Measuring Worldwide Resource Sustainability Related to Socio-economic Scenarios under Ecological Footprint Model

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Abstract: This paper describes the questions on the consequences of the assumptions about resource sustainability and economic growth and whether sustainability and economic growth foreclose each other. Specifically, it examines four questions by: (1) Identifying the main factors in earth resource consumption in the past 40 years; (2) Finding relationships among person's nutrition demands, food Ecological Footprint (EF) and income; (3) Formulating functional equations for resource surplus/overdraft periods; (4) Designing Socio-Economic Resource (SER) Matrix: A model to measure local (or national) trending toward sustainability/unsustainability. The main findings of this paper are: (1) EF=*f* (population, GDP). The results of our analysis are as follows: $EF_{1961\text{-}1978}=0.331519701X+0.5;$ $EF_{1979\text{-}1999}=0.5742425961X-1,$ X= population (billion); (2) Dietary energy supply (DES, kcal/person/day) and Food EF (the sum of arable and livestock EF) based on 1996 data. These results display an exponential growth model: $EF=70.584e^{0.001x}$; (3) GDP (per capita) and DES exhibit a logistic growth model, i.e., the logistic function *EF=367.86 and Ln(x) - 274.48.* [Nature and Science. 2004;2(3):19-29].

Keywords: ecological footprint (EF); socio-economic resource (SER); sustainability matrix; resource consumption; gross domestic product (GDP); dietary energy supply (DES)

1 Introduction

1.1 Population growth and resource consumption

As the world population continues to grow geometrically, great pressure is being placed on arable land, water, energy, and biological resources to provide an adequate supply of food while maintaining the integrity of our ecosystem. According to the World Bank and the United Nations, from 1 to 2 billion humans are now malnourished, reflecting a combination of insufficient food, low incomes, and inadequate distribution of food. This is the largest number of hungry humans ever recorded in history. In China about 80 million are now malnourished and hungry. Based on current rates of increase, the world population is projected to double from roughly 6 billion to more than 12 billion in less than 50 years (Pimentel et al., 1994). As the world population expands, the food problem will become increasingly severe, conceivably with the numbers of malnourished reaching 3 billion (David Pimentel et al., 1996). According to the United Nations, the World Population Prospects, world population rose up to 6.1 billion in 2000, and high population growth rates will take place in the less developed countries which can lease support it (Figure 1).

Underlying anthropogenic changes to natural environments (Sala et al., 2000; Wakermagel et al., 2002; Rosser and Mainka, 2002), one of the greatest threats to species biodiversity and ecosystems function, may result from the high density and rapid growth of the human populations (Kerr and Currie, 1995; Forester and Machlis, 1996; Kirkland and Ostfeld, 1999; Thompson and Jones, 1999; Cincotta et al., 2000; Cincotta and Engelman, 2000; Abbitt et al., 2000; McKinney, 2001; Harcourt et al., 2001; Harcourt and Parks, 2003; Balmford et al., 2001; Ceballos, 2002).

200 years ago almost everywhere, human beings were comparatively few, poor and at the mercy of the forces of nature, but 200 years from now, we expect, that almost everywhere they will be numerous, affluent and in control of the forces of nature. The future path of population growth is expected, by Kahn and his associates, to approximate an S-shaped logistic curve. This image suggests that an omniscient observer in 1976 looking backward through time and then forward into the future would see rather different things. The retrospective glance would reveal a period of exponential population growth, while the glance into the future would reveal continued growth, but with steadily declining growth rates, until, at the end of the next 200-year period,

growth would automatically come to a halt. By that time, however, the population would have increased to four times its current level and the average person in the world economy would be earning $20,000 a year (in constant dollars)—a far cry from the 1976 average of $1300 (Tom Tietenberg; Harper Collins, 1992).

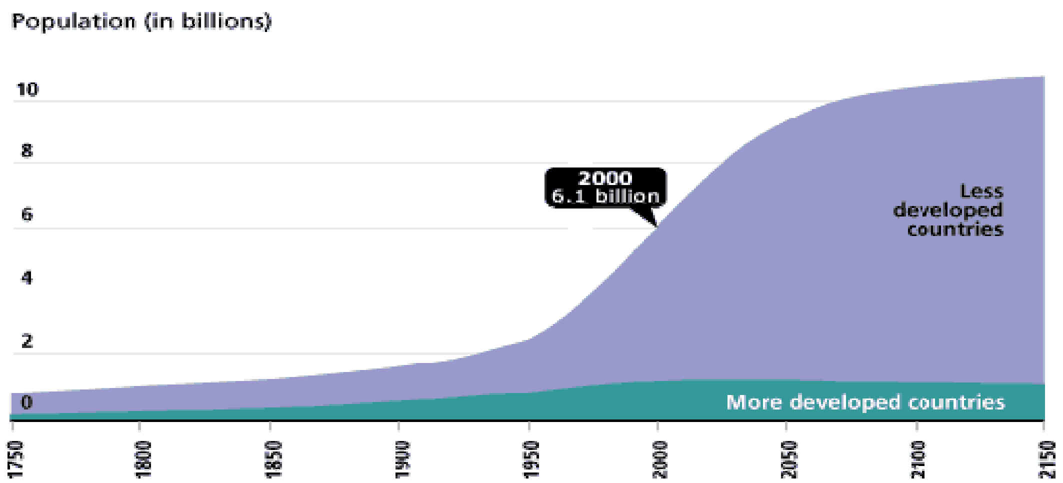

Figure 1. World population variation with time

Source: United Nations, World Population Prospects, 1998.

Economic analyses often overlook the biological and physical constraints that exist in all food production systems. The assumption is that market mechanisms and international trade are effective insurances against future food shortages. A rich economy is expected to guarantee a food supply adequate to meet a country's demand despite existing local ecological constraints. In fact, the contrary is true. When global biological and physical limits to domestic food production are reached, food importation will no longer be a viable option for any country. At that point, food importation for the rich can only be sustained by starvation of the powerless poor (David Pimentel et al., 1996).

Clearly socio-economic disparities and conservation ethics play a role in each nation (Sala et al., 2000; Kirkland and Ostfeld, 1999), and mediate variations in how dense human populations affect the viability of other species. More elaborate models considering the range of anthropogenic effects associated with economic development could refine the model, if such long-range economic conditions could reasonably be forecast (McKee et al., 2003).

1.2 The limits to growth

We can't continue to destroy the earth's life support system indefinitely. It just doesn't compute. Global warming, acid rain, holes in the ozone layer, the loss of genetic diversity and desertification are just a few of the problems that have surfaced in my lifetime (Jonathan White, 1994). An environment's carrying capacity is its maximum persistently supportable load (Catton, 1986).

In 1990 the nonrenewable resources remaining in the ground would have lasted 110 years at the 1990 consumption rates. No serious resource limits were in evidence. But, by 2020 the remaining resources will constitute only a 30-year supply. Why did this looming shortfall arise so fast? It is because exponential growth increases consumption and exhausts resources. Between 1990 and 2020 the world population will increase by 50% and industrial output will grow by 85%. The nonrenewable resource use rate will double. So many resources will be depleted that much more capital and energy will be required to find, extract, and refine what remains.

1.3 Measuring environmental impact and environment indicators

Ehrlich et al measured the impact of the global population as a fraction of the terrestrial net primary productivity. Projected increases in population alone could double this level of exploitation, causing the demise of many ecosystems on whose functional human beings depend.

$$I = PAT$$

The impact (I) of any population can be expressed as a product of three characteristics: the population's size (*P*), its affluence or per-capita consumption (*A*), and the environmental damage (*T*) inflicted by the technologies used to supply each unit of consumption (Ehrlich and Ehrlich 1990; Ehrlich and Holdren 1971; Holdren and Ehrlich 1974).

Up to now, there are many global and local environmental indicators, such as the more comprehensive overall green Gross Domestic Product (GDP), the Genius Progress Indicator (GPI) and so on.

1.4 Sustainability concept

The current objective of international development is to raise the developing world to the developed world on the present material standards. To achieve this objective, the Brundtland Commission argued for "more rapid economic growth in both industrial and developing countries" and suggested that "a five to ten fold increase in world industrial output can be anticipated by the time world population stabilizes some time in the next century" (WCED, 1987).

This does not prescribe a fixed state of harmony, or foreclose economic growth (Werner Hediger, 2004). Rather, the idea of sustainable development leads beyond the traditional, ecologically based conception of physical sustainability to the social and economic context of development (Adams, 1990). It involves concerns for environmental preservation and economic development, and correspondingly calls for an integrated approach to evaluating trade-offs between conservation and change. This is inherently dynamic and state dependent.

Yet, differences in disciplinary perspectives, and differences in the philosophical and ethical interpretation of sustainable development have resulted in competing concepts of sustainability that give priority to either economic or environmental objectives, such as the opposed paradigms of “weak” and “strong” sustainability (cf. Pearce et al., 1994; Turner et al., 1994; Hediger, 1999; Neumayer, 1999). In essence, they are based on different conceptions of capital theory. For example, the theoretical foundation of the weak sustainability paradigm lies in the neoclassical theory of economic growth and capital accumulation and its extension to include non-renewable resources (Solow, 1974, 1986; Hartwick, 1977, 1978a). However, the paradigm of strong sustainability is grounded in the thermodynamic foundation of a steady-state economy (Daly, 1972, 1974, 1977).

In the present study, we aim to analyze the following:

(i) To identify the main factors of earth resource consumption in the past 40 years;

(ii) To find relationships with person’s nutrition demand, food EF and income;

(iii) To formulate the function equations for resource Surplus/Overdraft periods; and

(iv) To set up Socio-Economic Resource (SER) Matrix: A tool to measure sustainability and unsustainability state.

2 Methodology

2.1 Assumption

We have proposed two hypotheses to explain why resources will be consumed fast or then in the past; the first point is the processes of nature are irreversibility. According to the Second Law of Thermodynamics, the entropy (a measure of disorder or chaos) of an isolated system (one that does not exchange matter, energy, or information with its environment) will remain unchanged for reversible processes but will increase for irreversible processes. Thus, irreversible systems, including all living systems, tend to become chaotic as their entropy increases. Nicolis and Prigogine (1989) speak of a “universal role of irreversibility in nature” and point out that the irreversibility of complex systems is not the result of “the complexity of the collective behavior of intrinsically simple objects” but rather is “due to the very structure of the dynamical systems”.

Our second assumption is that a natural resource can’t be replaced; that’s to say, the definition of resource used in this paper comes close to the strong sustainability demanded for nonrenewable resources.

2.2 Ecological Footprint Theory

This research is based on the ecological footprint (EF_p) of a study population, that is, the per capita footprint multiplied by population size (N): $EF_p= N(ef)$.

Conventional wisdom suggests that, because of technology and trade, human carrying capacity is infinitely expandable and therefore virtually irrelevant to demography and development planning. This article sets out to argue the contrary view that ecological carrying capacity should remain the fundamental basis for demographic accounting. A fundamental question for ecological economics is whether remaining stocks of natural capital are adequate to sustain the anticipated load of the human economy into the next century. Since mainstream (neoclassical) models are blind to ecological structure and function, they cannot even properly address this question. The present article therefore assesses the capital stocks, physical flows, and corresponding ecosystem areas required to support the economy using "ecological footprint" analysis. This approach shows that most so-called "advanced" countries are running massive unaccounted ecological deficits with the rest of the planet. Since not all countries can be net importers of carrying capacity, the material standards of the wealthy cannot be extended sustainable to even the present world population using prevailing technology. In this light, sustainability may well depend on such measures as greater emphasis on equity in international relationships, significant adjustments to prevailing terms of trade, increasing regional self-reliance, and policies to stimulate a massive increase in the material and energy efficiency of economic activity (William E. Rees). EF further argues for shifting the emphasis in development from global economic integration and inter-regional dependency toward intra-regional ecological balance and relative self-reliance (If all regions were in ecological steady-state the aggregate effect would be global stability). This position is compatible with Daly's and Goodland's (1993) recommended alternative "default position" on international trade, that we should strive "to reduce rather than increase the entanglements between nations".

2.3 Data source

This paper's data source includes FAO, World Bank, Redefining Progress (RP) report, UNSD and WWF report.

Table 1. Data Source

Organization	Property
Food and Agricultural Organization (FAO)	Dietary Energy Supply; Agricultural Production Indices
Redefining Progress (RP)	EF report
United Nations Development Programme (UNDP)	Human Development Report
United Nations Environment Programme (UNEP)	GNP, Population
World Wild Fund for Nature (WWF)	EF report

3 Results and Discussion

3.1 Population VS. Ecological Footprint

From 1961 to 1980, the global per capita Footprint declined by about one half hectare per person (Figure 2 – bottom curve); however, world EF still increased (Figure 2 – top curve). Increasing world population brought about per capita EF diminishing in this period. That's to say world population increases diluted each person's resource use. The above findings reflect the corresponding drop off of each person's welfare utility.

3.2 Income VS. Ecological Footprint

In order to explicate the economic variables related to resource consumption, we attempt to make use of GDP as economic indicator and EF as resource consumption to find out some relationship between the two factors.

Moreover, we make use of EF data for three years, 1996, 1999 and 2000, and the GIS tool for mapping to understand the space situation of the world's resources. The results reveal that apparently high EF countries are concentrated in high income or developed countries, such as North America, Western Europe Scandinavian and Japan (Figure 3); in addition, world EF and GDP have a significant relationship, EF increases along with GDP (Figure 4).

3.3 Resource Surplus/Overdraft Model

Humans have destroyed more than 30% of the ecosystems of the natural world since 1970 with serious depletion of the forest, freshwater and marine systems on which life depends (WWF, 1999). Footprint of Nations 2004 Update Released: Earth's Resources Overused by 15%.

According, based on WWF and Redefining Progress's report, we take Biocapacity as earth resource support source and the EF as resource consumption and find out the critical point of earth maximum sustainable use occurred in 1979 (1961~1999), that means earth resource surplus (Earth Biocapacity supply minus Ecological Footprint demand＞0) in 1961~1979; in other words, human beings are overdrawing from the earth's resource bank and caught in an situation of what was called the earth resource Surplus in 1979 (Earth Biocapacity supply minus Ecological Footprint demand＜0).

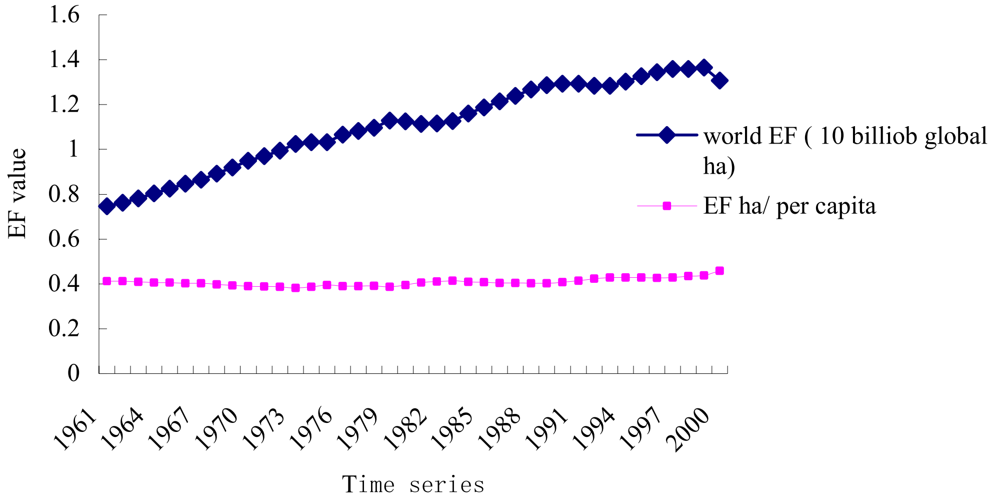

Figure 2. World and per capita EF trend from 1961 to 2000

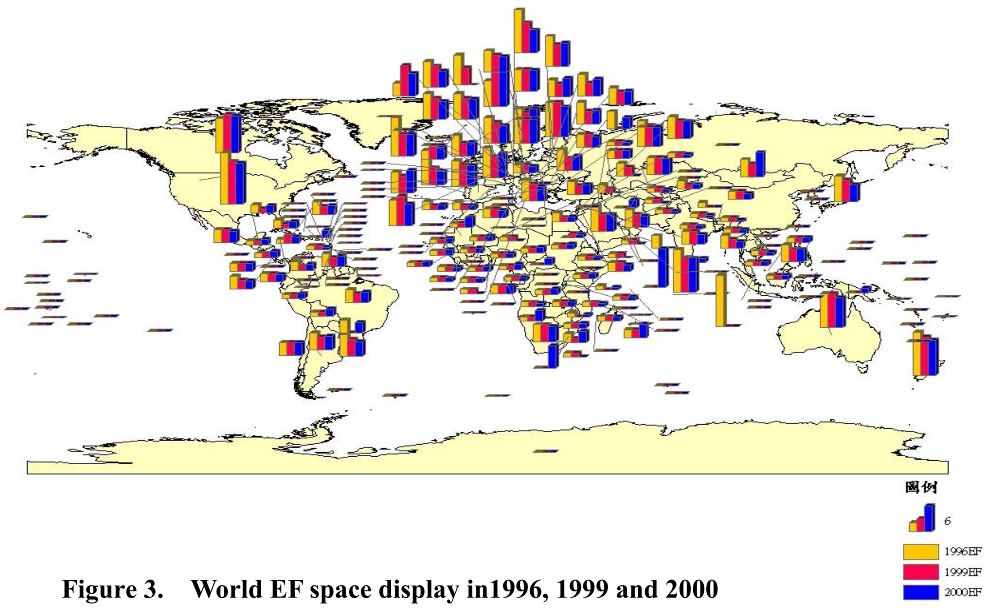

Figure 3. World EF space display in1996, 1999 and 2000

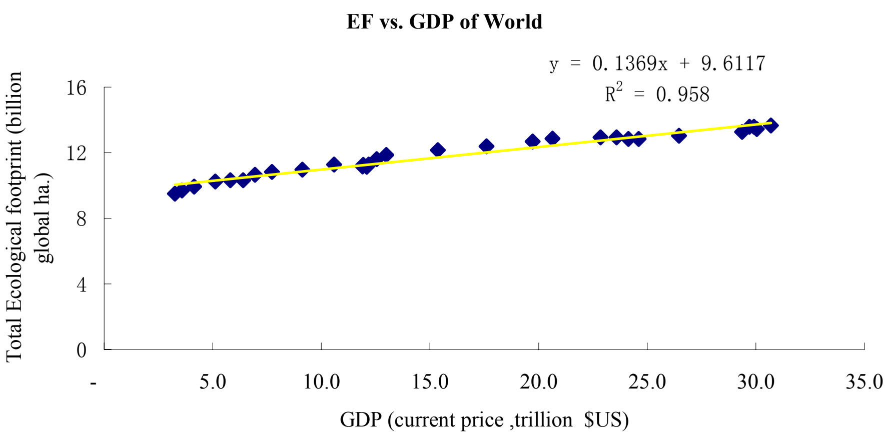

Figure 4. EF and GNP

First, we hypothesize natural resource consumption function in these periods as:

EF= f (population , GDP).

Then, we prove the functional equation between resource consumption (independent variable) and population independent variable in these periods. The results are as follows:

$EF_{1961\text{-}1978}=0.331519701X+0.5$ (1)

X=population (billion)

$EF_{1979\text{-}1999}=0.5742425961X\text{-}1$ (2)

X= population (billion)

In addition, in trying to explain why critical point was breached, we found that people had begun to consume and waste earth resources excessively by the 1970's, such as higher consumption of arable forest, pasture and productive sea in 1960's than in later periods, thus resulting in resource overshoot in the later periods (after 1970's).

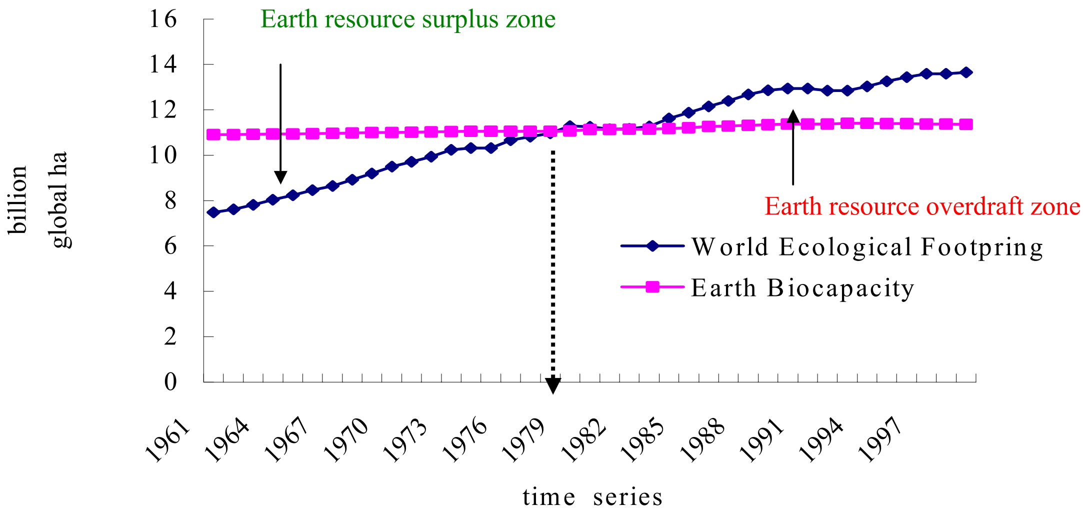

Figure 5. Earth share of productive area per capita from 1961 to 1999

3.4 Nutritional Demand and Food EF

According to Maslow's Holistic Dynamic Needs Hierarchy (Physiological, Safety, Belongingness and Love, Esteem, Self-Actualization), the physiological needs would come first in each person's search for satisfaction. Physiological needs are biological needs consisting of needs for oxygen, food, water, and a relatively constant body temperature (Abraham Maslow, 1970)**.**

In view of the human's basic physiological need and the Chinese proverb "To the people foodstuffs are all important", we tried to use dietary energy supply (DES, kcal/person/day) and Food EF (the sum of arable and livestock EF) based on 1996 data. Our results exhibit in an exponential growth model:

$EF=70.584e^{0.001x}$ (3)

Besides, GDP (per capita) and DES in logistic growth model; the logistic function:

$EF = 367.86Ln(x) - 274.48$ (4)

From Figures 6, 7 and Table 2, we can observe clearly each person's nutritional demand, food EF and income retain a positive regression.

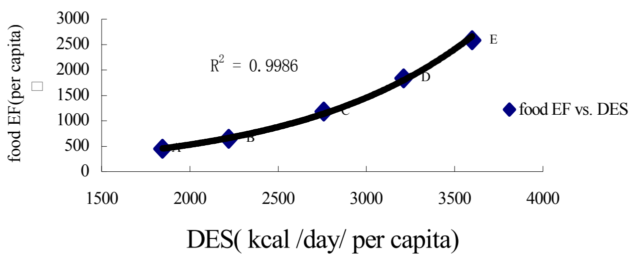

Figure 6. Food EF and Dietary Energy Supply's relationship (1996 data)

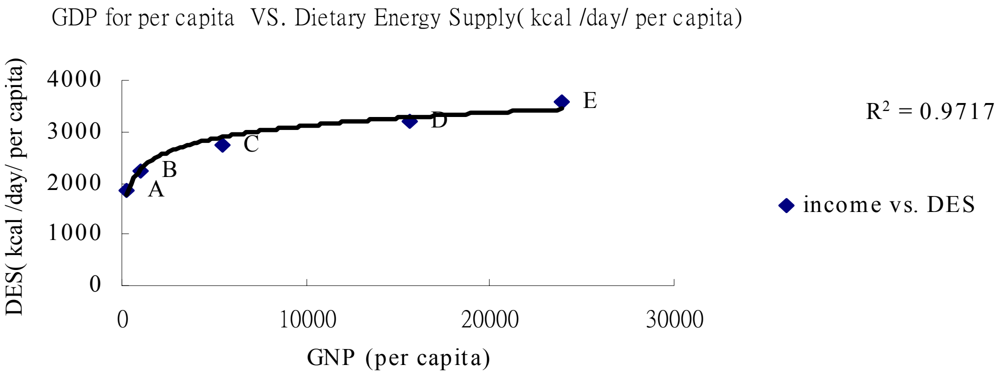

Figure 7. Dietary Energy Supply and income's relationship (1996 data)

Table 2. Different groups of Dietary Energy Supply and income (1996 data)

Group	Countries	Average GDP (US$/ Per capita)
A	Afghanistan, Somalia, Eritrea, Mozambique, Ethiopia, Haiti, Democratic Republic of the Congo, Chad, Angola, Central African Republic, Zambia, Cambodia, Kenya , Madagascar	256.21
B	Mongolia, Sierra Leone, United Republic Of Tanzania, Yemen, Zimbabwe, Malawi, Bangladesh, Rwanda, Niger, Liberia, Mali, Togo, Azerbaijan, Guinea, Bolivia, Namibia, Lesotho, Armenia, Uganda, Bosnia and Herzegovina, Cameroon, Tajikistan, Botswana, Burkina Faso, Iraq, Peru, Gambia, Nepal, Nicaragua, Thailand, Honduras, Cuba, Benin, Philippines, India, Senegal, Croatia, Kyrgyzstan, Venezuela, Vietnam, Gabon, Paraguay	983.64
C	Albania, Ecuador, Panama, El Salvador, Nigeria, Ghana, Uzbekistan, Turkmenistan, Jamaica, Netherlands Antilles, Jordan, Saudi Arabia, Colombia, Chile, China, Latvia, Lithuania, Uruguay, Costa Rica, Russian Federation, Belize, Malaysia, Estonia, Brazil, Indonesia, Iran , South Africa, Ukraine, Japan, Romania, Mauritius, Australia, Finland, Algeria, Kuwait	5475.9
D	Slovakia, Czech Republic, Slovenia, Canada, Belarus, Argentina, Iceland, Mexico, Sweden, Morocco, Netherlands, Tunisia, United Kingdom, Israel, Switzerland, Egypt, Spain, Germany, Republic of Korea, Syrian Arab Republic, Poland, Norway, United Arab Emirates, Hungary, Austria, New Zealand, France, Belgium, Greece	15629
E	Ireland, United States, Portugal, Denmark, Sri Lanka, Hong Kong, Malaysia	23890

3.5 Socio-Economic Resource (SER)

Matrix: The model to measure local (or national) trending toward sustainability/unsustainability.

We attempted to design a Socio-Economic Resource Matrix (SER) to evaluate local or country toward sustainability/unsustainability. The factors of SER consist of: EF increasing /decreasing rate, GDP growth/dropping rate and Population growth/lowering rate.

Therefore, SER Matrix can be used to measure parts of social welfare. So, we can distinguish four key concepts of sustainability that marks A~Z characterized and defined by different requirements as below:

Zone A is characterized by GDP (+); Pop. (-); EF (-)

Zone B is characterized by GDP (-); Pop. (-); EF (-)

Zone C is characterized by GDP (+); Pop. (+); EF (-)

Zone D is characterized by GDP (-); Pop. (+); EF (-)

Zone E is characterized by GDP (+); Pop. (-); EF (+)

Zone F is characterized by GDP (-); Pop. (-); EF (+)

Zone G is characterized by GDP (+); Pop. (+); EF (+)

Zone H is characterized by GDP (-); Pop. (+); EF (+)

Factors	EF (+)	EF(-)
GDP (+) Pop. (-)	E	A
GDP (-) Pop. (-)	F	B
GDP (+) Pop. (+)	G	C
GDP (-) Pop. (+)	H	D

optimum

Unsustainability ◄·········► Sustainability

Figure 8. the Socio-Economic Resource Matrix

Note: A zone is the optimum state; H zone is the worst state

In sum, in the optimum states country or region trend up and right in this matrix like Zone A; on the contrary, in worsening states they trend down and left like Zone H.

Specifically, we make use of a SER Matrix to examine the A, H group from 1996 to 1999. A group consists of Botswana, Latvia, Albania, Lithuania, Jordan, Hungary, Mozambique, Romania, Sudan, Poland; average GDP US $14340700 and EF 2.95 ha (per capita) (Figures 9,10).

In addition, H group includes Eritrea, Afghanistan, Chad, Niger, Burkina Faso, Mali, Uganda, Nigeria, Zambia, Mauritania, Benin, Yemen, Guinea, Lesotho, Senegal, Cameroon, Namibia, Gabon, Croatia, Norway, average GDP US$128,308,50; EF 1.275 ha (per capita) (Figures 11, 12).

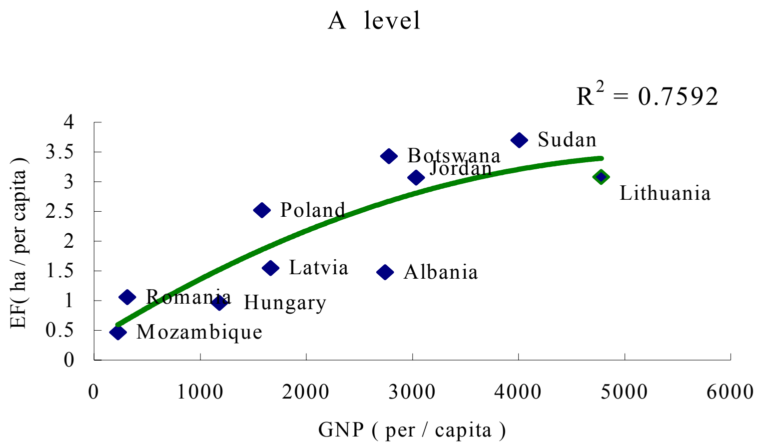

Figure 9. EF and GNP's relationship at A level's countries from 1996 to 1999

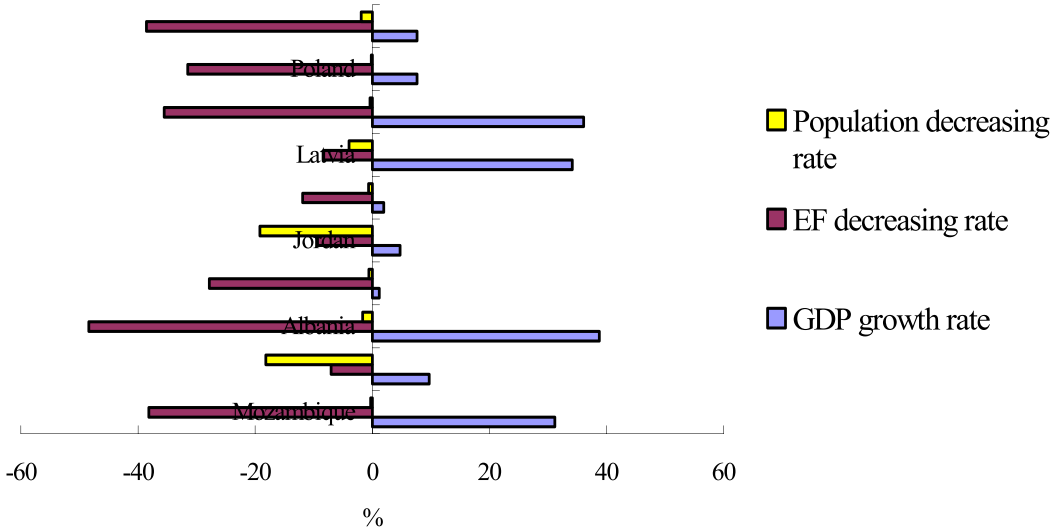

Figure 10. GDP, Population and EF variation rate at A level from 1996 to 1999

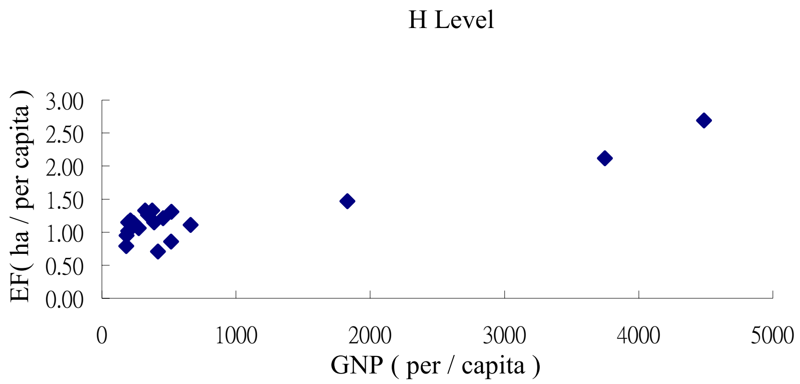

Figure 11. EF and GNP relationship at H level 's countries

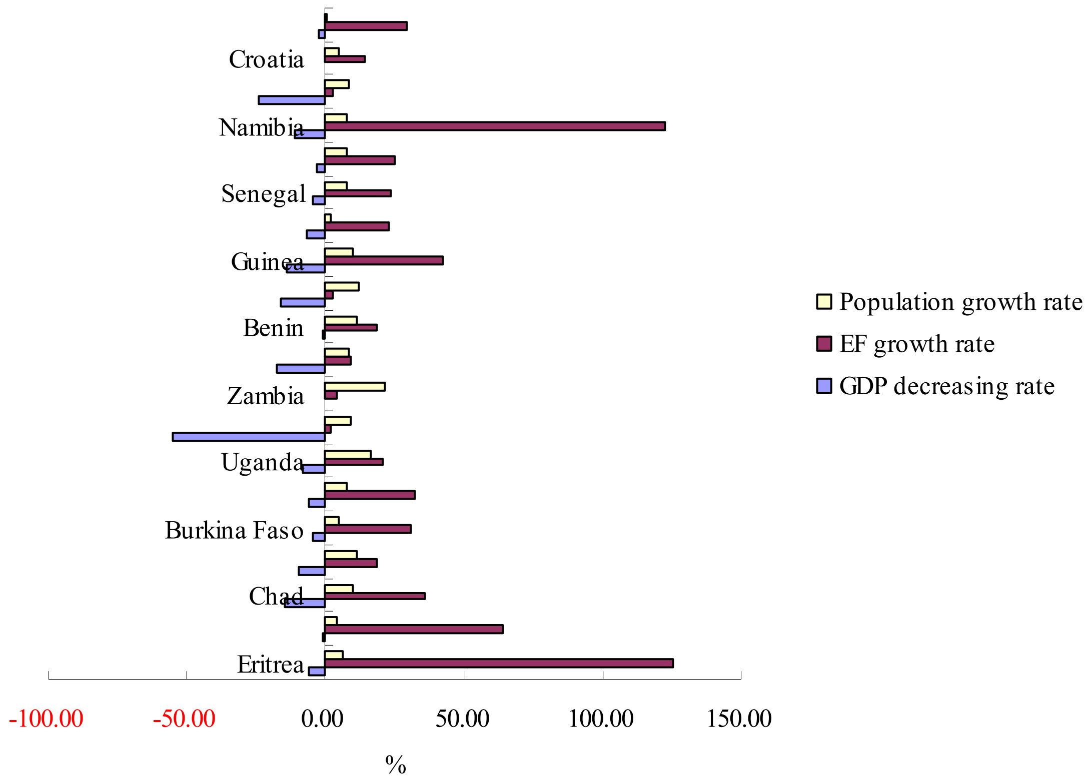

Figure 12. GDP, population and EF variation rate at H level from 1996 to 1999

4 Conclusion

This article demonstrates that economic growth (GDP increase) and population are two key factors in a positive relationship, and have a multiplier effect on resource consumption.

What is more, we can use this Socio-Economic Resource Matrix not only to examine social welfare for replenishing the UN Human Welfare Index (HWI) and other sustainability indicators but also in the future.

We know that natural resources are not shared fairly by all. And, on the basic of this result, we can deny the rightness of Albert A. Bartlett's two claims that starving people do not care about sustainability, and if sustainability is to be achieved, the necessary leadership and resources must be supplied by people who are not starving (Albert A. Bartlett).

In this article, it is identified that global over population is the main key dominating resource overuse. At the some time, if it's true that Gaia Hypothes's Mother Earth is alive, human beings absolutely must follow the right ways to keep it working well:

Law 1: decreasing EF.
Law 2: lowering population.
Law 3: increasing GDP.

Like René Dubos (1994), I do not blindly oppose progress. I oppose blind progress. However, the SER Matrix is an absolute system tool to examine sustainability in extensive fields. People have to turn away completely and thoroughly from wrong and unsustainable lifestyles to more energy efficient and sustainable ways, and only by doing so humanity can enjoy hopeful prospects and share in good conscience in nature's bounty.

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