

**‘People, Planet and Prosperity’:
The Determinants of Humanity’s Environmental Footprint**

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Abstract

Environmental or ‘ecological’ footprints have been widely used in recent years as indicators of resource consumption and waste absorption transformed on the basis of biologically productive land area required per capita with prevailing technology. They represent a partial measure of the extent to which the planet, its regions, or nations are moving along a sustainable development pathway. Such footprints vary between countries at different stages of economic development and varying geographic characteristics. The determinants of environmental footprints in some 113 countries from around the world have been evaluated. Dimensional analysis techniques from engineering and the physical sciences are employed to determine the relative significance of population density, economic wealth, and pollutant emission intensity. Variations about the resulting power-law correlation suggest the extent to which individual nations are currently frugal or profligate in terms of their resource use and environmental impacts. The scatter associated with footprints, or closely related parameters, also indicates the uncertainty inherent within the international datasets needed to compute them, as well as differences in local climate and terrain. Nevertheless, national footprints reflect the need for humanity to live within the regenerative capacity of the biosphere in order to ensure ‘environmental sustainability’.

Keywords: Environmental footprints; Resource use; Carbon emissions; International development; Sustainability

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1. Introduction

Environmental, or ‘ecological’, footprints (sometimes referred to as the ‘eco-footprints’ (Costanza, 2000)) have been widely used in recent years as indicators of resource consumption and waste absorption transformed on the basis of biologically productive land area required per capita with prevailing technology. They represent a partial measure of the extent to which the planet, its regions, or nations are moving along a sustainable development pathway. Such footprints vary between countries at different stages of economic development and varying geographic characteristics. The present contribution attempts to identify the underlying relations within this environment and development nexus. National environmental footprints for high, medium and low-income countries from around the world were analysed, using footprint data from a study supported by the World Wide Fund for Nature (WWF). [The Fund is still known by its original name of the ‘World Wildlife Fund’ in North America.] Their influential “*Living Planet Report 2002*” (Loh, 2002) covered all nation states having populations greater than 1 million (except Bhutan, Oman and Singapore, for which insufficient 1999 data was available). The determinants of these WWF national environmental footprints have been evaluated using dimensional analysis techniques commonly employed in engineering and the physical sciences. An aggregate dataset consisting of some 113 countries¹ was assembled from data in the WWF inventory and various other international databases (BP, 2004; The World Bank, 2002) that

¹ The terms 'country', 'nation', 'nation state' and 'state' are used interchangeably in the present text. They refer to a territory bounded by defined limits (that could include a commonwealth or federal republic, as in the case of Australia and the USA respectively), whose population has common citizenship.

together provide statistical indicators of environmental footprints, population size, land area, economic wealth, energy use, and carbon emissions at the turn of the Millennium (roughly 1999-2000). Dimensional analysis techniques were employed to determine the relative significance of population density, economic wealth, and pollutant emission intensity on national environmental footprints *per capita*. Variations about the resulting power-law correlation suggest the extent to which individual nation states are currently frugal or profligate in terms of their resource use and environmental impacts. These national footprints reflect the need for humanity to live within the regenerative capacity of the biosphere in order to ensure what is sometimes termed 'environmental sustainability'.

2. The Sustainable Development Context

Over a period of some 15-20 years, the international community has been grappling with the task of defining 'sustainable development'. It came to particular prominence as a result of the so-called Brundtland Report (WCED, 1987) published under the title "*Our Common Future*"; the outcome of four years of study and debate by the World Commission on Environment and Development led by the former Prime Minister of Norway, Gro Harlem Brundtland. This Commission argued that the time had come to couple economy and ecology, so that the wider community would take responsibility for both the causes and the consequences of environmental damage. It envisaged sustainable development as a means by which the global system would satisfy "the needs of the present without compromising the ability of future generations to meet their own needs". The notion therefore involves a strong element of intergenerational ethics. More recently, sustainability has been the subject of renewed interest and debate in the context of the 2002 World Summit on Sustainable Development in Johannesburg. Here the strapline "people, planet, prosperity" was adopted to reflect the requirement that sustainable development implies the balancing of economic and social development with environmental protection: the so-called 'Three Pillars'. [In the context of the business sector, this strapline has sometimes been paraphrased as "people, planet, profits", or the 'triple bottom line' (Parkin, 2000).] But further confusion about this modern paradigm is added by the large number of formal definitions for sustainable development that can be found in the literature. Parkin (2000) refers to more than two hundred.

Parkin (2000) and Porritt (2000) have stressed that sustainable development is only a process or journey towards a destination, which is 'sustainability'. The end-game cannot easily be defined from a scientific perspective, although Porritt (2000) argues that the attainment of sustainability can be measured against a set of four 'system conditions'. He draws these from 'The Natural Step' (TNS); an initiative by the Swedish cancer specialist, Karl-Henrick Robèrt (see, for example, Broman *et al.*, 2000). Its system conditions put severe constraints on economic development, and may be viewed (Hammond, 2004) as being impractical or 'utopian'. One of them, for example, suggests that finite materials (including fossil fuels) should not be extracted at a faster rate than they can be re-deposited in the Earth's crust on geological timescales. This may be contrasted with the present rapid rate of fossil fuel depletion on the global scale: leading to estimates for resource to production ratios of 20-40 years for oil, 40-70 years for natural gas, and 80-240 years for coal (Hammond, 1998). Upham (2000) argues that TNS moves beyond (scientific and other) knowledge in signposting action for the business sector. He contends that it represents a political and ethical statement rather than any justifiable scientific consensus. TNS certainly implies that the ultimate goal of sustainability is rather a long way off when compared with the present conditions on the planet. Parkin (2000) suggests 2050-2100 or beyond. More recently, a significant step forward has been taken by Graedel and Klee (2002) in trying to establish a quantifiable, long-term target for sustainability from an 'industrial ecology' perspective. They suggest a framework, or series of steps, to permit the establishment of the sustainable (or limiting) rate of natural resource use, which can then be contrasted with the current rate of consumption. The process is illustrated for the case of three common materials employed or emitted by industrial societies: zinc, germanium, and greenhouse gases. Unfortunately, the Graedel and Klee procedure requires the establishment of equal planetary shares of materials/emissions on a 50-year timescale. They acknowledge that the idea of an 'Earth share' or quota of this sort is controversial, and that the chosen timescale is somewhat arbitrary. An alternative quantitative indicator that may be able to better track humanity's pathway towards sustainability is the environmental footprint considered here. It is in keeping with an interpretation of sustainable development devised by several leading international nature conservation and environmental

organisations (the IUCN, UNEP and WWF (1991)) as “improving the quality of human life while living within the carrying capacity of supporting ecosystems”.

3. Methods

3.1 Environmental Footprint Analysis: The Background

The use of environmental footprint analysis has grown in popularity over recent years. Its origins, as well as the strengths and weaknesses of the method, are reviewed here. Such footprints provide a simple, but often graphic, measure of the environmental impact of human activity: whether or not, in the foreseeable future, humanity will be able to "tread softly on the Earth". Resources used and wastes produced by a defined population are converted to a common basis: the area of productive land and aquatic ecosystems sequestered (in hectares) from whatever source in global terms. Its roots lie in earlier ideas, such as 'Ghost Acres' developed by Borgstrom (1972) and similar concepts, like 'net primary production' (NPP) from the land and oceans, devised by Ehrlich (1968) in the late 1960s. Rees used footprint analysis in its earlier form of the 'Regional Capsule' to teach planning students for some 20 years (see the now standard text on the technique by Wackernagel and Rees (1996)). The terms 'environmental footprint' and 'ecological footprint' are often used interchangeably; although the former expression was preferred by Doughty and Hammond (1997 and 2004) for their interdisciplinary study of the sustainability of cities. Ecology is that branch of biology dealing with the interaction of species and their surroundings. 'Human ecology', sometimes used for the study of humans and their environment, is closer to the usage implied by footprint analysis (Doughty and Hammond, 1997 and 2004).

Footprint calculations involve several steps. Initially the *per capita* land area appropriated for each major category of consumption is determined. In the version of footprint analysis employed by Wackernagel and Rees (1996), and the most widely adopted, four consumption categories are identified: energy use, the built environment (the land area covered by a settlement and its connecting infrastructure), food, and forestry products. This is a restricted subset of all goods and services consumed, which was determined by the practical requirements of data gathering and influenced by the development of the

technique in a Canadian setting. Nevertheless, unconnected work by Friends of the Earth Europe (1995) using the related 'Environmental Space' concept, adopted a similar set of categories. In order to calculate the *per capita* footprint (*ef*) in global hectares (ha), the appropriated land area for each consumption category is then summed. This computation leads to a matrix of consumption categories and land use requirements, which is ideally suited to a spreadsheet implementation. In order to determine the total footprint for a given country, region or community (EF), the *per capita* figure is simply multiplied by the relevant population size (N). However, this is generally a less useful parameter for comparative purposes between countries or communities with different sized populations (Doughty and Hammond, 1997 and 2004). It would not be helpful, for example, to contrast Peru with Switzerland that have essentially the same total environmental footprint (an EF of around 29.5 M ha in 2000), but very different population sizes and *per capita* national incomes. They are therefore categorised in the World Bank (2002) database as being medium and high-income countries respectively. Their *per capita* footprints (*ef*) in 2000 are likewise quite disparate: 1.15 and 4.12 ha respectively (Loh, 2002).

Footprint analysis thus implies judgements about the relative weighting of the various consumption categories, and their environmental impact. It reduces all such impacts to a common basis in terms of global hectares *per capita*. The International Institute for Environment and Development (IIED, 1996) described the process of analysis whereby all environmental impacts are aggregated into a simple index as "resource reductionism". They likened it to traditional measures of economic welfare, such as the Gross Domestic Product (GDP) or Gross National Income (GNI). Nevertheless, it provides a useful basis for contrasting the footprint of human activity with the available productive area, biocapacity, or 'carrying capacity'. The consequences of human consumption can then be graphically viewed against the 'natural capital' of a nation, region, or the planet as a whole.

Environmental footprint analysis is a 'static' process that provides a measure of aggregate environmental burdens at some specified date (or year). It is nevertheless a valuable technique in a toolkit of measures that can aid the assessment of sustainable development, although it is arguably weak in terms of social inequalities or poverty within and between

different countries and societies. Clearly environmental footprint analysis would need to be supplemented by the use of other measures to account for these broader elements of human welfare. In Costanza (2000), contributors noted that this aggregate indicator has a number of advantages and disadvantages. It can be used as an effective pedagogic device (or awareness raising tool) for illustrating human resource use and waste generation, employing a simple measure (land area) that advocates view as readily understandable. As an area-based sustainability indicator, it incorporates trade flows and some regard this as leading to arguments against international trade (Costanza, 2000); analogous to the 'ethical' or 'fair' trading debate. The variant used by the WWF (Loh, 2002), and analysed here, is in effect a 'consumption footprint', which can be defined in terms of trade flows via a national balance equation:

$$\text{Consumption footprint} = \text{production footprint} + \text{imports} - \text{exports},$$

where the imports and exports are obviously converted into a footprint equivalent basis (ha). Thus, a product that is manufactured in Japan, but is imported into the United Kingdom (UK), will contribute to the British, not the Japanese, environmental footprint. Loh (2004) has noted that, as a consequence, this can exaggerate the footprints of export-driven economies, and *vice versa*. The uncertainties and deficiencies of using environmental footprints (and related parameters) as, albeit partial, sustainability indicators include problems associated with boundary definitions, data gathering, and the basis for weighing the various consumption and associated impacts (Doughty and Hammond, 1997 and 2004). Its adoption as a tool for decision-making in a policy or planning context depends on an understanding of these assumptions and uncertainties.

3.2 Environmental Footprints of Nation States

Over recent years, the WWF has supported a study to determine the environmental footprints of most countries in the world, and consequently of the whole planet (Loh, 2002). Its influential *Living Planet Report 2002* covered 146 countries with populations

greater than 1 million² (see Figure 1). WWF then carried out footprint assessments based on six consumption categories: 'food and forestry products' were subdivided into those accruing from cropland, grazing land, forest and fishing grounds. A number of specific countries have been identified here from amongst the data points illustrated in Figure 1. These have been chosen from across the different geo-economic groups, but are otherwise arbitrary. Some of the most dominant nations in terms of population size and economic wealth are amongst those highlighted. The headline findings from the WWF study (Loh, 2002) were that the global environmental footprint grew by 80% over the period 1961-1999, and that the Earth had already overshoot its 'carrying capacity' by some 20% at the end of the Millennium. Humanity had, by this time, reached a population size of a little over 6 billion (compared with about 3 billion in 1960). Projections by the WWF, employing footprint calculations made by Mathis Wackernagel and several associates, suggested that humanity might require around two Earth-sized planets to meet its resource demands by 2050 (Loh, 2002). That could only be achieved by exploiting fossil fuels laid down over geological timescales. The most recent in the "*Limits to Growth*" series of reports (Meadows *et al.*, 2004) also indicates that, under many of their scenarios to the end of the 21st Century, the planet's footprint would overshoot its biocapacity limits before stabilising under the more favourable ones. They based their latest World3 computer model projections on a proxy measure quite close to that of the WWF global footprint. However, the *Living Planet Report 2002* was criticised by researchers at Denmark's national Environmental Assessment Institute (Jørgensen *et al.*, 2002); a body at the time directed by the controversial environmentalist and statistician, Bjørn Lomborg (McDowell, 2002). The authors argue (Jørgensen *et al.*, 2002) that footprint analysis provides only a snapshot of current resource use, and should not be employed to 'predict' the future. The WWF results (Loh, 2002) were viewed as amounting to something of a 'doomsday' scenario (Jørgensen *et al.*, 2002) in the tradition of Thomas Malthus' population projections in the 19th Century (Wrigley and Souden, 1986) and the *Limits to Growth* study in 1970s (for the most recent update, see Meadows *et al.*, 2004). Criticisms of environmental footprint methodology

² Shortly after the present analysis was completed, the WWF published a revised version of their '*Living Planet Report*' (Loh, 2004). This provides national environmental footprint data updated by two years in comparison with that analysed here.

along the lines of those discussed earlier (Costanza, 2000; Doughty and Hammond, 1997 and 2004) were also noted, particularly relating to the dominant influence of fossil fuels. The Danish Institute's researchers believe that it underestimates the potential of a switch to renewable energy technologies in lowering the planetary footprint (Jørgensen *et al.*, 2002). Indeed 'technological optimists' typically argue that new technology will enable humanity to overcome biophysical limits (Costanza, 2000), thereby making development sustainable. This is a view that has generated an articulate group of detractors over recent decades; see, for example, Ehrlich (1968) and Porritt (2000).

It is evident from the WWF national footprint data (Loh, 2002) presented in Figure 1 that the greatest environmental impact is associated with the United States of America (USA). It has both quite a large population and a high *per capita* income. This has resulted in criticism from amongst some environmentalists. A commonly heard, and true, statement is to the effect that the USA contributed about 23% of humanity's carbon emissions in 2000 with only 4.5% of the world's population. However, the Peoples Republic of China (denoted as 'China' in this, and subsequent, figures) is not far behind in terms of the absolute size of its environmental footprint. In fact both China and India, the two most populous countries in the world (with 21.0 and 16.4% global population shares respectively), have a greater impact than any of the other so-called industrialised countries, such as Japan, the Russian Federation (identified as 'Russia' in the figures), and the UK. The last nation should be taken as representative of the main players in the European Union, including France and Germany, that tend to be clustered together in many of the figures displayed here, because they have similar population sizes and *per capita* incomes. Developing nations with small populations and low incomes inevitably have the lowest environmental footprint or impact on the planet.

4. Results and Discussion

4.1 The Determinants of National Environmental Footprints

The national footprints computed in the WWF study (Loh, 2002), as well as other parameters from international datasets, have been employed here in order to find the main determinants of humanity's environmental impact. Dimensional analysis and scaling arguments (see, for example, Duncan (1953) and Kline (1986)), widely used in the engineering and physical sciences, have been employed for this purpose. It was initially postulated that:

National environmental footprints (ef) = function {population density (PD), economic wealth (GNI), energy intensity (EI), and carbon emissions ratio (CR)},

where *per capita* GNI is in purchasing power parity (ppp) terms (The World Bank, 2002). The energy intensity is the primary energy consumption per unit of GNI (Hammond, 2000), and the carbon ratio is the emissions per unit of energy consumed. [Carbon emissions are used simply as a 'proxy' for a variety of chemical pollutants.] Here primary energy is restricted to commercially traded sources only. Non-commercial fuels, such as animal wastes, peat and wood, play an important role in many developing countries, but they are poorly recorded in national energy statistics (BP, 2004). Goldemberg (1996) estimates that such non-commercial sources contribute around 23% of the total energy consumed in the 'Majority South'; the African, Asian and Latin American regions of the world. Fossil fuel consumption typically accounts for between some 33% and 60% of national environmental footprints for low-income and high-income countries respectively. Clearly there are other factors that could influence the size of footprints, including variations in local climate, different terrains and soil productivity, but for which there are not suitable international indicators or readily available datasets. The above expression can be reformulated as a power-law correlating equation in common with practice in the engineering sciences:

$$ef = \text{constant} \{PD^m \text{GNI}^n \text{EI}^p \text{CR}^q\}$$

In order to determine the empirical coefficients in this expression, a range of international statistics for 1999-2000 were utilised: population size in millions and land area in km² from the WWF (Loh, 2002), *per capita* GNI in international dollars [\$(2000)ppp] from the World Bank's "*World Development Report 2002*" (The World Bank, 2002), primary energy use in EJ from the "*BP Statistical Review of World Energy 2004*" (BP, 2004), and CO₂ emissions in Mt again from the World Bank (2002) [then carbon = $12 \times \text{CO}_2 / (12+32) \sim 0.273 \text{ CO}_2$, on the basis of molecular weights]. Limited availability of some of this data meant that the number of countries in the consolidated set was reduced to 113 nations; still a good representation of the international community. However, the countries that had to be omitted from this final dataset were generally from amongst the low-income nations, where statistical sources are relatively scarce. In addition, data quality and comparability are both significant issues, particularly in regard to developing countries. This needs to be borne in mind when interpreting derived parameters and their graphical presentation.

The 'constant' in the above power-law correlation effectively includes a unit converter that ensures that the equation satisfies the so-called 'principle of homogeneity of dimensions' (Duncan, 1953). Correlation yielded $p \sim q \sim 0$ (see also Figures 2 and 3), which implies that the primary energy intensities [MJ/\$(2000)ppp] and carbon ratios [mg C/J] are themselves relatively independent of *per capita* economic wealth. Countries like Bangladesh, Ethiopia, and Mozambique have energy intensities well below the mean value, whereas Russia and the Czech Republic have relatively high intensities that suggest profligate use of energy. In the case of the Russian Federation, as with other countries of the Former Soviet Union, this ultimately stems from their early emphasis on a strategy of economic development through industrialisation, and on the relative inefficiency of their heavy industries under the pre-1990 Communist regimes. Other industrialised nations, including Australia, the UK and the USA, have energy intensities close to the international mean. But several of the developing countries, including China and Thailand, are also grouped close to the mean intensity. The carbon ratio, on the other hand, generally reflects the extent to which nations are dependent on particular types of energy resource - principally coal, oil, natural gas and nuclear power. The latter, together with 'renewable' energy technologies, provide a near-zero carbon resource. Carbon ratios associated with

unsustainably burnt wood, coal, oil and natural gas (taken from Hoffert *et al.* (1998)) are illustrated in Figure 3. National carbon ratios are even more closely clustered around the global mean value than are the energy intensities, with just a few low-value outliers - such as the East African country of Uganda, which principally draws carbon-free hydropower from the Owen Falls Dam at the origin of the River Nile close to Lake Victoria.

When the values for the exponents p and q were substituted into the original ef expression, and the remaining empirical coefficient and exponents determined, this yielded the following power-law correlation:

$$ef = 0.00658 PD^{-1/4} GNI^{2/3}$$

A comparison between the results obtained from this expression and national data are presented graphically in Figures 4 and 5. The correlation equation has been used to illustrate the effect of population density in Figure 4. Here the actual dataset encompassed the range $0.02 < PD < 9.35$, with Australia and Bangladesh being close to the extremes of low and high densities respectively. It needs to be recognised that, the scatter of data around the correlating equation (as depicted in Figure 5) amounts to an uncertainty interval in ef equivalent to a standard deviation of some 100%. This would appear large to a physical scientist, but is in keeping with the scatter inherent in many datasets related to human affairs found in the domain of social scientists. Several factors give rise to this broad spread in the correlated ef data; the uncertainty associated with international datasets needed to compute them, as well as differences in local climate, terrain and soil productivity previously cited. The power-law curve shows that countries in the three main socio-economic groups (low-income, middle-income, and high-income categories as defined by the World Bank (2002)) are generally clustered together. But an individual country's environmental impact is largely related to its stage of economic development. National environmental footprints are strongly dependent on economic wealth ($n = 2/3$) and only weakly on population density ($m = -1/4$).

A number of inferences can be readily made from the data presented in Figure 5. Nations above the power-law correlation curve are generally profligate in terms of their use of natural capital, whilst those below the curve are relatively frugal. Countries such as Bangladesh, China, Russia and the USA fall almost exactly on the power-law curve. In order to illustrate the use of the correlating equation depicted in Figure 5, consider a relatively poor and densely populated country like Bangladesh. Its position, on the power-law data correlation, implies that it has a footprint typical (that is, close to the 'mean' value) of nation states with a similar combination of income and population density. The same arguments apply to China, Russia and the USA in regard to their economic welfare and area density. In contrast, Argentina, Australia, Mozambique and Peru (which fall significantly below the correlating equation) are seen to be more sparing in their use of natural capital, whereas the Czech Republic, Ethiopia, Uganda and the UK conversely exhibit relative profligacy. Nation states that are placed above and below the curve are distributed across the spectrum of socio-economic groups; national consumption patterns of biophysical resources do not appear to be related to wealth or poverty *per se*. The dominance of fossil fuel consumption in the footprints of (particularly) high-income countries obviously means that these states rely on resources laid down over geological timescales. Such energy technologies will need to be replaced by nuclear or renewable energy sources, coupled with measures aimed at significantly improving energy efficiency, over the longer term as fossil fuels are depleted.

4.2 Overshooting National Carrying Capacity

A comparison between national footprints and the biocapacities of individual countries provides a means of illustrating how much a nation state overshoots its 'carrying capacity'; see Figure 6. Here the overshoot ratio (OR) is defined as:

$$\text{Overshoot ratio} = \text{national environmental footprint} / \text{available productive area},$$

in terms of national footprints (EF) and their corresponding biocapacities (BC). In line with the findings of the WWF study (Loh, 2002), that the planet had overshoot its footprint by some 20% in 2000, many of the individual countries shown in Figure 6 display an

overshoot ratio greater than unity. The USA is one of these, but it is exceeded by many other nations, including the Czech Republic, Japan and the UK (and likewise the European Union generally). China, India and Uganda have environmental footprints that are roughly in balance with their available productive areas (i.e., OR = 1). But sparsely populated countries, such as Argentina and Australia (the continental part of Oceania, together with Tasmania), as well as many of the developing countries, including Bangladesh, Mozambique and Peru, can be seen (Figure 6) to live well within their carrying capacity.

4.3 Some Implications for International Negotiations on Greenhouse Gas Emissions

The debate that preceded the Kyoto Protocol focussed on alternative ways of allocating greenhouse gas (GHG) emission quotas, including cumulative national emissions ('grandfather rights' (RCEP, 2000)); favoured by many developing countries, but against which the industrialised countries score poorly. Environmentalists have tended to argue that ecological burdens, including CO₂ emissions that are believed to be the main stimulant for global warming, should be shared in *per capita* terms. This alludes to what economists view as the 'strong' interpretation of sustainability (see, for example, the discussion in Porritt, 2000), which requires that life-supporting natural capital is maintained on such a *per capita* basis. This challenge is reflected in Figure 7, where carbon emissions are contrasted with GNI for the countries in the present dataset. *Per capita* emissions are closely associated with economic wealth, and hence with the United Nations Development Programme (UNDP) ranking according to their Human Development Index (HDI). Industrialised countries, particularly the USA, emit a large fraction of total greenhouse gases, and might be required to significantly curtail their carbon emissions in any future mitigation regime. This would place severe constraints on economic development in North America, Australia and New Zealand, the European Union, and Japan. It is for this reason that Australia and the USA, for example, have been reluctant to ratify the Kyoto Protocol with its modest overall GHG reduction target of 5% for the so-called Annex 1 (industrialised) countries on a 2008-2012 timescale against a 1990 baseline. Recently the Royal Commission for Environmental Pollution in the UK (RCEP, 2000) has advocated a target of a 60% reduction in CO₂ emissions by 2050, and perhaps 80% by 2100, in order to stabilise global warming at an acceptable level. They support a strategy of 'contraction and

convergence' whereby nations' GHG emission quotas converge to the same *per capita* level, and then all quotas would contract at the same rate to a sustainable target some time in the 22nd Century. On that timeline, many of the other environmental effects that contribute to global and national footprints will have come to the fore. In the transitional, or 'contraction', phase quotas for the developed countries would fall, while those of poorer developing nations would rise with economic wealth and (hopefully) well-being; thereby removing 'grandfather rights'.

Whatever the fate of the Kyoto process in the short term, following its entry into force amongst Annex 1 nations after ratification by the Russian Federation early in 2005, an effective successor regime will need to be negotiated in order to equitably share the future burden of climate change mitigation. A mechanism for an international exchange of views between the major energy consuming nations was agreed at the G8 Gleneagles Summit in July 2005 (to be known as the 'Dialogue on Climate Change, Clean Energy and Sustainable Development'). It would embrace both representatives of the G8 industrialised countries and of developing nations, such as China and India. In parallel, a new 'Asia-Pacific Partnership on Clean Development and Climate' was established later that month with six founding partners: Australia, China, India, Japan, South Korea and the USA. This regional group represents over half the world's economy, population, energy use, and GHG emissions. It seeks to transfer clean, more efficient technologies, build technical capacity, and reduce the carbon intensities of countries around the Asia-Pacific rim. But it does not envisage legally-binding GHG emission reduction targets of the sort incorporated into the Kyoto Protocol, and against which progress could be monitored. Each of these international exchanges will be in addition to the ongoing negotiations within the ambit of the UN Framework Convention on Climate Change (UNFCCC). Insights derived from environmental footprinting discussed here, such as the need for humanity (and, more debatably, individual countries) to live within biocapacity constraints, may aid the post-Kyoto negotiations that will ultimately need to take place amongst all the major nations and geo-economic groupings on the planet; the interdependent 'crew' of 'Spaceship Earth'. They may put into perspective the future GHG burden sharing arrangements between the wealthy nations of the northern hemisphere and the Majority South. This could be achieved

by including national biocapacity-related constraints within a modified 'contraction and convergence' quota allocation scheme.

5. Concluding Remarks

Sustainability assessment techniques may be used to inform an extended process of global decision-making within international bodies, such as the United Nations system (particularly the IPCC, the UNDP, and the UNEP), the World Bank and International Monetary Fund, and the World Trade Organisation. Environmental footprint analysis might constitute an important part of integrated appraisal within a framework of 'systems thinking' more generally. A key element of the sustainable development pathway is the need to focus on greatly improving the efficiency of resource use, and on reducing carbon (and other pollutant) emissions. Such actions would lower the environmental footprint of differing countries or regions of the world. This will clearly move humanity towards 'sustainability', although it is impractical to achieve the very strict system conditions laid down under 'The Natural Step' (Broman *et al.*, 2000; Hammond, 2004). Equity arguments will persist about whether burden sharing should be made on a *per capita* basis, or account should be taken of the relative economic wealth of developed and developing nations. Nevertheless, footprint analysis provides a tool for coupling (in present terms, 'balancing') considerations of economy and ecology, along the lines advocated in the influential Brundtland report (WCED, 1987), and for raising awareness of global sustainability issues amongst the wider populous. The correlation of national footprints reported here indicates the extent to which countries are utilising natural capital above and beyond that expected at their income levels as they move along a pathway towards sustainability. That may aid the inevitable international debate over the sharing of global resources and the resulting environmental burdens.

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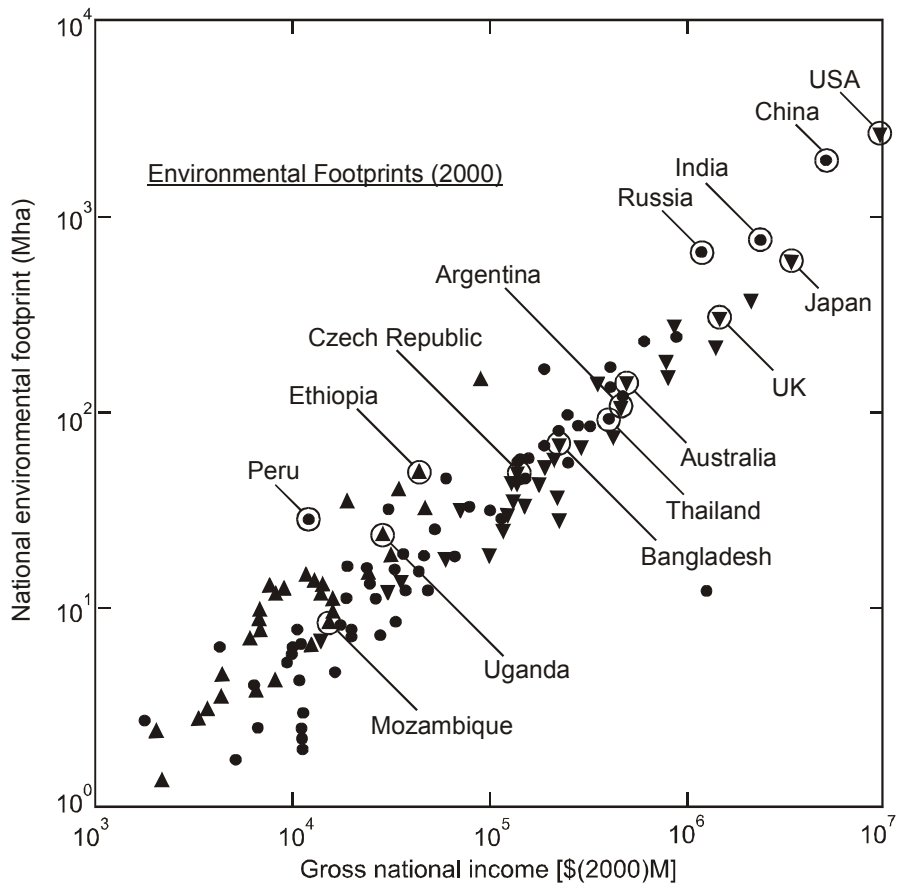
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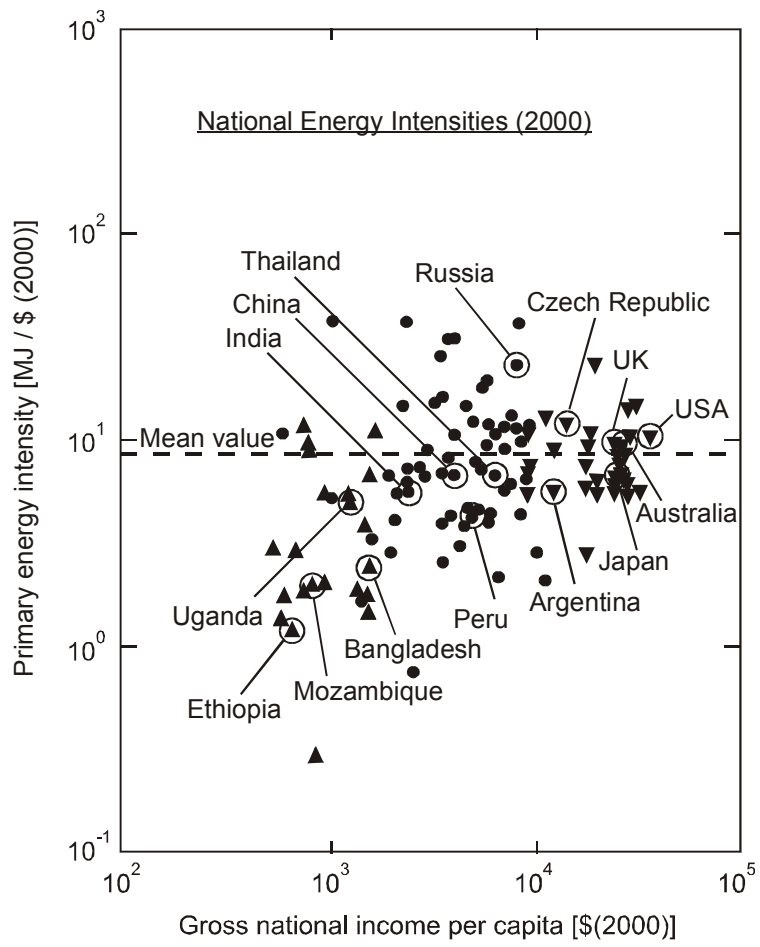
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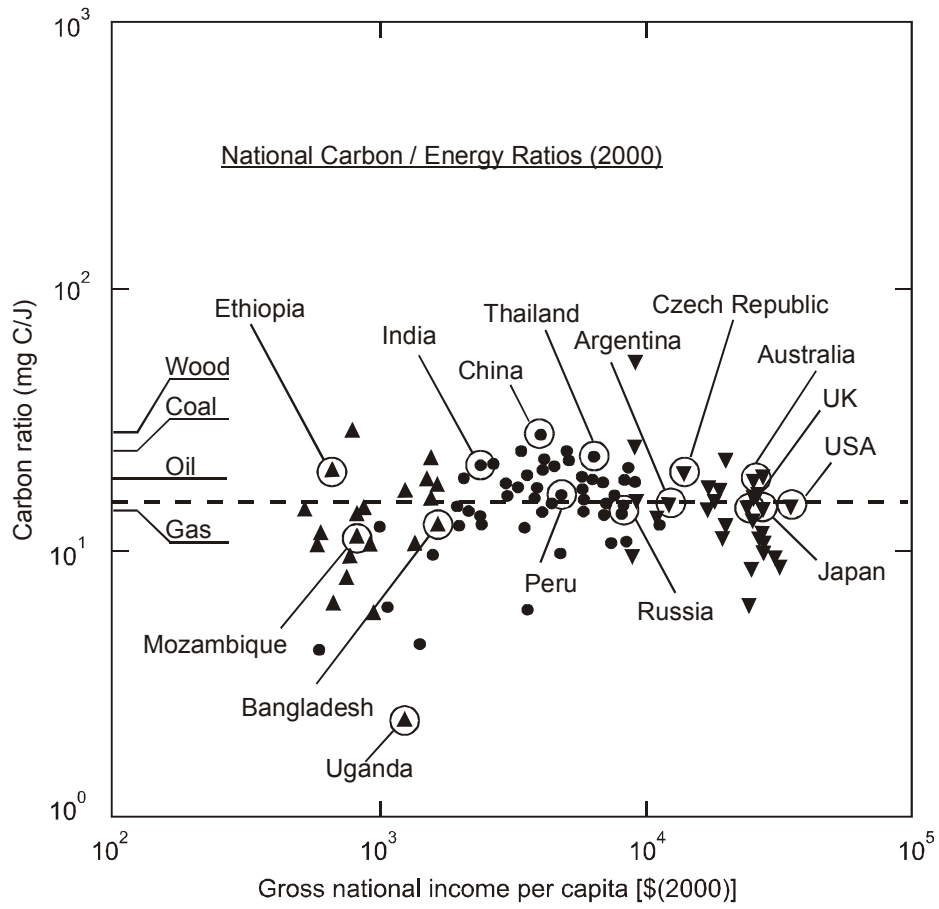
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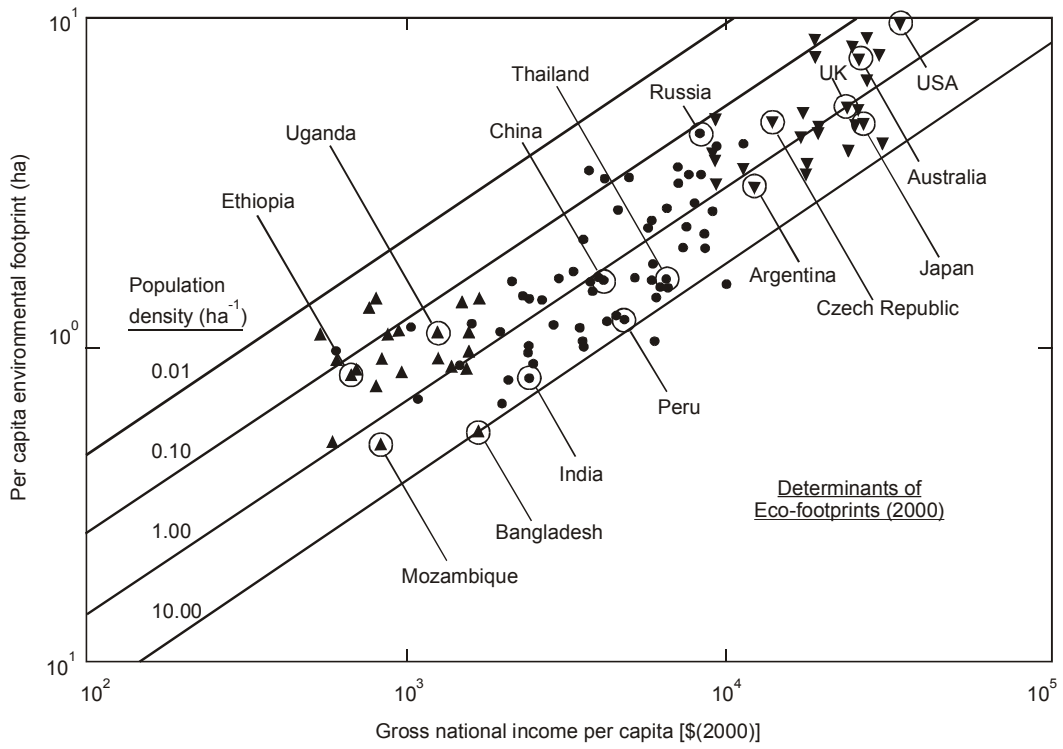
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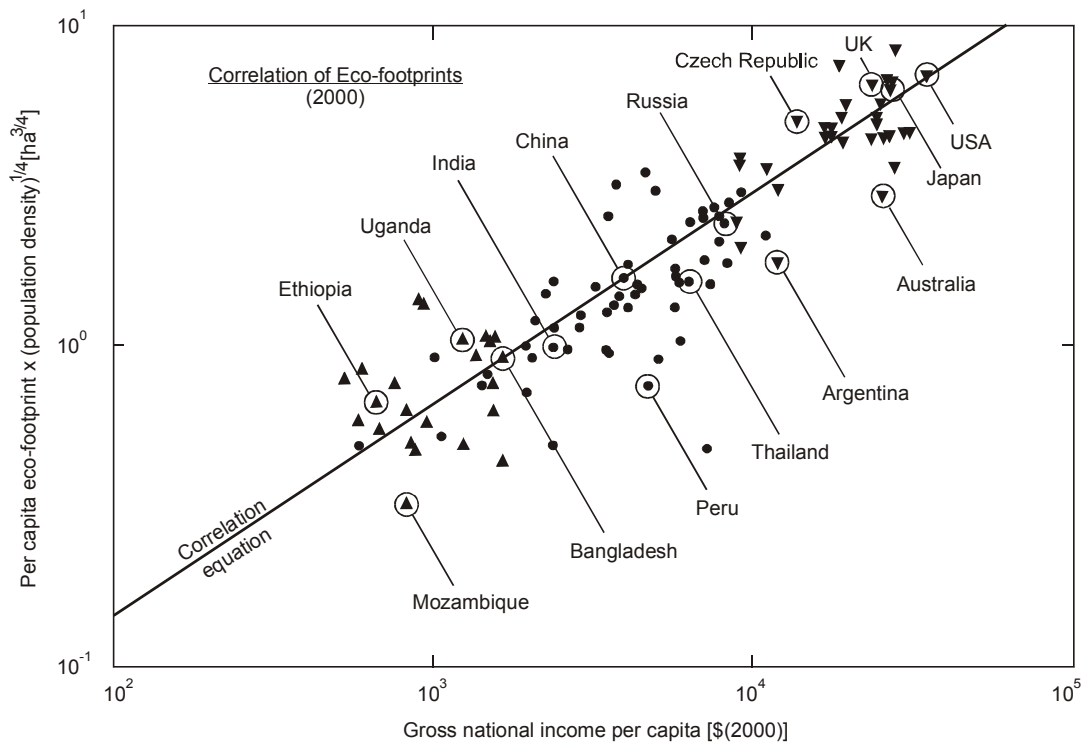
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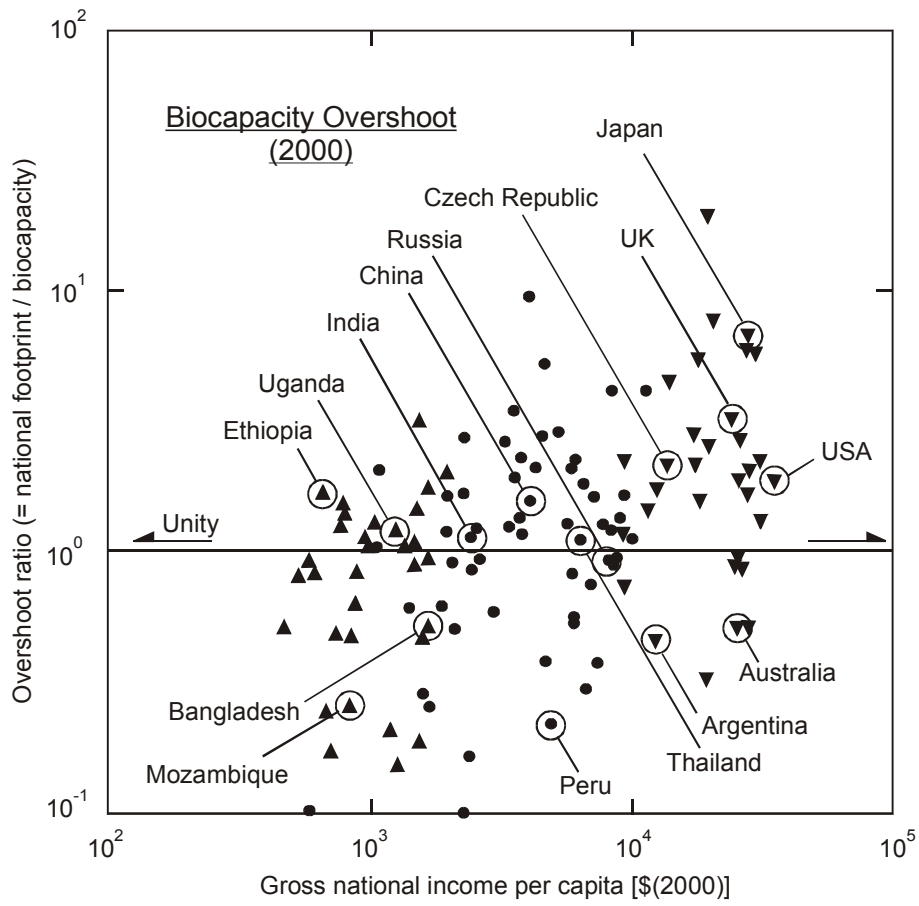
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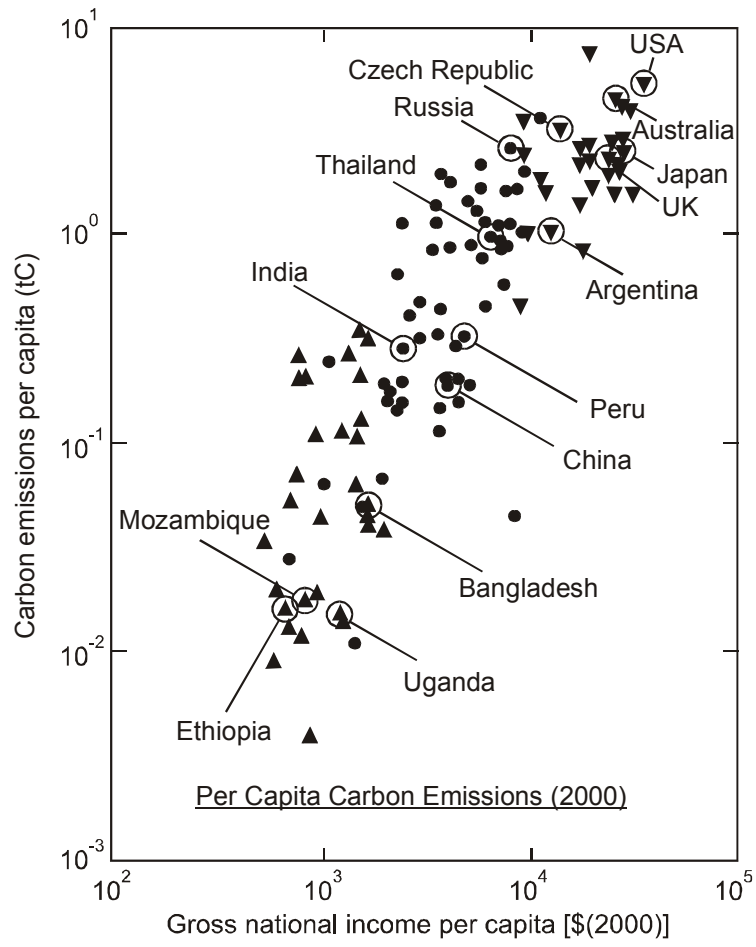
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