is a measure of the output:input efficiency of the natural resources. Because the EF is a good indicator (and unified description) of the various natural resources consumption, and Rees (2000) points out that EF corresponds closely to Ehrlich and Holdren (1971) well-known definition of human impact on the environment: *I* = PAT, where *I* is impact, *P* is population, *A* is affluence, and *T* is technology, which means EF considers the elements of population and technology impact on the environment. The population and technology elements are important to the RP. So the RP concept, and its calculation method based on EF, is fully consistent with the productivity definition in the economic sense.

This paper uses gross domestic product (GDP) as the output, which indicates the total output of a country, and ecological footprint (EF) as the indicator to describe all types of natural resource input, so the RP can be represented as:

RP = GDP/EF

EF analysis is one informative area-based indicators of sustainability (Rees, 1996). This paper introduces the EF into the calculation of RP, which expands the role of the EF and combines it with economic analysis, to become one of the indicators used to measure national and regional economic development and a usable tool for governments' developing macroeconomic policies.

3. Case study

3.1. China's EF calculation and its results in 1997–2011

The commonly used methods for calculating EF include the compound approach (Wackernagel and Rees, 1996; Wackernagel et al., 1999), the component approach (Simmons et al., 2000; Gossling et al., 2002; Kuzyk, 2012) and the input:output approach (Bicknell et al., 1998; Ferng, 2001, 2009). In this paper, the calculation of the EF from 1997 to 2011 for China is mainly based on the compound approach put forward by Mathis Wackernagel (Wackernagel and Rees, 1996; Wackernagel et al., 1999). The EF is the sum of its three parts, the biological resources footprint (EF_{br}), the energy footprint (EF_{energy}) and the built-up footprint ($EF_{built\text{-}up}$) (Fig. 1).

3.1.1. Biological resource footprint (EF_{br})

Biological resources footprint (EF_{br}) records biological resources products, which include agricultural products, animal products, forest products and aquatic products, where aquatic products include freshwater and marine products. So EF_{br} includes the arable footprint, grazing footprint, forest footprint and fishing footprint (Eq. (1)).

$$EF_{br} = \sum_{j=1}^{4}(EF_{br-m})_j - (EF_{br-nt})_j = \sum_{j=1}^{4}(EF_{br-m})_j - \sum_{j=1}^{4}(EF_{br-nt})_j (j = 1, 2, 3, 4) \quad (1)$$

The real consumption of biological resources cannot be calculated directly, so the trade adjustment method is used. The steps are as follows. First, calculate the biological resources manufacturing footprint ($EF_{br\text{-}m}$) based on national statistics of biological production (Eq. (2)). Second, calculate the biological resources net export trade footprint ($EF_{br\text{-}nt}$) based on national trade data of biological resources. Third deduct $EF_{br\text{-}nt}$ from $EF_{br\text{-}m}$.

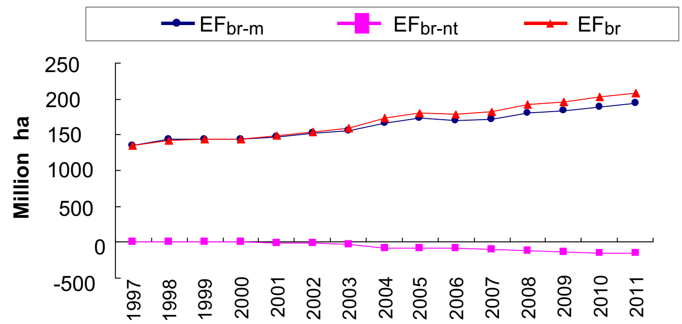

Fig. 2. EF_{br}, $EF_{br\text{-}m}$ and $EF_{br\text{-}nt}$ for China 1997–2011 (Ha).
China Statistical Yearbooks (http://www.stats.gov.cn) and FAO Production Yearbooks (http://www.fao.org) for 1997–2011.

$$(EF_{br-m})_j = \sum_{i=1}^{n_j} \frac{p_{ij}}{Yij} \times EQ_j \quad (2)$$

$$(EF_{br-nt})_j = ET_j - IT_j \quad (3)$$

where EF_{br} = biological resources footprint; $EF_{br\text{-}m}$ = the total biological resources manufacturing footprint; $EF_{br\text{-}nt}$ = the total biological resources net export trade footprint; *j* = the four biological resources; productive land including arable land, grazing land, forest land and fishing area; $(EF_{br\text{-}m})_j$ = the jth biological resources manufacturing footprint; Y_{ij} = the global average unit production of the ith biological resource of the jth biological productive land; P_{ij} = the ith biological resource production of the jth biological productive land; n_j = the resource types of jth biological productive land; EQ_j = the jth equivalence factor of biological resources; $(EF_{br\text{-}nt})_j$ = the jth biological resources net export trade footprint; ET_j = the jth biological resources export trade footprint; IT_j = the jth biological resources import trade footprint.

Eq. (3) shows the import and export trade footprint of biological resources. China's EF_{br} has increased over the past 15 years by 54% from 1352.04 million ha in 1997 to 2086.87 million ha in 2011 (Fig. 2). The biological resources import trade footprint has been bigger than the export trade footprint since 2000, so the $EF_{br\text{-}nt}$ became negative. At the same time, the absolute value of the $EF_{br\text{-}nt}$ increased year-by-year, showing that the degree of dependence of China's consumption of biological resources on imports has been gradually increasing.

Fig. 2 shows that China's EF_{br} comprises $EF_{br\text{-}m}$ and $EF_{br\text{-}nt}$. As the $EF_{br\text{-}nt}$ is positive before 2000, EF_{br} is smaller than $EF_{br\text{-}m}$. When the $EF_{br\text{-}nt}$ becomes negative (and its absolute value increases), EF_{br} becomes increasingly greater than $EF_{br\text{-}m}$.

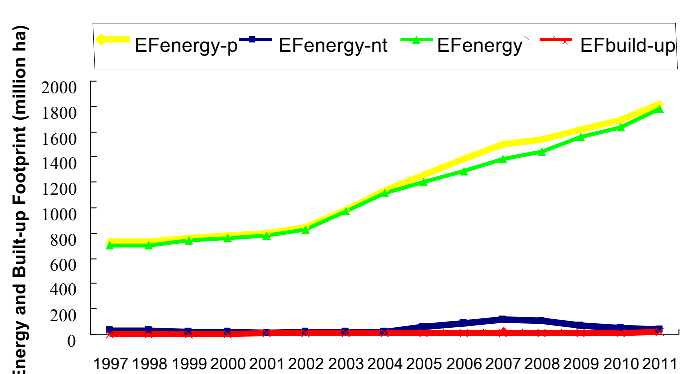

Fig. 3. China's EF_{energy}, $EF_{energy\text{-}p}$ and $EF_{energy\text{-}nt}$ (1997–2011).
China Statistical Yearbooks (http://www.stats.gov.cn) and FAO Production Yearbooks (http://www.fao.org) for 1997–2011.

Table 2
China's RP, total EF and percentage of EF_{br}, EF_{energy} and $EF_{built\text{-}up}$ (1997–2011).

Year	Composition ratio (%)			EF of China (million ha)	RP of China (yuan/ha)
	EF_{br}	EF_{energy}	$EF_{built\text{-}up}$		
1997	65.75	34.06	0.18	2056.2	3841
1998	66.83	32.99	0.18	2122.6	3976
1999	65.92	33.89	0.19	2176.2	4121
2000	65.19	34.60	0.20	2203.3	4503
2001	65.38	34.40	0.21	2269.0	4833
2002	64.90	34.87	0.23	2366.0	5086
2003	61.99	37.76	0.25	2562.1	5301
2004	60.64	39.10	0.25	2862.8	5585
2005	53.75	45.85	0.40	3022.5	6119
2006	57.74	41.95	0.31	3082.4	7018
2007	56.56	43.10	0.34	3211.5	8277
2008	56.99	42.67	0.34	3369.2	9321
2009	55.56	44.09	0.35	3526.0	9668
2010	55.19	44.43	0.38	3686.3	10892
2011	53.75	45.85	0.40	3882.7	12179

3.1.2. Energy footprint (EF_{energy})

This paper uses the carbon sequestration method (Liu, 2009) to calculate the EF_{energy}. Firstly, the energy production footprint ($EF_{energy\text{-}p}$) is calculated; secondly, the energy net export trade footprint ($EF_{energy\text{-}nt}$) is calculated. Finally, deduct the former from the latter. $EF_{energy\text{-}p}$ is the energy consumption in the production process, not the final energy consumption in the consumption of various items, so a trade adjustment must be made. As the "materialized" energy consumption in a variety of import and export commodities is difficult to calculate for each commodity, the value assessment method is used to estimate the materialized energy consumption in the trading activity. This is expressed below in Eqs. (4)–(6):

$$EF_{energy} = EF_{energy-p} - EF_{energy-nt} \quad (4)$$

$$EF_{energy-p} = \frac{EC \times ED \times CD \times TCR}{CS \times EQ} \quad (5)$$

$$EF_{energy-n} = EF_{energy-p} \times S \quad (6)$$

where EF_{energy} = energy footprint; $EF_{energy\text{-}p}$ = energy production footprint; $EF_{energy\text{-}nt}$ = energy net export trade footprint; EC = energy consumption; ED = energy density (the world's average calorific standard unit of fossil energy, 29.4 GJ per ton of standard coal); CD = carbon density (unit heat rate of carbon emissions standards, coal, 0.026 t standard coal/GJ, oil, 0.020 t standard coal/GJ, natural gas, 0.015 t standard coal/GJ); TCR = terrestrial carbon responsibility (69%); CS = carbon sequestration (tonnes Carbon per hectare per annum, 0.95 t/ha); EQ = equivalence factor of 1.1 for energy land; *S* = net exports of goods as a proportion of China's GDP (share).

3.1.3. Built-up land footprint ($EF_{built\text{-}p}$)

The method of calculation of built-up footprint ($EF_{built\text{-}up}$) comes from Wackernagel et al. (1999). The main methodology is converting hydro-electric consumption into biological productive land. The calculation is as follows Eq. (7):

$$EF_{built-up} = \frac{CN}{AE \times EQ} \quad (7)$$

where $EF_{built\text{-}up}$ = built-up footprint; CN = the amount of hydro-electric energy consumed (GJ/year); AE = the average global energy footprint (GJ/ha per year); EQ = equivalence factor of 2.8 for built-up land.

In order to facilitate comparison, this paper uses the equivalence factors which were used by Wackernagel et al. (1999) to calculate the ecological footprint of 52 countries. China's EF_{energy} and $EF_{built\text{-}up}$ from 1997 to 2011 is shown in Fig. 3. The EF_{energy}, dominated by fossil fuels, was the fastest growing component of China's EF over the 15 year period, and it increased by nearly 400% from 700.431 million ha in 1997 to 1780.32 million ha in 2011, which also shows a high dependence on energy during economic development. The energy trade adjustment mainly includes coal, coke (including semi-coke), crude oil and refined oil. Oil imports were always greater than exports and coal imports were less than exports upto and including 2008 after that the position reversed. The data shows that the $EF_{energy\text{-}nt}$ trend first decreased, then increased and finally decreased again, but the absolute changes are not large. China's $EF_{built\text{-}up}$ is almost too small to be seen in Fig. 3, but has an upward trend.

Table 2 shows China's total EF and the relative proportions of the EF_{br}, EF_{energy} and $EF_{built\text{-}up}$ from 1997 to 2011. The total EF, increased by 83.83% from 2056.2 million ha in 1997 to 3882.7 million ha in 2011. The EF_{br} accounts for more than half of the total EF,

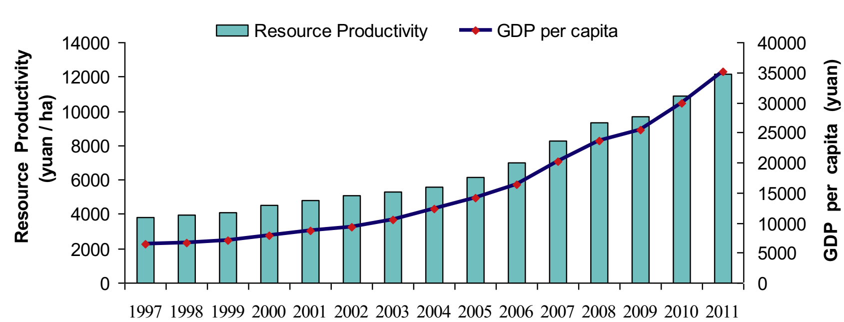

Fig. 4. China's RP and GDP per capita in 1997–2011.

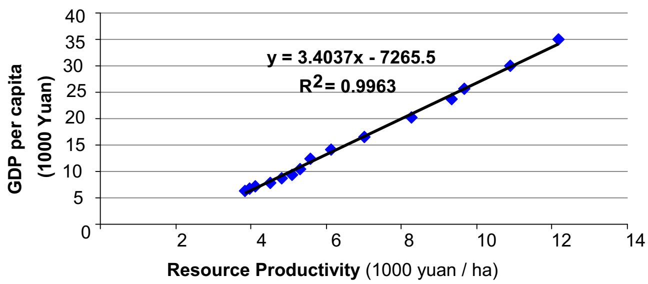

Fig. 5. Corelation–China's GDP per capita and RP.

but its share was reduced from 65.75% in 1997 to 53.75% in 2011. The proportion of EF_{energy} increased to nearly 50% in 2011. The proportion of $EF_{built-up}$ is small, but shows a growth trend.

China's EF_{energy} is the difference in value between $EF_{energy-p}$ and $EF_{energy-nt}$. The amount of $EF_{energy-nt}$ is not big, but it is positive, so the EF_{energy} is smaller than the $EF_{energy-p}$. The value of $EF_{built-up}$ is very small.

3.2. China's resource productivity (RP) from 1997 to 2011

Table 2 shows China's RP for 1997–2011. The RP increased dramatically from 3841 yuan/ha in 1997 to 12,179 yuan/ha in 2011, more than tripling (Table 2 and Fig. 4). From the Table 2, we can see that the composition ratio of biological resource footprint (EF_{br}) account for more than half of the total EF, and the composition ratio of energy footprint (EF_{energy}) is growing fast. The growth of RP before 2005 is not fast, the growth has quickened significantly after 2005.

In this paper we present calculations of China's RP for 1997–2011. This period of time covers the part of China's entry into the market economy and as a new member of World Trade Organization. The economy of China is growing fast. During this period, technology improvements play an important part in the improving efficiency of resources utilization. He and Chen (2009) also point out that technology improvements have created much-improved resource utilization.

4. New applications of RP

4.1. Analyzing the relationship between China's RP and GDP per capita 1997–2011

Both the RP and GDP per capita grew during the period, with the GDP growth rate being higher than that of RP (Fig. 4). Regression analyses show that: RP and GDP per capita (Fig. 5) and EF and GDP per capita (Fig. 6) have a significantly positive correlation; per capita GDP can be represented by the RP.

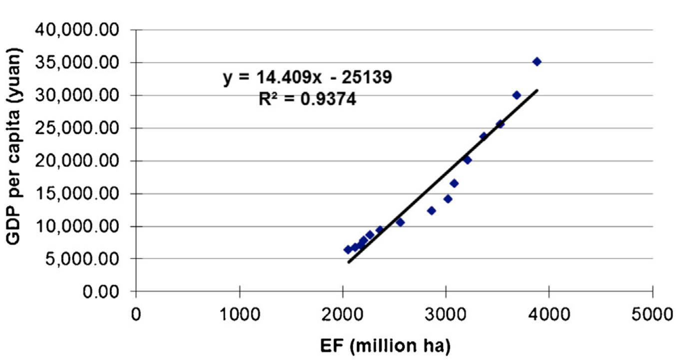

Fig. 6. Corelation–China's EF and GDP per capita.

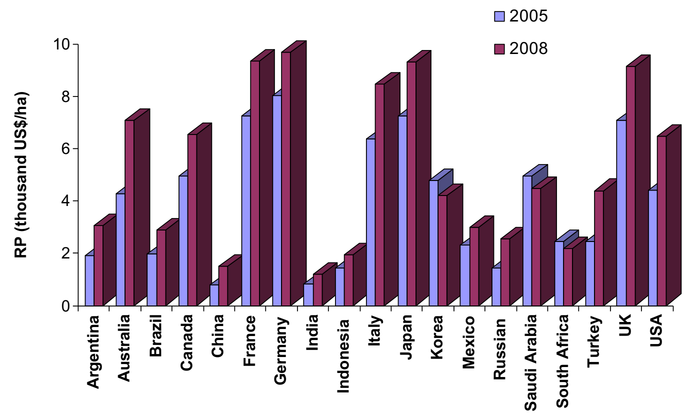

Fig. 7. G20 RP in 2005 and 2008 (excludes European Union (EU) due to changing membership and Germany, UK, France and Italy are already included).

The size of the per capita GDP can be used to indicate the economic development level of a country or region. So the value of the RP can reflect the degree of economic development of a country or region, and the EF indirectly can be seen as measuring the level of economic development, thereby expanding its applications.

4.2. Analysis of RP of the G20 countries

In order to better explain the RP impact on economic development, this paper compares the RP of the G20 with that of China and analyzes the relationship between RP and per capita GDP. The G20 countries are selected for analysis because they have worldwide representatives. As the members (Appendix 1) of G20 are from the developed and less-developed countries, the G20's GDP accounts for about 90% of world GDP and their population accounts for about 65% of the world population. Previous scholars have used the G20 countries for example to analyze the world carbon emissions performance problems and for empirical analysis of world ecological well-being performance.

We uses the EF data of G20 members from Living Plant Report 2008 (WWF, 2008) and the Living Plant Report 2012 (WWF, 2012) reported by World Wildlife Fund for Nature (WWF) to calculate the RP of the G20 members in 2005 and 2008. The data both from the WWF, the calculation method of EF is the same, so authors consider the EF data in 2005 and 2008 have comparability. The data of the GDP of G20 members come from the International Statistical Yearbook.

Fig. 7 shows that the RP of the G20 increased except for Korea, Saudi Arabia and South Africa. These three countries' GDP growth rate is less than the growth rate of the EF, precipitating a fall in their RP. The growth rate of Korea's GDP was 9.97%, which was less than the growth rate of its EF at 24.60%. The GDP growth rate of Saudi Arabia was 48.16%, while its EF growth rate was 63.44%.The growth rate of South Africa's GDP was 14.00%, with an EF growth rate of 28.28%. The other countries' GDP growth rates were greater than the growth rate of their EF.

Though China's RP is small, its growth rate is the highest at 85.78%, followed by Australia and Argentina, whose growth rates were 65.05% and 61.20%, respectively. In 2008, Germany's RP was the highest, at 9688 US$/ha, followed by France and Japan at 9357 US$/ha and 9306 US$/ha, respectively. India's RP is the lowest, only 1188 US$/ha in 2008, (less than 12.5% of Germany's), followed by China and Indonesia, at 1494 US$/ha and 1937 US$/ha. Australia's GDP per capita is the highest; in 2008 it reached 47,218 US$, followed by United States and France, with 46,571 US$ and 45,943 US$ respectively. India's GDP per capita is the lowest at

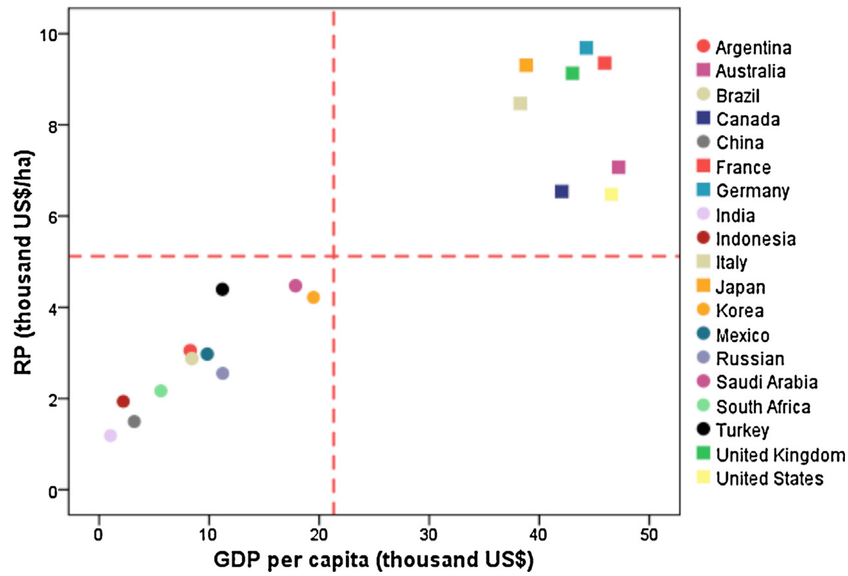

Fig. 8. G20 RP and GDP per capita in 2008.

only 1022 US$, less than 2.3% of Australia's, with Indonesia and China next lowest at only 2188 US$ and 3183 US$ respectively.

This paper uses Figs. 8 and 9 and Table 3 to identify gaps between the RP's of G20 members in 2008. The average value of G20 RP is 5.12 per thousand US$/ha and the GDP per capita is 23.39 per thousand US$ (Fig. 8). In the Fig. 8 and Table 3, it can be clearly seen that the G20 is divided into two categories. One category includes eight countries (Australia, Canada, France, Germany, Italy, Japan, United Kingdom and United States) with high RP and high GDP per capita, which showed by square in Fig. 8. The other category includes eleven countries (Argentina, Brazil, China, India, Indonesia, Korea, Mexico, Russion, Saudi Arabia, South Africa and Turkey) with low RP and low GDP per capita, which showed by circle in Fig. 8.

This paper also uses another way to explain the two categories more clearly (Fig. 9). This paper takes the RP and GDP per capita deduct the average value of G20 respectively. The results can be seen in the Fig. 9. The countries with higher RP and GDP per capita than the average value shows above the *X* axis, and the countries with lower RP and GDP per capita than the average value shows under the *X* axis. The two categories are the same as the Fig. 8.

Table 3 categorizes G20 members using this criterion and ascribing each to a different zone. There are eight countries (Australia, Canada, France, Germany, Italy, Japan, United Kingdom and United States), which are all the economically developed countries in the first zone with high RP and high GDP per capita. The other countries are all less-developed countries with low RP and low GDP per capita. The high RP and low GDP per capita zone and low RP and high GDP per capita zone have no countries. Therefore, it is clear that the RP has a positive correlation with economic development and increasing the RP (by improving the relationship between EF and GDP) would be an effective way of driving economic development.

5. Discussion

The EF methodology converts the regional resource and energy consumption into a variety of biologically productive areas; the calculation method is not complicated, but the specific calculations differ. Though using the same calculation method, calculating different products and different classification of the biological resources all lead to different results to some extent. This is inevitable as Wackernagel (2009) points out the results of EF can never be wholly accurate, and that applies to any model. With the widespread use of the EF, the calculation method is modified for the specific study object. Lenzen and Murray (2001) modifies ecological footprint method to add emissions land to calculation the emissions of CO_2 and other greenhouse gases in the need for a

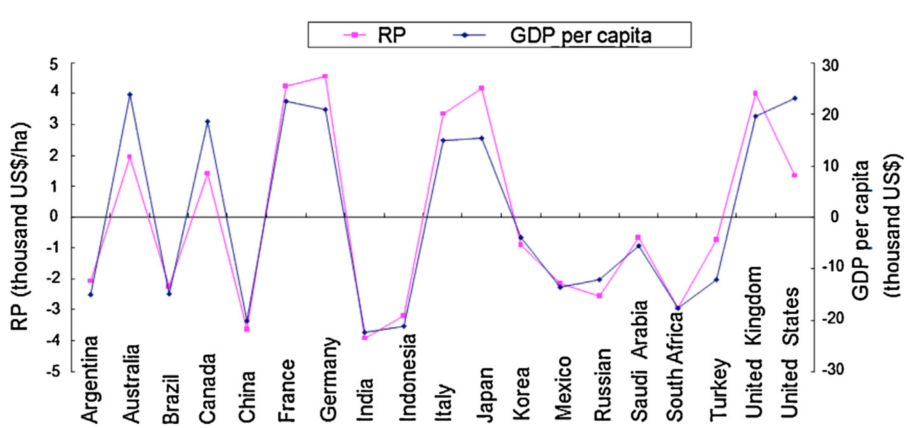

Fig. 9. G20 RP and GDP values (per capita) based on 2008 averages (excludes European Union (EU) due to changing membership and Germany, UK, France and Italy are already included).

Table 3
G20 classification based on RP and GDP per capita (US$/ha).

	High RP ≥ 5.12 (thousand US$/ha)	Low RP < 5.12 (thousand US$/ha)
High GDP per capita ≥ 23.39 (thousand US$)	Australia, Canada, France, Germany, Italy, Japan, United Kingdom, United States	
Low GDP per capita < 23.39 (thousand US$)		Argentina, Brazil, China, India, Indonesia, Korea, Mexico, Russian, Saudi Arabia, South Africa, Turkey

regional approach. van Vuuren and Smeets (2000) considers addition of carbon dioxide emissions to calculate the EF of Bhutan, Costa Rica and the Netherlands.

Combining EF with other tools or methods and using it for the evaluation of resources and economic development is a developing methodology. This paper attempts to use the EF indirectly for economic analysis, using it as the proxy input measure for natural resources, with GDP as the output to compute RP.

6. Conclusions

This paper presents a novel way to calculate the RP by including the EF, not only expanding the application of the EF, but also providing a very good solution to the problem of unified quantization of natural resources in calculating RP. The relationship between the RP and per capita GDP is analyzed (horizontally) using time series with China used as an example to calculate the RP between 1997 and 2011. China's RP over these 15 years is rapidly increasing driven by the advancement of technology and economic development. The same relationship is also analyzed (vertically) by comparative analysis using the G20 countries in 2008. This shows that G20 RP is significantly different from country to country.

Dividing the countries into zones is a new approach. Each zone represents different levels of performance for per capita GDP and RP, but all of them indicate that the bigger the RP, the larger the per capita GDP. There is a dichotomy in resource utilization, for historical and economic reasons, between G20 members and a distinct gap between the RP of the developed and the less-developed countries, but all need to develop RP. Being able to measure (and monitor) RP while including the EF in the calculation will provide the benchmark from which to progress sustainably and meet increasing (and changing) consumer demand without adding to long term global damage. A low RP directly affects the level of economic development. Decision makers concerned about the overuse of resources should therefore focus on the RP, given its strong correlation with development and work on improving the relationship between EF and GDP to get necessary efficiency gain, whether it be by land sharing or land sparing systems to meet increased demand sustainably (Sutton et al., 2012).

The RP calculated by EF is simple, practical and has high applicability. From the regression analyses using the GDP and EF per capita and RP of China in 1997–2011, and the zone classification of the G20 according to their RP and per capita GDP in 2008, it is clear that the RP is an effective tool for judging economic development of a country or region. The GDP is the world's most commonly used economic indicator, which is easy to get the data. The data of a country or region' EF can be calculated or get from Global Footprint Network or 'Living Planet Report'. So the RP with this paper's method can be easily used and analyzed by any country or region. According to the changes of time series, RP can reflect the level of economic development, which can be used a tool of governments to make macroeconomic policies.

The RP of the paper suggested approach analysis also has some limitations. It is a static measure whereas the economy and nature are dynamic systems. The RP is an eco-economic camera, each analysis provides a snapshot of current level of economic development using natural resources. In addition to this, it cannot take into account the social system (e.g., social well-being) and the impact of the environment (e.g., air pollution and deforestation).

This method of calculation, however, is not related to the population base. So for China, the huge population base is still an issue to be reckoned with given that per capita EF is 2.13 ha, far less than the world average EF of 2.7 ha, but the total amount of China's EF accounts for 15.9% of total global EF, indicating a potential future ecological safety problem (WWF, 2012). Ideally, analysis of the economic development of a country or region should consider the population issues.

The shift of focus from a more values driven environmental assessment approach to a more quantitative approach, and from measuring local impact to developing relatively simple general models that can identify problem trends, and the extent of problem impacts, so action becomes an imperative and can be planned, renders more valuable the use of an indicator such as the RP calculations (proposed in this paper), especially since they are measured per capita bringing in the population dimension.

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Appendix 1.

G20 members

G20 members include the G8 countries, namely, USA, Japan, Germany, UK, France, Italy, Canada and Russia; and the 11 emerging and developing countries, namely, Argentina, Australia, Brazil, China, India, Indonesia, Mexico, Saudi Arabia, South Korea, South Africa and Turkey; and the EU. The European Union is represented by the president of the European Council and by the European Central Bank.

G20 accounted for 90 per cent of the world GDP and nearly 80 per cent of world trade in 2011. G20 represents two thirds of world population.

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